Technical Report

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Recommended Practice for Determining Exhaust Emissions from Heavy-Duty Engines Under Transient Conditions

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NOTICE

Technical Reports do not necessarily represent final EPA decisions or positions. They are intended to present technical analysis of issues using data which are currently available. The purpose in the release of such reports is to facilitate the exchange of technical information and to inform the public of technical developments which may form the basis for a final EPA decision, position or regulatory action.

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Office of Air and Waste Management
U.S. Environmental Protection Agency

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I. Foreward

The Emission Control Technology Division (ECTD) of EPA has been involved in the development of transient engine cycles and the associated test procedures for some time now. The attached recommended practice is the culmination of these efforts. The procedures described in this recommended practice are currently being used by EPA and a contractor in the performance of baseline testing of 1969 and 1973 heavy-duty (HD) engines.

These procedures are expected to form the basis for new test procedures that will be implemented concurrently with the new, more stringent emission levels for 1983 model year HD vehicles. The more stringent emission standards are required by the Clean Air Act Amendments of August 1977. A Notice of Proposed Rulemaking (NPRM) incorporating the new standards and transient test procedure will be forthcoming.

The test procedure consists of a cold start transient engine test after a minimum 12-hour soak. A hot start test follows the cold start test after a hot soak of 20 minutes. The exhaust emissions are diluted with ambient air and a continuous proportional sample is collected for analysis, during the cold and hot start tests. A constant volume sampler (CVS) is required to obtain a continuous proportional emission sample. The recommended practice, as written, assumes that emissions will be bagged over the cold start test and the hot start test. Consequently, only two sample bags need analyzing. However, any number of bags may be used. A minimum of two bag samples are required though.

Organizationally, the attached test procedure is arranged in a format similar to the light-duty vehicle (LDV) emission regulations. In fact, certain sections are copied nearly verbatim (e.g., §86.1309 Exhaust gas sampling system and §86.1319 CVS calibration). The sections that are in common with LDV are identified with a check mark next to the section number. In the upcoming NPRM common sections may not be repeated, instead they may only be referenced. However, for completeness all common sections are included in this recommended practice.

Finally, EPA has issued a number of technical reports relating to the development of the transient test procedure. The following list summarizes all pertinent reports issued to date. Any report listed may be obtained from the EPA Mobile Source Air Pollution Control Laboratory in Ann Arbor, Michigan.

EPA Report Number	Technical Report Title	Author	Date
HDV 76-03	Engine Horsepower Modeling for Diesel Engines	C. France	Oct. 1976
HDV 76-04	Engine Horsepower Modeling for Gasoline Engine	L. Higdon	Dec. 1976
HDV 77-01	Selection of Transient Cycles for Heavy-Duty Engines	T. Wysor & C. France	Nov. 1977
HDV 78-01	Category Selection for Transient Heavy-Duty Chassis and Engine Cycles	C. France	May 1978
HDV 78-02	Selection of Transient Cycles for Heavy-Duty Vehicles	T. Wysor & C. France	June 1978
HDV 78-03	Truck Driving Patterns and Use Survey, Phase II, Final Report, Part II Los Angeles	L. Higdon	May 1978
HDV 78-04	Transient Cycles Arrangement for Heavy-Duty Engine and Chassis Emission Testing	C. France	July 1978
HDV 78-05	Analysis of Hot/Cold Cycle Requirements for Heavy-Duty Vehicles	C. France	July 1978
HDV 78-06	A Preliminary Examination of the Repeatability of the Heavy-Duty Transient Dynamometer Emission Test	W. Clemmens	June 1978

Other reports available through the National Technical Information Servce (U.S. Dept. of Commerce, 5285 Port Royal Road, Springfield, VA 22161) are:

Report Number	Report Title	Author	Date
APT.D-1523	Heavy Duty Vehicle Driving Pattern and Use Survey, Final Report Part I, New York City	J.C. Cosby, Wilbur Smith & Associates	May 1973
EPA-460/ 3-75-005	Heavy Duty Vehicle Driving Pattern and Use Survey: Part II - Los Angeles Basin Final Report	Wilbur Smith & Associates	Feb. 1974
EPA-460/ 3-77-009	Truck Driving Pattern and Use Survey Phase II - Final Report, Part I	Wilbur Smith & Associates	June 1977

NOTE: The draft final report addressing heavy-duty vehicle cycle development has been submitted to EPA by Olson Laboratories (EPA's heavy-duty cycle development contractor). The report will be available for release about September 1978.

II. Heavy-Duty Transient Emission Test Procedure

§86.1304-83 Section numbering; construction.

(a) The model year of initial applicability is indicated by the section number. The two digits following the hyphen designate the first model year for which a section is effective. A section remains effective until superseded.

Example: Section §86.1311-83 applies to the 1983 and subsequent model years until superseded. If a section §86.1311-85 is promulgated it would take effect beginning with the 1985 model year; §86.1311-83 would apply to model years 1983 and 1984.

(b) A section reference without a model year suffix refers to the section applicable for the appropriate model year.

(c) Unless indicated, all provisions in this subpart apply to both gasoline-fueled and diesel heavy-duty engines.

§86.1305-83 Introduction; structure of subpart.

(a) This subpart describes the equipment required and the procedures to follow in order to perform exhaust emission tests on gasoline-fueled and diesel heavy-duty engines. Subpart A sets forth the testing requirements and test intervals necessary to comply with EPA certification procedures.

(b) Four topics are addressed in this subpart. Sections 86.1306 through 86.1315 set forth specifications and equipment requirements; §§86.1316 through 86.1326 discuss calibration methods and frequency; test procedures and data requirements are listed (in approximately chronological order) in §§86.1327 through 86.1342; and calculation formulas are found in §86.1344.

§86.1306-83 Equipment required and specifications; overview.

(a) This subpart contains procedures for exhaust emissions tests on diesel or gasoline-fueled heavy-duty engines. Equipment required and specifications are as follows:

(1) Exhaust emission tests. All engines subject to this subpart are tested for exhaust emissions. Diesel and gasoline-fueled engines are tested identically with the exception of hydrocarbon measurements; diesel engines require a heated hydrocarbon detector, §86.1309. Necessary equipment and specifications appear in sections 86.1308 through 86.1311.

(2) Fuel, analytical gas, and engine cycle specifications. Fuel specifications for exhaust emission testing and for service accumulation for gasoline-fueled and diesel engines are specified in §86.1313. Analytical gases are specified in §86.1314. The EPA Heavy-Duty Transient Engine Cycles for use in exhaust testing are specified in §86.1315 and Appendix XI.

§86.1307-83 [Reserved]

§86.1308-83 Dynamometer and engine equipment specifications.

(a) Engine dynamometer.

(1) The engine dynamometer system must be capable of transiently controlling engine torque and rpm, simultaneously on a transient cycle. The transient torque, and rpm schedules listed in §86.1315 and Appendix XI must be followed within the accuracy requirements specified in §86.1315. In addition, to these general requirements, the dynamometer shall meet the following accuracy specifications:

(i) Engine speed shall be accurate to within 2 percent of point at all speeds.

(ii) Engine torque at the flywheel shall be accurate to within 3 percent of point at all torque settings above 10 percent of full-scale. Below 10 percent of full-scale the accuracy shall be within 5 percent of point.

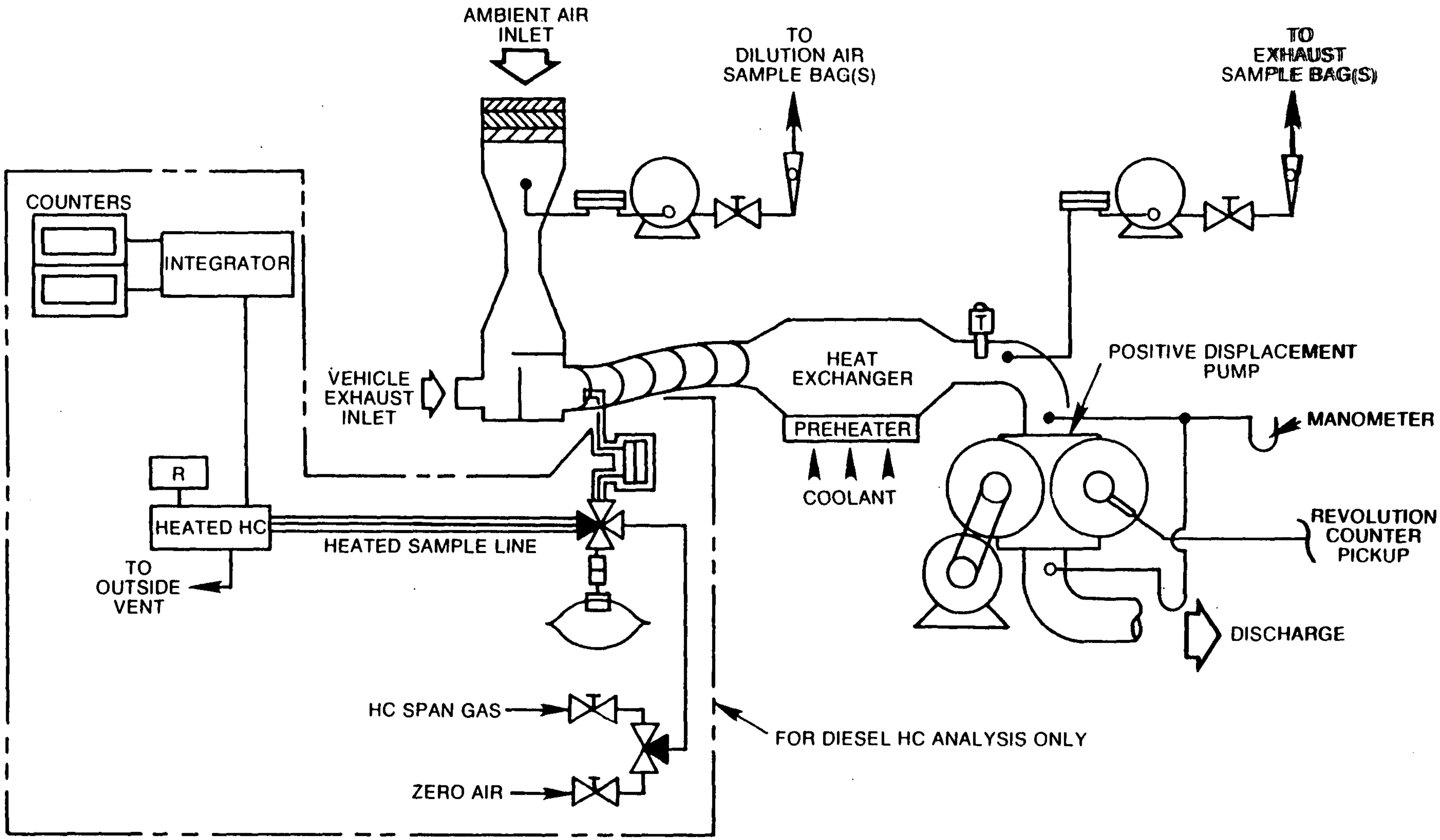
(2) Dynamometer calibration weights. A minimum of 6 calibration weights for each range used are required. The weights must be equally spaced and accurate to 0.5 percent.

§86.1309-83 Exhaust gas sampling system.

(a) (1) General. The exhaust gas sampling system is designed to measure the true mass emissions of engine exhaust. In the CVS concept of measuring mass emissions, two conditions must be satisfied; the total volume of the mixture of exhaust and dilution air must be measured, and a continuously proportioned sample of volume must be collected for analysis. Mass emissions are determined from the sample concentration and total flow over the test period.

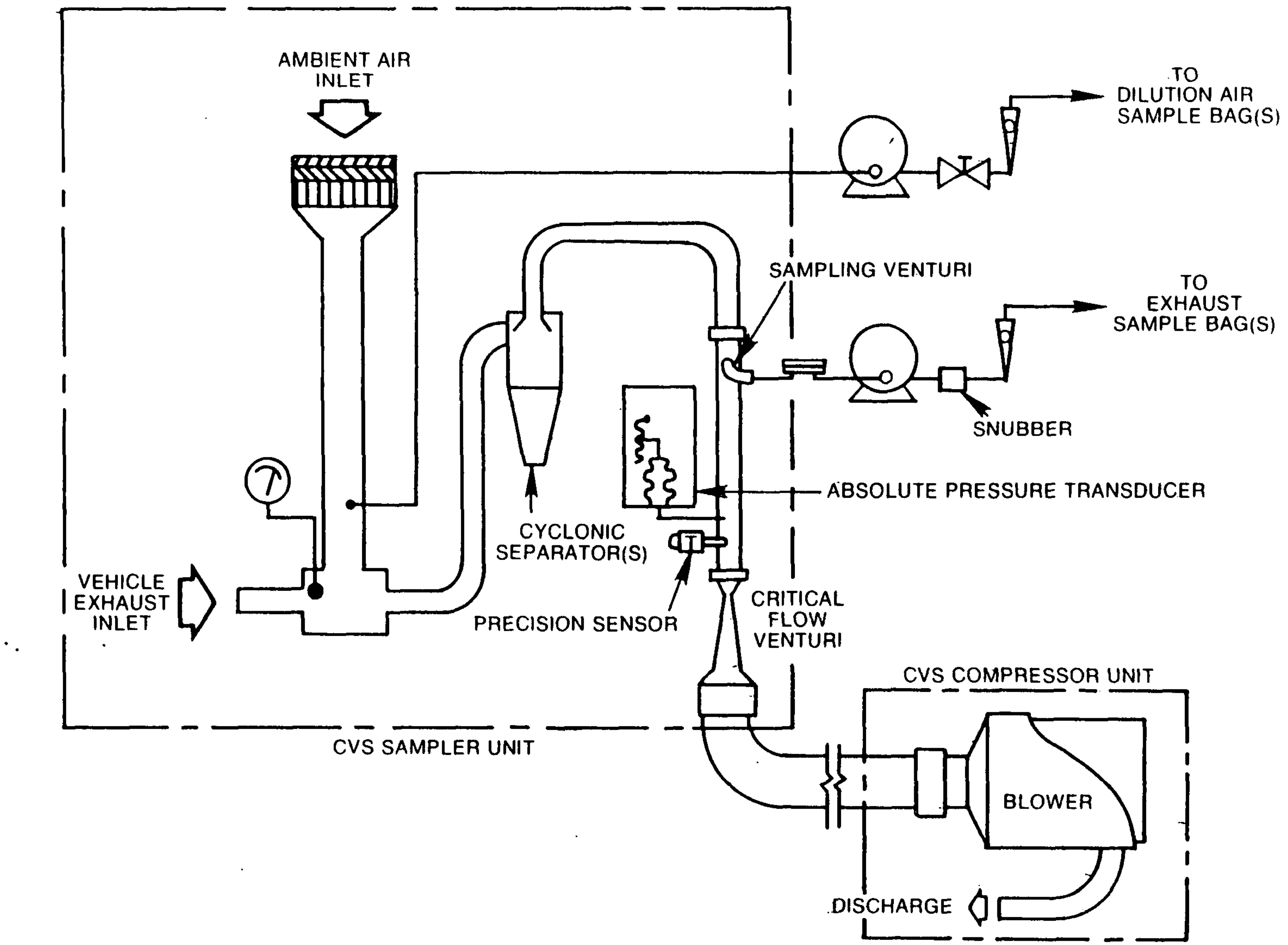
(2) Positive displacement pump. The positive displacement pump - constant volume sampler (PDP-CVS), Figure N83-1, satisfies the first condition by metering at a constant temperature and pressure through the pump. The total volume is measured by counting the revolutions made by the calibrated positive displacement pump. The proportional sample is achieved by sampling at a constant flow rate.

(3) Critical flow venturi. The operation of the critical flow venturi - constant volume sampler (CFV-CVS), Figure N83-2, is based upon the principles of fluid dynamics associated with critical flow. Proportional sampling throughout temperature excursions is maintained by use of a small CFV in the sample line. The variable mixture flow rate is maintained at sonic velocity, which is directly proportional to the



(SEE FIG. N83-3 FOR SYMBOL LEGEND)

FIGURE N83-1 — EXHAUST GAS SAMPLING SYSTEM PDP-CVS



(SEE FIG. N83-3 FOR SYMBOL LEGEND)

FIGURE N83-2 — EXHAUST GAS SAMPLING SYSTEM (CFV-CVS) square root of the gas temperature, and is computed continuously. Since the pressure and temperature are the same at both venturi inlets, the sample volume is proportional to the total volume.

(4) Diesel sampling. Diesel engines require a heated flame ionization detector (HFID) for hydrocarbon analysis. The sample must be taken as close as practical to the mixing point of the dilution air and exhaust sample. The HFID, by design, draws its sample at a constant flow rate. Unless compensation for varying flow is made the HFID must be used with a constant flow system to insure a representative sample.

(5) Other systems. Other sampling systems may be used if shown to yield equivalent results, and if approved in advance by the Administrator (e.g., a heat exchanger with the CFV-CVS; an electronic flow integrator without a heat exchanger, with the PDP-CVS; or, for diesel HC measurements, an electronic flow compensator with the CFV-CVS).

(b) Component description, PDP-CVS. The PDP-CVS, Figure D83-1, consists of a dilution air filter and mixing assembly, heat exchanger, positive displacement pump, sampling system, and associated valves, pressure and temperature sensors.

The PDP-CVS shall conform to the following requirements:

(1) Static pressure variations at the tailpipe(s) of the engine shall remain within ± 5 inches of water (1.2 kPa) of the static pressure variations measured during a dynamometer engine cycle with no connection to the tailpipe(s). (Sampling systems capable of maintaining the static pressure to within ± 1 inch of water (0.25 kPa) will be used by the Administrator if a written request substantiates the need for this closer tolerance.)

(2) The gas mixture temperature, measured at a point immediately ahead of the positive displacement pump, shall be within ± 10°F (5.6°C) of the designed operating temperature at the start of the test. The gas mixture temperature variation from its value at the start of the test shall be limited to ± 10°F (5.6°C) during the entire test. The temperature measuring system shall have an accuracy and precision of ± 2°F (1.1°C).

(3) The pressure gauges shall have an accuracy and precision of ± 3 mm Hg (0.4 kPa).

(4) The flow capacity of the CVS shall be large enough to eliminate water condensation in the system.

(5) Sample collection bags for dilution air and exhaust

samples shall be sufficient size so as not to impede sample flow.

(c) Component description, CFV-CVS. The CFV-CVS, Figure D83-2 consists of a dilution air filter and mixing assembly, cyclone particulate separator(s), sampling venturi, critical flow venturi, sampling system, and assorted valves, pressure and temperature sensors.

The CFV-CVS shall conform to the following requirements:

(1) Static pressure variations at the tailpipe(s) of the vehicle shall remain within ± 5 inches of water (1.2 kPa) of the static pressure variations measured during a dynamometer engine cycle wth no connection to the tailpipe(s). (Sampling systems capable of maintaining the static pressure to within ± 1 inch of water (0.25 kPa) will be used by the Administrator if a written request substantiates the need for this closer tolerance.)

(2) The temperature measuring system shall have an accuracy and precision of ± 2°F (1.1°C) and a response time of 0.100 seconds to 62.5 percent of a temperature change (as measured in hot silicone oil).

(3) The pressure measuring system shall have an accuracy and precision of $\pm$ 3 mm Hg (0.4 kPa).

(4) The flow capacity of the CVS shall be large enough to virtually eliminate water condensation in the system.

(5) Sample collection bags for dilution air and exhaust samples shall be of sufficient size so as not to impede sample flow.

§86.1310-83 [Reserved]

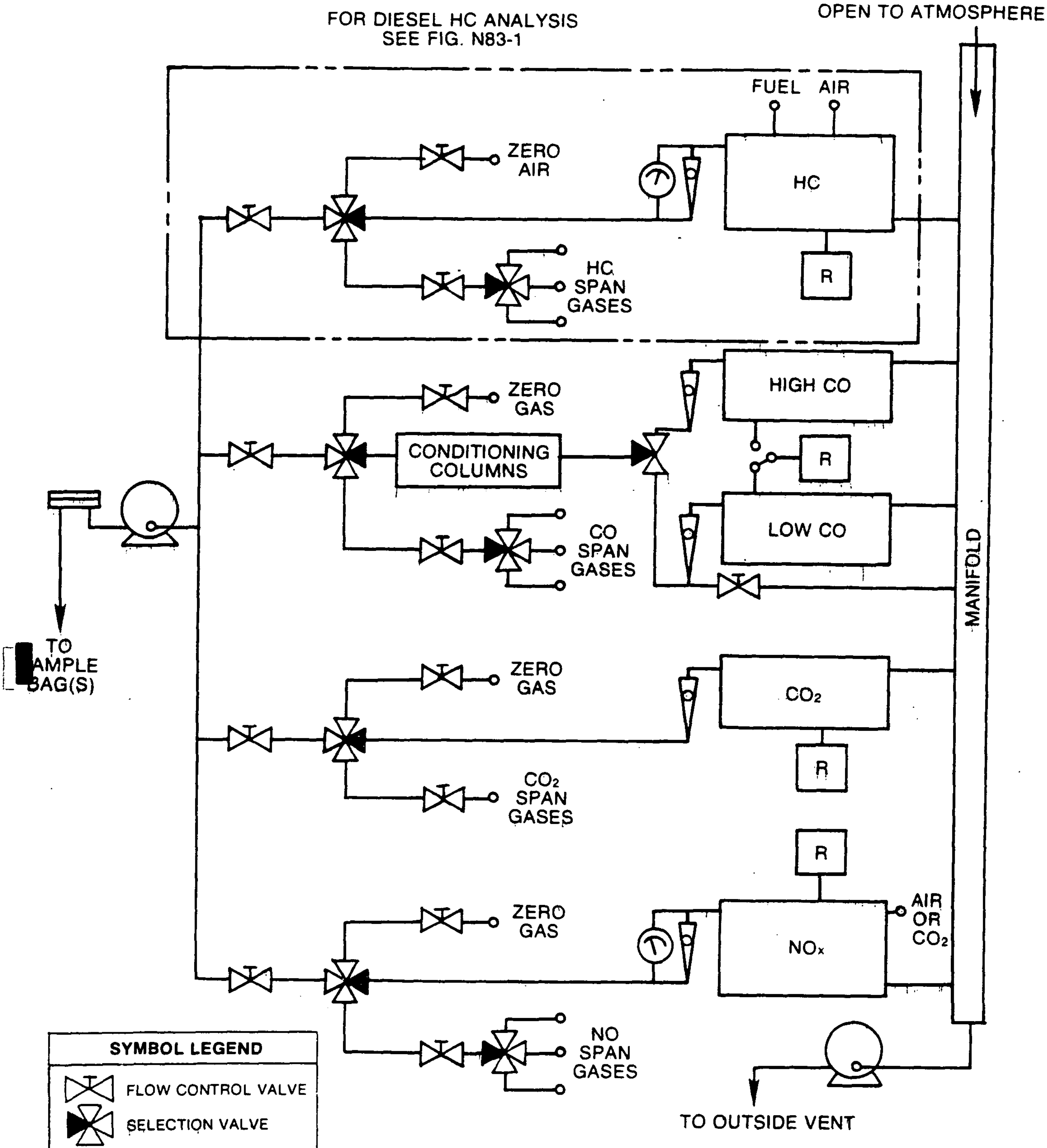
§86.1311-83 Exhaust gas analytical system.

