SAE J1826 APR89

Turbocharger Gas Stand Test Code

**SAE Recommended Practice
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TURBOCHARGER GAS STAND TEST CODE

1. **PURPOSE:**

    The purpose of this SAE Recommended Practice is to provide a recommended 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. The resulting data are intended for use in turbocharger component performance assessment and development and for engine/turbocharger matching.

2. **SCOPE:**

    The test procedures outlined in this recommended practice are applicable to single rotor turbochargers having either fixed- or variable-geometry with the following caveat:

    At this stage in the development of variable-geometry (VG) turbochargers, it would be impractical to generate a detailed practice to cover all types of VG turbochargers which may evolve. However, there is a requirement to quote performance data within a stipulated degree of accuracy and to furnish comprehensive performance information. This will form a basis for this document where further refinements may be added as experience and necessity dictate.

3. **TERMINOLOGY:**

    (See also 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 <u>Variable-Geometry Turbocharger</u>: Turbocharger incorporating moving parts such as, but not limited to, compressor inlet guide vanes, variable-geometry compressor diffusor, moveable turbine inlet nozzle vanes and/or a wastegate.

3.1.3 <u>Auxiliary Equipment</u>: Equipment not directly associated with the compression or expansion processes, but necessary for proper turbocharger/engine system operation, such as:

    a. actuator for variable-geometry device (example: wastegate actuator).

3.2 <u>Turbocharger Performance</u>: (See also SAE J922, section 3.)

3.2.1 <u>Flow</u>:

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

Corrected compressor air mass flow =

$$\frac{\text{Compressor air mass flow} \times \sqrt{\dfrac{\text{Compressor-inlet total absolute temperature (K)}}{298 \text{ K}}}}{(\text{Compressor inlet total absolute pressure (kPa)}/100 \text{ kPa})}$$

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

Turbine gas flow parameter =

$$\frac{\text{Turbine gas flow} \times \sqrt{\text{Turbine-inlet total absolute temperature (K)}}}{\text{Turbine inlet total absolute pressure (kPa)}}$$

3.2.2 <u>Pressure Ratio (Expansion Ratio)</u>:

$$\text{Compressor pressure ratio} = \frac{\text{Outlet-air static absolute pressure (kPa)}}{\text{Inlet-air total absolute pressure (kPa)}}$$

$$\text{Turbine expansion ratio} = \frac{\text{Inlet-gas total absolute pressure (kPa)}}{\text{Outlet-gas static absolute pressure (kPa)}}$$

3.2.3 <u>Efficiency</u>:

$$\text{Compressor efficiency} = \frac{\text{Isentropic enthalpy rise across compressor stage calculated using compressor pressure ratio}}{\text{Actual total enthalpy rise across compressor stage}}$$

3.2.3 (Continued):

Combined turbine x mechanical efficiency =

$$\frac{\text{Actual total enthalpy rise across compressor stage}}{\text{Isentropic enthalpy drop across turbine stage}}$$
calculated using turbine expansion ratio

3.2.4 Speed Parameter:

Corrected compressor speed =

$$\frac{\text{Compressor impeller speed (r/min)}}{\sqrt{\dfrac{\text{Compressor-inlet total absolute temperature (K)}}{298 \text{ K}}}}$$

$$\text{Turbine speed parameter} = \frac{\text{Turbine rotor speed (r/min)}}{\sqrt{\text{Turbine inlet total absolute temperature (K)}}}$$

3.2.5 Surge: 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.

4. TEST MEASUREMENT AND ACCURACY:

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

4.1 Airflow ±1%

4.2 Pressure ±0.5%

4.3 Temperature ±0.5%

4.4 Speed ±0.5%

4.5 Duct diameters at static pressure measuring stations ±0.5%.

5. APPARATUS/TEST STAND:

5.1 2-Loop Hot Gas Stand: The most commonly used test stand is the independent gas circuit (2-loop) hot gas stand as shown in Fig. 1.

5.2 1-Loop (Bootstrap) Hot Gas Stand: Less frequently used for component development and performance. Shown in Fig. 2. Useful for extended durability testing.

