



SURFACE VEHICLE STANDARD

J1826™**APR2022**Issued 1989-04
Revised 2022-04

Superseding J1826 MAR1995

(R) Turbocharger Gas Stand Test Code

RATIONALE

SAE J1826 provides a standard for establishing the performance of turbocharger components. The standard has been expanded to contain definitions of surge and soft surge, choke line, added requirements for data points per speed line and number of speed lines, added definition of the measurement section geometries, and updates of the data reporting formats and improved illustrations.

1. SCOPE

The test procedures outlined in this SAE Standard are applicable to turbocharging systems having either fixed- or variable-geometry.

1.1 Purpose

The purpose of this document is to provide a laboratory test procedure and presentation format for establishing the component performance for a turbocharger. It is intended that this test procedure be used to determine turbocharger compressor and turbine performance characteristics for passenger cars, off-highway, and commercial vehicle. The resulting data are intended for use in turbocharger component performance assessment and development and for engine/turbocharger matching. In particular, the intent is to provide well defined data in a consistent format for engine simulation programs.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this specification to the extent specified herein. Unless otherwise indicated, the latest issue of SAE publications shall apply.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

SAE J922 Turbocharger Nomenclature and Terminology

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2.2 Related Publications

The following publications are provided for information purposes only and are not a required part of this SAE Technical Report.

2.2.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

SAE J244 Measurement of Intake Air or Exhaust Gas Flow of Diesel Engines

SAE J1349 Engine Power Test Code - Spark Ignition and Compression Ignition - As Installed Net Power Rating

TSB003 Rules for SAE Use of SI (Metric) Units

2.2.2 Other Publications

Shepard, D.G., "Principles of Turbomachinery," MacMillan.

Keenan and Kaye, "Gas Properties," John Wiley & Sons.

Holman, J.P., "Experimental Methods for Engineers," McGraw-Hill.

3. DEFINITIONS AND TERMINOLOGY

Also refer to SAE J922, Section 2.

3.1 Turbocharger Hardware

3.1.1 FIXED-GEOMETRY TURBOCHARGER

Turbocharger having no moving parts in the aerodynamic flowpath other than the compressor impeller and turbine rotor.

3.1.2 VARIABLE-GEOMETRY TURBOCHARGER

Turbocharger incorporating moving parts such as, but not limited to, compressor inlet guide vanes, variable-geometry compressor diffuser, moveable turbine inlet nozzle vanes (VNT), and/or a wastegate.

3.2 Turbocharger Performance

Also refer to SAE J922, Section 3.

3.2.1 FLOW

Compressor air mass flow = kg/s of air mass flow through the compressor.

Corrected compressor air mass flow =

$$\text{Compressor air mass flow} \times \frac{\sqrt{(T_1(\text{Compressor inlet total absolute temperature (K)})/298\text{K})}}{(P_1(\text{Compressor inlet total absolute pressure (kPa)})/100\text{kPa})} \quad (\text{Eq. 1})$$

Turbine gas flow = kg/s of gas flow through the turbine

$$\text{Turbine gas flow parameter} = \frac{\text{Turbine gas flow} \times \sqrt{T_3(\text{Turbine inlet total absolute temperature (K)})}}{P_3(\text{Turbine inlet total absolute pressure (kPa)})} \quad (\text{Eq. 2})$$

3.2.2 PRESSURE RATIO (EXPANSION RATIO)

$$\text{Compressor pressure ratio} = \frac{P_2(\text{Outlet air total absolute pressure (kPa)})}{P_1(\text{Inlet air total absolute pressure (kPa)})} \quad (\text{Eq. 3})$$

$$\text{Turbine expansion ratio} = \frac{P_3(\text{Inlet gas total absolute pressure (kPa)})}{P_4(\text{Outlet gas static absolute pressure (kPa)})} \quad (\text{Eq. 4})$$

3.2.3 EFFICIENCY

$$\text{Compressor efficiency} = \frac{\text{Isentropic total enthalpy rise across compressor stage calculated using compressor pressure ratio}}{\text{Actual total enthalpy rise across compressor stage}} \quad (\text{Eq. 5})$$

$$\text{Combined turbine x mech. efficiency} = \frac{\text{Actual total enthalpy rise across compressor stage}}{\text{Isentropic total enthalpy drop across turbine stage calculated using turbine expansion ratio}} \quad (\text{Eq. 6})$$

3.2.4 SPEED PARAMETER

$$\text{Corrected compressor speed} = \frac{\text{Compressor impeller speed } \left(\frac{r}{min}\right)}{\sqrt{\frac{T_1(\text{Compressor inlet total absolute temperature (K)})}{298K}}} \quad (\text{Eq. 7})$$

$$\text{Turbine speed parameter} = \frac{\text{Turbine rotor speed } \left(\frac{r}{min}\right)}{\sqrt{T_3(\text{Turbine inlet total absolute temperature (K)})}} \quad (\text{Eq. 8})$$

3.2.5 SURGE

Surge is indicated as a line on the left-hand side of a compressor map as determined on a steady-flow test stand. Surge is the boundary of an area of severe flow reversal combined with audible coughing and banging. The position of the surge line is influenced by the characteristics of the full compressor-test stand system. Additionally, the practical definition of the surge line has typically been imprecise, making it difficult to compare data from different sources. From a consistency perspective, surge is defined by this standard as the onset of increased fluctuations in compressor outlet pressure. This is recognized as a very conservative approach. A hard surge line at which flow reversal occurs may also be indicated. A more detailed definition is provided below.