(a) Schematic drawings. Figure N83-3 is a schematic drawing of the exhaust gas analytical system. The schematic of the hydrocarbon analysis train for diesel engines is shown as part of Figure N83-1. Since various configurations can produce accurate results, exact conformance with either drawing is not required. Additional components such as instruments, valves, solenoids, pumps and switches may be used to provide additional information and coordinate the functions of the component systems.

(b) Major component description. The analytical system, Figure N83-3, consists of a flame ionization detector (FID) for the determination of hydrocarbons, nondispersive infrared analyzers (NDIR) for the determination of carbon monoxide and carbon dioxide and a chemiluminescence analyzer (CL) for the determination of oxides of nitrogen. A heated flame ionization detector (HFID) is used for the continuous determination of hydrocarbons from diesel engines, Figure N83-1.

The exhaust gas analytical system shall conform to the following requirements:

(1) The CL requires that the nitrogen dioxide present in the sample be converted to nitric oxide before analysis.



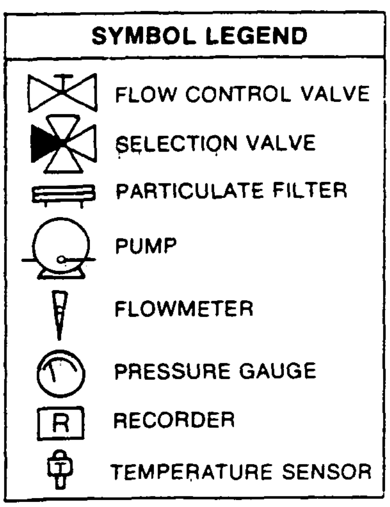


FIGURE N83-3 EXHAUST GAS ANALYTICAL SYSTEM

Other types of analyzers may be used if shown to yield equivalent results and if approved in advance by the Administrator.

(2) The carbon monoxide (NDIR) analyzer may require a sample conditioning column containing $CaSO_4$, or indicating silica gel to remove water vapor and containing ascarite to remove carbon dioxide from the CO analysis stream.

(i) If CO instruments which are essentially free of CO_2 and water vapor interference are used, the use of the conditioning column may be deleted, see §86.1322 and §86.1344.

(ii) A CO instrument will be considered to be essentially free of CO_2 and water vapor interference if its response to a mixture of 3 percent CO_2 in N_2 which has been bubbled through water at room temperature produces an equivalent CO response, as measured on the most sensitive CO range, which is less than 1 percent of full scale CO concentration on ranges above 300 ppm full scale or less than 3 ppm on ranges below 300 ppm full scale, see §86.1322.

(3) For diesel engines a continuous sample shall be measured using a heated analyzer train as shown in Figure N83-1. The train shall include a heated continous sampling line, a heated particulate filter, and a heated hydrocarbon

instrument (HFID) complete with heated pump, filter and flow control system.

(i) The response time of this instrument shall be less than 1.5 seconds for 90 percent of full-scale response.

(ii) Sample transport time from sampling point to inlet of instrument shall be less than 4 seconds.

(iii) The sample line and filter shall be heated to a set point ± 10°F (± 5.6°C) between 300 and 390°F (149 and 199°C).

(c) <u>Other analyzers and equipment</u>. Other types of analyzers and equipment may be used if shown to yield equivalent results and if approved in advance by the Administrator.

§86.1312-83 [Reserved]

§86.1313-83 Fuel specifications.

(a) Gasoline.

(1) Gasoline having the following specifications will be used by the Administrator in exhaust emission testing. Gasoline having the following specifications or substantially equivalent specifications approved by the Administrator, shall be used by the manufacturer in exhaust testing, except that the lead and octane specifications do not apply.

Item	ASTM	Leaded	Unleaded
Octane, research, minimum	D2699	98	93
Pb. (organic), gm/U.S. gallon		1.4(1)	0.00-0.05
Distillation range:			
IBP, °F	D86	75-95	75-95
10 percent point, °F	D86	120-135	120-135
50 percent point, °F	D86	200-230	200-230
90 percent point, °F	D86	300-325	300-325
EP, °F (maximum)	D86	415	415
Sulphur, weight percent, (max)	D1266	0.10	0.10
Phosphorus, gm/U.S. gallon (max)		0.01	0.005
RVP, psi	D323	8.7-9.2	8.7-9.2
Hydrocarbon composition:			
Olefins, percent, (max)	D1319	10	10
Aeromatics, percent (max)	D1319	35	35
Saturates	D1319	(2)	(2)

(1) Minimum.

(2) Remainder.

(2) Gasoline representative of commercial gasoline which will be generally available through retail outlets shall be used in service accumulation. For leaded gasoline the minimum lead content shall be 1.4 grams per U.S. gallon, except that where the Administrator determines that vehicles represented by a test vehicle will be operated using gasoline of different lead content than that prescribed in this paragraph, he may consent in writing to use of a gasoline with a different lead content. The octane rating of the gasoline used shall be not higher than 1.0 Research octane number above the minimum recommended by the manufacturer and have a minimum sensitivity of 7.5 octane numbers, where sensitivity is defined as the Research octane number minus the Motor octane number. The Reid Vapor Pressure of the gasoline used shall be characteristic of the motor fuel used during the season in which the service accumulation takes place.

(3) The specification range of the gasoline to be used under paragraph (a)(2) of this section shall be reported in accordance with §86.083-21(b)(3).

(b) Diesel fuel.

(1) The diesel fuels employed for testing shall be clean and bright, with pour and cloud points adequate for operability. The diesel fuel may contain nonmetallic additives as

follows: Cetane improver, metal deactivator, antioxidant, dehazer, antirust, pour depressant, dye, and dispersant.

(2) Diesel fuel meeting the following specifications, or substantially equivalent specifications approved by the Administrator, shall be used in exhaust emissions testing. The grade of diesel fuel recommended by the engine manufacturer commercially designated as "Type 1-D" or "Type 2-D" grade diesel fuel shall be used.

Item	ASTM	Type 1-D	Type 2-D
Cetane	D613	48-54	42-50
Distillation range:			
IBP °F	D86	330-390	340-400
10 percent point, °F	D86	370-430	400-460
50 percent point, °F	D86	410-480	470-540
90 percent point, °F	D86	460-520	550-610
EP, °F	D86	500-560	580-660
Gravity, °API	D287	40-44	33-37
Total Sulfur, percent	D129 or D2622	0.05-0.20	0.2-0.5
Hydrocarbon composition:			
Aromatics, percent	D1319	8 (1)	27 (1)
Parafins, Naphthenes, Olefins	D1319	(2)	(2)
Flashpoint, °F (minimum)	D93	120	130
Viscosity, Centistokes	D445	1.6-2.0	2.0-3.2

(1) Minimum.

(2) Remainder.

(3) Diesel fuel meeting the following specifications, or substantially equivalent specifications approved by the Administrator, shall be used in service accumulation. The grade of

diesel fuel recommended by the engine manufacturer, commercially designated as "Type 1-D" or "Type 2-D" grade diesel fuel shall be used.

Item	ASTM	Type 1-D	Type 2-D
Cetane (minimum)	D613	42-56	30-58
Distillation range:			
90 percent point, °F	D86	440-530	540-630
Gravity °APM	D287	39-45	30-42
Total sulfur, percent (minimum)	D129 or D2622	0.05(1)	0.2
Flashpoint, °F (minimum)	D93	120	130
Viscosity, centistokes	D455	1.2-2.2	1.5-4.5

(1) Minimum.

(4) Other petroleum distillation fuel specifications:

(i) Other petroleum distillate fuels may be used for testing and service accumulation provided they are commercially available, and

(ii) Information, acceptable to the Administrator, is provided to show that only the designated fuel would be used in customer service, and

(iii) Use of a fuel listed under paragraphs (b)(2) and (b)(3) of this section would have a detrimental effect on emissions or durability, and

(iv) Written approval from the Administrator of the fuel specifications must be provided prior to the start of testing.

(5) The specification range of the fuels to be used under paragraphs (b)(2), (b)(3), and (b)(4) of this section shall be reported in accordance with §86.083-21(b)(3).

§86.1314-83 Analytical gases.

(a) Analyzer gases.

(1) Gases for the CO and CO_2 analyzers shall be single blends of CO and CO_2 respectively using nitrogen as the diluent.

(2) Gases for the hydrcarbon analyzer shall be single blends of propane using air as the diluent.

(3) Gases for the NOx analyzer shall be single blends of NO named as NOx with a maximum NO_2 concentration of 5 percent of the nominal value using nitrogen as the diluent.

(4) Fuel for the FID shall be a blend of 40 $\pm$ 2 percent hydrogen with the balance being helium. The mixture shall contain less than 1 ppm equivalent carbon response. 98 to 100% hydrogen fuel may be used with advance approval of the Administrator.

(5) The allowable zero gas (air or nitrogen) impurity concentrations shall not exceed 1 ppm equivalent carbon response, 1 ppm carbon monoxide, 0.04 percent (400 ppm) carbon dioxide and 0.1 ppm nitric oxide.

(6)(a) "Zero-grade air" includes artificial "air" consisting of a blend of nitrogen and oxygen with oxygen concentrations between 18 and 21 mole percent.

(b) Calibration gases shall be traceable to within 1 percent of NBS gas standards, or other gas standards which have been approved by the Administrator.

(c) Span gases shall be accurate to within 2 percent of true concentration, where true concentration refers to NBS gas standards, or other gas standards which have been approved by the Administrator.

(7) The use of proportioning and precision blending devices to obtain the required gas concentrations is allowable provided their use has been approved in advance by the Administrator.

§86.1315-83 Heavy-duty transient engine cycle.

(a) The heavy-duty transient engine cycles for gasoline-fueled and diesel engines are listed in Appendix XI. These second-by-second listings are designed to represent transient torque and rpm maneuvers characteristic of heavy-duty vehicles. Both rpm and torque are normalized in these listings. To unnormalize rpm use the following equation:

$$\text{Actual RPM} = \frac{\%\text{RPM}(\text{Measured Rated RPM} - \text{Curb Idle RPM})}{100} + \text{Curb Idle RPM}$$

Torque is normalized to the maximum torque at the rpm listed with it. Therefore, to unnormalize the torque values in the cycle, the maximum torque curve for the engine in question must be used. The generation of the maximum torque curve is described in §86.1332.

(b) Example of the unnormalization procedure. The following test point shall be unnormalized:

%RPM	%Torque
43	82

The test engine has these values:

Measured Rated RPM = 3800
Curb Idle RPM = 600
Maximum Torque = $-.823 \times 10^{-11}\ \text{RPM}^4 + .709 \times 10^{-7}\ \text{RPM}^3 - .220 \times 10^{-3}\ \text{RPM}^2 + .286\ \text{RPM} + 25.031$

Calculate actual RPM:

$$\text{Actual RPM} = \frac{\%\text{RPM}(\text{Rated RPM} - \text{Idle RPM})}{100} + \text{Idle RPM}$$

$$\text{Actual RPM} = \frac{43(3800 - 600)}{100} + 600$$

Actual RPM = 1976

Calculate actual torque:

Maximum torque at 43% RPM or 1976 RPM =

$$-.823 \times 10^{-11}(1976^4) + .709 \times 10^{-7}(1976^3)$$
$$-.220 \times 10^{-3}(1976^2) + .286(1976) + 25.031 = 153 \text{ ft-lbs.}$$

(c) Engine speed and torque shall be recorded at least once every second during the cold start test and hot start test. The torque and rpm feedback signals may be electrically filtered.

(d) Cycle validation.

(1) To reduce errors between the feedback and reference (cycle trace) values the engine speed and torque feedback signals may be shifted a maximum of $\pm$ 5 seconds with respect to the reference speed and torque traces. If the feedback signals are shifted, both must be shifted the same amount.

(2) Calculate the brake horsepower for each pair of engine speed and torque values recorded. Also calculate the reference brake horsepower for each pair of engine speed and torque reference values.

(3) Linear regressions of feedback value on reference value shall be performed for speed, torque and brake horsepower. The method of least-square shall be used. The equation shall have the form:

$$y = mx + b$$

where:

y = The estimated feedback (actual) value of speed (in rpm), torque (in ft-lbs.), or brake horsepower.

m = Slope of the regression line.

x = The reference value (speed, torque, or brake horsepower).

b = The y intercept of the regression line.

(4) The standard error of estimate (SE) of y on x and the coefficient of determination (r^2) shall be calculated for each regression line.

(5) All speed points except the initial 24 $\pm$ 1 second idle period of the cold and hot start cycles shall be included when performing the speed regression.

(6) All torque points except the following points shall be included when performing the torque regression:

(i) All torque points measured during the initial 24 ± 1 second idle period of the cold and hot start cycle.

(ii) All torque points where the throttle is wide-open and negative torque error occurs.

(7) All points included in the regression on torque shall be used when performing the regression on brake horsepower.

(8) For a valid test the following criteria must be met for both cycles (cold start and hot start), individually:

(i) Regression line tolerances.

	Speed	Torque	Brake Horsepower
Standard Error of Estimate (SE) of y on x	100 rpm	10% of max. engine torque (in ft-lbs)	5% of maximum brake horsepower
Slope of the Regression Line, m	.970-1.020	.850-1.020	.900-1.020
Coefficient of Determination, r^2	.9700(1)	.8800(1)	.9200(1)
y Intercept of the Regression Line, b	± 50 rpm	± 10.0 ft-lbs.	± 5.0 BHP

(1) Minimum.

(ii) The integrated brake horsepower-hour for each cycle (cold and hot start) shall be between -15% and +5% of the integrated brake horsepower-hour for the reference cycle or the test is void. All torque and speed data points including closed throttle and wide-open throttle must be used to calculate the integrated brake horsepower-hour. The free idle points do not have to be included in the calculation, however if included, the reference cycle and the engine data must be treated in a consistent manner. For the purposes of this calculation, negative torque values (i.e., motoring horsepower) shall be set equal to zero and included.

§86.1316-83 Calibrations; frequency and overview.

(a) Calibrations shall be performed as specified in §§86.1318 through 86.1326.

(b) At least monthly or after any maintenance which could alter calibration, the following calibrations and checks shall be performed:

(1) Calibrate the hydrocarbon analyzer, carbon dioxide analyzer, carbon monoxide analyzer, and oxides of nitrogen analyzer.

(2) Calibrate the engine dynamometer flywheel torque and speed measurement transducers.

(3) Calibrate the engine flywheel torque and speed feedback signals.

(c) At least weekly or after any maintenance which could alter calibration, the following calibrations and checks shall be performed:

(1) Check the oxides of nitrogen converter efficiency, and

(2) Perform a CVS system verification.

(d) The CVS positive displacement pump or critical flow venturi shall be calibrated following initial installation, major maintenance or as necessary when indicated by the CVS system verification (described in §86.1319).

(e) Sample conditioning columns, if used in the CO analyzer train, should be checked at a frequency consistent with observed column life or when the indicator of the column packing begins to show deterioration.

§86.1317-83 [Reserved]

§86.1318-83 Engine dynamometer system calibration.

(a) The engine flywheel torque and engine speed measurement transducers shall be calibrated at least once each month.

(b) The engine flywheel torque and engine speed feedback signal shall be within ±3% and ±2% of the engine flywheel torque and engine speed transducer values, respectively. The torque and speed feedback signals shall be calibrated at least once each month.

(c) Other engine dynamometer system calibrations shall be performed as dictated by good engineering practice and manufacturer's recommendations.

§86.1319-83 CVS calibration.

The CVS is calibrated using an accurate flowmeter and restrictor valve. Measurements of various parameters are made and related to flow through the unit. Procedures used by EPA for both PDP and CFV are outlined below. Other procedures yielding equivalent results may be used if approved in advance by the Administrator.

After the calibration curve has been obtained, verification of the entire system can be performed by injecting a known mass of gas into the system and comparing the mass indicated by the system to the true mass injected. An indicated error does not necessrily mean that the calibration is wrong, since other factors can influence the accuracy of the system, e.g. analyzer calibration. A verification procedure is found in paragraph (c) of this section.

(a) PDP calibration.

(1) The following calibration procedure outlines the equipment, the test configuration, and the various parameters which must be measured to establish the flow rate of the CVS pump. All the parameters related to the pump are simultaneously measured with the parameters related to a flowmeter

which is connected in series with the pump. The calculated flow rate, ft^3/min., (at pump inlet absolute pressure and temperature) can then be plotted versus a correlation function which is the value of a specific combination of pump parameters. The linear equation which relates the pumpflow and the correlation function is then determined. In the event that a CVS has a multiple speed drive, a calibration for each range used must be performed.

(2) This calibration procedure is based on the measurement of the absolute values of the pump and flowmeter parameters that relate the flow rate at each point. Three conditions must be maintained to assure the accuracy and integrity of the calibration curve. First, the pump pressures should be measured at taps on the pump rather than at the external piping on the pump inlet and outlet. Pressure taps that are mounted at the top center and bottom center of the pump drive headplate are exposed to the actual pump cavity pressure, and therefore reflect the absolute pressure differentials. Secondly, the temperature stability must be maintained during calibration. The laminar flowmeter is sensitive to inlet temperature oscillations which cause the data points to be scattered. Gradual changes ($\pm$ 2°F (1.1°C)) in temperature are acceptable as long as they occur over a period of several minutes. Finally, all connections between the flowmeter and the CVS pump must be absolutely void of any leakage.

(3) During an exhaust emission test the measurement of these same pump parameters enables the user to calculate the flow rate from the calibration equation.

(4) Connect a system as shown in Figure N83-4. Although particular types of equipment are shown, other configurations that yield equivalent results may be used if approved in advance by the Administrator. For the system indicated, the following data with given accuracy are required:

CALIBRATION DATA MEASUREMENTS

Parameter	Sym	Units	Tolerances
Barometric pressure (corrected)	P_B	in. Hg (kPa)	±.01 in. Hg (±.034 kPa)
Ambient temperature	T_A	°F (°C)	±.5°F (±.28°C)
Air temperature into LFE	ETI	°F (°C)	±.25 °F (±.14 °C)
Pressure depression upstream of LFE	EPI	in. H_2O (kPa)	±.05 in. H_2O (±.001 kPa)
Pressure drop across the LFE matrix	EDP	in. H_2O (kPa)	±.005 in. H_2O (±.001 kPa)
Air temperature at CVS pump inlet	PTI	°F (°C)	±.5°F (±.28°C)
Pressure depression at CVS pump inlet	PPI	in. Fluid (kPa)	±.05 in. Fluid (±.022 kPa)
Specific gravity of manometer fluid (1.75 oil)	Sp. G	-	-
Pressure head at CVS pump outlet	PPO	in. Fluid (kPa)	±.05 in. Fluid (±.022 kPa)
Air Temperature at CVS pump outlet (optional)	PTO	°F (°C)	±.5°F (±.28°C)
Pump revolutions during test period	N	Revs	± 1 Rev.
Elapsed time for test period	t	s	±.05 s

(5) After the system has been connected as shown in Figure N83-4, set the variable restrictor in the wide open

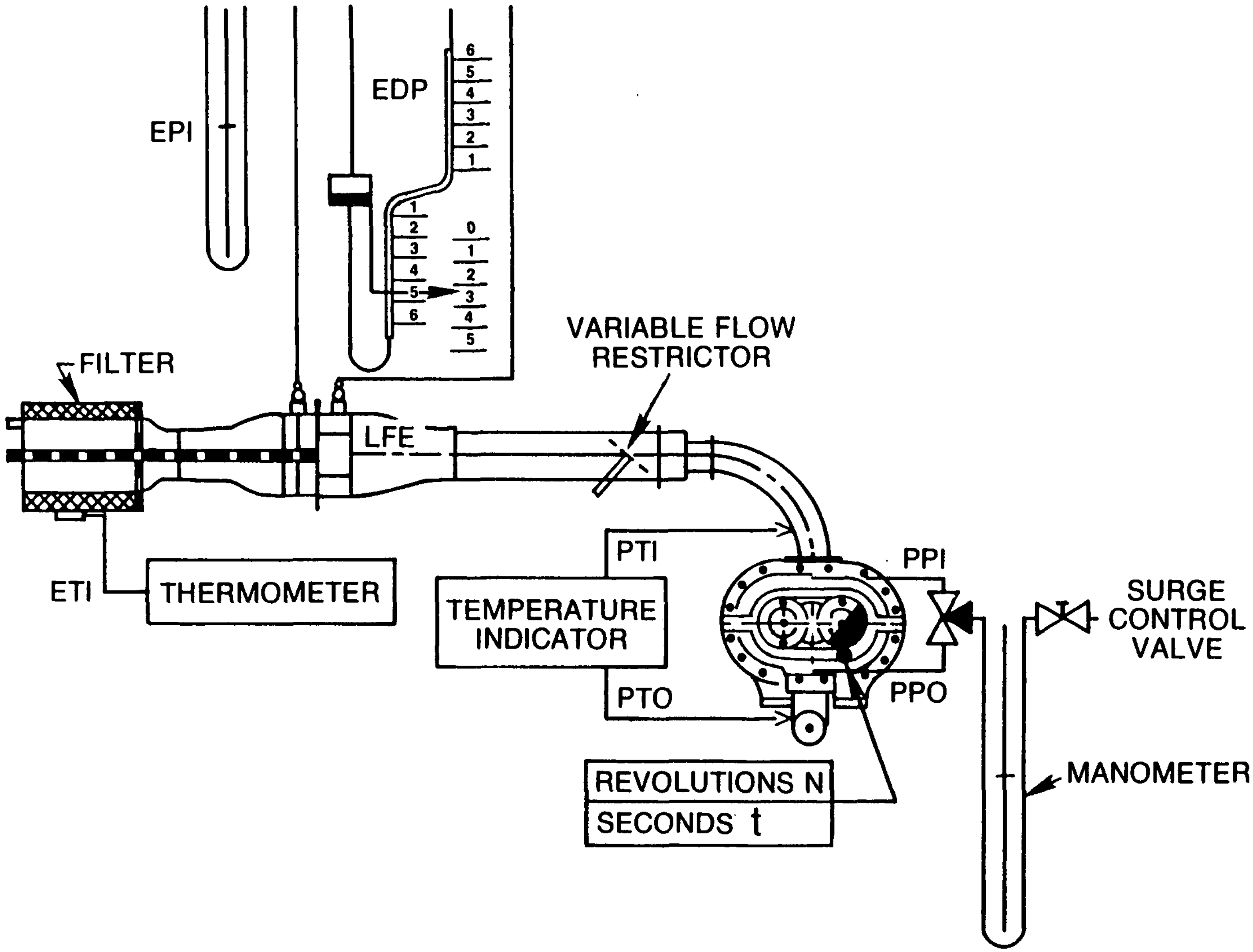


FIGURE N83-4 — PDP-CVS CALIBRATION CONFIGURATION position and run the CVS pump for 20 minutes. Record the calibration data.