5.3 Turbine Dynamometer: Used for extended mapping of turbocharger turbine well outside the range of matched compressor and turbine flow and power. See Fig. 3.

6. TEST PROCEDURE:

6.1 Installation: The test turbocharger shall be representative of the manufacturer's production units. Extraordinary nonproduction gaskets, sealants, etc. shall not be used.

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: The compressor housing (cover) shall be insulated.

6.2 Lubrication: The turbocharger shall be supplied with SAE 30 lubricating oil at 350 kPa and 100°C unless otherwise specified by the manufacturer.

6.3 Cooling Liquid: Normally turbocharger housings are tested dry, with no insulation (except as noted in 6.1.2). However, if any turbocharger housings are ordinarily liquid cooled in the end application, testing can be performed with a supply of the appropriate coolant. In this event, the supply conditions (pressure, temperature and flow rate) shall be agreed upon by the tester and end user, and recorded on the performance maps.

6.4 Operating Conditions: Operating speeds and the number of data points per speedline vary with the turbocharger manufacturer. However, good practice dictates that point and line spacing be sufficiently close that undue interpolation is not necessary. Common practice is to begin testing at the lowest desired speed and move from high flow to low flow (surge) on the speed line.

6.4.1 Stabilization Criteria: Data shall not be taken until reasonable thermal stability is achieved (example: successive computations of compressor $\Delta T/T$ (($T_{out}-in)/T_{in}$) vary by less than 1/2%).

7. DATA ACQUISITION AND COMPUTATIONS:

7.1 Minimum data to be recorded. The instrumentation list accompanying Fig. 3 can be used with appropriate test stand schematic (Figs. 1-3) to identify necessary data. In addition, the upper portions of Figs. 4 and 5 display additional data (held fixed during a given test) to be recorded.

7.2 Gas Properties: Most 2-loop gas stands use diesel fuel as the source of heat for the turbine inlet gas. The following are useful relationships for computation of the gas properties:

7.3 Nomenclature:

T – Temperature, K

$\quad$ K = 273.15 + °C

$\quad$ °C = 5/9 (°F – 32)

$\quad$ K = Degrees Kelvin

$\quad$ °C = Degrees Celsius

$\quad$ °F = Degrees Fahrenheit

γ – Ratio of specific heats

A/F – Gravimetric Air-to-Fuel Ratio

h – Enthalpy, kJ/kg

Cp – Specific Heat, kJ/(kg – K)

R – Gas Constant, kJ/(kg – K)

7.4 Air:

$\gamma_a = 1.42592 - 8.03974 \times 10^{-5}\,T$

$h_a = 0.919848\,T^{1.01457}$

$R_a = 0.28699$

$C_{Pa} = R_a \dfrac{\gamma a}{\gamma a - 1}$

7.5 Combustion Products:

$h_c = 2.3260\,(0.1284 + 2.3 \times 10^{-4}A/F)\,(1.8\,T)^A$

where $A = 1.0954 - 2.967 \times 10^{-4}A/F$

$R_c = 5.38038 \times 10^{-3}\,(53.341 - 0.4425/A/F)$

$C_{Pc} = 4.1868\,(0.0717 + A/F \times 10^{-4})\,(1.8T)^B$

where $B = 0.1883 - 2.903 \times 10^{-4}A/F$

$\gamma_c = C_{Pc} / (C_{Pc} - R_c)$

8. DATA PRESENTATION:

(See also SAE J922, section 4.)

8.1 Performance curves for compressor, turbine and bearing system losses are shown in Figs 4 and 5. At present, for variable-geometry turbochargers, multiples of the figures shown, each at fixed-geometry increments, shall be used.

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

8.2.1 <u>Compressor Data Format</u>:

Line 1:   Description (supplier, model name, compressor nomenclature, reference test number) A15, A10, A20, A10

Line 2:   Inlet diameter (mm), outlet diameter (mm), inlet type, outlet type, impeller inertia (N-m-s^2) F10, F10, A15, A15, F10

Line 3, 4, 5:   Additional comments (can be left blank) A80

Line 6 – N: Corrected speed (r/min), corrected mass flow (kg/s), pressure ratio (T-S), efficiency (decimal) F10, F10, F10, F10

Note: Corrected mass flow rates are listed in ascending order.   Speeds are also listed in ascending order.

