Chapter 2: Exhaust Emission Test Cycle and Test Procedures

2.1 Introduction

In order for EPA to successfully regulate exhaust emissions from small nonroad engines, the Agency strives to establish test procedures and cycles which ensure technologies used by manufacturers not only meet the emission standards when tested over the required test procedures, but also result in a predictable emission reduction in actual use. Test procedures are specified to a level of detail necessary to produce accurate, repeatable results.

2.2 Phase 1 test procedures and test cycle

The Phase 1 test procedure is described in 40 CFR Part 90, Subparts D and E. The Phase 1 test procedure is based upon well established and accepted on-highway exhaust emission methods and equipment, with some modification to take into account the unique nature of small SI engines. The procedures are designed to accurately measure engine emission performance. A description of the Phase 1 test cycle and procedure can be found in the final RIA for the Phase 1 rule.(Ref. 1) The Phase 1 test cycles (two for nonhandheld and one for handheld engines) are comprised of a series of steady state 'modes'. A mode is a specified engine speed and load condition, during which the engine is stabilized and emissions are sampled. The emission results for all of the modes are combined using 'weighting factors' into a single number for each pollutant.

Three distinct cycles (sets of modes) are used for small engines: (1) engines used in non-handheld intermediate speed applications; (2) engines used in non-handheld rated speed applications; and, (3) engines used in handheld applications. The test cycle for non-handheld intermediate speed engines consists of six different speed/load modes, five load conditions that span the load range of the engine at intermediate speed and one no-load condition at idle speed. The test cycle for non-handheld rated speed applications also consists of six different modes, five load conditions at rated speed and one no-load condition at idle speed. The test cycle for handheld applications consist of 2 modes, one full load condition at rated speed and one no-load condition at idle speed.

The Agency determined during the Phase 1 rulemaking, based on the information available at the time, that for the range of technologies expected to be used to meet the Phase 1 standards, that the Phase 1 test cycle and weighting factors were appropriate.

2.3 Agency review of Phase 1 test cycle and procedure for proposed Phase 2 rule

Prior to proposing Phase 2 emission standards for small nonroad engines, the Agency first undertook, with the cooperation of the engine industry and members of the Negotiated Rulemaking Committee, a test program to determine if the Phase 2 rule should contain a change in the test cycle. The Agency has found for other mobile source categories that stead-state test cycles often do not result in real in-use emission reductions and that 'transient' test cycles which more closely mimic real world operating conditions are necessary. A transient cycle means a combination of speed and/or load conditions which vary with time, such as the on-highway Federal Test Procedure for light-duty vehicles or heavy duty engines.

During the Reg/Neg process the Agency expressed concerns regarding the ability of the Phase 1 steady-state test cycles to adequately predict in-use emission reductions for a Phase 2 rule which would result in different engine technologies being employed. The Reg/Neg committee established a Test Procedure Task Group to examine the existing Phase 1 test cycle and procedure and make recommendations to the committee regarding any appropriate changes. (Ref. 2) The Test Procedure Task Group established two subgroups to examine the Phase 1 steady state non-handheld and handheld test cycles.

2.3.1 Review of Non-handheld Test Cycle

The Test Procedure Task Group established a Nonhandheld Subgroup, consisting of one EPA technical staff person and two industry engineers, to develop and carry-out a test program to determine if "future" technology non-handheld engine emission reductions could be predicted with the use of a steady state test cycle or if a transient test cycle was necessary. This task group undertook a test program lasting several months which included; development of a transient test cycle and procedure, development of a comparable steady state test cycle, development of a "future" technology engine, and completing a series of emission tests. The work done by the Nonhandheld Subgroup is well documented in their final report. (Ref. 3)

The Nonhandheld Subgroup developed a representative transient cycle based on field data for a walk-behind rotary mower application, referred to as the grass cutting duty cycle (GCDC). The Nonhandheld Subgroup also developed a steady-state cycle with a comparable load-factor to the GCDC which could be used for comparative purposes. The Nonhandheld Subgroup utilized three test engines for comparison testing between transient and steady-state operations; two baseline technology engines and one future technology engine. The baseline engines were single-cylinder OHV walk-behind mower engines, the future technology was based on the same model, but with an experimental carburetor and accelerator pump which allowed the engine to perform at enleaned air-fuel ratios and rely on the accelerator pump for accelerations. Table 2-01 contains a summary of the relevant data from the Nonhandheld Subgroup final report regarding the comparison between steady-state and transient results.