(6) Reset the retrictor valve to a more restricted condition in an increment of pump inlet depression (about 4" H_2O (1.0 kPa)) that will yield a minimum of six data points for the total calibration. Allow the system to stabilize for 3 minutes and repeat the data acquisition.

(7) <u>Data analysis</u>:

(i) The air flow rate, Qs, at each test point is calculated in standard cubic feet per minute from the flow-meter data using the manufacturer's prescribed method.

(ii) The air flow rate is then converted to pump flow, V_o, in cubic feet per revolution at absolute pump inlet temperature and pressure.

$$V_o = \frac{Qs}{n} \times \frac{T_p}{528} \times \frac{29.92}{P_p}$$

Where:

V_o = Pump flow, ft^3/revolution (m^3/revolution) at T_p, P_p.

Qs = Meter air flow rate in standard cubic feet per minute, standard conditions are 68°F, 29.92 in. Hg (20°C, 101.3 kPa).

n = Pump speed in revolutions per minute.

T_p = Pump inlet temperature R(K)
= PTI + 460
for SI units, T_p - PTI + 273

P_p = Absolute pump inlet pressure, in. Hg (kPa)
= P_B - PPI (Sp. Gr./13.57)
for SI units, $P_p = P_B$ - PPI

Where:

P_B = barometric pressure, in. Hg (kPa).

PPI = Pump inlet depression, in. fluid (kPa).

Sp. Gr. = Specific gravity of manometer fluid relative to water.

(iii) The correlation function at each test point is then calculated from the calibration data.

$$x_o = \frac{1}{n}\sqrt{\frac{\Delta p_p}{P_e}}$$

Where:

x_o = correlation function.

Δp_p = The pressure differential from pump inlet to pump outlet, in. Hg (kPa).

= $P_e - P_p$

P_e = Absolute pump outlet pressure, in. Hg (kPa)
= P_B + PPO (Sp. Gr./13.57)
for SI units, $P_e = P_B$ + PPO

Where:

PPO = Pressure head at pump oulet, in. fluid (kPa).

(iv) A linear least squares fit is preformed to generate the calibration equations which have the forms:

$V_o = D_o - M(X_o)$

$n = A - B(\Delta P_p)$

D_o, M, A, and B are the slope-intercept constants describing the lines.

(8) A CVS system that has multiple speeds should be calibrated on each speed used. The calibration curves generated for the ranges will be approximately parallel and the intercept values, D_o, will increase as the pump flow range decreases.

(9) If the calibration has been performed carefully, the calculated values from the equation will be within ± 0.50 percent of the measured value of V_o. Values of M will vary from one pump to another, but values of D_o for pumps of same make, model, and range should agree within $\pm$ 3 percent of each other. Particulate influx from use will cause the pump slip to decrease as reflected by lower values for M. Calibrations should be performed at pump start-up and after major maintenance to assure the stability of the pump slip rate. Analysis of mass injection data will also reflect pump slip stability.

(b) <u>CVF calibration</u>

(1) Calibration of the CFV is based upon the flow equation for a critical venturi. Gas flow is a function of inlet pressure and temperature:

$$Q_s = \frac{K_v P}{\sqrt{T}}$$

Where:

Q_s = flow,

K_v = calibration coefficient,

P = absolute pressure,

T = absolute temperature.

The calibration procedure described below establishes the value of the calibration coefficient at measured values of pressure, temperature and air flow.

(2) The manufacturer's recommended procedure shall be followed for calibrating electronic portions of the CFV.

(3) Measurements necessary for flow calibration are as follows:

Calibration Data Measurements

PARAMETER	SYM	UNITS	TOLERANCES
°Barometric Pressure (corrected)	P_B	in. Hg (kPa)	±.01 in. Hg (±.034 kPa)
°Air temperature, flowmeter	ETI	°F (°C)	±.25°F (±.14°C)
°Pressure depression upstream of LFE	EPI	in. H_2O (kPa)	±.05 in. H_2O (±.012 kPa)
°Pressure drop across LFE matrix	EDP	in. H_2O (kPa)	±.005 in. H_2O (±.001 kPa)
°Air flow	Q_s	ft^3/min. (m^3/min.)	±.5%
°CFV inlet depression	PPI	in. fluid (kPa)	±.05 in. fluid (±.022 kPa)
°Temperature at venturi inlet	T_v	°F (°C)	±.5°F (±.28°C)
Specific gravity of manometer fluid (1.75 oil)	Sp. Gr.	--	--

(4) Set up equipment as shown in Figure N83-5 and check for leaks. Any leaks between the flow measuring devices and the critical flow venturi will seriously affect the accuracy of the calibration.

(5) Set the variable flow restrictor to the open position, start the blower, and allow the system to stabilize. Record data from all instruments.

(6) Vary the flow restrictor and make at least 8 readings across the critical flow range of the venturi.

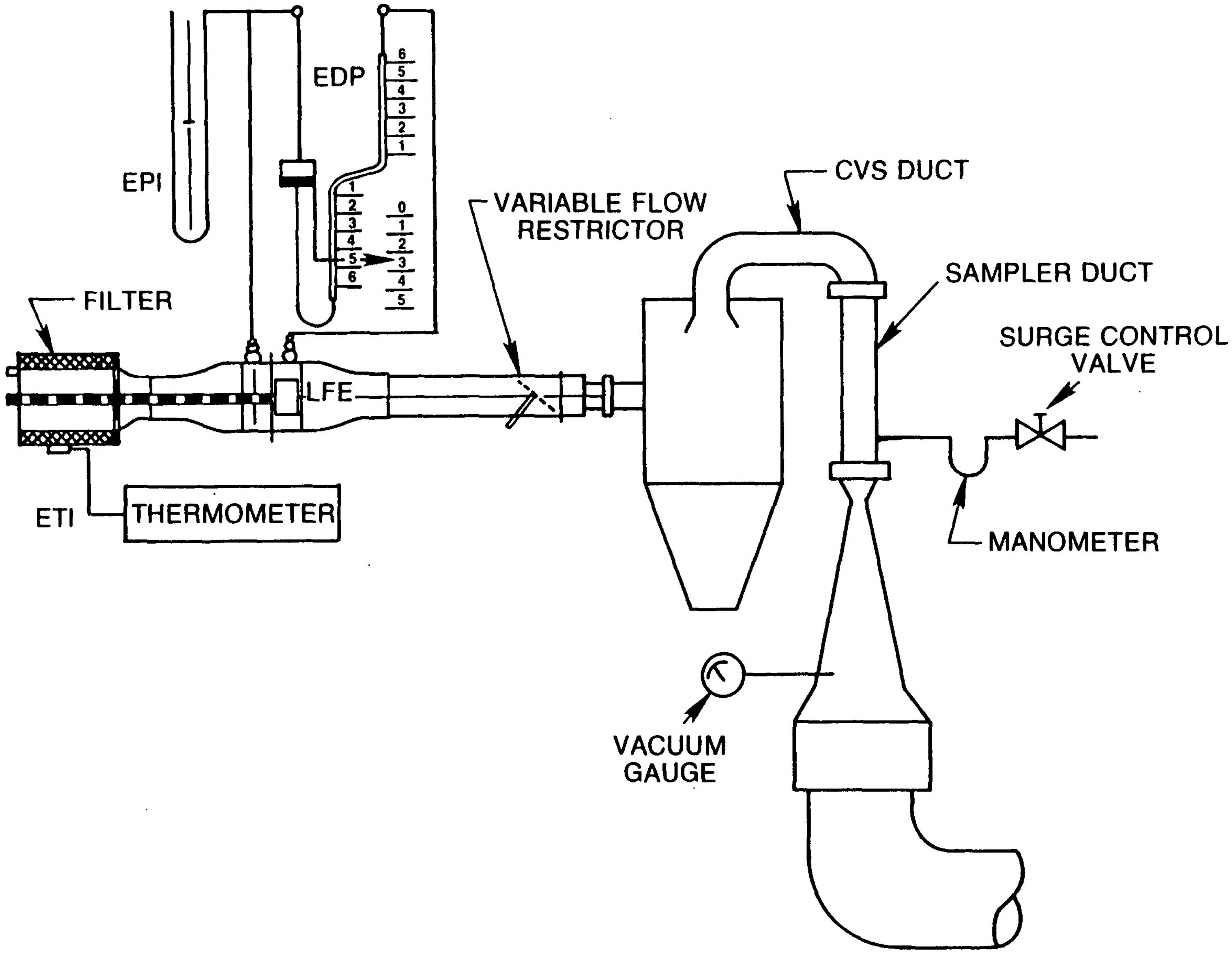


FIGURE N83-5 — CFV-CVS CALIBRATION CONFIGURATION

(7) Data analysis. The data recorded during the calibration are to be used in the following calculations:

(i) The air flow rate, Q_s, at each test point is calculated in standard cubic feet per minute from the flow meter data using the manufacturer's prescribed method.

(ii) Calculate values of the calibration coefficient for each test point:

$$K_v = \frac{Q_s \sqrt{T_v}}{P_v}$$

Where:

Q_s = Flow rate in standard cubic feet per minute, standard conditions are 68°F, 29.92 in. Hg (20°C, 101.3 kPa).

T_v = Temperature at venturi inlet, R(K).

P_v = Pressure at venturi inlet, mm Hg (kPa).

$= P_B$ - PPI (Sp. Gr./13.57).

for SI units: $P_v = P_B - PPI$

Where:

PPI = Venturi inlet pressure depression, in. fluid (kPa).

Sp. Gr. = Specific gravity of manometer fluid, relative to water.

(iii) Plot K_v as a function of venturi inlet pressure. For sonic flow, K_v will have a relatively constant value. As pressure decreases (vacuum increases), the venturi becomes unchoked and K_v decreases. See Figure N83-6.

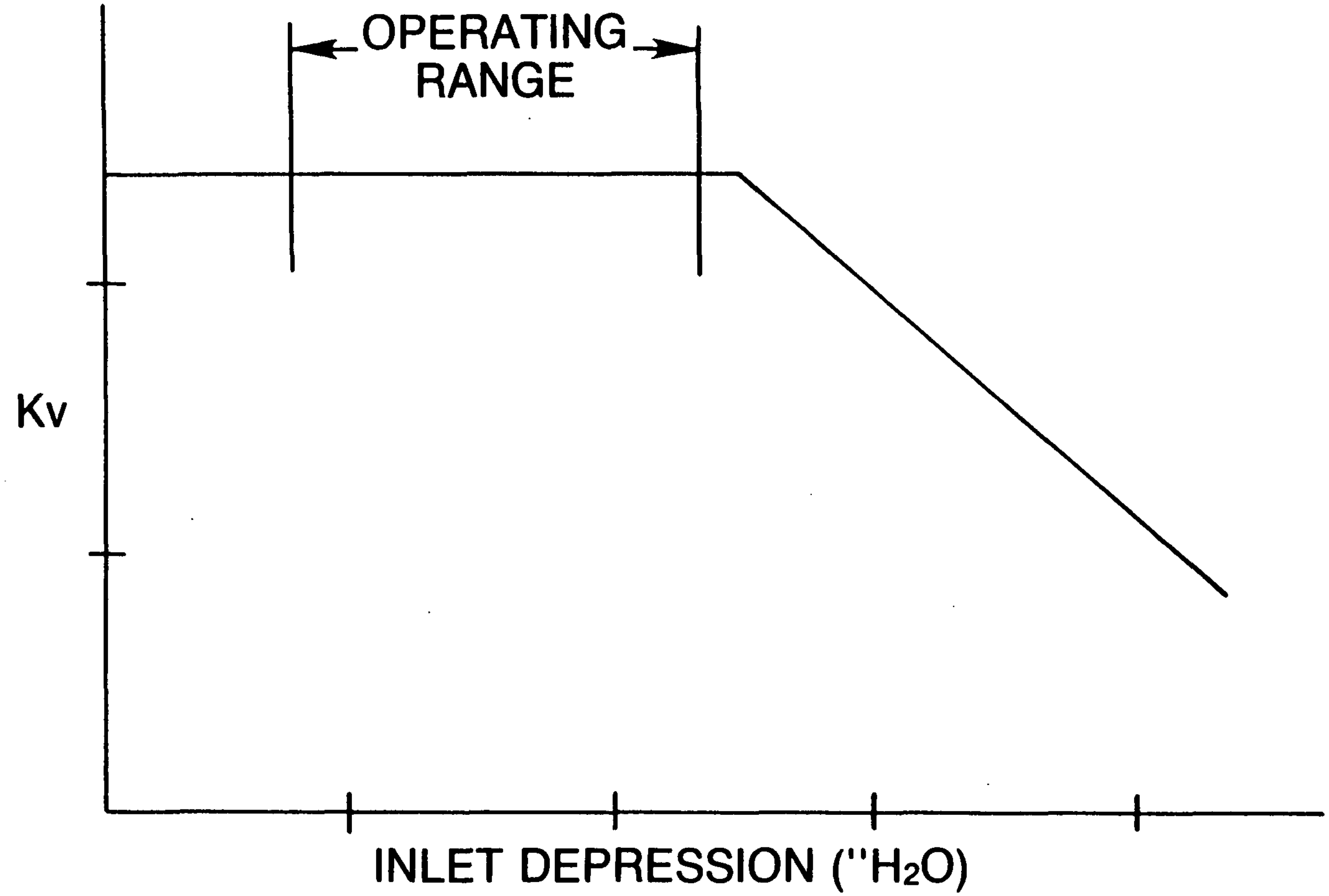


FIGURE N83-6 — SONIC FLOW CHOKING

(iv) For a minimum of 8 points in the critical region calculate an average K_v and the standard deviation.

(v) If the standard deviation exceeds 0.3% of the average K_v take corrective action.

(c) <u>CVS system verification</u>.

The following "gravimetric" technique can be used to verify that the CVS and analytical instruments can accurately measure a mass of gas that has been injected into the system. (Verification can also be accomplished by constant flow metering using critical flow orifice devices.)

(1) Obtain a small cylinder that has been charged with pure propane or carbon monoxide gas (caution - carbon monoxide is poisonous).

(2) Determine a reference cylinder weight to the nearest 0.01 grams.

(3) Operate the CVS in the normal manner and release a quantity of pure propane or carbon monoxide into the system during the sampling period (approximately 5 minutes).

(4) The calculations of §86.1344 are performed in the normal way except in the case of propane. The density of

propane (17.30 g/ft^3/carbon atom (0.6109 kg/m^3/carbon atom)) is used in place of the density of exhaust hydrocarbons. In the case of carbon monoxide, the density of 32.97 g/ft^3 (1.164 kg/m^3) is used.

(5) The gravimetric mass is subtracted from the CVS measured mass and then divided by the gravimetric mass to determine the percent accuracy of the system.

(6) The cause for any discrepancy greater than ± 2 percent must be found and corrected.

§86.1320-83 [Reserved]

§86.1321-83 Hydrocarbon analyzer calibration.

The FID hydrocarbon analyzer shall receive the following initial and periodic calibration. The HFID shall be operated to a set point $\pm$ 10°F ($\pm$5.5°C) between 300 and 390°F (149 and 199°C).

(a) Initial and period optimization of detector response. Prior to its introduction into service and at least annually thereafter the FID hydrocarbon analyzer shall be adjusted for optimum hydrocarbon response. Alternate methods yielding equivalent results may be used, if approved in advance by the Administrator.

(1) Follow the manufacturer's instructions for instrument start-up and basic operating adjustment using the appropriate fuel (see §86.1314) and zero-grade air.

(2) Optimize on the most common operating range. Introduce into the analyzer, a propane in air mixture with a propane concentration equal to approximatley 90% of the most common operating range.

(3) Select an operating fuel flow rate that will give near maximum response and least variation in response with minor fuel flow variations.

(4) To determine the optimum air flow, use the fuel flow setting determined above and vary air flow.

(5) After the optimum flow rates have been determined, they are recorded for future reference.

(b) Initial and periodic calibration. Prior to its introduction into service and monthly thereafter the FID hydrocarbon analyzer shall be calibrated on all normally used instrument ranges. Use the same flow rate as when analyzing samples.

(1) Adjust analyzer to optimize performance.

(2) Zero the hydrocarbon anlyzer with zero-grade air.

(3) Calibrate on each normally used operating range with propane in air calibration gases having nominal concentrations of 15, 30, 45, 60, 75 and 90 percent of that range. For each range calibrated, if the deviation from a least-squares best-fit straight line is 2% or less of the value at each data point, concentration values may be calculated by use of a single calibration factor for that range. If the deviation exceeds 2% at any point, the best-fit non-linear equation which represents the data to within 2% of each test point shall be used to determine concentration.

§86.1322-83 Carbon monoxide analyzer calibration.

The NDIR carbon monoxide analyzer shall receive the following initial and periodic calibrations:

(a) Initial and periodic interference check. Prior to its introduction into service and annually thereafter the NDIR carbon monoxide analyzer shall be checked for response to water vapor and CO_2:

(1) Follow the manufacturer's instructions for instrument start-up and operation. Adjust the analyzer to optimize performance on the most sensitive range to be used.

(2) Zero the carbon monoxide analyzer with either zero-grade air or zero-grade nitrogen.

(3) Bubble a mixture of 3 percent CO_2 in N_2 through water at room temperature and record analyzer response.

(4) An analyzer resonse of more than 1 percent of full scale for ranges above 300 ppm full scale or more than 3 ppm on ranges below 300 ppm full scale will require corrective action. (Use of conditioning columns is one form of corrective action which may be taken.)

(b) Initial and periodic calibration. Prior to its introduction into service and monthly thereafter the NDIR carbon monoxide analyzer shall be calibrated.

(1) Adjust the analyzer to optimize performance.

(2) Zero the carbon monoxide analyzer with either zero-grade air or zero-grade nitrogen.

(3) Calibrate on each normally used operating range with carbon monoxide in N_2 calibration gases having nominal concentrations of 15, 30, 45, 60, 75, and 90 percent of that range. Additional calibration points may be generated. For each range calibrated, if the deviation from a least-squares best-fit straight line is 2 percent of less of the value at each data point, concentration values may be calculated by use of a single calibration factor for that range. If the deviation exceeds 2 percent at any point, the best-fit non-linear equation which represents the data to within 2% of each test point shall be used to determine concentration.

§86.1323-83 Oxides of nitrogen analyzer calibration.

The chemiluminescent oxides of nitrogen analyzer shall receive the following initial and periodic calibration.

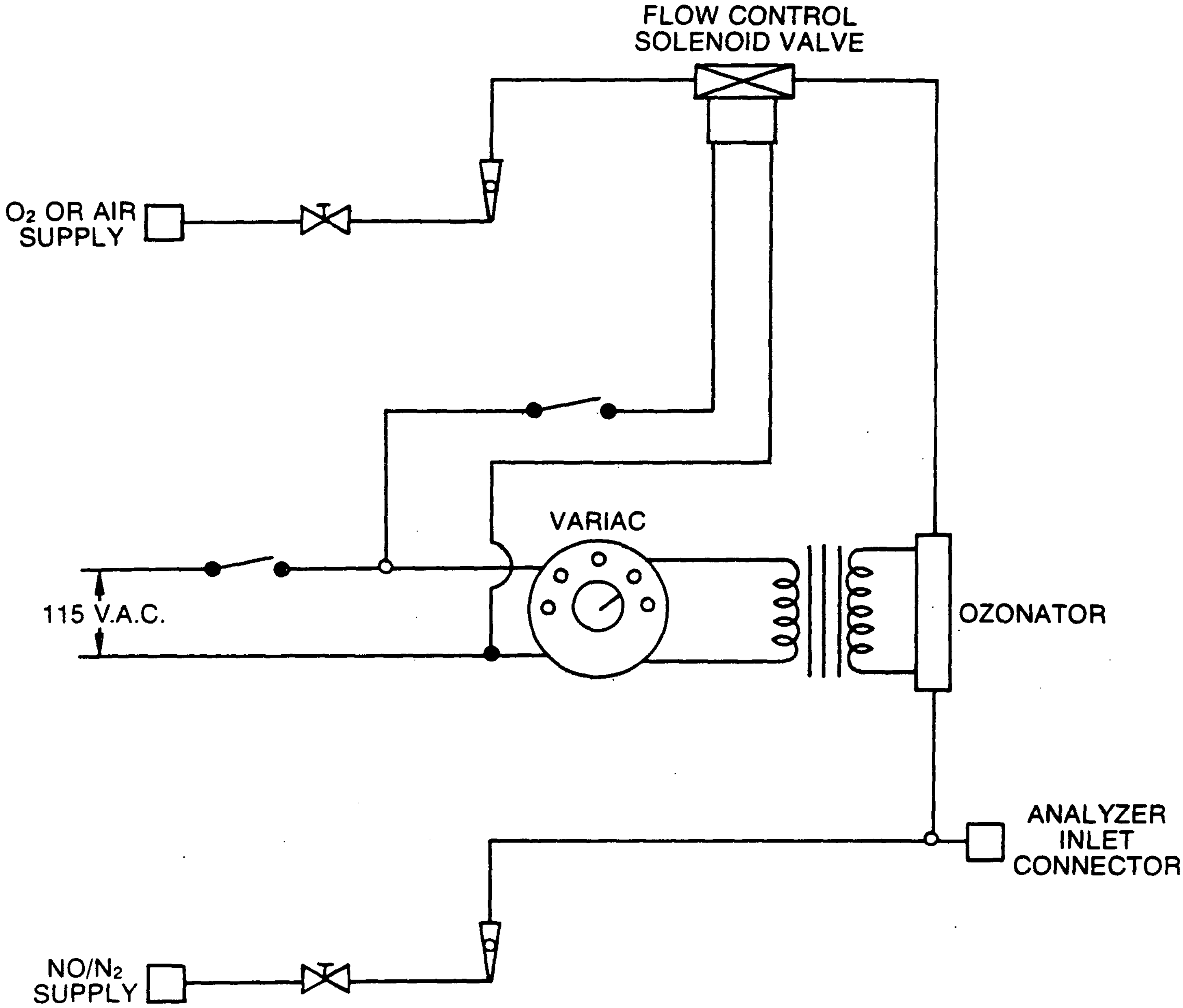
(a) Prior to its introduction into service and weekly thereafter the chemiluminescent oxides of nitrogen analyzer shall be checked for NO_2 to NO converter efficiency. Figure N83-7 is a reference for the following steps:

(1) Follow the manufacturer's instructions for instrument start-up and operation. Adjust the analyzer to optimize performance.