Example:

SUPPLIER		ABC1	6789XY-C		87.0323C
76.2	50.0	HOSE		HOSE	0.0678
46250.00	0.032	1.2150	0.5250		
46250.00	0.050	1.2150	0.5800		
46250.00	0.056	1.2100	0.6300		
46250.00	0.065	1.2100	0.6520		
46250.00	0.081	1.2050	0.6550		
46250.00	0.097	1.1800	0.6180		
46250.00	0.116	1.1500	0.5200		
84100.00	0.084	1.8000	0.6850		
84100.00	0.094	1.8100	0.6950		
84100.00	0.116	1.8200	0.7210		
84100.00	0.138	1.8100	0.7200		
84100.00	0.166	1.7600	0.7130		
84100.00	0.191	1.6900	0.6650		
84100.00	0.216	1.5350	0.5370		
105850.00	0.129	2.4200	0.6920		
105850.00	0.143	2.4200	0.7000		
105850.00	0.161	2.4200	0.7110		
105850.00	0.189	2.3800	0.7180		
105850.00	0.210	2.3100	0.7000		
105850.00	0.234	2.1500	0.6380		
105850.00	0.247	1.8600	0.5370		
120300.00	0.154	2.9000	0.6540		
120300.00	0.175	2.9000	0.6700		
120300.00	0.193	2.8750	0.6850		
120300.00	0.218	2.8300	0.6850		
120300.00	0.238	2.6950	0.6520		
120300.00	0.256	2.5000	0.5850		
120300.00	0.261	2.1500	0.5000		

8.2.2 <u>Turbine Data Format</u>:

Line 1:   Description (supplier, model name, turbine nomenclature, reference test number) A15, A10, A20, A10

Line 2:   Test compressor, housing type, discharge connection description A20, A20, A20

Line 3:   Inlet gas temperature (°C) or turbine inlet-to-compressor discharge temperature ratio (K/K), oil type, oil temperature (°C), rotor/shaft inertia (N-m-s^2) F10, A10, F10, F10

Line 4:   Cooling liquid description (if any), inlet temperature (°C), inlet pressure (kPa) A20, F10, F10

Line 5, 6, 7:   Additional comments (can be blank) A80

Line 8 – N: Speed parameter (r/min–$\sqrt{K}$), mass flow parameter (kg–$\sqrt{K}$/s–kPa), expansion ratio (T–S), turbine x mechanical efficiency (decimal) F10, F10, F10, F10

Note: Expansion ratios are listed in ascending order. Speeds are also listed in ascending order.

Example:

```
SUPPLIER        ABC1         6789XY-T         87.0323T
ABC1   6789XY-C      HI SILICON              107.5 MM MARMAN
3.1       10W30        100.0         0.1442
NONE        0           0

    2100.00       0.074       1.1390       0.5060
                        .
                        .
                        .
            Progression similar to compressor
                        .
                        .
                        .
    4840.00       0.142       2.7580       0.6180
```

9. <u>REFERENCES</u>:

SAE J244 JUN83, Measurement of Intake Air or Exhaust Gas Flow of Diesel Engines

SAE J916 MAY85, Rules for SAE Use of SI (Metric) Units

SAE J1349 JUN85, Engine Power Test Code--Spark Ignition and Diesel

Principles of Turbomachinery, D. G. Shepherd, MacMillan

9. (Continued):