3.2.5.1 SOFT SURGE

Complete flow reversal is not present, but there is some degree of separation and flow reversal in the compressor. To provide the most complete information on this, a map of coefficient of variation of pressure, along with the rate at which the pressure is sampled (see 4.2 regarding minimum sampling rate), taken at the compressor inlet (P_1) should be provided as a function of corrected mass flow and compressor pressure ratio. See Figure 1. It is hard to completely differentiate soft surge, because the condition has a gradual onset—as compared to full surge, which is an absolute condition. Industry definitions of soft surge could vary considerably, based on the definition and detection method.

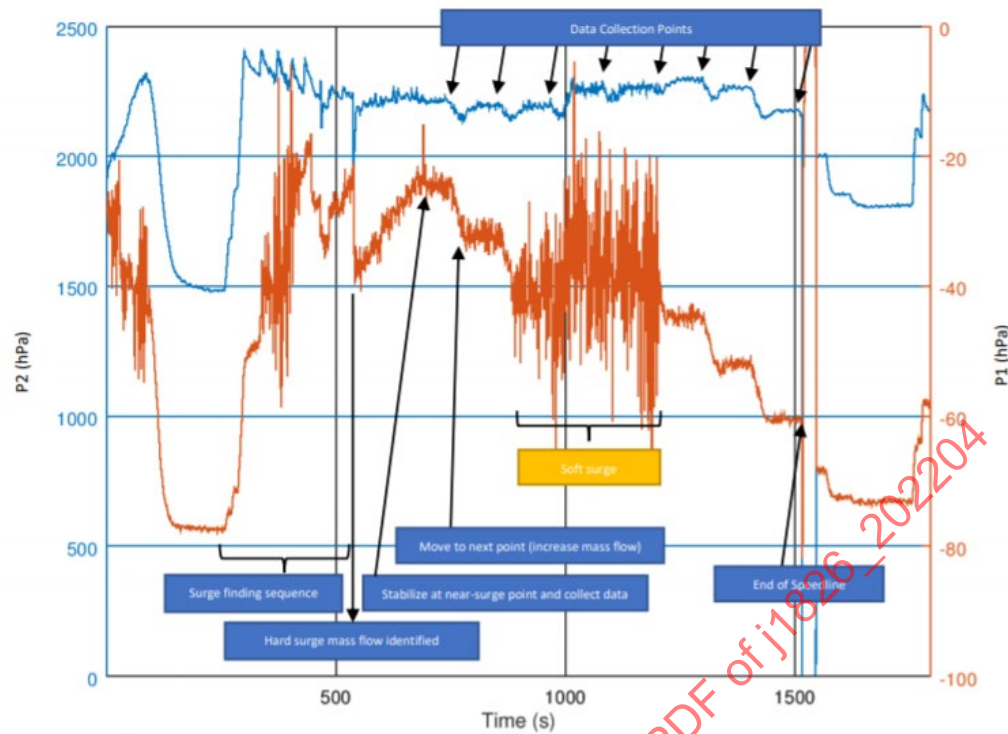


Figure 1 - Illustration of soft surge

NOTE: This time series is from a compressor speed line with a significant amount of soft surge. P2 (blue line) does not show the soft surge as readily as P1 (orange line). Figure 1 shows the pressure signals (1 Hz sample rate) as the test progresses through the surge sequence and test points. Soft surge begins around $t = 800$ seconds.

3.2.5.2 HARD SURGE

Hard surge is defined as complete flow reversal as indicated by pressure fluctuations at the compressor discharge and positive pressure at the compressor inlet. This will be observed as a sharp rise in the level of fluctuation ("knee of the curve") detected in a particular experimental configuration as illustrated in Figure 2 (taken from SAE paper 2015-01-1280).