(2) Zero the oxides of nitrogen analyzer with zero-grade air or zero-grade nitrogen.

(3) Connect the outlet of the NOx generator to the sample inlet of the oxides of nitrogen analyzer which has been set to the most common operating range.

(4) Introduce into the NOx generator analyzer-system an NO in nitrogen (N_2) mixture with a NO concentration equal to approximately 80 percent of the most common operating range. The NO_2 content of the gas mixture shall be less than 5 percent of the NO concentration.



(SEE FIG. N83-3 FOR SYMBOL LEGEND)

FIGURE N83-7 — NO_x CONVERTER EFFICIENCY DETECTOR

(5) With the oxides of nitrogen analyzer in the NO mode, record the concentration of NO indicated by the analyzer.

(6) Turn on the NOx generator O_2 (or air) supply and adjust the O_2 (or air) flow rate so that the NO indicated by the analyzer is about 10 percent less than indicated in step (5). Record the concentration of NO in this NO + O_2 mixture.

(7) Switch the NOx generator to the generation mode and adjust the generation rate so that the NO measured on the analyzer is 20 percent of that measured in step (5). There must be at least 10 percent unreacted NO at this point. Record the concentration of residual NO.

(8) Switch the oxides of nitrogen analyzer to the NOx mode and measure total NOx. Record this value.

(9) Switch off the NOx generator but maintain gas flow through the system. The oxides of nitrogen analyzer will indicate the NOx in the NO + O_2 mixture. Record this value.

(10) Turn of the NOx generator O_2 (or air) supply. The analyzer will now indicate the NOx in the original NO in N_2 mixture. This value should be no more than 5 percent above the value indicated in step (4).

(11) Calculate the efficiency of the NOx converter by substituting the concentrations obtained into the following equation:

$$\text{Percent Efficiency} = [1 + (\frac{a - b}{c - d})\ ] \times 100$$

where: a = concentration obtained in step (8),

b = concentration obtained in step (9),

c = concentration obtained in step (6),

d = concentration obtained in step (7).

If converter efficiency is not greater than 90% corrective action will be required.

(b) Initial and periodic calibration. Prior to its introduction into service and monthly thereafter the chemiluminescent oxides of nitrogen analyzer shall be calibrated on all normally used instrument ranges. Use the same flow rate as when analyzing samples. Proceed as follows:

(1) Adjust analyzer to optimize performance.

(2) Zero the oxides of nitrogen analyzer with zero-grade air or zero-grade nitrogen.

(3) Calibrate on each normally used operating range with

NO in N_2 calibration gases with nominal concentrations of 15, 30, 45, 60, 75 and 90 percent of that range. For each range calibrated, if the deviation from a least-squares best-fit straight line is 2% of less of the value at each data point, concentration values may be calculated by use of a single calibration factor for that range. If the deviation exceeds 2% at any point, the best-fit non-linear equation which represents the data to within 2% of each test point shall be used to determine concentration.

§86.1324-83 Carbon dioxide analyzer calibration.

Prior to its introduction into service and monthly thereafter the NDIR carbon dioxide analyzer shall be calibrated as follows:

(a) Follow the manufacturer's instructions for instrument start-up and operation. Adjust the analyzer to optimize performance.

(b) Zero the carbon dioxide analyzer with either zero-grade air or zero-grade nitrogen.

(c) Calibrate on each normally used operating range with carbon dioxide in N_2 calibration gases having nominal concentrations of 15, 30, 45, 60, 75, and 90 percent of that range. Additional calibration points may be generated. For each range calibrated, if the deviation from a least-squares best-fit straight line is 2 percent of less of the value at each data point, concentration values may be calculated by use of a single calibration factor for that range. If the deviation exceeds 2 percent at any point, the best-fit non-linear equation which represents the data to within 2% of each test point shall be used to determine concentration.

§86.1325-83 [Reserved]

§86.1326-83 Calibration of other equipment.

Other test equipment used for testing shall be calibrated as often as required by the manufacturer or as necessary according to good practice.

§86.1327-83 Engine dynamometer test procedures; overview.

(a) The engine dynamometer test procedure is designed to determine the brake-specific emission of hydrocarbons, carbon monoxide, and oxides of nitrogen. The test procedure consists of a "cold" start test after a minimum 12-hour and a maximum 36-hour soak as described in §86.1332. A "hot" start test follows the "cold" start test after a hot soak of 20 minutes. The exhaust emissions are diluted with ambient air and a continuous proportional sample is collected for analysis during the cold and hot start tests. The composite samples collected in bags are analyzed for hydrocarbons (except diesel hydrocarbons which are analyzed continuously), carbon monoxide, carbon dioxide, and oxides of nitrogen. A parallel sample of the dilution air is similarly analyzed for hydrocarbon, carbon monoxide, carbon dioxide, and oxides of nitrogen.

(b) Engine torque and rpm shall be recorded continuously during both the cold and hot start tests. Data points shall be recorded at least once every second.

(c) Using the torque and rpm feedback signals the brake horsepower is integrated with respect to time for the cold and hot cycles. This produces a brake horsepower-hour value that enables the brake-specific emissions to be determined (see

§86.1344, Calculations; exhaust emissions).

(d)(1) When an engine is tested for exhaust emissions or is operated for service accumulation on an engine dynamometer, the complete engine shall be tested, with all emission control devices installed and functioning.

(2) Evaporative emission controls need not be connected if data are provided to show that normal operating conditions are maintained in the engine induction system.

(3) On air cooled engines, the fan shall be installed.

(4) Additional accessories (e.g., oil cooler, alternators, air compressors, etc.) may be installed with advance approval by the Administrator.

(5) The engine must be equipped with a production type starter.

(e) <u>Engine cooling</u>. Means of engine cooling which will maintain the engine operating temperatures (e.g., intake air, oil, water, etc.) at approximately the same temperature as specified by the manufacturer shall be used. Auxiliary fan(s) may be used to maintain engine cooling during operation on the dynamometer.

(f) Exhaust system.

(1) A chassis-type exhaust system shall be used. The exhaust system shall meet the following requirements.

(i) For all catalyst systems, the distance from the exhaust manifold flange(s) to the catalyst shall be the same as in the vehicle configuration unless the manufacturer provides data showing equivalent performance at another location.

(ii) The exhaust back pressures shall typify those seen in the actual vehicle exhaust system configuration.

§86.1328-78 [Reserved]

§86.1329-83 [Reserved]

§86.1330-83 Test sequence, general requirements.

The test sequence shown in Figure N83-8 shows the major steps encountered as the test engine undergoes the procedures subsequently described. The average ambient temperature of the engine intake air shall be maintained at 25°C ±5°C (77°F ± 9°F) throughout the test sequence. During the generation of the maximum torque curve and the exhaust emission test runs, the humidity level shall be maintained at 75 ± 15 grains of water per pound of dry air and the barometer pressure shall not deviate more than 1 in. Hg from the value measured at the beginning of the test sequence.

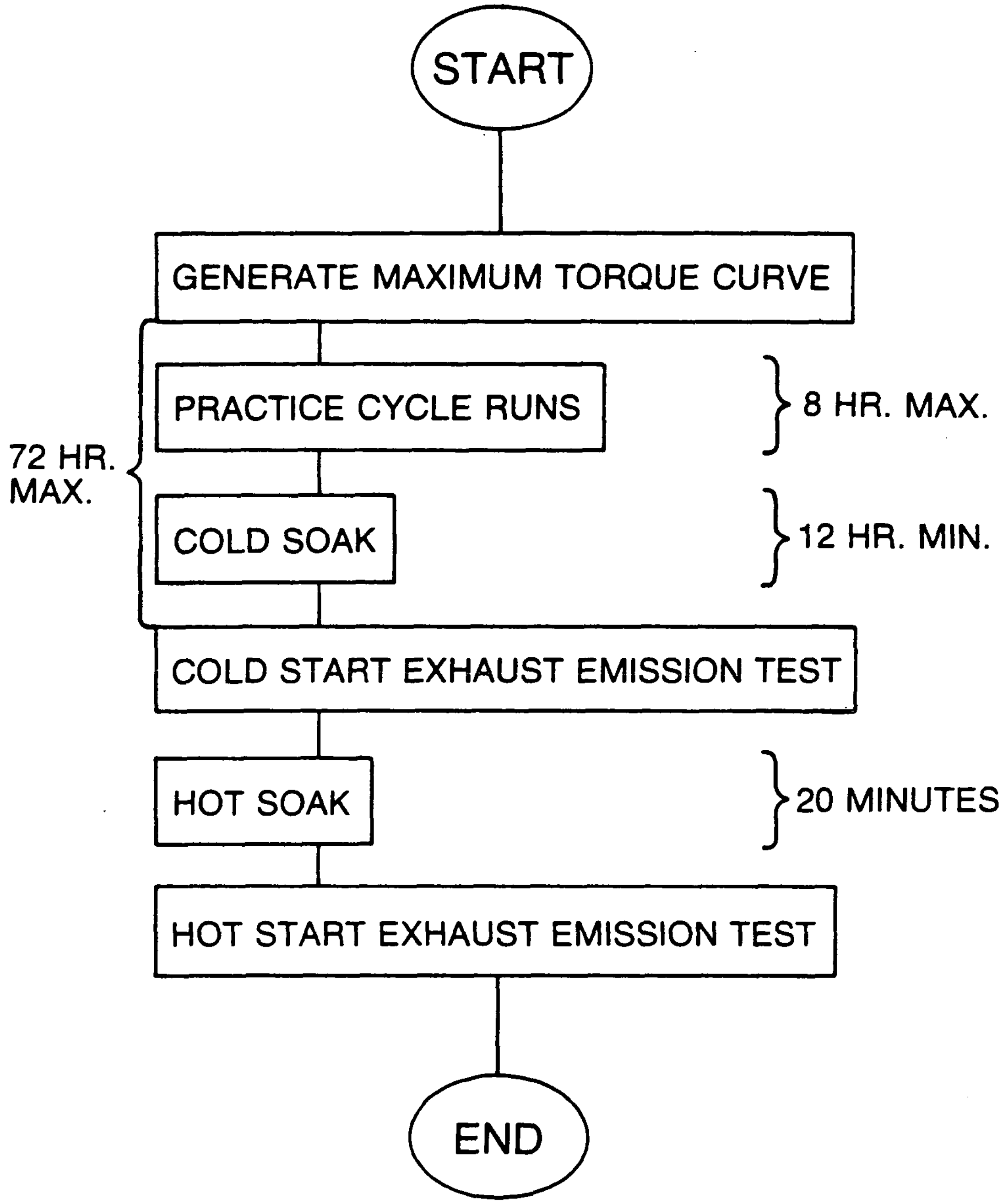


FIGURE N83-8 — TEST SEQUENCE

§86.1331-83 [Reserved]

§86.1332-83 Pre-test procedures.

(a) Mount test engine on the engine dynamometer.

(b) Determine maximum engine speed.

(1) Gasoline-fueled.

(i) For ungoverned engines the maximum engine speed shall be the manufacturer's recommended maximum safe operating speed.

(ii) For governed engines the maximum engine speed shall be the speed at which there is at least a 50 percent drop-off in torque.

(2) Diesel fueled. The maximum engine speed shall be the manufacturer's rated speed.

(c) Determine minimum engine speed.

(1) Gasoline-fueled. The minimum engine speed is calculated from the following equation:

minimum speed = (curb idle - 200 rpm) or 400 rpm, whichever is greater.

(2) Diesel fueled. The minimum engine speed is calculated from the following equation:

minimum speed = 0.6(rated speed).

(d) Determine maximum torque curve.

(1) Gasoline-fueled.

(i) Start the engine and operate at zero load in accordance with the manufacturer's start-up and warm-up procedures for 1 minute ± 30 seconds.

(ii) Operate the engine at a torque equivalent to 10 ± 3 percent of the most recent determination of maximum torque for 4 minutes ± 30 seconds at 2000 rpm.

(iii) Operate the engine at a torque equivalent to 55 ± 5 percent of the most recent determination of maximum torque for 35 minutes ± 1 minute at 2000 rpm.

(iv) Option. If the engine has been operating on service accumulation for a minimum of 40 minutes, the service accumulation may be substituted for step (1)(i) through (1)(iii).

(v) Operate the engine at idle.

(vi) Open the throttle fully.

(vii) While still maintaining wide-open throttle and full-load obtain minimum engine speed. Maintain minimum engine speed for 15 seconds.

(viii) Record the average torque during the last 5 seconds.

(ix) In 100 rpm increments determine the maximum torque curve from minimum speed to maximum speed. Hold each test point for 15 seconds and record the average torque over the last 5 seconds.

(2) Diesel fueled.

(i) Start the engine and operate at idle for 2 to 3 minutes.

(ii) Operate the engine at approximately 50 percent power at the peak torque speed for 5 to 7 minutes.

(iii) Operate the engine at rated speed and maximum horsepower for 25 to 30 minutes.

(iv) Option. It is permitted to pre-condition the engine at rated speed and maximum horsepower until the oil and water temperatures are stabilized. The temperatures are defined as stabilized if they are maintained within 2 percent of point for 2 minutes. The engine must be operated a minimum of 10 minutes for this option. This optional procedure may be substituted for step (iii).

(v) Option. If the engine has been operating on service accumulation for a minimum of 40 minutes, the service accumulation may be substituted for steps (i) through (iii).

(vi) Unload the engine and measure the curb idle speed.

(vii) Operate the engine at wide-open throttle and minimum engine speed. Maintain minimum engine speed for 30 seconds.

(viii) Record the average torque over the last 5 seconds.

(ix) In 200 rpm increments determine the maximum torque curve from minimum speed to the maximum speed (rated speed). Hold each test point for 30 seconds and record the average torque over the last 5 seconds.

(x) Unload the engine, maintain wide-open throttle, and measure the high idle speed.

(e) Mapping curve generation.

(1) Gasoline-fueled.

(i) Fit all data points recorded under (d)(1) of this section with a cubic spline curve generation technique. The resulting curve is the mapping curve and will be used to convert the normalized torque values in the engine cycles (see Appendix I) to actual torque values.

(2) Diesel.

(i) Calculate the torque at curb idle using the equation below. Assume a BMEP of 90 PSI.

$$T = \frac{(BMEP)D\ 5252}{(12)(33000)x}$$

where: BMEP = brake mean effective pressure, psi;
T = engine torque, lb.-ft.;
D = total piston displacement, cubic inches;
x = number of revolutions required for each power stroke delivered per cylinder - 2 for a four-stroke cycle engine and 1 for a two-stroke cycle engine.

(ii) Fit all the torque values recorded under (d)(2) of this section with a cubic spline curve generation technique.

(iii) Draw a straight-line from the maximum torque at curb idle (as calculated in (e)(2)(i) of this section) to the maximum torque at minimum speed (as calculated from the cubic spline curve generated in (e)(2)(ii) of this section).

(iv) Draw a straight-line between the maximum torque at rated speed (curve value) and zero torque at high idle rpm.

(v) The complete mapping curve is shown in Figure N83-9.

The resulting mapping curve is used to convert the normalized torque values in the engine cycles (see Appendix I) to actual torque values.

(f) <u>Engine preparation</u>.

(i) Before the cold soak, practice cycle runs may be performed, but emissions may not be measured. A maximum of 8 hours of practice is allowed.

(ii) After any practice runs turn the engine off and allow to cold soak at 60° to 80°F for a minimum of 12 hours and a maximum of 36 hours.

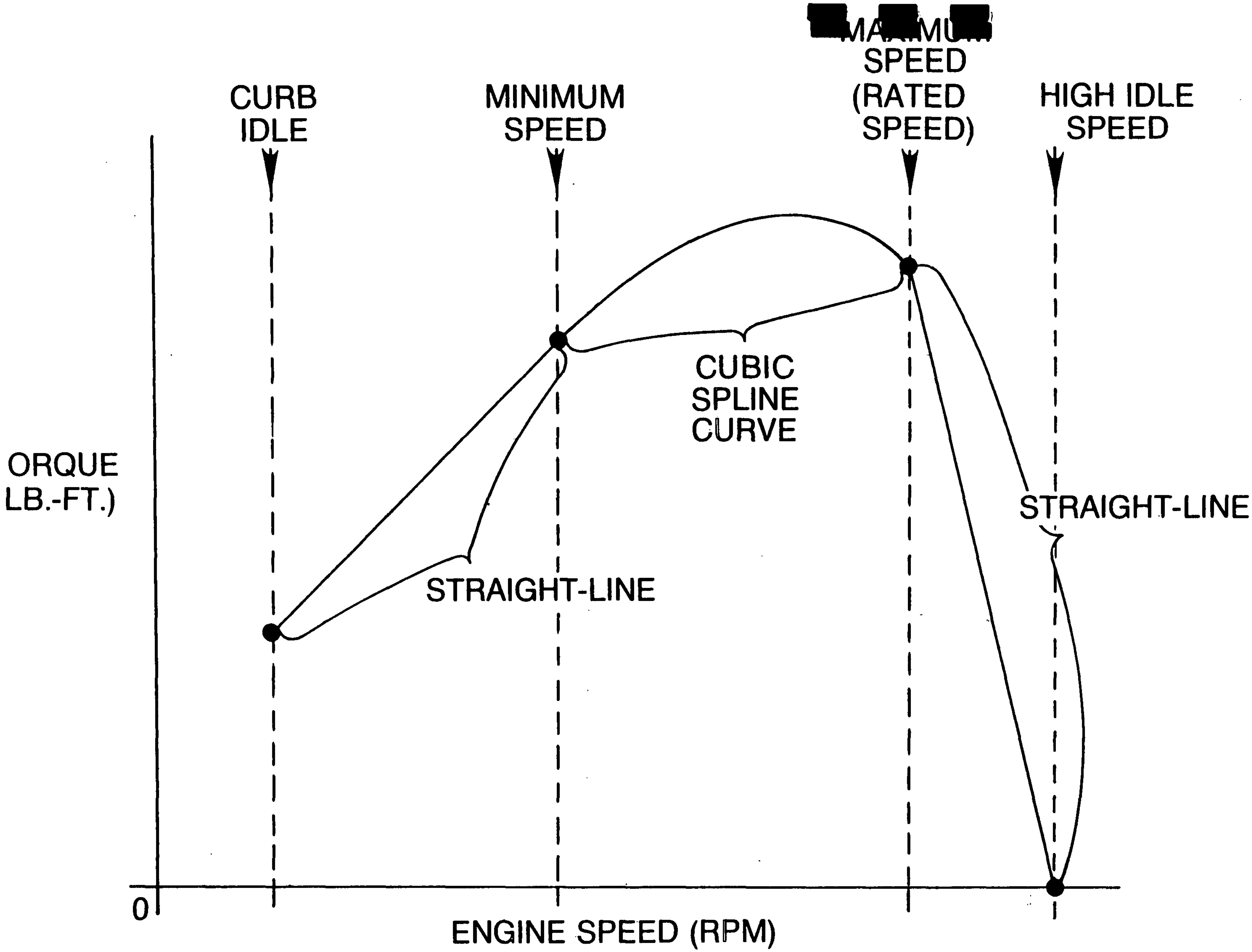


FIGURE N83-9 — MAPPING CURVE FOR DIESEL ENGINES

§86.1333-83 [Reserved]

§86.1334-83 [Reserved]

§86.1335-83 [Reserved]

§86.1336-83 Engine starting and restarting.

(a) Gasoline-fueled engines. This paragraph (b) applies to gasoline-fueled engines only.

(1) The engine shall be started with a production engine starting-motor according to the manufacturer's recommended starting procedures in the owner's manual. The 24 $\pm$ 1 second free idle period shall begin when the engine starts.

(2) Choke operation:

(i) Engines equipped with automatic chokes shall be operated according to the manufacturer's operating instructions in the owner's manual, including choke setting and "kick-down" from cold fast idle.

(ii) Engines equipped with manual chokes shall be operated according to the manufacturer's operating instructions in the owner's manual.

(3) The operator may use the choke, throttle, etc. where necessary to keep the engine running.

(4) If the manufacturer's operating instructions in the owner's manual do not specify a warm engine starting procedure, the engine (automatic- and manual-choke engines) shall be

started by depressing the throttle about half way and cranking the engine until it starts.

(b) Diesel engines. The engine shall be started with a production engine starting-motor according to the manufacturer's recommended starting procedures in the owner's manual. The 24 ± 1 second free idle period shall begin when the engine starts.

(c)(1) If the engine does not start after 15 seconds of cranking, cranking shall cease and the reason for failure to start shall be determined. The gas flow measuring device (or revolution counter) on the constant volume sampler (and the hydrocarbon integrator when testing diesel vehicles, see §86.1337, Engine dynamometer test run) shall be turned off and the sample selector valves placed in the "standby" position during this diagnostic period. In addition, either the CVS should be turned off or the exhaust tube disconnected from the tailpipe during the diagnostic period. If failure to start is an operational error, the engine shall be rescheduled for testing from a cold start.

(2) If a failure to start occurs during the cold portion of the test and is caused by an engine malfunction, corrective action of less than 30 minutes duration may be taken (according to §86.083-25), and the test continued. The sampling system shall be reactivated at the same time cranking begins.

When the engine starts, the timing sequence shall begin. If failure to start is caused by engine malfunction and the engine cannot be started, the test shall be voided and corrective action may be taken according to §86.083-25. The reasons for the malfunction (if determined) and the corrective action taken shall be reported to the Administrator.

(3) If a failure to start occurs during the hot start portion of the test and is caused by engine malfunction, the engine must be started within one minute of key on. The sampling system shall be reactivated at the same time cranking begins. When the engine starts, the transient engine cycle timing sequence shall begin. If the engine cannot be started within one minute of key on, the test shall be voided, corrective action taken, (according to §86.083-25), and the engine rescheduled for testing. The reason for the malfunction (if determined) and the corrective action taken shall be reported to the Administrator.

(d) If the engine "false starts", the operator shall repeat the recommended starting procedure (such as resetting the choke, etc.).

(e) <u>Engine stalling</u>.

(1) If the engine stalls during the initial idle period

of either the cold or hot start test, the engine shall be restarted immediately and the test continued. If the engine cannot be started before the first non-idle record of the cycle, the test shall be voided.

(2) If the engine stalls anywhere in the cycle, except the initial idle period, the test shall be voided.

§86.1337-83 Engine dynamometer test run.