Table 2-01

Summary of Results from Nonhandheld Transient/Steady State Cycle Program

Test Engine	Cycle	Avg. HC (g/kW-hr	Avg. NOx (g/kW-hr)	Avg. CO (g/kW-hr)
Engine #1	steady-state	10.50	3.06	322
Engine #1	transient	10.50	3.34	272
Engine #2	steady-state	16.43	2.37	441
Engine #2	transient	17.90	2.04	453
Engine #3, Enleaned w/Accelerator Pump	steady-state	5.61	5.47	83
Engine #3, Enleaned w/Accelerator Pump	transient	5.31	3.88	51

The steady-state cycle results shown in Table 2-01 are based on the Nonhandheld Subgroup's steady-state cycle which was developed to have the same load factor as the transient GCDC. As discussed in Chapter 3 of this draft RSD, the Agency is proposing standards for Class I and Class II engines which can be meet by either SV and OHV technology such as the OHV technology used in Engines #1 and #2. The Agency estimates the proposed Class I and II engine standards will not require the level of enleanment or an accelerator such as the technology employed by Engine #3. Therefore, based on the relatively minor differences in HC and NOx emissions between the steady-state and transient cycles for Engines #1 and #2, the Agency concludes a steady-state cycle is appropriate for Phase 2 nonhandheld engines.

During discussions with nonhandheld engine manufacturers within the

Test Procedure Task Group, engine manufacturers and the Agency generally agreed that the Phase 1 test procedure practice of using fixed throttle operation during the steady state cycle was not considered an ideal test method for characterizing real-world emissions from engines equipped with engine rotational speed governors. For Phase 1 engines, 40 CFR 91.409 allows a manufacturer to choose between using the engines speed governor or using an external throttle controller to maintain engine speed and load. The Agency is concerned that as standards become more stringent the potential negative effects from artificial control of an engines throttle valve may become increasingly important.

Based on discussion during the meetings of the Test Procedure Task Group and the Agency's desire to maintain an appropriate relationship between the Federal Test Procedure and real world operation, the Agency is proposing that Phase 2 Class I and II engines equipped with engine speed governors must utilize the governor during the test cycle, except for the 100% load mode, during which fixed throttle operation may be used to determine the wide open throttle condition. The specific changes are contained in proposed regulatory modifications to Subpart E of 40 CFR Part 90.

2.3.2 Review of Handheld Test Cycle

The Test Procedure Task Group established by the Reg/Neg committee also examined the Phase 1 handheld test cycle and it's viability as a Phase 2 test cycle. The work performed by the Handheld Subgroup is well documented in their final report. (Ref. 4)

The Handheld Subgroup choose a Class IV chain saw as the test engine used to evaluate the effect of transient operation on a future technology engine, the Handheld Subgroup choose a Class IV chain saw, which was tested in a baseline configuration and with a modified carburetor which included a leaner calibration and an accelerator pump to simulate a 'future technology' engine. The Handheld Subgroup choose a chain saw application because "The chain saw was picked because chain saws have the highest amount of throttle activations from idle to WOT" (see Ref. 4 to this Chapter), e.g., chain saw use is considered to be the most transient of handheld engine applications. The Handheld Subgroup used in-field engine operating data to determine the appropriate weighting between wide-open throttle (WOT, e.g., maximum load) and idle conditions for chain saw use was 70 percent WOT, and 30 percent idle. The Handheld Subgroup choose as a representative set of transient test cycles for chain saw operation three cycles. Of the three transient cycles, the Handheld Workgroup determined the "20 second" cycle to be the most appropriate for chain saw applications. The 20 second cycle fluctuated between WOT and idle at a rate of 14 seconds WOT followed by 6 seconds of idle which was repeated for a total cycle time of 360 seconds, or 18 repetitions of the WOT/idle change. The steady-state comparison cycle was a two mode test identical to the Phase 1 handheld engine test cycle, but with weighting factors adjusted to match the specific operating conditions of chain saws, 0.7 for the maximum power mode, and 0.3 for the idle mode. Table 2-02 contains a summary of the relevant emission test results collected by the Handheld Subgroup.