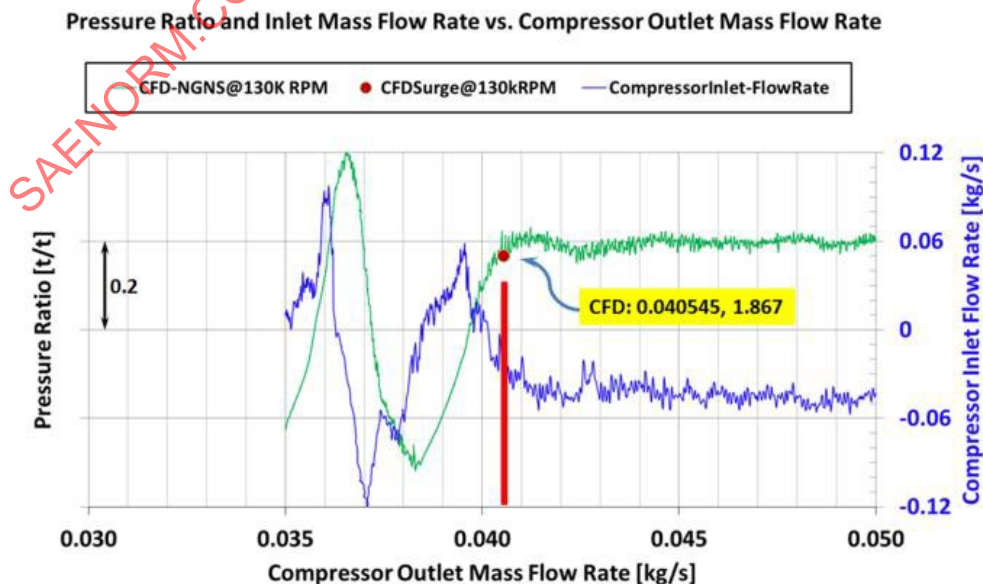


Figure 2 - Illustration of hard surge

3.2.5.3 MEASUREMENT OF HARD SURGE

It is not possible to hold and collect a steady state value at an unsteady point. Use the following iterative process to detect surge: (a) reduce flow until hard surge is detected, (b) quickly move to a higher flow condition that is stable with positive mass flow and record data, (c) slowly decrease flow in sufficiently fine resolution to determine the closest stable point to surge and record data.

3.2.6 CHOKE LINE DEFINITION

Choke is defined as a line on the right-hand side of the compressor map; where flow theoretically reaches Mach 1. On each speed line, the recommended choke point is defined as a minimum of 45% compressor efficiency or as limited by the turbocharger system. However defined, this must be specified on the map.

3.2.7 MEASUREMENT POINTS ALONG A SPEED LINE

A minimum of ten data points, evenly distributed by mass flow, should be taken across each speed line to include the surge point and the choke point as defined above.

3.2.8 SPEED LINES

A minimum of eight speed lines should be taken. With one being the maximum design shaft speed limit.

4. TEST MEASUREMENT AND ACCURACY

The test measurements as follows are required in turbocharger performance determination. The measurement accuracies specified do not include human or other probable errors in the reading.

- 4.1 Airflow $\pm 1\%$ of measured value.
- 4.2 Pressure $\pm 0.5\%$ of measured value. For calculation of the required C.O.V. of P1 and P2, minimum pressure sampling rate of 100 Hz must be used.
- 4.3 Temperature ± 0.5 °C general accuracy. Matched RTDs are recommended for compressor inlet and outlet measurements. Shielded thermocouples are recommended for turbine side measurements but are not required.
- 4.4 Speed $\pm 0.5\%$.
- 4.5 Declared duct diameters at static pressure measuring stations, used in calculating total pressure, must be ± 0.25 mm.

5. APPARATUS/TEST STAND

5.1 Two-Loop Hot Gas Stand

The most commonly used test stand is the independent gas circuit (two-loop) hot gas stand as shown in Figure 3.