(a) The following steps shall be taken for each test:

(1) Prepare the engine and dynamometer for the cold start test.

(2) With the sample selector valves in the "standby" position, connect evacuated sample collection bags to the dilute exhaust and dilution air sample collection systems.

(3) Start the CVS (if not already on), the sample pumps, the temperature recorder, the engine cooling fan(s) and the heated hydrocarbon analysis recorder (diesel only). (The heat exchanger of the constant volume sampler, if used, diesel hydrocarbon analyzer continuous sample line and filter (if applicable) shall be preheated to their respective operating temperatures before the test begins.)

(4) Adjust the sample flow rates to the desired flow rate and set the gas flow measuring devices to zero.

NOTE: CFV-CVS sample flowrate is fixed by the venturi design.

(5) Attach the CVS flexible exhaust tube to engine tailpipe(s).

(6) Follow the manufacturer's choke and throttle instructions for cold starting. Simultaneously start the engine and begin exhaust and dilution air sampling. For Diesel engines, turn on the hydrocarbon analyzer system integrator and mark the recorder chart.

(7) As soon as it is determined that the engine is started, start a "free idle" timer.

(8) Allow the engine to idle freely with no-load for 24 $\pm$ 1 seconds.

(9) Begin the transient engine cycles such that the first non-idle record of the cycle occurs at 25 $\pm$ 1 seconds. The free idle time is included in the 25 $\pm$ 1 seconds.

(10) On the last record of the cycle cease sampling, immediately turn the engine off, and start a hot soak timer.

(11) Immediately after the engine is turned off, turn off the engine cooling fan(s) if used, and the CVS blower. As soon as possible transfer the "cold start cycle" exhaust and dilution air samples to the analytical system and process the

samples according to §83.1340 obtaining a stabilized reading of the exhaust sample on all analyzers within 20 minutes of the end of the sample collection phase of the test.

(12) Allow the engine to soak for 20 $\pm$ 1 minutes.

(13) Prepare the engine and dynamometer for the hot start test.

(14) With the sample selector valves in the "standby" position, connect evacuated sample collection bags to the dilute exhaust and dilution air sample collection systems.

(15) Start the CVS (if not already on), the sample pumps, the temperature recorder, the engine cooling fan and the heated hydrocarbon analysis recorder (diesel only). (The heat exchanger of the constant volume sampler, if used, diesel hydrocarbon analyzer continuous sample line and filter (if applicable) shall be preheated to their respective operating temperatures before the test begins.)

(16) Adjust the sample flow rates to the desired flow rate and set the gas flow measuring devices to zero.

NOTE: CFV-CVS sample flowrate is fixed by the venturi design.

(17) Follow the manufcturer's choke and throttle instruction for hot starting. Simultaneously start the engine and begin exhaust and dilution air sampling.

(18) As soon as it is determined that the engine is started, start a "free idle" timer.

(19) Allow the engine to idle freely with no-load for 24 $\pm$ 1 seconds.

(20) Begin the transient engine cycle such that the first non-idle record of the cycle occurs at 25 $\pm$ 1 seconds. The free idle is included in the 25 $\pm$ 1 seconds.

(21) On the last record of the cycle cease sampling and turn off the engine.

(22) As soon as possible transfer the "hot start cycle" exhaust and dilution air samples to the analytical system and process the samples according to §86.1340 obtaining a stabilized reading of the exhaust sample on all analyzers within 20 minutes of the end of the sample collection phase of the test.

(23) Disconnect the exhaust tube from the engine tail-

pipe(s).

(24) The CVS may be turned off, if desired.

§86.1338-83 [Reserved]

§86.1339-83 [Reserved]

§86.1340-83 Exhaust sample analysis.

The following sequence of operations shall be performed in conjunction with each series of measurements:

(a) Zero the analyzers and obtain a stable zero reading. Recheck after tests.

(b) Introduce span gases and set instrument gains. In order to avoid corrections, span and calibrate at the same flow rates used to analyze the test sample. Span gases should have concentrations equal to 75 to 100 percent of full scale. If gain has shifted significantly on the analyzers, check the calibrations. Show actual concentrations on chart.

(c) Check zeros; repeat the procedure in paragraphs (a) and (b) of this section if required.

(d) Check flow rates and pressures.

(e) Measure HC, CO, CO_2 and NOx concentrations of samples.

(f) For diesel engines, continuously record (integrate electronically if desired) dilute hydrocarbon emission levels during test. Background samples are collected in sample bags and analyzed as above.

(g) Check zero and span point. If difference is greater than 2% of full scale, repeat the procedure in paragraphs (a) through (f).

§86.1341-83 [Reserved]

§86.1342-83 Records required.

The following information, as applicable, shall be recorded for each test:

(a) Engine description and specification. A copy of the information specified in this paragraph must accompany each engine sent to the Administrator for compliance testing. The manufacturer need not record the information specified in this paragraph for each test if the information, with the exception of subparagraph (3) is included in the manufacturer's Part I.

(1) Engine-system combination.

(2) Engine identification numbers.

(3) Number of hours of operation accumulated on engine.

(4) Manufacturer's rated maximum horsepower and torque.

(5) Manufacturer's rated maximum horsepower and torque speeds.

(6) Engine displacement.

(7) Governed speed.

(8) Maximum safe engine speed (ungoverned engines).

(9) Manufacturer's start-up procedure.

(10) Curb-idle rpm.

(11) Maximum exhaust system back pressure (Diesel engines only).

(b) Test data; general. This information may be recorded at any time between 4 hours prior to the test and 4 hours after the test.

(1) Engine-system combination.

(2) Engine identification number.

(3) Instrument operator(s).

(4) Engine operator(s).

(5) Number of hours of operation accumulated on the engine prior to beginning the test sequence (Figure N83-8).

(6) Fuel identification, including H/C ratio.

(7) Date of most recent analytical assembly calibration.

(8) All pertinent instrument information such as tuning, gain, serial numbers, detector number, calibration curve numbers, etc. As long as this information is traceable, it may be summarized by system number or analyzer identification numbers.

(c) Test data; pre-test.

(1) Date and time of day.

(2) Test number.

(3) Engine intake air temperature.

(4) Barometric pressure.

(5) Engine intake humidity.

(6) Maximum torque curve as determined in §86.1332.

(7) Measured maximum horsepower and torque speeds.

(8) Measured maximum horsepower and torque.

(9) Maximum engine speed.

(10) Minimum engine speed.

(11) High idle engine speed (diesel engines only).

(12) Calculated torque at curb-idle (diesel engines only).

(13) Fuel consumption at maximum power and torque (diesel engines only).

(14) Curb-idle fuel flow rate.

(d) Test data.

(1) Total number of hours of operation accumulated on the engine prior to starting emission test.

(2) Cold soak time interval.

(3) Recorder charts: Identify zero, span, exhaust gas, and dilution air sample traces.

(4) Test cell barometric pressure.

NOTE: A central laboratory barometer may be used:

Provided, That individual test cell barometric pressure are shown to be within ±0.1 percent of the barometric pressure at the central barometer location.

(5) Engine intake air temperature and humidity.

(6) Pressure of the mixture of exhaust and dilution air entering the CVS metering device, the pressure increase across the device, and the temperature at the inlet. The temperature maybe recorded continuously or digitally to determine temperature variations.

(7) The number of revolutions of the positive displacement pump accumulated during each test phase while exhaust samples are being collected. The number of standard cubic feet metered by a critical flow venturi during each test phase would be the equivalent record for a CFV-CVS.

(8) The humidity of the dilution air.

NOTE: If conditioning columns are not used (see §86.1322 and §86.1344) this measurement can be deleted. If the conditioning columns are used and the dilution air is taken from the test cell, the ambient humidity can be used for this measurement.

(9) Temperature set point of the heated sample line and heated hydrocarbon detector temperature control system (for diesel engines only).

(10) Integrated brake horsepower-hours for each test phase.

(11) Record engine torque and engine rpm continuously. The maximum time interval between recorded data points is one second.

(12) Total number of hours of operation accumulated on the engine after completing the test sequence described in Figure N83-8.

§86.1343-83 [Reserved]

§86.1344-83 Calculations;exhaust emissions.

(a) The final reported emission test results shall be computed by use of the following formula:

$$A_{wm} = \frac{1/7(g_C) + 6/7(g_H)}{1/7(BHP\text{-}Hr_C) + 6/7(BHP\text{-}Hr_H)}$$

Where:

A_{wm} = Weighted mass emission level (HC, CO, CO_2. or NOx) in grams per brake horsepower hour.

g_C = Mass emission level in grams, measured during the cold start test.

g_H = Mass emissions level in grams, measured during the hot start test.

$BHP\text{-}HR_C$ = Total brake horsepower-hour (brake horsepower integrated with respect to time) for the cold start test.

$BHP\text{-}HR_H$ = Total brake horspower-hour (brake horsepower integrated with respect to time) for the hot start test.

(b) The mass of each pollutant for the cold start test and the hot start test is determined from the following equations:

(1) Hydrocarbon mass:

$$HC_{mass} = V_{mix} \times Density_{HC} \times (HC_{conc}/1{,}000{,}000)$$

(2) Oxides of nitrogen mass:

$$NOx_{mass} = V_{mix} \times Density_{NO_2} \times K_H \times (NOx_{conc}/1{,}000{,}000)$$

(3) Carbon monoxide mass:

$$CO_{mass} = V_{mix} \times Density_{CO} \times (CO_{conc}/1{,}000{,}000)$$

(4) Carbon dioxide mass:

$$CO_{2mass} = V_{mix} \times Density_{CO_2} \times (CO_{2conc}/100)$$

(c) Meaning of symbols:

(1) HC_{mass} = Hydrocarbon emissions, in grams per test phase.

Density = Density of hydrocarbons is 16.33 g/ft^3 (.5767 kg/m^3), assuming an average carbon to hydrogen ratio of 1:1.85, at 68°F (20°C) and 760 mm Hg (101.3 kPa) pressure.

HC_{conc} = Hydrocarbon concentration of the dilute exhaust sample corrected for background, in ppm carbon equivalent, i.e., equivalent propane X 3.

$$HC_{conc} = HC_e - HC_d[1 - (1/DF)]$$

where:

HC_e = Hydrocarbon concentration of the dilute exhaust sample or, for diesel, average hydrocarbon concentration of the dilute exhaust sample as calculated from the integrated HC traces, in ppm carbon equivalent.

HC_d = Hydrocarbon concentration of the dilution air as measured, in ppm carbon equivalent.

(2) NOx_{mass} = Oxides of nitrogen emissions, in grams per test phase.

$Density_{NO2}$ = Density of oxides of nitrgen is 54.16 g/ft^3 (1.913 kg/m^3), assuming they are in the form of nitrogen dioxide, at 68°F (20°C) and 760 mm Hg (101.3 kPa) pressure.

NOx_{conc} = Oxides of nitrogen concentration of the dilute exhaust sample corrected for background, in ppm.

$$NOx_{conc} = NOx_e - NOx_d\ [1 - (1/DF)]$$

where:

NOx_e = Oxides of nitrogen concentration of the dilute exhaust sample as measured, in ppm.

NOx_d = Oxides of nitrogen concentration of the dilute air as measured, in ppm.

(3) CO_{mass} = Carbon monoxide emissions, in grams per test phase.

$Density_{CO}$ = Density of carbon monoxide is 32.97 g/ft^3 (1.164 kg/m^3), at 68°F (20°C) and 760 mm Hg (101.3 kPa) pressure.

CO_{conc} = Carbon monoxide concentration of the dilute exhaust sample corrected for background, water vapor, and CO_2 extraction, in ppm.

$CO_{conc} = CO_e - CO_d [1 - (1/DF)]$

where:

CO_e = Carbon monoxide concentration of the dilute exhaust sample volume corrected for water vapor and carbon dioxide extraction, in ppm. The calculation assumes the carbon to hydrogen ratio of the fuel is 1:1.85.

$CO_e = [1 - 0.01925CO_{2e} - 0.000323R]CO_{em}$

Where:

CO_{em} = Carbon monoxide concentration of the dilute exhaust sample as measured, in ppm.

CO_e = Carbon dioxide concentration of the dilute exhaust sample, in percent.

R = Relative humidity of the dilution air, in percent (see §86.1342).

CO_d = Carbon monoxide concentration of the dilution air corrected for water vapor extraction, in ppm.

$CO_d = (1 - 0.000323R)CO_{dm}$

Where:

CO_{dm} = Carbon monoxide concentration of the dilution air sample as measured, in ppm.

NOTE: If a CO instrument which meets the criteria specified in §86.1311 is used and the conditioning column has been deleted, CO_{em} can be substituted directly for CO_e and CO_{dm} can be substituted directly for CO_d.

(4) CO_{2mass} = Carbon dioxide emissions, in grams per test phase.

$Density_{CO2}$ = Density of carbon dioxide is 51.85 g/ft^3 (1.843 kg/m^3), at 68°F (20°C) and 760 mm Hg (101.3 kPa) pressure.

CO_{2conc} = Carbon dioxide concentration of the dilute exhaust sample corrected for background, in percent.

$$CO_{2conc} = CO_{2e} - CO_{2d}[1 - (1/DF)]$$

Where:

CO_{2d} = Carbon dioxide concentration of the dilution air as measured, in percent.

(5) $DF = 13.4[CO_{2e} + (HC_e + CO_e) \times 10^{-4}]$

K_H = Humidity correction factor.

$K_H = 1/[1 - 0.0047(H - 75)]$
for SI units $= 1/[1 - 0.0329(H - 10.71)]$

Where:

H = Absolute humidity in grains (grams) of water per pound (kilogram) of dry air.

$H = [(43.478)R_a \times P_d]/[P_B - (P_d \times R_a/100)]$
for SI units, $H = [(6.211)R_a \times P_d]/[P_B - (P_d \times R_a/100)]$

R_a = Relative humidity of the ambient air, in percent.

P_d = Saturated vapor pressure, in mm Hg (kPa) at the ambient dry bulb temperature.

P_B = Barometric pressure, in mm Hg (kPa).

V_{mix} = Total dilute exhaust volume in cubic feet per test phase corrected to standard conditions (528°R (293°K) and 760 mm Hg (101.3 kPa)).

For PDP-CVS, V_{mix} is:

$$V_{mix} = V_o \times \frac{N(P_B - P_4)(528\ R)}{(760\ mm\ Hg)(T_p)}$$

for SI units,

$$V_{mix} = V_o \times \frac{N(P_B - P_4)(293.15\ K)}{(101.3\ kPa)(T_p)}$$

Where:

V_o = Volume of gas pumped by the positive displacement pump, in cubic feet (cubic metres) per revolution). This volume is dependent on the pressure differential across the positive displacement pump.

N = Number of revolutions of the positive displacement pump during the test phase while samples are being collected.

P_B = Barometric pressure, in mm Hg (kPa).

P_4 = Pressure depressions below atmospheric measured at the inlet to the positive displacement pump, in mm Hg (kPa) (during an idle mode).

T_p = Average temperature of dilute exhaust entering positive displacement pump during test, °R (°K).

(d) Sample calculation of mass values of exhaust emissions:

(1) Assume the following test results:

	Cold Start Cycle Test Results	Hot Start Cycle Test Results
V_{mix}	6924 ft^3	6873 ft^3
R	30.2%	30.2%
R_a	30.2%	30.2%
P_B	735 mm Hg	735 mm Hg
P_d	22.676 mm Hg	22.676 mm Hg
HC_e	132.07 ppm C equiv.	86.13 ppm C equiv.
NOx_e	7.86 ppm	10.98 ppm
CO_{em}	171.22 ppm	114.28 ppm
CO_{2e}	.178%	.381%
HC_d	3.60 ppm C equiv.	8.70 ppm C equiv.
NOx_d	0.0 ppm	0.10 ppm
CO_{dm}	0.89 ppm	0.89 ppm
CO_{2d}	0.0%	0.038%
BHP-HR	0.259	0.347

Then:

<u>Cold Start Test</u>

$$H = [(43.478)(30.2)(22.676)]/[735 - (22.676)(30.2)/100]$$

$$= 41 \text{ grains of water per pound of dry air.}$$

$$K_H = 1/[1 - 0.0047(41-75)] = 0.862$$

$$CO_e = [1 - 0.01925(.178) - 0.000323(30.2)]171.22$$

$$= 169.0 \text{ ppm}$$

$$CO_d = [1 - 0.000323(30.2)]0.89 = .881 \text{ ppm}$$

$$DF = 13.4/[.178 + (132.1 + 168.9)(10^{-4})] = 64.265$$

$$HC_{conc} = 132.1 - 3.6[1-(1/64.265)] = 128.6 \text{ ppm}$$

$$HC_{mass} = 6924(16.33)(128.6/1{,}000{,}000) = 14.53 \text{ grams}$$

$$NOx_{conc} = 7.86 - 0.0[1 - (1/64.265)] = 7.86 \text{ ppm}$$

$$NOx_{mass} = 6924(54.16)(.862)(7.86/1{,}000{,}000) = 2.54 \text{ grams}$$

$$CO_{conc} = 169.0 - .881[1 - (1/64.265)] = 168.0 \text{ ppm}$$

$$CO_{mass} = 6924(32.97)(168.0/1{,}000{,}000) = 38.35 \text{ grams}$$

$$CO_{2conc} = .178 - 0[1 - 1/64.265)] = .178\%$$

$$CO_{2mass} = 6924(51.85)(.178/100) = 639 \text{ grams}$$

<u>Hot Start Test</u>

Assume similar calculations result in the following:

$HC_{mass} = 8.72$ grams

$NOx_{mass} = 3.49$ grams

$CO_{mass} = 25.70$ grams

$CO_{2mass} = 1226$ grams

(2) Weighted mass emission results:

$$HC_{wm} = \frac{1/7(14.53) + 6/7(8.72)}{1/7(0.259) + 6/7(0.347)}$$

= 28.6 grams/BHP-HR

$$NOx_{wm} = \frac{1/7(2.54) + 6/7(3.49)}{1/7(0.259) + 6/7(0.347)}$$

= 10.0 grams/BHP-HR

$$CO_{wm} = \frac{1/7(38.35) + 6/7(25.70)}{1/7(0.259) + 6/7(0.347)}$$

= 82.2 grams/BHP-HR

$$CO_{2wm} = \frac{1/7(639) + 6/7(1226)}{1/7(0.259) + 6/7(0.347)}$$

= 3415 grams/ BHP-HR

(e) The final reported brake-specific fuel consumption (BSFC) shall be computed by use of the following formula:

$$BSFC = \frac{1/7(M_C) + 6/7(M_H)}{1/7(BHP\text{-}HR_C) + 6/7(BHP\text{-}HR_H)}$$

Where:

BSFC = brake-specific fuel consumption in pounds of fuel per brake horsepower-hour (lbs/BHP-HR)

M_C = mass of fuel, in pounds, used by the engine during the cold start test.

M_H = mass of fuel, in pounds, used by the engine during the hot start test.

$BHP\text{-}HR_C$ = total brake horsepower-hours (brake horsepower integrated with respect to time) for the cold start test.

$BHP\text{-}HR_H$ = total brake horsepower-hours (brake horsepower integrated with respect to time) for the hot start test.

(f) The mass of fuel for the cold start and hot start test is determined from the following equation:

$$M = (G_s/R)(1/453.6)$$

(g) Meaning of symbols:

M = Mass of fuel, in pounds, used by the engine during the cold or hot start test.

G_s = Grams of carbon measured during the cold or hot start test.

$$G_s = [12.011/(12.011 + \alpha(1.008))]HC_{mass} + 0.429CO_{mass} + 0.273\ CO_{2mass}$$

where:

HC_{mass} = Hydrocarbon emissions, in grams for cold or hot start test.

CO_{mass} = Carbon monoxide emissions, in grams for cold or hot start test.

CO_{2mass} = Carbon dioxide emissions, in grams for cold or hot start test.

α = The measured hydrogen to carbon ratio of the fuel.