Table 2-02
Summary of Results from Handheld Transient/Steady State Cycle Program

Test Engine	Cycle	Avg. HC (g/kW-hr	Avg. NOx (g/kW-hr)	Avg. CO (g/kW-hr)
Class IV Chain Saw w/ Accelerator Pump	Steady-State	113	2.35	99
Class IV Chain Saw w/ Accelerator Pump	20 -Second Transient	113	1.96	109
Class IV Chain Saw w/ No Accelerator Pump	Steady-State	111	2.20	109
Class IV Chain Saw w/ No Accelerator Pump	20-Second Transient	120	2.20	89

The emission results for this experimental test engine are well below the proposed Phase 2 Class IV HC+NOx level of 172 g/kW-hr, this is likely due to the lean carburetor calibration, as evident by the very low CO emission rates. As discussed in Chapter 3 of this draft RIA, the Agency does not expect manufacturers will apply accelerator pumps or very lean calibrations in order to meet the proposed Phase 2 standards. However, the Agency does expect manufacturers to incorporate changes such as leaner calibrations along with changes to combustion chamber and porting designs. The Agency expects these changes will result in engine designs similar to the test engine used by the Handheld Subgroup, except for the use of an accelerator pump. Table 2-02 indicates that, even if manufacturers choose to meet the proposed Phase 2 standards by either lean carburetor calibration, or with lean carburetor calibrations combined with an accelerator pump, a transient test cycle is not necessary to predict emission results at this level of control. Therefore, the Agency is proposing to use the Phase 1 two-mode steady state test procedure for Phase 2 handheld engines.

In addition to examining the possible need for a transient test cycle for a Phase 2 program, the Test Procedure Task Group also examined the appropriateness of weighting factors for the two-mode steady state cycle. The Phase 1 test procedure specifies a weighting factor of 0.90 for Mode 1 (maximum power mode) and 0.10 for Mode 2 (idle mode). The analysis and recommendation of the industry group which studied the weighting factor issue is well documented in their final report.(Ref. 5) A group of handheld engine manufacturers collected field cycle data on several handheld applications: 12 trimmers/brush cutter, 4 chain saws, and 6 blowers. The industry group proposed a methodology to determine the appropriate handheld test cycle weighting factors which determined the average WOT/idle time percentages for each application (trimmers/brush cutters, chain saws, and blowers), and weighted these by the HC emissions inventory impact from each application. The HC emissions inventory impact of each application was determined by the following formula;

$$\text{Emissions Inventory Impact} = (TU \times HU \times LF \times HP \times EM) \div TE$$

where, TU = total units sold per year per application, HU = annual hours of use per application, LF = load factor per application , HP = average rated horsepower per application, EM = engine emission factor (g/HP-hr) per application, TE = total emissions per year for all applications. The results of the analysis performed by members of the handheld engine industry indicate that appropriate the weighting factors for handheld engines is 0.85 for Mode 1 and 0.15 for Mode 2.

The Agency is proposing to modify the weighting factors for Phase 2 engines to reflect the results of the analysis performed by industry. Thought these new weighting factors are only slightly different from the 0.90/0.10 values used for Phase 1, the Agency believes the Phase 2 program is an appropriate time to make this minor change.

2.4 Additional changes to Phase 1 test procedure

In order to accommodate the proposed optional non-methane hydrocarbon (NMHC) standard for natural gas fueled nonhandheld engines, the Agency is proposing to incorporate by reference the appropriate sections from 40 CFR Part 86 which relate to the measurement of methane emissions from spark-ignited engines. These appropriate sections were published as part of a final rulemaking titled "Standards for Emissions From Natural Gas-Fueled, and Liquefied Petroleum Gas-Fueled Motor Vehicles and Motor Vehicle Engines, and Certification Procedures for Aftermarket Conversions" see 59 FR 48472, published on September 21, 1994. The specific sections being incorporated can be found in the proposed regulatory language contained in this proposal at §90.301(d) and §90.401(d).

Chapter 2 References

1. “Regulatory Support Document, Control of Air Pollution, Emission Standards for New Nonroad Spark-Ignition Engines at or Below 19 kiloWatts” US EPA, May 1995, EPA Air Docket A-93-25, Docket Item #V-B-01.

2. Handouts and Notes from all Meetings of the Test Procedure Task Group held during the Phase 2 Regulatory Negotiation are available in EPA Air Docket A-93-92.

3. "Transient Versus Steady State Test Procedure Evaluation of Small Utility Engines”, EPA Air Docket A-93-29, Docket Item II-M-27.

4. “Final Report - Handheld Subgroup of the Test Procedure Task Group”, EPA Air Docket A-93-29, Docket Item II-M-40.

5. “Hand Held Composite Duty Cycle”, Dec. 30, 1994, EPA Air Docket A-96-55, Docket Item II-D-18