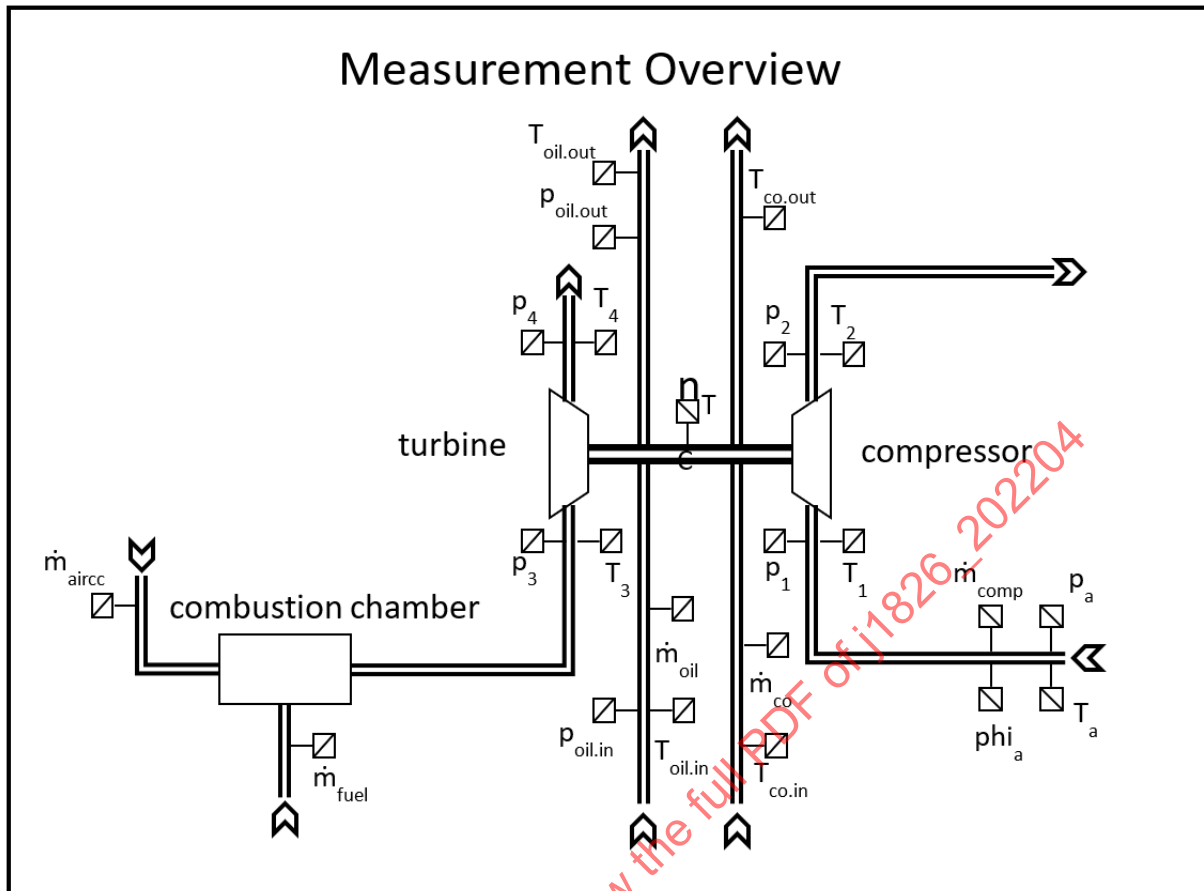


Figure 3 - Two-loop hot gas stand

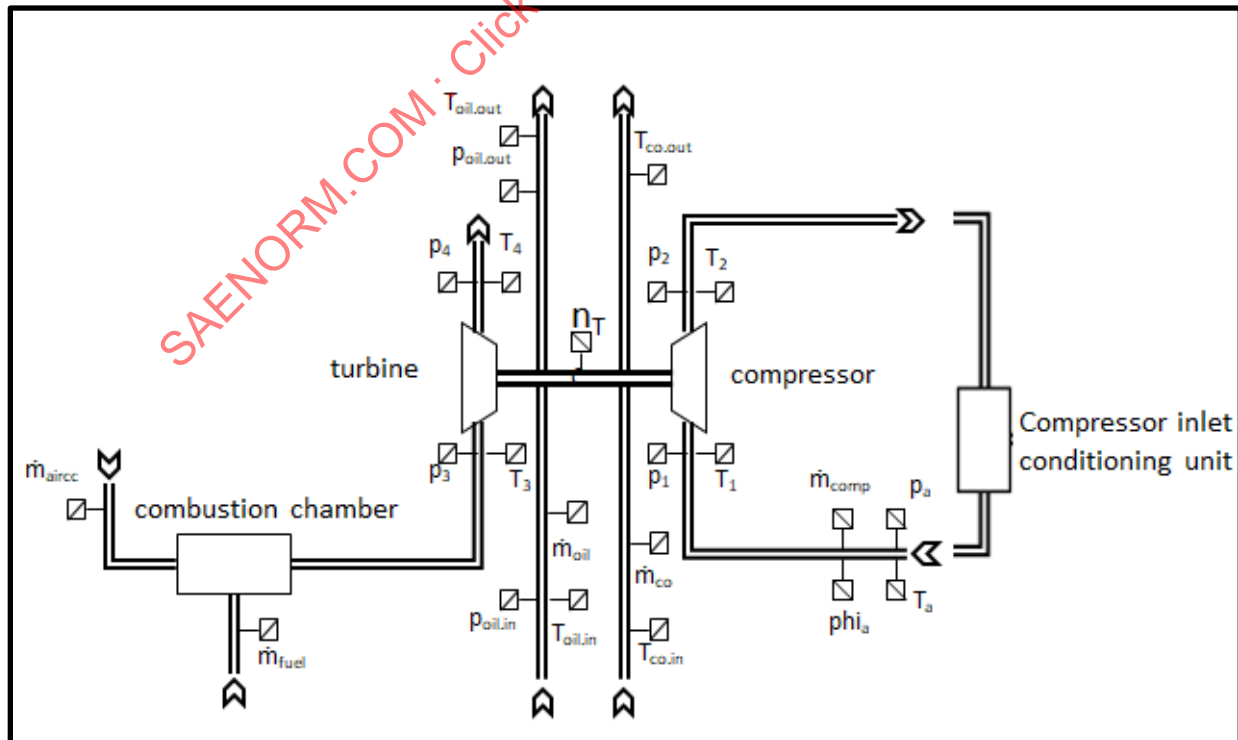


Figure 4 - Closed loop compressor side gas stand

The following guidelines are recommended as best practices for measurement section geometry.

5.1.1 Straight Piping Upstream and Downstream of Measurement Points (MP)

At all four locations around the turbocharger the piping shall be straight for at least 10D (diameters) distance from the turbo to enable flow settling before and after each measurement location. The cross-sectional areas of the pipes at the measurement locations shall match the corresponding inlet/outlet cross-sections as closely as possible. However, if the maximum flow velocity in the tube exceeds 0.3M or if the diameter at the turbocharger interface is below 25 mm, the diameter of the measurement tube shall be larger and the diameter shall be adapted with conical connectors of maximum 15 degree cone angle. The location of measurement points on compressor side is shown in Figure 5.