R = The grams of carbon in the fuel per gram of fuel

$$R = 12.011/[12.011 + \alpha(1.008)]$$

(h) Sample calculation of brake-specific fuel consumption:

(1) Assume the following test results:

	Cold Start Cycle Test Results	Hot Start Cycle Test Results
BHP-HR	6.945	7.078
α	1.85	1.85
HC_{mass}	37.08 grams	28.82 grams
CO_{mass}	357.69 grams	350.33 grams
CO_{2mass}	5419.62 grams	5361.32 grams

Then:

G_s for cold start test =
$$[12.011/(12.011 + (1.85)(1.008))](37.08) + 0.429(357.69) + 0.273(5419.62) = 1665.10 \text{ grams}$$

G_s for hot start test =
$$[12.011/(12.011 + (1.85)(1.008))](28.82) + 0.429(350.33) + 0.273(5361.32) = 1638.88 \text{ grams}$$

$$R = 12.011/[12.011 + 1.85(1.008)] = .866$$

$$M_c = (1665.10/.866)(1/453.6) = 4.24 \text{ lbs.}$$

$$M_H = (1638.88/.866)(1/453.6) = 4.17 \text{ lbs.}$$

(2) Brake-specific fuel consumption results:

$$BSFC = \frac{1/7(4.24) + 6/7(4.17)}{1/7(6.945) + 6/7(7.078)} = .592 \text{ lbs.of fuel/BHP-HR}$$

APPENDIX XI

Heavy-Duty Transient Engine Cycles (Gasoline and Diesel)

Gasoline Heavy-Duty Transient Engine Cycle

RECORD (SEC)	%RPM	%POWER	RECORD (SEC)	%RPM	%POWER	RECORD (SEC)	%RPM	%POWER	RECORD (SEC)	%RPM	%POWER
0.	0.0	0.0	50.	0.0	0.0	100.	63.66	23.42	150.	0.0	2.16
1.	0.0	0.0	51.	0.0	10.11	101.	64.14	17.84	151.	0.0	0.0
2.	0.0	0.0	52.	4.32	46.40	102.	59.58	3.76	152.	0.0	0.0
3.	0.0	0.0	53.	8.90	45.17	103.	38.00	42.26	153.	0.0	0.0
4.	0.0	0.0	54.	1.95	50.00	104.	39.09	30.00	154.	0.83	MOTORING
5.	0.0	0.0	55.	3.33	41.68	105.	40.00	30.00	155.	2.00	MOTORING
6.	0.0	0.0	56.	4.00	89.46	106.	34.85	47.18	156.	0.54	MOTORING
7.	0.0	0.0	57.	13.76	55.60	107.	32.03	10.33	157.	0.0	MOTORING
8.	0.0	0.0	58.	26.43	26.96	108.	34.00	33.48	158.	0.0	MOTORING
9.	0.0	0.0	59.	33.85	6.16	109.	34.00	50.00	159.	0.0	MOTORING
10.	0.0	0.0	60.	36.00	MOTORING	110.	33.02	20.69	160.	0.0	MOTORING
11.	0.0	0.0	61.	34.45	MOTORING	111.	25.54	MOTORING	161.	0.0	0.0
12.	0.0	0.0	62.	34.00	MOTORING	112.	15.57	MOTORING	162.	0.0	0.0
13.	0.0	0.0	63.	35.64	MOTORING	113.	14.00	MOTORING	163.	0.0	0.0
14.	0.0	0.0	64.	32.99	27.39	114.	14.47	27.64	164.	0.0	0.0
15.	0.0	0.0	65.	36.00	80.00	115.	18.00	4.49	165.	0.0	0.0
16.	0.0	0.0	66.	41.63	74.37	116.	17.13	MOTORING	166.	0.0	MOTORING
17.	0.0	0.0	67.	60.41	26.76	117.	16.00	MOTORING	167.	0.0	22.01
18.	0.0	0.0	68.	48.44	MOTORING	118.	10.02	MOTORING	168.	1.23	72.29
19.	0.0	0.0	69.	43.86	MOTORING	119.	9.81	MOTORING	169.	6.63	80.00
20.	0.0	0.0	70.	40.39	MOTORING	120.	5.88	MOTORING	170.	17.29	89.29
21.	0.0	0.0	71.	38.50	4.01	121.	4.00	MOTORING	171.	22.17	90.00
22.	0.0	0.0	72.	35.05	30.00	122.	4.00	MOTORING	172.	24.00	82.70
23.	0.0	0.0	73.	40.66	16.70	123.	2.93	MOTORING	173.	24.00	31.96
24.	0.0	0.0	74.	43.64	26.45	124.	0.62	MOTORING	174.	24.00	MOTORING
25.	-1.78	44.40	75.	45.96	MOTORING	125.	0.0	MOTORING	175.	22.57	MOTORING
26.	0.0	85.35	76.	47.10	MOTORING	126.	0.0	MOTORING	176.	22.00	MOTORING
27.	4.25	100.00	77.	49.29	MOTORING	127.	0.0	MOTORING	177.	13.88	MOTORING
28.	27.47	100.00	78.	37.10	MOTORING	128.	0.0	MOTORING	178.	10.00	MOTORING
29.	42.96	100.00	79.	36.00	MOTORING	129.	0.0	MOTORING	179.	9.31	MOTORING
30.	45.79	100.00	80.	34.47	MOTORING	130.	0.0	10.00	180.	3.99	MOTORING
31.	48.11	99.46	81.	32.15	MOTORING	131.	0.0	10.00	181.	0.0	0.0
32.	50.42	90.00	82.	31.67	MOTORING	132.	0.0	29.02	182.	0.0	0.0
33.	52.74	75.23	83.	28.49	13.89	133.	0.0	27.83	183.	0.0	0.0
34.	54.00	50.00	84.	32.38	90.00	134.	0.0	7.34	184.	0.0	0.0
35.	44.42	8.96	85.	36.00	90.00	135.	0.0	0.0	185.	0.0	0.0
36.	45.05	MOTORING	86.	41.69	90.00	136.	0.0	0.0	186.	0.0	0.0
37.	46.00	9.99	87.	45.74	90.00	137.	0.0	0.0	187.	0.0	0.0
38.	37.69	MOTORING	88.	49.95	80.00	138.	0.0	0.0	188.	0.0	0.0
39.	31.61	5.68	89.	49.10	80.00	139.	0.0	0.0	189.	0.0	0.0
40.	22.94	35.29	90.	50.59	62.97	140.	0.0	0.0	190.	0.0	0.0
41.	24.00	4.87	91.	45.99	34.98	141.	0.0	0.0	191.	0.0	0.0
42.	20.86	MOTORING	92.	42.76	7.23	142.	0.0	0.0	192.	0.0	0.0
43.	12.45	MOTORING	93.	35.12	MOTORING	143.	0.0	0.0	193.	0.0	0.0
44.	6.00	MOTORING	94.	32.06	67.92	144.	0.0	0.0	194.	0.0	0.0
45.	6.52	MOTORING	95.	35.53	62.55	145.	0.0	0.0	195.	0.0	0.0
46.	7.17	MOTORING	96.	46.57	68.60	146.	2.00	0.0	196.	0.0	0.0
47.	2.56	MOTORING	97.	49.77	48.85	147.	1.38	0.0	197.	0.0	0.0
48.	0.0	0.0	98.	52.00	60.00	148.	0.0	0.0	198.	0.0	0.0
49.	0.0	0.0	99.	58.06	60.00	149.	0.0	6.27	199.	0.0	0.0

Gasoline Heavy-Duty Transient Engine Cycle

RECORD (SEC)	%RPM	%POWER	RECORD (SEC)	%RPM	%POWER	RECORD (SEC)	%RPM	%POWER	RECORD (SEC)	%RPM	%POWER
200.	0.0	0.0	250.	0.0	0.0	300.	0.0	4.07	350.	48.22	50.00
201.	0.0	0.0	251.	0.0	0.0	301.	0.0	10.00	351.	59.21	58.69
202.	0.0	0.0	252.	0.0	0.0	302.	0.0	17.22	352.	67.18	70.00
203.	0.0	0.0	253.	0.0	0.0	303.	0.0	20.00	353.	71.00	70.00
204.	-2.52	6.30	254.	0.0	0.0	304.	0.0	20.37	354.	72.00	70.00
205.	-4.22	15.28	255.	0.0	0.0	305.	2.33	31.94	355.	72.13	68.08
206.	0.0	10.00	256.	0.0	0.0	306.	16.22	36.48	356.	74.89	28.94
207.	0.0	10.00	257.	0.0	0.0	307.	24.00	24.91	357.	68.91	MOTORING
208.	0.0	10.00	258.	0.0	0.0	308.	24.00	13.34	358.	49.71	MOTORING
209.	0.0	75.93	259.	0.0	0.0	309.	19.06	10.00	359.	41.84	MOTORING
210.	0.0	32.22	260.	0.0	0.0	310.	18.00	MOTORING	360.	38.30	MOTORING
211.	1.67	35.00	261.	0.0	0.0	311.	17.17	MOTORING	361.	35.93	MOTORING
212.	15.48	29.82	262.	0.0	0.0	312.	9.04	MOTORING	362.	28.00	MOTORING
213.	25.46	MOTORING	263.	0.0	0.0	313.	1.09	MOTORING	363.	23.40	MOTORING
214.	24.22	MOTORING	264.	0.0	0.0	314.	0.0	0.0	364.	10.16	MOTORING
215.	23.44	MOTORING	265.	0.0	0.0	315.	0.0	0.0	365.	4.72	MOTORING
216.	12.41	80.00	266.	0.0	0.0	316.	0.0	0.0	366.	0.82	5.90
217.	8.94	83.61	267.	0.0	0.0	317.	0.0	0.0	367.	-9.53	19.53
218.	7.26	84.82	268.	0.0	0.0	318.	0.0	0.0	368.	2.20	45.60
219.	16.70	80.00	269.	0.0	0.0	319.	0.0	0.0	369.	20.53	7.33
220.	24.67	63.33	270.	0.0	0.0	320.	0.0	0.0	370.	21.15	0.0
221.	0.24	79.81	271.	0.0	0.0	321.	0.0	0.0	371.	17.67	MOTORING
222.	0.0	8.52	272.	0.0	0.0	322.	0.0	0.0	372.	13.04	MOTORING
223.	0.0	0.0	273.	0.0	0.0	323.	0.0	0.82	373.	8.41	79.70
224.	0.0	0.0	274.	0.0	0.0	324.	0.37	41.08	374.	10.33	100.00
225.	0.0	0.0	275.	0.0	0.0	325.	2.68	90.00	375.	17.27	100.00
226.	0.0	0.0	276.	0.0	0.0	326.	6.00	94.99	376.	22.00	100.00
227.	0.0	0.0	277.	0.0	0.0	327.	11.94	100.00	377.	25.16	100.00
228.	0.0	0.0	278.	0.0	0.0	328.	15.63	100.00	378.	29.37	100.00
229.	0.0	0.0	279.	0.0	0.0	329.	41.26	90.28	379.	36.73	66.35
230.	0.0	0.0	280.	0.0	0.0	330.	46.26	90.00	380.	40.00	MOTORING
231.	0.0	0.0	281.	0.0	4.17	331.	44.56	67.08	381.	23.50	MOTORING
232.	0.0	0.0	282.	1.15	10.00	332.	36.00	1.12	382.	9.37	MOTORING
233.	0.0	17.59	283.	2.00	10.00	333.	27.58	50.12	383.	8.00	MOTORING
234.	0.0	19.63	284.	0.22	10.00	334.	23.52	90.00	384.	6.74	MOTORING
235.	0.0	10.00	285.	0.0	0.0	335.	24.00	90.00	385.	2.86	MOTORING
236.	0.0	10.00	286.	0.0	0.0	336.	26.29	70.00	386.	0.11	MOTORING
237.	0.0	10.00	287.	0.0	0.0	337.	30.00	65.38	387.	0.0	MOTORING
238.	0.0	3.34	288.	0.0	0.0	338.	30.00	34.47	388.	0.0	0.0
239.	0.0	0.0	289.	0.0	0.0	339.	30.00	10.00	389.	0.0	0.0
240.	0.0	0.0	290.	0.0	0.0	340.	30.00	10.00	390.	0.0	0.0
241.	0.0	0.0	291.	0.0	0.0	341.	30.00	10.00	391.	0.0	0.0
242.	0.0	0.0	292.	0.0	0.0	342.	30.18	60.00	392.	0.0	0.0
243.	0.0	0.0	293.	0.0	0.0	343.	40.00	58.25	393.	0.0	0.0
244.	0.0	0.0	294.	0.0	0.0	344.	40.67	50.00	394.	0.0	0.0
245.	0.0	0.0	295.	0.0	0.0	345.	41.02	50.00	395.	0.0	0.0
246.	0.0	0.0	296.	0.0	0.0	346.	40.00	50.00	396.	0.0	0.0
247.	0.0	0.0	297.	0.0	0.0	347.	41.61	50.00	397.	0.0	0.0
248.	0.0	0.0	298.	0.0	0.0	348.	42.00	50.00	398.	0.0	0.0
249.	0.0	0.0	299.	0.0	0.0	349.	46.00	50.00	399.	0.0	0.0

[redacted]END[redacted]

Gasoline Heavy-Duty Transient Engine Cycle

RECORD (SEC)	%RPM	%POWER	RECORD (SEC)	%RPM	%POWER	RECORD (SEC)	%RPM	%POWER	RECORD (SEC)	%RPM	%POWER
400.	0.0	0.0	450.	37.97	MOTORING	500.	23.77	91.15	550.	36.00	37.46
401.	0.0	0.0	451.	35.30	MOTORING	501.	28.08	90.00	551.	36.00	40.00
402.	0.0	0.0	452.	30.68	MOTORING	502.	30.00	86.01	552.	34.00	40.00
403.	0.0	0.0	453.	27.02	MOTORING	503.	32.85	80.70	553.	34.00	40.00
404.	0.0	0.0	454.	26.00	MOTORING	504.	32.86	100.00	554.	34.00	36.25
405.	0.0	0.0	455.	26.00	MOTORING	505.	33.37	100.00	555.	38.26	24.68
406.	0.0	0.0	456.	20.24	MOTORING	506.	36.00	100.00	556.	43.38	61.38
407.	0.0	0.0	457.	14.00	MOTORING	507.	51.77	100.00	557.	50.78	46.12
408.	0.0	0.0	458.	13.45	18.27	508.	60.57	95.72	558.	52.00	19.92
409.	0.0	0.0	459.	9.40	52.99	509.	64.00	70.00	559.	52.32	0.0
410.	0.0	0.0	460.	10.72	81.81	510.	64.91	70.00	560.	52.09	3.19
411.	0.0	0.0	461.	15.50	97.48	511.	75.83	70.00	561.	48.00	10.00
412.	0.0	0.0	462.	19.62	100.00	512.	82.00	70.00	562.	48.00	10.00
413.	0.0	0.0	463.	20.25	100.00	513.	85.72	51.42	563.	48.00	10.00
414.	0.0	0.0	464.	25.76	100.00	514.	86.17	49.14	564.	30.94	19.48
415.	0.0	0.0	465.	35.02	100.00	515.	88.49	35.13	565.	28.00	20.00
416.	0.0	0.0	466.	42.14	94.65	516.	90.00	15.99	566.	28.00	20.00
417.	0.0	0.0	467.	44.00	90.00	517.	91.12	26.74	567.	28.00	15.81
418.	0.0	0.0	468.	45.70	90.00	518.	92.00	32.85	568.	28.00	10.00
419.	2.27	20.00	469.	51.99	60.00	519.	93.74	30.00	569.	26.53	10.00
420.	2.82	14.11	470.	50.00	60.00	520.	89.29	MOTORING	570.	26.00	10.00
421.	0.0	0.0	471.	51.29	63.22	521.	66.00	41.87	571.	23.71	MOTORING
422.	0.0	0.0	472.	54.96	70.00	522.	67.38	56.88	572.	17.59	MOTORING
423.	0.0	0.0	473.	56.00	70.00	523.	80.02	54.96	573.	11.65	MOTORING
424.	0.0	0.0	474.	62.35	38.25	524.	93.95	66.34	574.	1.92	MOTORING
425.	0.0	0.0	475.	71.61	30.00	525.	97.63	63.69	575.	0.0	0.0
426.	0.0	0.0	476.	76.22	50.00	526.	94.11	60.00	576.	0.0	0.0
427.	0.0	0.0	477.	78.00	50.00	527.	85.66	MOTORING	577.	0.0	0.0
428.	0.0	0.0	478.	78.00	41.53	528.	70.00	MOTORING	578.	0.0	0.0
429.	0.0	0.0	479.	55.93	12.58	529.	69.11	MOTORING	579.	0.0	0.0
430.	0.0	0.0	480.	38.52	0.0	530.	66.80	MOTORING	580.	0.0	0.0
431.	0.26	0.78	481.	34.42	71.65	531.	64.48	MOTORING	581.	0.0	0.0
432.	16.60	31.83	482.	36.11	79.47	532.	53.00	44.98	582.	0.0	0.0
433.	45.32	29.78	483.	38.84	67.90	533.	52.73	49.27	583.	1.26	25.19
434.	43.00	10.00	484.	42.74	60.00	534.	62.00	40.00	584.	6.72	47.87
435.	40.69	10.00	485.	44.00	54.75	535.	62.00	43.88	585.	13.67	40.56
436.	35.12	10.00	486.	49.46	36.35	536.	64.18	44.55	586.	16.20	80.00
437.	28.18	19.70	487.	52.00	30.00	537.	53.36	4.88	587.	18.52	80.00
438.	28.26	47.45	488.	32.05	MOTORING	538.	46.28	15.79	588.	25.83	75.83
439.	30.00	30.00	489.	25.69	0.0	539.	46.00	19.83	589.	35.15	70.00
440.	30.00	30.00	490.	24.00	0.0	540.	45.65	10.00	590.	38.93	77.31
441.	30.00	30.00	491.	24.00	MOTORING	541.	45.99	10.00	591.	41.78	80.00
442.	34.54	30.00	492.	20.24	MOTORING	542.	48.05	10.00	592.	40.00	10.00
443.	36.00	30.00	493.	10.16	68.43	543.	44.71	3.54	593.	40.00	20.18
444.	36.43	30.00	494.	8.00	80.58	544.	48.82	MOTORING	594.	40.00	52.78
445.	43.84	30.00	495.	10.20	80.99	545.	51.92	66.82	595.	40.00	34.82
446.	50.00	30.00	496.	13.54	90.00	546.	47.53	MOTORING	596.	40.00	30.00
447.	50.00	24.56	497.	18.00	94.13	547.	36.31	9.23	597.	40.00	38.33
448.	50.00	20.00	498.	20.28	100.00	548.	17.73	55.68	598.	40.00	30.09
449.	50.00	MOTORING	499.	22.00	100.00	549.	29.43	38.22	599.	38.30	100.00

[redacted]END[redacted]

Gasoline Heavy-Duty Transient Engine Cycle

RECORD (SEC)	%RPM	%POWER	RECORD (SEC)	%RPM	%POWER	RECORD (SEC)	%RPM	%POWER	RECORD (SEC)	%RPM	%POWER
600.	40.61	100.00	650.	54.00	90.00	700.	72.09	100.00	750.	104.00	25.98
601.	42.00	100.00	651.	54.00	90.00	701.	73.60	100.00	751.	103.71	20.00
602.	42.00	100.00	652.	54.00	85.10	702.	72.00	100.00	752.	99.54	20.00
603.	42.00	100.00	653.	55.29	73.53	703.	72.00	100.00	753.	98.00	20.00
604.	42.00	100.00	654.	56.00	70.00	704.	72.00	100.00	754.	99.09	25.44
605.	42.00	100.00	655.	56.00	70.00	705.	72.00	100.00	755.	98.60	65.08
606.	42.50	97.50	656.	56.00	60.00	706.	72.00	100.00	756.	103.15	80.00
607.	43.19	85.93	657.	56.00	57.23	707.	72.29	100.00	757.	100.03	80.00
608.	43.13	85.65	658.	56.00	50.00	708.	73.39	100.00	758.	102.35	80.00
609.	44.00	90.00	659.	56.00	38.17	709.	72.92	100.00	759.	104.00	73.38
610.	44.00	90.00	660.	56.00	30.00	710.	74.00	100.00	760.	104.00	55.11
611.	44.00	80.00	661.	56.00	30.00	711.	74.00	100.00	761.	101.42	30.62
612.	44.00	80.00	662.	54.00	39.36	712.	77.73	100.00	762.	98.39	11.97
613.	44.70	80.00	663.	54.00	27.79	713.	78.00	100.00	763.	57.65	MOTORING
614.	46.00	74.91	664.	54.00	20.00	714.	77.50	100.00	764.	58.00	MOTORING
615.	46.00	63.34	665.	54.00	20.00	715.	76.00	100.00	765.	57.45	MOTORING
616.	46.00	60.00	666.	54.00	20.00	716.	76.00	100.00	766.	56.00	MOTORING
617.	46.00	60.00	667.	54.00	11.49	717.	76.00	100.00	767.	56.00	MOTORING
618.	44.00	10.00	668.	54.00	0.08	718.	72.49	100.00	768.	56.00	27.39
619.	44.00	10.00	669.	54.00	13.31	719.	71.79	100.00	769.	56.00	40.00
620.	43.09	10.00	670.	54.00	30.00	720.	67.16	100.00	770.	56.00	50.00
621.	42.00	10.00	671.	54.96	30.00	721.	72.70	100.00	771.	56.00	45.60
622.	42.00	10.00	672.	57.28	30.00	722.	75.02	100.00	772.	56.00	33.77
623.	43.85	19.26	673.	56.41	30.00	723.	73.34	100.00	773.	56.00	40.00
624.	50.00	90.00	674.	57.91	30.00	724.	73.64	91.78	774.	60.15	5.40
625.	50.00	90.00	675.	58.22	36.60	725.	74.00	31.21	775.	62.00	MOTORING
626.	50.00	90.00	676.	60.00	90.00	726.	78.27	28.63	776.	62.00	MOTORING
627.	50.00	90.00	677.	60.00	90.00	727.	80.00	17.05	777.	62.00	41.64
628.	50.00	90.00	678.	60.00	95.82	728.	80.00	5.48	778.	62.00	59.65
629.	48.26	90.00	679.	60.00	92.60	729.	80.00	MOTORING	779.	62.00	75.21
630.	48.00	89.73	680.	60.00	90.00	730.	80.00	MOTORING	780.	62.00	76.36
631.	48.37	80.00	681.	60.00	90.00	731.	80.00	63.93	781.	62.00	80.00
632.	49.32	80.00	682.	60.42	90.00	732.	84.00	80.00	782.	62.00	80.00
633.	48.00	80.00	683.	62.74	90.00	733.	85.43	82.39	783.	62.00	80.00
634.	48.00	80.00	684.	65.05	90.00	734.	87.62	93.96	784.	62.00	80.00
635.	48.00	80.00	685.	66.00	83.16	735.	84.00	100.00	785.	61.15	80.00
636.	48.00	70.28	686.	66.00	71.59	736.	84.00	100.00	786.	60.00	80.00
637.	48.00	70.00	687.	66.00	70.00	737.	84.00	91.32	787.	60.00	87.38
638.	48.00	70.00	688.	66.00	70.00	738.	86.00	100.00	788.	60.00	90.00
639.	48.00	74.44	689.	66.00	73.14	739.	86.73	100.00	789.	60.00	90.00
640.	48.00	61.96	690.	66.00	80.00	740.	90.00	96.59	790.	60.00	90.00
641.	49.52	50.00	691.	66.00	86.28	741.	91.99	90.00	791.	60.00	90.00
642.	50.00	50.00	692.	66.00	90.00	742.	94.00	90.00	792.	60.00	90.00
643.	50.00	40.00	693.	66.00	90.00	743.	95.63	81.87	793.	60.00	83.17
644.	50.00	44.62	694.	68.20	100.00	744.	96.00	89.70	794.	60.00	80.00
645.	50.78	60.00	695.	70.00	100.00	745.	100.00	98.72	795.	60.00	89.97
646.	52.00	49.09	696.	70.00	100.00	746.	100.57	78.60	796.	62.31	90.00
647.	52.00	40.00	697.	70.00	100.00	747.	102.88	50.00	797.	64.00	86.88
648.	52.00	40.00	698.	74.38	100.00	748.	104.00	73.99	798.	64.00	80.00
649.	52.04	40.89	699.	76.00	100.00	749.	104.00	90.00	799.	64.00	80.00