Gas Properties, Keenan and Kaye, John Wiley & Sons

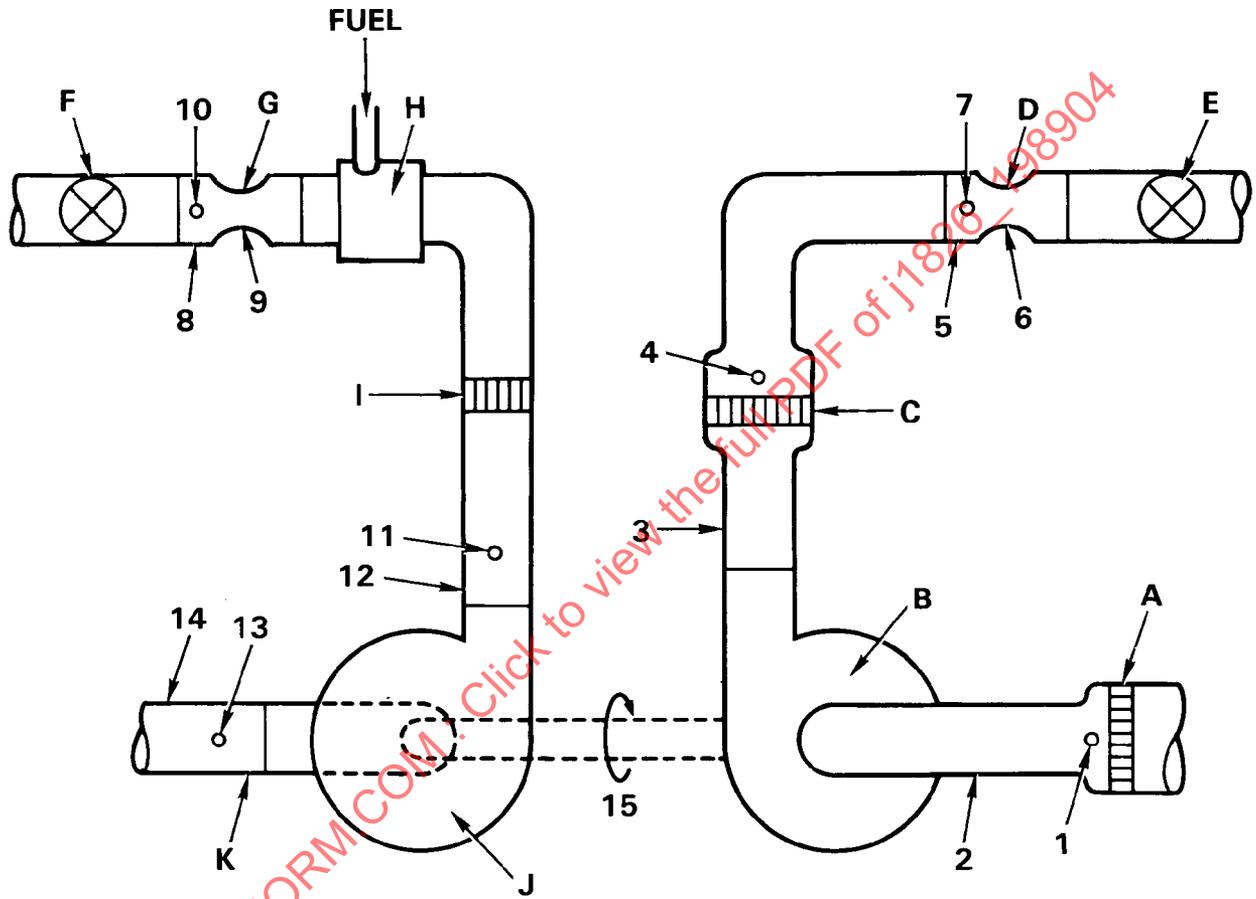Experimental Methods for Engineers, J. P. Holman, McGraw-Hill