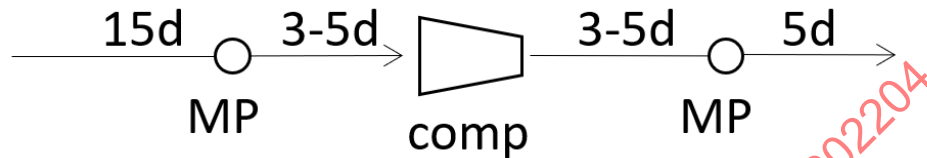


Figure 5

5.1.2 Flow Straighteners Upstream of Compressor

If there are any flow disturbances before compressor inlet, for example bends or other changes because of cabin set up or due to closed loop operation, flow straighteners shall be installed. Bends or area changes after straighteners are not allowed. The set up of measurement locations when using flow straighteners is shown in Figure 6.

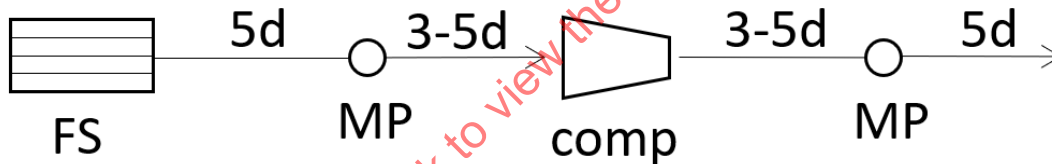


Figure 6

5.1.3 Flow Straighteners Upstream of Turbine

On the turbine side, if flow straighteners are used and the measurement points shall be installed according to Figure 7.

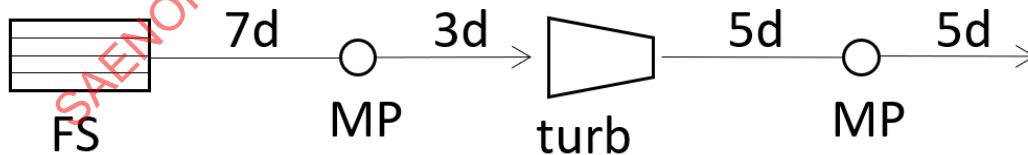


Figure 7

where:

d = tube diameter

MP = measuring point

comp = compressor

turb = turbine

FS = flow straightener

5.1.4 Non-Standard or Application Specific Piping Upstream and/or Downstream of Measurement Points (MP)

The piping of the hot gas test stand will influence the measured maps. For experimental set-ups where the compressor and/or turbine will be tested with vehicle specified air induction systems or exhaust manifolds, the specifications above regarding the turbine side do not have to be fulfilled in all points. Non-standard setups should be declared on the respective compressor and turbine maps. Similarly, installation of pipe bends in the immediate vicinity of the turbocharger should also be identified. In this case, the declaration of measurement points shall be reviewed in conversation between supplier and customer.

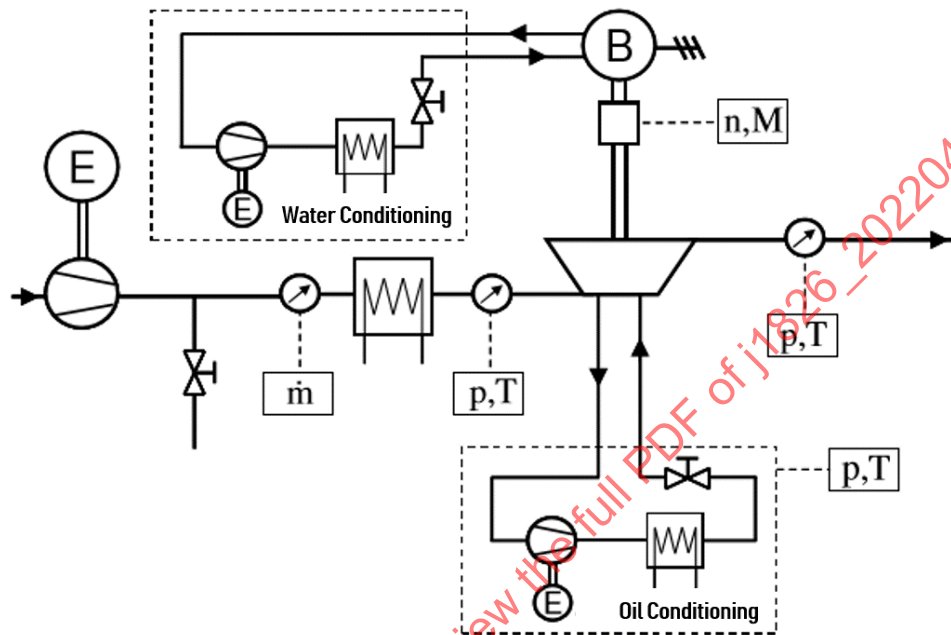


Figure 8 - Turbine dynamometer

6. TEST PROCEDURE

6.1 Installation

Extraordinary nonproduction gaskets, sealants, etc., shall not be used. The orientation of the centerline of the shaft shall be horizontal within ± 15 degrees. Oil drain orientation should also be within ± 15 degrees horizontal and unrestricted.