APPENDIX XI

Gasoline Heavy-Duty Transient Engine Cycle

RECORD (SEC)	%RPM	%POWER	RECORD (SEC)	%RPM	%POWER	RECORD (SEC)	%RPM	%POWER	RECORD (SEC)	%RPM	%POWER
800.	64.00	80.00	850.	88.13	100.00	900.	0.0	0.0	950.	3.33	41.68
801.	64.00	80.00	851.	89.21	100.00	901.	0.0	0.0	951.	4.00	89.46
802.	66.00	70.00	852.	95.76	100.00	902.	0.0	0.0	952.	13.76	55.60
803.	66.51	70.00	853.	100.23	100.00	903.	0.0	0.0	953.	26.43	26.96
804.	68.00	65.87	854.	102.00	100.00	904.	0.0	0.0	954.	33.85	6.16
805.	68.00	60.00	855.	104.59	100.00	905.	0.0	0.0	955.	36.00	MOTORING
806.	68.00	60.00	856.	112.71	100.00	906.	0.0	0.0	956.	34.45	MOTORING
807.	73.31	86.55	857.	113.01	100.00	907.	0.0	0.0	957.	34.00	MOTORING
808.	74.00	90.00	858.	112.00	100.00	908.	0.0	0.0	958.	35.64	MOTORING
809.	74.00	90.00	859.	104.00	MOTORING	909.	0.0	0.0	959.	32.99	27.39
810.	73.29	90.00	860.	103.56	MOTORING	910.	0.0	0.0	960.	36.00	80.00
811.	72.00	84.86	861.	102.75	MOTORING	911.	0.0	0.0	961.	41.63	74.37
812.	73.34	73.29	862.	102.94	MOTORING	912.	0.0	0.0	962.	60.41	26.76
813.	74.00	70.00	863.	99.24	MOTORING	913.	0.0	0.0	963.	48.44	MOTORING
814.	72.03	70.00	864.	94.61	MOTORING	914.	0.0	0.0	964.	43.86	MOTORING
815.	71.71	50.00	865.	93.99	MOTORING	915.	0.0	0.0	965.	40.39	MOTORING
816.	70.00	50.00	866.	92.32	MOTORING	916.	0.0	0.0	966.	38.50	4.01
817.	70.00	50.00	867.	93.36	MOTORING	917.	0.0	0.0	967.	35.05	30.00
818.	68.77	56.15	868.	92.00	MOTORING	918.	0.0	0.0	968.	40.66	16.70
819.	68.00	60.00	869.	90.73	MOTORING	919.	0.0	0.0	969.	43.64	26.45
820.	68.00	60.00	870.	88.42	MOTORING	920.	-1.78	44.40	970.	45.96	MOTORING
821.	68.00	58.28	871.	84.21	MOTORING	921.	0.0	85.35	971.	47.10	MOTORING
822.	68.00	40.00	872.	82.00	10.00	922.	4.25	100.00	972.	49.29	MOTORING
823.	68.00	48.01	873.	82.00	7.38	923.	27.47	100.00	973.	37.10	MOTORING
824.	68.00	60.00	874.	82.00	MOTORING	924.	42.96	100.00	974.	36.00	MOTORING
825.	68.00	60.00	875.	82.00	MOTORING	925.	45.79	100.00	975.	34.47	MOTORING
826.	68.00	60.00	876.	68.79	48.69	926.	48.11	99.46	976.	32.15	MOTORING
827.	68.00	60.00	877.	64.00	70.00	927.	50.42	90.00	977.	31.67	MOTORING
828.	68.00	61.87	878.	64.00	70.00	928.	52.74	75.23	978.	28.48	13.89
829.	68.00	70.00	879.	58.66	67.95	929.	54.00	50.00	979.	32.38	90.00
830.	69.00	70.00	880.	37.27	60.00	930.	44.42	8.96	980.	36.00	90.00
831.	70.00	70.00	881.	34.96	60.00	931.	45.05	MOTORING	981.	41.69	90.00
832.	70.00	70.00	882.	32.65	73.54	932.	46.00	9.99	982.	45.74	90.00
833.	70.00	70.00	883.	30.33	80.00	933.	37.69	MOTORING	983.	49.95	80.00
834.	70.00	70.00	884.	28.02	80.00	934.	31.61	5.68	984.	49.10	80.00
835.	70.00	70.00	885.	25.70	50.00	935.	22.94	35.29	985.	50.59	62.97
836.	70.00	70.00	886.	23.39	37.76	936.	24.00	4.87	986.	45.99	34.98
837.	73.61	70.00	887.	21.07	10.00	937.	20.86	MOTORING	987.	42.76	7.23
838.	76.00	62.41	888.	18.76	10.00	938.	12.45	MOTORING	988.	35.12	MOTORING
839.	76.00	60.00	889.	14.89	MOTORING	939.	6.00	MOTORING	989.	32.06	67.92
840.	76.00	100.00	890.	12.13	MOTORING	940.	6.52	MOTORING	990.	35.53	62.55
841.	76.92	100.00	891.	5.45	MOTORING	941.	7.17	MOTORING	991.	46.57	68.60
842.	80.78	100.00	892.	0.0	0.0	942.	2.56	MOTORING	992.	49.77	48.85
843.	82.00	100.00	893.	0.0	0.0	943.	0.0	0.0	993.	52.00	60.00
844.	83.40	100.00	894.	0.0	0.0	944.	0.0	0.0	994.	58.06	60.00
845.	84.00	100.00	895.	0.0	0.0	945.	0.0	0.0	995.	63.66	23.42
846.	83.97	90.00	896.	0.0	0.0	946.	0.0	10.11	996.	64.14	17.84
847.	82.35	90.00	897.	0.0	0.0	947.	4.32	46.40	997.	59.58	3.76
848.	85.33	93.31	898.	0.0	0.0	948.	8.90	45.17	998.	38.00	42.26
849.	89.95	100.00	899.	0.0	0.0	949.	1.95	50.00	999.	39.09	30.00

[redacted] PENL [redacted] I

Gasoline Heavy-Duty Transient Engine Cycle

RECORD (SEC)	%RPM	%POWER	RECORD (SEC)	%RPM	%POWER	RECORD (SEC)	%RPM	%POWER	RECORD (SEC)	%RPM	%POWER
1000.	40.00	30.00	1050.	2.00	MOTORING	1100.	-4.22	15.28	1150.	0.0	0.0
1001.	34.85	47.18	1051.	0.54	MOTORING	1101.	0.0	10.00	1151.	0.0	0.0
1002.	32.03	10.33	1052.	0.0	MOTORING	1102.	0.0	10.00	1152.	0.0	0.0
1003.	34.00	33.48	1053.	0.0	MOTORING	1103.	0.0	10.00	1153.	0.0	0.0
1004.	34.00	50.00	1054.	0.0	MOTORING	1104.	0.0	75.93	1154.	0.0	0.0
1005.	33.02	20.69	1055.	0.0	MOTORING	1105.	0.0	32.22	1155.	0.0	0.0
1006.	25.54	MOTORING	1056.	0.0	0.0	1106.	1.67	35.00	1156.	0.0	0.0
1007.	15.57	MOTORING	1057.	0.0	0.0	1107.	15.48	29.82	1157.	0.0	0.0
1008.	14.00	MOTORING	1058.	0.0	0.0	1108.	25.46	MOTORING	1158.	0.0	0.0
1009.	14.47	27.64	1059.	0.0	0.0	1109.	24.22	MOTORING	1159.	0.0	0.0
1010.	18.00	4.49	1060.	0.0	0.0	1110.	23.44	MOTORING	1160.	0.0	0.0
1011.	17.13	MOTORING	1061.	0.0	MOTORING	1111.	12.41	80.00	1161.	0.0	0.0
1012.	16.00	MOTORING	1062.	0.0	22.01	1112.	8.94	83.61	1162.	0.0	0.0
1013.	10.02	MOTORING	1063.	1.23	72.29	1113.	7.26	84.82	1163.	0.0	0.0
1014.	9.81	MOTORING	1064.	6.63	80.00	1114.	16.70	80.00	1164.	0.0	0.0
1015.	5.88	MOTORING	1065.	17.29	89.29	1115.	24.67	63.33	1165.	0.0	0.0
1016.	4.00	MOTORING	1066.	22.17	90.00	1116.	0.24	79.81	1166.	0.0	0.0
1017.	4.00	MOTORING	1067.	24.00	82.70	1117.	0.0	8.52	1167.	0.0	0.0
1018.	2.93	MOTORING	1068.	24.00	31.96	1118.	0.0	0.0			
1019.	0.62	MOTORING	1069.	24.00	MOTORING	1119.	0.0	0.0			
1020.	0.0	MOTORING	1070.	22.57	MOTORING	1120.	0.0	0.0			
1021.	0.0	MOTORING	1071.	22.00	MOTORING	1121.	0.0	0.0			
1022.	0.0	MOTORING	1072.	13.88	MOTORING	1122.	0.0	0.0			
1023.	0.0	MOTORING	1073.	10.00	MOTORING	1123.	0.0	0.0			
1024.	0.0	MOTORING	1074.	9.31	MOTORING	1124.	0.0	0.0			
1025.	0.0	10.00	1075.	3.99	MOTORING	1125.	0.0	0.0			
1026.	0.0	10.00	1076.	0.0	0.0	1126.	0.0	0.0			
1027.	0.0	29.02	1077.	0.0	0.0	1127.	0.0	0.0			
1028.	0.0	27.83	1078.	0.0	0.0	1128.	0.0	17.59			
1029.	0.0	7.34	1079.	0.0	0.0	1129.	0.0	19.63			
1030.	0.0	0.0	1080.	0.0	0.0	1130.	0.0	10.00			
1031.	0.0	0.0	1081.	0.0	0.0	1131.	0.0	10.00			
1032.	0.0	0.0	1082.	0.0	0.0	1132.	0.0	10.00			
1033.	0.0	0.0	1083.	0.0	0.0	1133.	0.0	3.34			
1034.	0.0	0.0	1084.	0.0	0.0	1134.	0.0	0.0			
1035.	0.0	0.0	1085.	0.0	0.0	1135.	0.0	0.0			
1036.	0.0	0.0	1086.	0.0	0.0	1136.	0.0	0.0			
1037.	0.0	0.0	1087.	0.0	0.0	1137.	0.0	0.0			
1038.	0.0	0.0	1088.	0.0	0.0	1138.	0.0	0.0			
1039.	0.0	0.0	1089.	0.0	0.0	1139.	0.0	0.0			
1040.	0.0	0.0	1090.	0.0	0.0	1140.	0.0	0.0			
1041.	2.00	0.0	1091.	0.0	0.0	1141.	0.0	0.0			
1042.	1.38	0.0	1092.	0.0	0.0	1142.	0.0	0.0			
1043.	0.0	0.0	1093.	0.0	0.0	1143.	0.0	0.0			
1044.	0.0	6.27	1094.	0.0	0.0	1144.	0.0	0.0			
1045.	0.0	2.16	1095.	0.0	0.0	1145.	0.0	0.0			
1046.	0.0	0.0	1096.	0.0	0.0	1146.	0.0	0.0			
1047.	0.0	0.0	1097.	0.0	0.0	1147.	0.0	0.0			
1048.	0.0	0.0	1098.	0.0	0.0	1148.	0.0	0.0			
1049.	0.83	MOTORING	1099.	-2.52	6.30	1149.	0.0	0.0			

[redacted]END[redacted]

Diesel Heavy-Duty Transient Engine Cycle

RECORD (SEC)	%RPM	%POWER	RECORD (SEC)	%RPM	%POWER	RECORD (SEC)	%RPM	%POWER	RECORD (SEC)	%RPM	%POWER
0.	0.0	0.0	50.	54.03	79.92	100.	0.0	0.0	150.	0.0	0.0
1.	0.0	0.0	51.	58.00	65.03	101.	0.0	0.0	151.	0.0	0.0
2.	0.0	0.0	52.	58.65	43.23	102.	0.0	0.0	152.	0.0	0.0
3.	0.0	0.0	53.	62.88	50.00	103.	0.0	0.0	153.	0.0	0.0
4.	0.0	0.0	54.	69.83	50.00	104.	0.0	0.0	154.	0.0	0.0
5.	0.0	0.0	55.	72.00	42.05	105.	0.0	0.0	155.	0.0	0.0
6.	0.0	0.0	56.	75.81	40.00	106.	0.0	0.0	156.	0.0	0.0
7.	0.0	0.0	57.	84.22	42.20	107.	0.0	0.0	157.	0.0	0.0
8.	0.0	0.0	58.	83.86	41.28	108.	0.0	0.0	158.	0.0	0.21
9.	0.0	0.0	59.	80.55	MOTORING	109.	0.0	0.0	159.	0.0	30.00
10.	0.0	0.0	60.	80.51	MOTORING	110.	0.0	0.0	160.	0.0	26.78
11.	0.0	0.0	61.	78.00	MOTORING	111.	0.0	0.0	161.	0.0	20.00
12.	0.0	0.0	62.	79.79	MOTORING	112.	0.0	0.0	162.	0.0	20.00
13.	0.0	0.0	63.	80.33	30.54	113.	0.0	0.0	163.	0.0	4.12
14.	0.0	0.0	64.	85.58	42.12	114.	0.0	0.0	164.	0.0	0.0
15.	0.0	0.0	65.	81.78	50.00	115.	0.0	0.0	165.	0.0	0.0
16.	0.0	0.0	66.	78.00	50.00	116.	0.0	0.0	166.	0.0	0.0
17.	0.0	0.0	67.	80.74	43.16	117.	0.0	0.0	167.	0.0	0.0
18.	0.0	0.0	68.	92.10	73.65	118.	0.0	0.0	168.	0.0	0.0
19.	0.0	0.0	69.	88.01	MOTORING	119.	0.0	0.0	169.	0.0	0.0
20.	0.0	0.0	70.	84.00	MOTORING	120.	0.0	0.0	170.	0.0	0.0
21.	0.0	0.0	71.	84.00	MOTORING	121.	0.0	0.0	171.	0.0	0.0
22.	0.0	0.0	72.	81.17	MOTORING	122.	0.0	0.0	172.	0.0	0.0
23.	0.0	0.0	73.	70.46	MOTORING	123.	0.0	0.0	173.	0.0	0.0
24.	0.0	0.0	74.	66.00	13.57	124.	0.0	0.0	174.	0.0	0.0
25.	0.0	3.67	75.	62.23	29.43	125.	0.0	0.0	175.	0.0	0.0
26.	0.0	47.69	76.	64.00	20.00	126.	0.0	0.0	176.	0.0	0.0
27.	3.11	59.41	77.	63.48	17.42	127.	0.0	0.0	177.	0.0	0.0
28.	9.09	84.54	78.	60.34	10.00	128.	0.0	0.0	178.	0.0	0.0
29.	15.62	80.00	79.	56.85	10.00	129.	1.77	MOTORING	179.	0.0	0.0
30.	33.49	80.00	80.	56.00	MOTORING	130.	1.60	MOTORING	180.	0.0	0.0
31.	37.93	79.29	81.	52.45	MOTORING	131.	0.0	MOTORING	181.	0.0	0.0
32.	31.20	38.25	82.	39.91	10.00	132.	0.0	0.0	182.	0.0	0.0
33.	21.99	26.67	83.	36.38	10.00	133.	2.14	9.28	183.	0.0	0.0
34.	30.00	15.10	84.	30.00	10.00	134.	3.08	0.0	184.	0.0	20.00
35.	22.23	16.47	85.	27.93	10.00	135.	0.0	0.0	185.	0.0	20.00
36.	19.61	28.05	86.	26.00	16.74	136.	0.0	0.0	186.	0.0	11.73
37.	20.00	20.38	87.	27.66	3.36	137.	0.0	0.0	187.	0.0	0.0
38.	18.33	MOTORING	88.	28.00	MOTORING	138.	0.0	0.0	188.	0.0	0.0
39.	6.55	MOTORING	89.	27.41	MOTORING	139.	0.0	0.0	189.	0.0	0.0
40.	15.82	MOTORING	90.	20.96	MOTORING	140.	0.0	0.0	190.	0.0	0.0
41.	23.63	MOTORING	91.	12.15	MOTORING	141.	0.0	0.0	191.	0.0	0.0
42.	17.51	MOTORING	92.	3.81	MOTORING	142.	0.0	0.0	192.	0.0	0.0
43.	14.19	62.52	93.	0.0	MOTORING	143.	0.0	0.0	193.	0.0	0.0
44.	16.64	69.36	94.	0.0	MOTORING	144.	0.0	0.0	194.	0.0	0.0
45.	27.77	60.00	95.	0.0	0.91	145.	0.0	0.0	195.	0.0	0.0
46.	37.03	63.79	96.	0.0	7.52	146.	0.0	0.0	196.	0.0	0.0
47.	47.36	75.36	97.	0.0	0.0	147.	0.0	5.51	197.	0.0	0.0
48.	54.77	80.00	98.	0.0	0.0	148.	0.0	11.34	198.	0.0	0.0
49.	57.70	80.00	99.	0.0	0.0	149.	0.0	0.0	199.	0.0	0.0

Diesel Heavy-Duty Transient Engine Cycle

RECORD (SEC)	%RPM	%POWER	RECORD (SEC)	%RPM	%POWER	RECORD (SEC)	%RPM	%POWER	RECORD (SEC)	%RPM	%POWER
200.	0.0	0.0	250.	23.05	60.97	300.	0.0	0.0	350.	0.0	0.0
201.	0.0	0.0	251.	18.20	27.34	301.	0.0	0.0	351.	0.0	0.0
202.	0.0	0.0	252.	12.84	43.71	302.	0.0	0.0	352.	0.0	0.0
203.	0.0	0.0	253.	10.10	68.95	303.	0.0	0.0	353.	0.0	0.0
204.	0.0	0.0	254.	3.79	68.95	304.	0.0	0.0	354.	0.0	0.0
205.	0.0	0.0	255.	1.48	44.28	305.	0.0	0.0	355.	0.0	0.0
206.	0.0	0.0	256.	0.0	0.0	306.	0.0	0.0	356.	0.0	0.0
207.	0.0	0.0	257.	0.0	0.0	307.	0.0	0.0	357.	0.0	0.0
208.	0.0	0.0	258.	0.0	0.0	308.	0.0	0.0	358.	0.0	0.0
209.	0.0	0.0	259.	0.0	0.0	309.	0.0	0.0	359.	0.0	0.0
210.	0.0	0.0	260.	0.0	0.0	310.	0.0	0.0	360.	0.0	0.0
211.	0.0	0.0	261.	0.0	0.0	311.	0.0	0.0	361.	0.0	0.0
212.	0.0	0.0	262.	0.0	0.0	312.	0.0	0.0	362.	0.0	0.0
213.	0.0	0.0	263.	0.0	24.97	313.	0.0	0.0	363.	0.0	0.0
214.	0.0	73.41	264.	0.0	17.16	314.	0.0	0.0	364.	0.0	0.0
215.	0.0	90.00	265.	0.0	6.20	315.	0.0	0.0	365.	0.0	0.0
216.	31.30	81.30	266.	0.0	10.00	316.	0.0	0.0	366.	0.0	0.0
217.	41.15	90.00	267.	0.0	10.00	317.	0.0	0.0	367.	0.0	0.0
218.	44.00	90.00	268.	0.0	0.0	318.	0.0	0.0	368.	0.0	0.0
219.	46.41	90.00	269.	0.0	0.0	319.	0.0	0.0	369.	0.0	0.0
220.	51.04	82.41	270.	0.0	0.0	320.	0.0	0.0	370.	0.0	0.0
221.	66.66	80.00	271.	0.0	0.0	321.	0.0	15.55	371.	0.0	0.0
222.	75.03	90.00	272.	0.0	0.0	322.	0.0	20.00	372.	0.0	0.0
223.	89.85	90.00	273.	0.0	0.0	323.	24.18	19.08	373.	0.0	0.0
224.	96.78	93.88	274.	0.0	0.0	324.	23.00	10.00	374.	0.0	0.0
225.	96.91	50.94	275.	0.0	0.0	325.	11.56	1.86	375.	0.0	0.0
226.	94.60	17.02	276.	0.0	0.0	326.	6.87	MOTORING	376.	0.0	0.0
227.	99.16	28.60	277.	0.0	0.0	327.	6.00	MOTORING	377.	0.0	29.59
228.	100.00	39.83	278.	0.0	0.0	328.	0.72	MOTORING	378.	-1.50	87.46
229.	100.00	30.00	279.	0.0	0.0	329.	0.0	0.0	379.	8.88	100.00
230.	100.00	26.69	280.	0.0	0.0	330.	0.0	0.0	380.	46.04	100.00
231.	100.98	20.00	281.	0.0	0.0	331.	0.0	0.0	381.	76.89	100.00
232.	100.71	20.00	282.	0.0	0.0	332.	0.0	0.0	382.	80.00	100.00
233.	100.00	36.06	283.	0.0	0.0	333.	0.0	0.0	383.	82.14	94.64
234.	96.16	40.00	284.	0.0	0.0	334.	0.0	0.0	384.	85.39	83.07
235.	95.77	30.00	285.	0.0	0.0	335.	0.0	0.0	385.	87.70	88.51
236.	94.55	32.75	286.	0.0	0.0	336.	0.0	0.0	386.	92.00	79.83
237.	96.86	35.68	287.	0.0	0.0	337.	0.0	0.0	387.	92.00	61.66
238.	99.18	30.00	288.	0.0	0.0	338.	0.0	0.0	388.	94.58	66.77
239.	100.00	44.93	289.	0.0	0.0	339.	0.0	0.0	389.	102.88	60.00
240.	101.81	50.00	290.	0.0	0.0	340.	0.0	0.0	390.	106.00	72.76
241.	86.54	MOTORING	291.	0.0	0.0	341.	0.0	0.0	391.	109.18	8.43
242.	63.56	MOTORING	292.	0.0	0.0	342.	0.0	0.0	392.	111.91	MOTORING
243.	56.00	MOTORING	293.	0.0	0.0	343.	0.0	0.0	393.	82.00	MOTORING
244.	46.00	MOTORING	294.	0.0	0.0	344.	0.0	0.0	394.	79.33	MOTORING
245.	41.86	45.18	295.	0.0	0.0	345.	0.0	0.0	395.	71.15	MOTORING
246.	38.31	78.47	296.	0.0	0.0	346.	0.0	0.0	396.	68.84	MOTORING
247.	35.98	80.00	297.	0.0	0.0	347.	0.0	0.0	397.	78.35	49.17
248.	31.03	80.00	298.	0.0	0.0	348.	0.0	0.0	398.	82.00	70.00
249.	25.36	80.00	299.	0.0	0.0	349.	0.0	0.0	399.	80.65	69.46