FUEL

FIGURE 1 - 2-Loop Hot Gas Stand
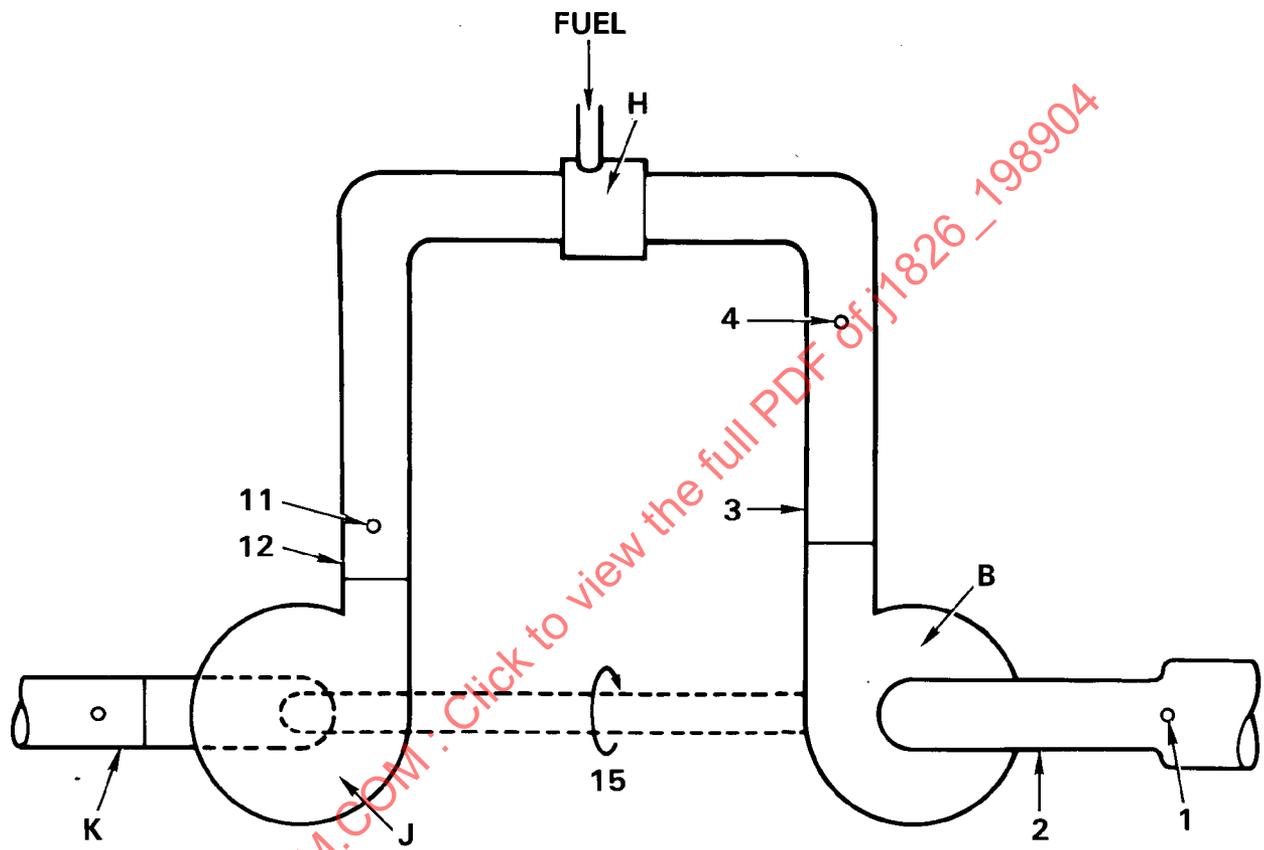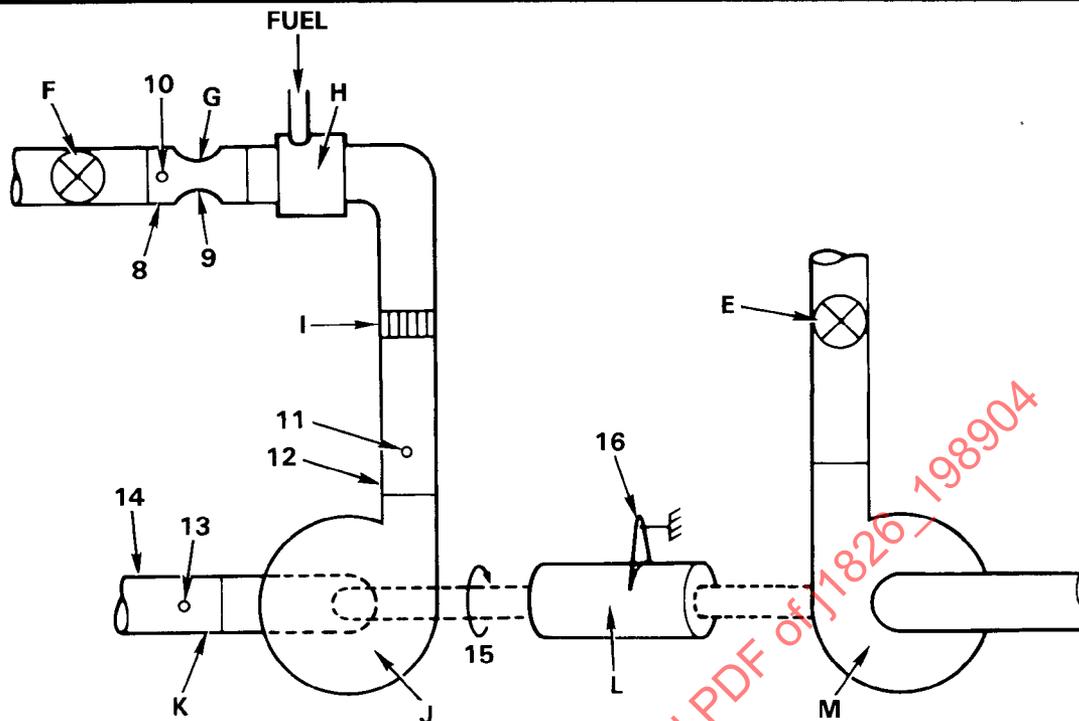
FIGURE 2 - 1-Loop (Bootstrap) Hot Gas Stand