6.1.1 Leak Checking

In many production turbochargers, some small leakage is expected. However, leakage in the test stand and instrumentation shall be limited to that of good laboratory practice.

6.1.2 Insulation

6.1.2.1 The compressor housing (cover) shall not be insulated, but it is recommended that the air temperature in the test facility should be tightly controlled to $25\text{ °C} \pm 2\text{ °C}$. Not insulating the turbocharger helps to ensure the isentropic nature of the compressor map for use in engine simulations. Excessive air velocity (from test cell air handling equipment) across the turbocharger can also influence the measured map and thus should be avoided.

6.1.2.2 The turbine housing should normally not be insulated. Exceptions can be made for specific applications using an insulated turbine housing or heat shields, but in that case, the use of the insulation must be called out on the map.

6.1.2.3 All ducting to and from both the compressor and turbine should be insulated where practical.

6.1.3 Lubrication

- 6.1.3.1 The turbocharger shall be supplied with lubricating oil at $400 \text{ kPag} \pm 20 \text{ kPa}$ and $90 \text{ }^{\circ}\text{C} \pm 2 \text{ }^{\circ}\text{C}$ unless otherwise specified by the manufacturer for application-specific performance and called out on the map. Viscosity of the oil should be matched to the specific application and noted on the map. In the absence of a manufacturer's specification for light-duty applications, SAE5W20 oil is recommended; for heavy-duty applications, SAE15W40 oil is recommended.

6.1.4 Cooling Liquid

- 6.1.4.1 For aerodynamic characterization, turbocharger housings are tested dry, with no insulation or cooling liquid (except as noted in 6.1.2). For any turbocharger housings which are ordinarily liquid cooled in the end application, testing can be performed with a supply of the appropriate coolant. In this event, the coolant should be supplied at a temperature of $90 \text{ }^{\circ}\text{C} \pm 2 \text{ }^{\circ}\text{C}$ and 130 kPag coolant inlet pressure and the coolant inlet and outlet temperatures, mass flow and coolant specific heat need to be measured and recorded. If there are any deviations to the coolant supply temperature and coolant pressure it must be noted.

6.2 Operating Conditions

Common practice is to begin testing at the lowest desired speed and move from high flow to low flow (surge) on the speed line.

6.2.1 Stabilization Criteria

Data shall not be taken until thermodynamic stability is achieved (example: successive computations of compressor efficiency shall vary by less than 1/2%). Additionally the boundary and operating conditions at the turbocharger (mass flow, turbocharger speed, pressure and temperatures) must be held at steady-state conditions (within 1/2% over a 10 second period) during data acquisition.

The minimum time required to reach thermodynamic steady state is a function of turbocharger size and flow range. It is recommended to allow at least 45 seconds per point to reach stability. In some cases, more time is required.

6.2.2 Turbine Inlet Gas Temperatures

Standard gas temperature for turbine inlet is $600 \text{ }^{\circ}\text{C} \pm 10 \text{ }^{\circ}\text{C}$. It is important to control to this temperature as closely as possible due to the heat transfer effects on efficiency calculations. The turbine inlet temperature shall be called out on the map. A single turbine inlet temperature must be maintained across the entire map.

Non-standard maps may be acquired at other turbine inlet temperatures. On all compressor maps, the turbine inlet temperature must be noted on the map. The turbine temperature has been observed to have a marked effect on measured compressor efficiency.

6.2.3 Compressor Inlet Conditions

6.2.3.1 Compressor Inlet Temperature

298 K (25 °C).

6.2.3.2 Compressor Inlet Pressure

100 kPa.

6.2.3.3 Compressor Inlet Humidity

30 to 70% relative humidity; for extremely dry or humid conditions, corrections to the thermodynamic calculations must be made.

6.3 Testing of Variable Geometry Turbochargers

For any variable geometry device, it is necessary to run maps with the variable devices in multiple positions. For example, the testing should be done in the maximum and minimum practical flow settings and a reasonable number of intermediate positions with a minimum of three intermediate positions for a total of five positions if the hardware is capable. Include peak efficiency.

6.3.1 Compressor Testing When Driven by a Variable Geometry Turbine

Actuation for a variable geometry turbine should be set to the mid-flow position, or a position where the full compressor map can be measured, and locked for the duration of the test. The tested position should be noted in the map data file.

6.3.2 For turbochargers equipped with a wastegate, the turbine maps and compressor maps need only be generated with the wastegate in the closed position.