Diesel Heavy-Duty Transient Engine Cycle

RECORD (SEC)	%RPM	%POWER	RECORD (SEC)	%RPM	%POWER	RECORD (SEC)	%RPM	%POWER	RECORD (SEC)	%RPM	%POWER
400.	92.85	60.00	450.	86.16	29.18	500.	93.71	80.00	550.	0.0	0.0
401.	97.48	60.00	451.	88.00	20.00	501.	94.87	80.00	551.	0.0	0.0
402.	98.95	60.00	452.	87.21	20.00	502.	103.60	80.00	552.	0.0	2.60
403.	100.74	60.00	453.	86.00	20.00	503.	101.23	41.89	553.	0.0	20.00
404.	103.68	43.17	454.	87.42	20.00	504.	95.48	24.85	554.	0.0	20.00
405.	104.00	10.04	455.	88.00	11.32	505.	98.00	50.00	555.	0.0	7.96
406.	80.62	20.00	456.	77.84	MOTORING	506.	99.79	50.00	556.	0.0	0.0
407.	83.37	20.00	457.	72.00	MOTORING	507.	106.21	46.82	557.	0.0	0.0
408.	81.06	15.29	458.	71.32	MOTORING	508.	110.84	MOTORING	558.	0.0	78.53
409.	80.00	10.00	459.	70.00	0.04	509.	98.55	MOTORING	559.	1.85	60.00
410.	76.86	MOTORING	460.	70.00	MOTORING	510.	70.95	MOTORING	560.	11.10	63.88
411.	74.11	MOTORING	461.	74.88	MOTORING	511.	67.27	MOTORING	561.	16.00	70.00
412.	71.60	MOTORING	462.	74.06	MOTORING	512.	60.96	MOTORING	562.	30.05	70.00
413.	70.58	MOTORING	463.	67.74	MOTORING	513.	48.03	MOTORING	563.	42.88	70.00
414.	78.00	MOTORING	464.	66.00	MOTORING	514.	52.31	MOTORING	564.	56.10	70.00
415.	80.29	1.45	465.	64.23	MOTORING	515.	54.00	MOTORING	565.	63.39	66.52
416.	80.54	17.30	466.	62.00	MOTORING	516.	65.27	MOTORING	566.	70.66	59.94
417.	78.23	11.13	467.	55.94	MOTORING	517.	78.00	MOTORING	567.	72.98	80.00
418.	78.45	19.55	468.	54.00	MOTORING	518.	57.61	MOTORING	568.	77.87	86.46
419.	84.36	24.16	469.	66.43	MOTORING	519.	42.58	MOTORING	569.	88.03	90.00
420.	72.16	80.00	470.	75.21	70.00	520.	38.81	MOTORING	570.	90.00	90.00
421.	79.10	74.83	471.	86.00	54.53	521.	22.37	MOTORING	571.	92.23	100.00
422.	90.09	16.04	472.	86.00	24.56	522.	3.52	MOTORING	572.	94.00	100.00
423.	74.04	MOTORING	473.	88.81	MOTORING	523.	0.0	0.0	573.	94.86	100.00
424.	68.02	MOTORING	474.	90.00	MOTORING	524.	-1.46	36.39	574.	96.00	100.00
425.	68.53	MOTORING	475.	105.48	MOTORING	525.	-0.23	5.75	575.	97.46	100.00
426.	59.39	MOTORING	476.	74.00	MOTORING	526.	0.0	0.0	576.	108.84	100.00
427.	63.54	MOTORING	477.	73.34	MOTORING	527.	0.0	0.0	577.	110.00	83.92
428.	70.00	2.38	478.	71.02	10.00	528.	0.0	0.0	578.	104.77	MOTORING
429.	73.10	17.76	479.	76.46	29.38	529.	0.0	0.0	579.	87.50	MOTORING
430.	72.13	MOTORING	480.	81.61	40.00	530.	0.0	0.0	580.	90.00	0.0
431.	67.27	MOTORING	481.	78.16	30.39	531.	0.0	0.0	581.	91.38	MOTORING
432.	36.03	MOTORING	482.	74.13	26.46	532.	0.0	0.0	582.	81.84	MOTORING
433.	20.75	MOTORING	483.	90.00	0.0	533.	0.0	0.0	583.	65.99	MOTORING
434.	11.49	MOTORING	484.	90.87	0.0	534.	0.0	0.0	584.	63.68	MOTORING
435.	-2.09	MOTORING	485.	92.00	MOTORING	535.	0.0	0.0	585.	60.73	MOTORING
436.	-0.73	MOTORING	486.	93.50	MOTORING	536.	0.0	0.0	586.	57.05	MOTORING
437.	8.57	60.00	487.	94.00	MOTORING	537.	0.0	0.0	587.	53.47	MOTORING
438.	30.55	61.93	488.	94.13	MOTORING	538.	0.0	0.0	588.	50.42	MOTORING
439.	67.10	63.00	489.	88.96	MOTORING	539.	0.0	0.0	589.	44.31	MOTORING
440.	86.03	39.85	490.	63.25	MOTORING	540.	0.0	0.0	590.	37.58	37.91
441.	89.33	30.00	491.	62.00	MOTORING	541.	0.0	0.0	591.	33.48	20.00
442.	91.64	30.00	492.	49.54	45.37	542.	0.0	0.0	592.	31.16	20.00
443.	97.88	10.40	493.	52.49	86.99	543.	0.0	0.0	593.	26.85	20.00
444.	97.73	1.37	494.	64.00	90.00	544.	0.0	MOTORING	594.	22.13	20.00
445.	96.00	10.00	495.	64.99	90.00	545.	0.0	0.0	595.	9.31	MOTORING
446.	96.00	0.96	496.	71.93	93.22	546.	-0.75	MOTORING	596.	0.0	0.0
447.	96.00	MOTORING	497.	78.87	95.21	547.	-0.56	MOTORING	597.	0.0	0.0
448.	85.27	28.34	498.	82.00	83.64	548.	4.00	MOTORING	598.	0.0	0.0
449.	87.54	30.76	499.	86.76	80.00	549.	0.68	MOTORING	599.	0.0	0.0

A[redacted]DIX [redacted]

Diesel Heavy-Duty Transient Engine Cycle

RECORD (SEC)	%RPM	%POWER	RECORD (SEC)	%RPM	%POWER	RECORD (SEC)	%RPM	%POWER	RECORD (SEC)	%RPM	%POWER
600.	0.0	0.0	650.	88.00	94.45	700.	81.70	MOTORING	750.	94.59	87.05
601.	0.0	0.0	651.	88.00	90.00	701.	85.16	MOTORING	751.	96.00	57.40
602.	0.0	0.0	652.	88.00	90.00	702.	84.52	MOTORING	752.	96.00	42.19
603.	0.0	0.0	653.	90.00	90.00	703.	82.21	MOTORING	753.	96.00	42.33
604.	0.0	0.0	654.	89.63	90.00	704.	79.89	MOTORING	754.	96.00	40.00
605.	0.0	0.0	655.	88.68	90.00	705.	77.58	MOTORING	755.	96.00	38.37
606.	2.52	6.30	656.	90.00	90.00	706.	76.00	6.31	756.	96.00	12.83
607.	10.30	17.87	657.	90.00	90.00	707.	79.16	0.0	757.	96.00	MOTORING
608.	13.89	20.00	658.	91.63	81.86	708.	75.16	27.36	758.	96.00	MOTORING
609.	20.20	20.00	659.	92.00	80.00	709.	72.00	40.00	759.	96.00	MOTORING
610.	24.07	22.59	660.	90.00	81.29	710.	72.00	40.00	760.	97.74	7.37
611.	33.33	17.50	661.	89.43	92.86	711.	74.00	38.44	761.	100.05	19.74
612.	40.30	MOTORING	662.	87.11	100.00	712.	74.00	30.00	762.	102.00	11.83
613.	47.85	MOTORING	663.	86.00	100.00	713.	74.00	30.00	763.	102.00	26.81
614.	66.00	7.78	664.	86.00	100.00	714.	74.00	36.28	764.	103.00	49.96
615.	68.00	10.93	665.	89.66	100.00	715.	72.43	47.86	765.	104.00	60.00
616.	67.59	32.04	666.	90.00	99.27	716.	68.23	59.43	766.	102.37	60.00
617.	66.00	40.00	667.	90.46	90.00	717.	73.80	50.00	767.	103.94	60.00
618.	67.04	40.00	668.	92.78	90.00	718.	72.52	50.00	768.	104.00	40.00
619.	68.00	40.00	669.	95.09	90.00	719.	74.00	45.85	769.	104.00	25.75
620.	68.00	48.33	670.	100.22	82.97	720.	72.85	57.18	770.	103.12	MOTORING
621.	75.93	99.53	671.	102.00	80.00	721.	76.38	62.70	771.	100.80	MOTORING
622.	78.00	100.00	672.	102.00	70.18	722.	81.55	60.00	772.	100.00	MOTORING
623.	78.00	100.00	673.	102.00	80.00	723.	80.18	60.00	773.	101.83	44.88
624.	77.07	100.00	674.	97.34	50.07	724.	83.60	60.00	774.	102.00	36.40
625.	76.00	100.00	675.	87.02	MOTORING	725.	83.44	56.40	775.	102.00	MOTORING
626.	76.00	100.00	676.	86.00	MOTORING	726.	86.00	50.00	776.	102.00	MOTORING
627.	76.00	100.00	677.	73.12	22.19	727.	87.35	50.00	777.	100.91	MOTORING
628.	75.63	100.00	678.	75.77	39.62	728.	86.34	50.00	778.	101.40	MOTORING
629.	73.00	97.50	679.	75.76	48.80	729.	86.00	40.11	779.	100.28	MOTORING
630.	76.81	90.00	680.	75.11	37.23	730.	88.29	61.47	780.	97.97	MOTORING
631.	80.26	90.00	681.	78.00	34.34	731.	88.78	63.92	781.	96.00	MOTORING
632.	83.44	90.00	682.	80.37	40.00	732.	86.92	50.00	782.	96.00	10.00
633.	84.00	98.79	683.	77.51	47.49	733.	86.76	50.00	783.	96.00	0.23
634.	84.00	100.00	684.	81.44	50.00	734.	87.55	42.24	784.	96.00	MOTORING
635.	83.61	100.00	685.	82.13	39.36	735.	88.00	49.34	785.	96.00	MOTORING
636.	82.00	100.00	686.	84.00	27.79	736.	86.00	50.91	786.	94.08	MOTORING
637.	83.02	94.91	687.	84.00	16.21	737.	86.00	67.45	787.	78.00	MOTORING
638.	86.67	90.00	688.	84.00	15.36	738.	86.00	81.88	788.	77.45	MOTORING
639.	89.65	90.00	689.	85.39	26.93	739.	87.13	70.00	789.	71.67	28.96
640.	90.00	99.81	690.	86.00	30.00	740.	89.44	77.21	790.	67.18	80.00
641.	89.45	100.00	691.	86.00	30.08	741.	91.76	88.78	791.	66.50	87.48
642.	86.00	100.00	692.	85.67	40.00	742.	90.07	89.65	792.	71.43	90.00
643.	86.00	95.47	693.	84.65	40.00	743.	92.00	80.00	793.	74.13	90.00
644.	87.22	90.00	694.	86.00	35.20	744.	92.70	80.00	794.	75.56	92.20
645.	88.00	90.00	695.	87.28	30.00	745.	94.00	80.00	795.	74.75	100.00
646.	88.00	80.74	696.	88.00	22.05	746.	94.00	80.00	796.	77.07	94.65
647.	88.00	79.17	697.	86.09	MOTORING	747.	94.00	80.00	797.	79.38	83.08
648.	88.00	77.21	698.	83.78	MOTORING	748.	94.00	80.00	798.	80.00	71.51
649.	88.00	100.00	699.	81.47	MOTORING	749.	94.00	81.37	799.	80.01	69.93

[redacted] A [redacted] DIX [redacted]

Diesel Heavy-Duty Transient Engine Cycle

ECORD (SEC)	%RPM	%POWER	RECORD (SEC)	%RPM	%POWER	RECORD (SEC)	%RPM	%POWER	RECORD (SEC)	%RPM	%POWER
800.	82.33	58.36	850.	104.00	0.30	900.	0.0	0.0	950.	54.77	80.00
801.	84.00	50.00	851.	103.63	11.87	901.	0.0	0.0	951.	57.70	80.00
802.	84.00	59.58	852.	100.62	13.12	902.	0.0	0.0	952.	54.03	79.92
803.	84.00	76.36	853.	98.00	5.01	903.	0.0	0.0	953.	58.00	65.03
804.	84.00	80.00	854.	96.68	10.00	904.	0.0	0.0	954.	58.65	43.23
805.	84.00	70.49	855.	96.00	MOTORING	905.	0.0	0.0	955.	62.88	50.00
806.	82.00	80.00	856.	96.00	MOTORING	906.	0.0	0.0	956.	69.83	50.00
807.	81.47	82.66	857.	96.00	MOTORING	907.	0.0	0.0	957.	72.00	42.05
808.	80.00	90.00	858.	95.43	MOTORING	908.	0.0	0.0	958.	75.81	40.00
809.	77.68	90.00	859.	94.00	MOTORING	909.	0.0	0.0	959.	84.22	42.20
810.	74.52	75.24	860.	94.00	MOTORING	910.	0.0	0.0	960.	83.86	41.28
811.	77.58	78.96	861.	95.52	5.18	911.	0.0	0.0	961.	80.55	MOTORING
812.	81.89	80.00	862.	97.83	MOTORING	912.	0.0	0.0	962.	80.51	MOTORING
813.	80.42	80.00	863.	98.00	MOTORING	913.	0.0	0.0	963.	78.00	MOTORING
814.	82.00	83.68	864.	98.00	MOTORING	914.	0.0	0.0	964.	79.79	MOTORING
815.	83.05	79.50	865.	97.22	MOTORING	915.	0.0	0.0	965.	80.33	30.54
816.	84.00	70.00	866.	96.00	6.35	916.	0.0	0.0	966.	85.58	42.12
817.	84.00	61.60	867.	96.00	12.98	917.	0.0	0.0	967.	81.78	50.00
818.	84.00	50.03	868.	96.00	10.00	918.	0.0	0.0	968.	78.00	50.00
819.	86.00	60.00	869.	95.93	10.00	919.	0.0	0.0	969.	80.74	43.16
820.	86.00	60.00	870.	92.00	10.00	920.	0.0	0.0	970.	92.10	73.65
821.	86.00	69.39	871.	92.00	10.00	921.	0.0	0.0	971.	88.01	MOTORING
822.	88.51	73.73	872.	92.98	14.89	922.	0.0	0.0	972.	84.00	MOTORING
823.	88.43	70.00	873.	94.00	13.54	923.	0.0	0.0	973.	84.00	MOTORING
824.	88.00	70.00	874.	90.79	42.12	924.	0.0	0.0	974.	81.17	MOTORING
825.	94.00	70.99	875.	88.08	40.40	925.	0.0	0.0	975.	70.46	MOTORING
826.	94.51	80.00	876.	86.23	30.00	926.	0.0	0.0	976.	66.00	13.57
827.	95.17	80.00	877.	88.00	32.75	927.	0.0	3.67	977.	62.23	29.43
828.	95.14	80.00	878.	87.14	44.32	928.	0.0	47.69	978.	64.00	20.00
829.	94.54	80.00	879.	84.82	50.00	929.	3.11	59.41	979.	63.48	17.42
830.	94.00	80.00	880.	82.51	50.00	930.	9.09	84.54	980.	60.34	10.00
831.	94.00	77.89	881.	82.00	50.00	931.	15.62	80.00	981.	56.85	10.00
832.	94.00	31.99	882.	82.12	40.00	932.	33.49	80.00	982.	56.00	MOTORING
833.	94.00	43.57	883.	83.13	35.64	933.	37.93	79.29	983.	52.45	MOTORING
834.	94.00	60.28	884.	80.00	20.00	934.	31.20	38.25	984.	39.91	10.00
835.	94.00	63.29	885.	84.26	51.95	935.	21.99	26.67	985.	36.39	10.00
836.	94.00	76.57	886.	86.62	66.21	936.	30.00	15.10	986.	30.00	10.00
837.	94.00	89.86	887.	84.31	60.00	937.	22.23	16.47	987.	27.93	10.00
838.	94.29	90.00	888.	81.99	9.96	938.	19.61	28.05	988.	26.00	16.74
839.	97.80	87.00	889.	79.35	1.61	939.	20.00	20.38	989.	27.66	3.36
840.	102.91	80.00	890.	75.36	19.56	940.	18.33	MOTORING	990.	28.00	MOTORING
841.	104.00	73.85	891.	73.05	40.00	941.	6.55	MOTORING	991.	27.41	MOTORING
842.	104.00	62.28	892.	70.73	8.35	942.	15.82	MOTORING	992.	20.96	MOTORING
843.	104.00	69.29	893.	68.42	MOTORING	943.	23.63	MOTORING	993.	12.1[illegible]	MOTORING
844.	106.00	70.00	894.	47.15	8.95	944.	17.51	MOTORING	994.	3.81	MOTORING
845.	106.00	62.70	895.	35.79	10.00	945.	14.19	62.52	995.	0.0	MOTORING
846.	106.00	40.00	896.	32.95	7.38	946.	16.64	69.36	996.	0.0	MOTORING
847.	104.88	40.00	897.	29.16	MOTORING	947.	27.77	60.00	997.	0.0	0.91
848.	104.00	32.85	898.	16.47	MOTORING	948.	37.03	63.79	998.	0.0	7.52
849.	104.00	30.00	899.	2.13	MOTORING	949.	47.36	75.36	999.	0.0	0.0

[redacted]DIX[redacted]

Diesel Heavy-Duty Transient Engine Cycle

RECORD (SEC)	%RPM	%POWER	RECORD (SEC)	%RPM	%POWER	RECORD (SEC)	%RPM	%POWER	RECORD (SEC)	%RPM	%POWER
1000.	0.0	0.0	1050.	0.0	11.34	1100.	0.0	0.0	1150.	31.03	80.00
1001.	0.0	0.0	1051.	0.0	0.0	1101.	0.0	0.0	1151.	25.36	80.00
1002.	0.0	0.0	1052.	0.0	0.0	1102.	0.0	0.0	1152.	23.05	60.97
1003.	0.0	0.0	1053.	0.0	0.0	1103.	0.0	0.0	1153.	18.20	27.34
1004.	0.0	0.0	1054.	0.0	0.0	1104.	0.0	0.0	1154.	12.84	43.71
1005.	0.0	0.0	1055.	0.0	0.0	1105.	0.0	0.0	1155.	10.10	68.95
1006.	0.0	0.0	1056.	0.0	0.0	1106.	0.0	0.0	1156.	3.79	68.95
1007.	0.0	0.0	1057.	0.0	0.0	1107.	0.0	0.0	1157.	1.49	44.28
1008.	0.0	0.0	1058.	0.0	0.0	1108.	0.0	0.0	1158.	0.0	0.0
1009.	0.0	0.0	1059.	0.0	0.0	1109.	0.0	0.0	1159.	0.0	0.0
1010.	0.0	0.0	1060.	0.0	0.21	1110.	0.0	0.0	1160.	0.0	0.0
1011.	0.0	0.0	1061.	0.0	30.00	1111.	0.0	0.0	1161.	0.0	0.0
1012.	0.0	0.0	1062.	0.0	26.78	1112.	0.0	0.0	1162.	0.0	0.0
1013.	0.0	0.0	1063.	0.0	20.00	1113.	0.0	0.0	1163.	0.0	0.0
1014.	0.0	0.0	1064.	0.0	20.00	1114.	0.0	0.0	1164.	0.0	0.0
1015.	0.0	0.0	1065.	0.0	4.12	1115.	0.0	0.0	1165.	0.0	24.97
1016.	0.0	0.0	1066.	0.0	0.0	1116.	0.0	73.41	1166.	0.0	17.16
1017.	0.0	0.0	1067.	0.0	0.0	1117.	0.0	90.00	1167.	0.0	6.20
1018.	0.0	0.0	1068.	0.0	0.0	1118.	31.30	81.30	1168.	0.0	10.00
1019.	0.0	0.0	1069.	0.0	0.0	1119.	41.15	90.00	1169.	0.0	10.00
1020.	0.0	0.0	1070.	0.0	0.0	1120.	44.00	90.00	1170.	0.0	0.0
1021.	0.0	0.0	1071.	0.0	0.0	1121.	46.41	90.00	1171.	0.0	0.0
1022.	0.0	0.0	1072.	0.0	0.0	1122.	51.04	82.41	1172.	0.0	0.0
1023.	0.0	0.0	1073.	0.0	0.0	1123.	66.66	80.00	1173.	0.0	0.0
1024.	0.0	0.0	1074.	0.0	0.0	1124.	75.03	90.00	1174.	0.0	0.0
1025.	0.0	0.0	1075.	0.0	0.0	1125.	89.85	90.00	1175.	0.0	0.0
1026.	0.0	0.0	1076.	0.0	0.0	1126.	96.78	93.88	1176.	0.0	0.0
1027.	0.0	0.0	1077.	0.0	0.0	1127.	96.91	50.94	1177.	0.0	0.0
1028.	0.0	0.0	1078.	0.0	0.0	1128.	94.60	17.02	1178.	0.0	0.0
1029.	0.0	0.0	1079.	0.0	0.0	1129.	99.16	28.60	1179.	0.0	0.0
1030.	0.0	0.0	1080.	0.0	0.0	1130.	100.00	39.83	1180.	0.0	0.0
1031.	1.77	MOTORING	1081.	0.0	0.0	1131.	100.00	30.00	1181.	0.0	0.0
1032.	1.60	MOTORING	1082.	0.0	0.0	1132.	100.00	26.69	1182.	0.0	0.0
1033.	0.0	MOTORING	1083.	0.0	0.0	1133.	100.98	20.00	1183.	0.0	0.0
1034.	0.0	0.0	1084.	0.0	0.0	1134.	100.71	20.00	1184.	0.0	0.0
1035.	2.14	9.28	1085.	0.0	0.0	1135.	100.00	36.06	1185.	0.0	0.0
1036.	3.08	0.0	1086.	0.0	20.00	1136.	96.16	40.00	1186.	0.0	0.0
1037.	0.0	0.0	1087.	0.0	20.00	1137.	95.77	30.00	1187.	0.0	0.0
1038.	0.0	0.0	1088.	0.0	11.73	1138.	94.55	32.75	1188.	0.0	0.0
1039.	0.0	0.0	1089.	0.0	0.0	1139.	96.86	35.68	1189.	0.0	0.0
1040.	0.0	0.0	1090.	0.0	0.0	1140.	99.18	30.00	1190.	0.0	0.0
1041.	0.0	0.0	1091.	0.0	0.0	1141.	100.00	44.93	1191.	0.0	0.0
1042.	0.0	0.0	1092.	0.0	0.0	1142.	101.81	50.00	1192.	0.0	0.0
1043.	0.0	0.0	1093.	0.0	0.0	1143.	86.54	MOTORING	1193.	0.0	0.0
1044.	0.0	0.0	1094.	0.0	0.0	1144.	63.56	MOTORING	1194.	0.0	0.0
1045.	0.0	0.0	1095.	0.0	0.0	1145.	56.00	MOTORING	1195.	0.0	0.0
1046.	0.0	0.0	1096.	0.0	0.0	1146.	46.00	MOTORING	1196.	0.0	0.0
1047.	0.0	0.0	1097.	0.0	0.0	1147.	41.86	45.18	1197.	0.0	0.0
1048.	0.0	0.0	1098.	0.0	0.0	1148.	38.31	78.47	1198.	0.0	0.0
1049.	0.0	5.51	1099.	0.0	0.0	1149.	35.98	80.00	1199.	0.0	0.0