COMPONENTS

A COMPRESSOR INLET FLOW STRAIGHTENER
B COMPRESSOR STAGE
C COMPRESSOR DISCHARGE FLOW STRAIGHTENER
D COMPRESSOR FLOW MEASURING SECTION
E COMPRESSOR THROTTLE VALVE
F TURBINE THROTTLE VALVE
G TURBINE FLOW MEASURING SECTION
H BURNER
I TURBINE INLET FLOW STRAIGHTENER
J TURBINE STAGE
K DISCHARGE DUCT
L DYNAMOMETER
M LOAD COMPRESSOR (OPTIONAL)

INSTRUMENTATION

1 COMPRESSOR INLET TOTAL TEMPERATURE
2 COMPRESSOR INLET STATIC PRESSURE
3 COMPRESSOR DISCHARGE STATIC PRESSURE
  (TOTAL OPTIONAL)
4 COMPRESSOR DISCHARGE TOTAL TEMPERATURE
5 FLOW MEASURING SECTION INLET STATIC
  PRESSURE
6 PRESSURE DIFFERENTIAL
7 FLOW MEASURING SECTION TOTAL TEMPERATURE
8 FLOW MEASURING SECTION INLET STATIC
  PRESSURE
9 PRESSURE DIFFERENTIAL
10 FLOW MEASURING SECTION TOTAL TEMPERATURE
11 TURBINE INLET TOTAL TEMPERATURE
12 TURBINE INLET TOTAL PRESSURE
   (STATIC OPTIONAL IF TOTAL CALCULATED)
13 TURBINE DISCHARGE TOTAL TEMPERATURE
14 TURBINE DISCHARGE STATIC PRESSURE
15 SHAFT SPEED
16 TORQUE