7. DATA ACQUISITION AND COMPUTATIONS

7.1 Minimum data to be recorded are summarized here:

Table 1 - Test variables to be measured

Property	Description	Unit
T_1	Air temperature before compressor	°C
T_2	Air temperature after compressor	°C
T_3	Exhaust gas temperature before turbine	°C
T_4	Exhaust gas temperature after turbine	°C
$T_{co.in}$	Coolant inlet temperature	°C
$T_{co.out}$	Coolant outlet temperature	°C
$T_{oil.in}$	Oil inlet temperature	°C
$T_{oil.out}$	Oil outlet temperature	°C
T_a	Ambient temperature	°C
p_1	Static air pressure before compressor (absolute)	kPa
p_2	Static air pressure after compressor (absolute)	kPa
p_3	Static exhaust gas pressure before turbine (absolute)	kPa
p_4	Static exhaust gas pressure after turbine (absolute)	kPa
$p_{oil.in}$	Absolute oil inlet pressure	kPa
$p_{oil.out}$	Absolute oil outlet pressure	kPa
p_a	Ambient pressure	kPa
n_{TC}	Turbo charger speed	1/min
$\dot{m}_{fuel}$	Fuel mass flow	kg/s
$\dot{m}_{aircc}$	Combustion chamber air mass flow	kg/s
$\dot{m}_{comp}$	Compressor mass flow	kg/s
$\dot{m}_{co}$	Coolant mass flow	kg/s
$\dot{m}_{oil}$	Oil mass flow	kg/s
ϕ_a	Relative ambient humidity	%
pos_{WG}	WG actuator position	%
pos_{VTG}	VTG actuator position	%
T_{cci}	Air temperature entering combustion chamber	°C
P_{cci}	Air pressure entering combustion chamber	kPa
RH_{cci}	Air relative humidity entering combustion chamber	%

7.2 Gas Properties

As most industry test facilities have proprietary methods for calculating the compressor and turbine efficiency reported in the SAE data format along with the air and exhaust gas properties used in the compressor and turbine efficiency calculations; SAE does not specify a standard method for calculating the exhaust gas enthalpies, or specific heat values. Commercially available software packages and/or other methods may be used to obtain these properties which are very specific to the fuel on the specific test stand used to generate the turbocharger maps. The specifics of these calculations are not required as part of the data reporting.

8. DATA PRESENTATION

Also refer to SAE J922, Section 4.

- 8.1 Performance curves for compressor and turbine (with bearing losses included) are shown in Figures 9 and 10. At present, for variable-geometry turbochargers, multiples of the figures shown, each at described fixed-geometry increments, shall be used.