NOTE:
RECOMMENDED TURBINE DISCHARGE PIPE DIAMETER (D_2) TO BE BETWEEN 1.0 AND 1.5 TIMES THE ROTOR EXIT
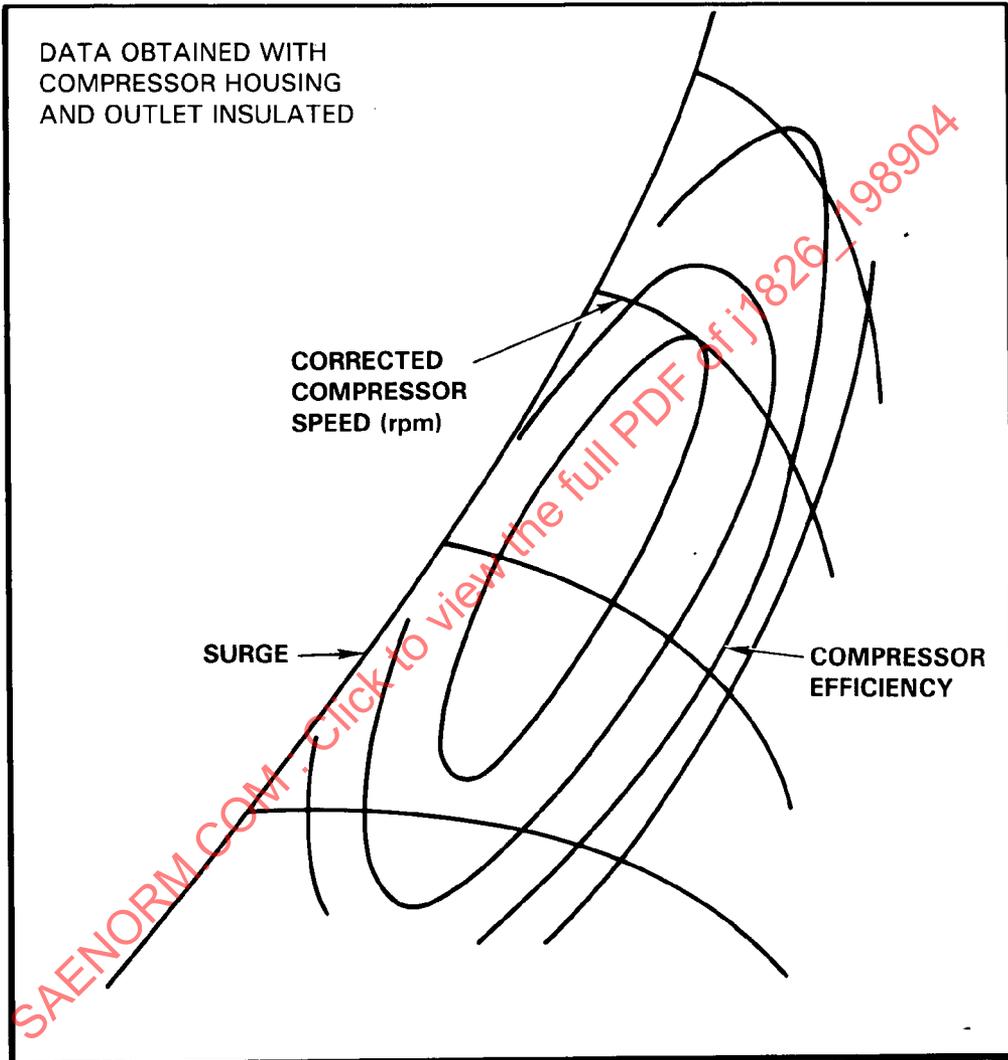DIAMETER (D_1). STATIC PRESSURE TAPS TO BE PLACED 2 TO 3 PIPE DIAMETERS (L) DOWNSTREAM OF ROTOR

FIGURE 3 – Turbine Dynamometer

INLET DIA._____(mm)*   * =   AT PRESSURE
OUTLET DIA._____(mm)*   MEASURING STATIONS
INLET TYPE:_____
OUTLET TYPE:_____
IMPELLER INERTIA:_____(N-m-s^2)

DATA OBTAINED WITH
COMPRESSOR HOUSING
AND OUTLET INSULATED

CORRECTED
COMPRESSOR
SPEED (rpm)

SURGE →

COMPRESSOR
EFFICIENCY

COMPRESSOR PRESSURE RATIO (TOTAL-TO-STATIC)

CORRECTED COMPRESSOR AIR MASS FLOW (kg/s)

FIGURE 4 – Typical Turbocharger Compressor Performance Graph