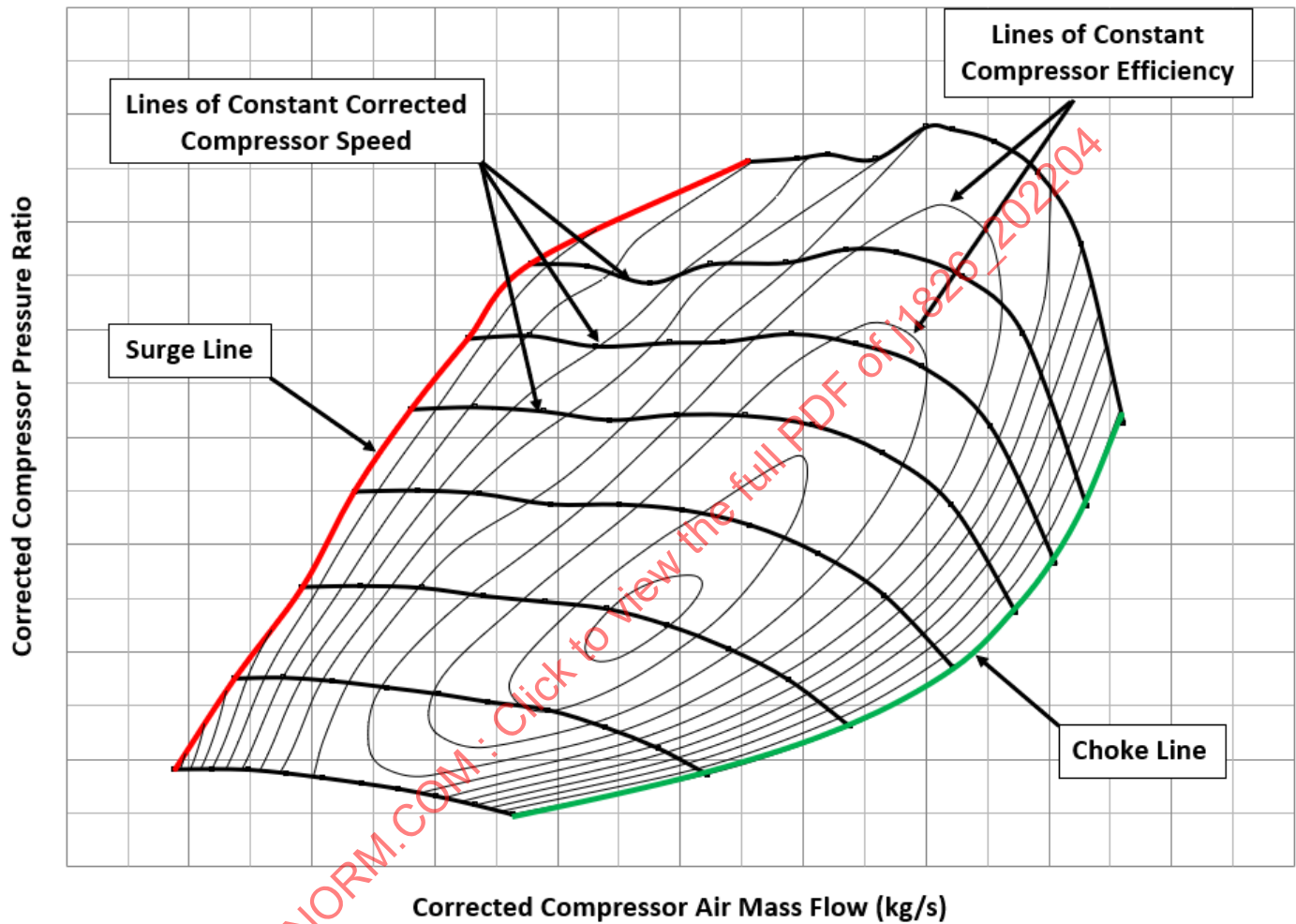


Figure 9 - Sample compressor map
Courtesy of © Borg Warner

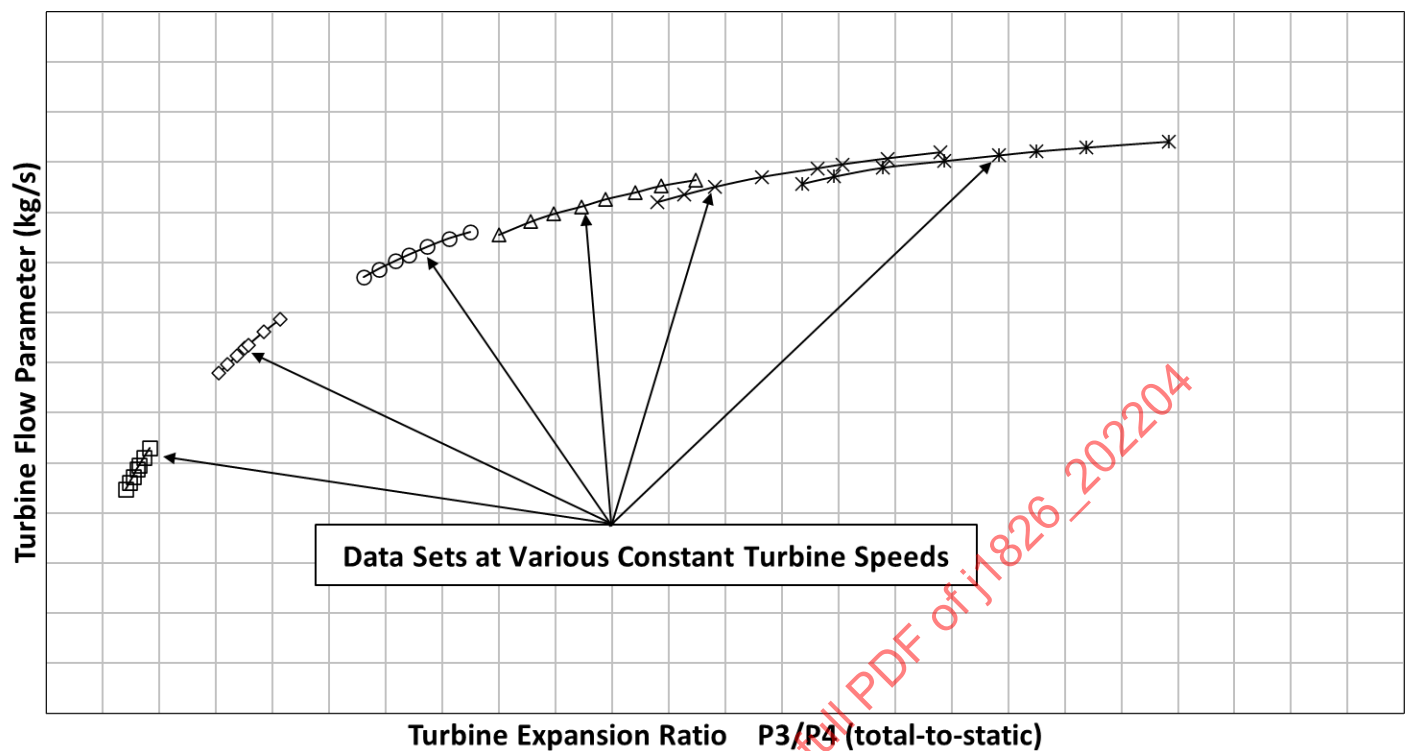


Figure 10 - Sample turbine map

Courtesy of © Borg Warner

8.2 Formatting for electronic data transfer and computer simulation are recommended as follows:

8.2.1 Compressor Data - Header Format (see Figure 11)

8.2.1.1 Compressor description.

8.2.1.2 Inlet measurement section diameter (mm) at pressure measuring station.

8.2.1.3 Outlet measurement section diameter (mm) at pressure measuring station.

8.2.1.4 Inlet type (open or closed loop).

8.2.1.5 Outlet type (open or closed loop).

8.2.1.6 Impeller Inertia (N-m-s²).

8.2.1.7 Lubricating oil type.

8.2.1.8 Lubrication oil temperature.

8.2.1.9 If liquid cooling is used include the following:

8.2.1.9.1 Description of coolant.

8.2.1.9.2 Coolant temperature into the compressor housing.

8.2.1.9.3 Coolant temperature out of the housing.