maximum restrictions you specify for that particular engine.

§ 1065.510 Engine mapping procedures.

(a) *Torque map.* Map your engine's torque while it is mounted on the dynamometer. Use the torque curve resulting from the mapping to convert the normalized torque values in the engine cycle to actual torque values for the test cycle. Make sure the speed ranges at least from the warm no-load idle speed to 105 percent of the maximum test speed. Because you determine the maximum test speed from the torque map, you may have to perform a preliminary torque map to determine the full mapping range. You may perform this preliminary torque map while the engine warms up. To map the engine, do the following things in sequence:

(1) Warm up the engine so oil and water temperatures (on an absolute scale such as the Kelvin scale) vary by less than two percent for two minutes; or until the thermostat opens if the engine-coolant system includes a thermostat.

(2) Operate the engine at the warm no-load idle speed.

(3) Fully open the throttle.

(4) While maintaining wide-open throttle and full-load, keep the engine at minimum speed for at least 15 seconds. Record the average torque during the last 5 seconds.

(5) In increments of 100±20 rpm, determine the maximum torque curve for the full speed range. Hold each test point for 15 seconds and record the average torque over the last 5 seconds. You may use larger increments for engines with maximum test speed over 4000 rpm, as long as you include at least 40 points and space them evenly.

(6) Fit all data points recorded with a cubic spline, Akima, or other technique we approve in advance. The resultant curve must be accurate to within ±1.0 ft-lbs. of all recorded engine torques.

(b) *Torque map with continual engine speed sweep.* In place of paragraphs (a)(1) through (a)(4) of this section, you may do a continual sweep of engine speed. While operating at wide-open throttle, increase the engine speed at an average rate of 8±1 rpm/sec over the full speed range. You may use higher sweeping rates for naturally-aspirated engines, in accordance with good engineering judgment. Record speed and torque points at a rate of at least one point per second. Connect all points generated under this approach by linear interpolation.

(c) *Alternate mapping.* You may use other mapping techniques if you believe those in paragraphs (a) and (b) of this section are unsafe or unrepresentative for any engine or engine family. These alternate techniques must satisfy the intent of the specified mapping procedures—to determine the maximum available torque at all engine speeds that occur during the test cycles. Report deviations from this section's mapping techniques for reasons of safety or representativeness. In no case, however, may you use descending continual sweeps of engine speed for governed or turbocharged engines.

(d) *Replicate tests.* You need not map an engine before every test, but you do need to remap the engine in any of the following situations:

(1) Good engineering judgment determines that an unreasonable amount of time has passed since the last map.

(2) The barometric pressure before the test begins has changed more than 25 mm Hg from the average barometric pressure observed during the map.

(3) The engine has undergone physical changes or recalibration that might affect its performance.

(e) *Power map.* Where applicable, generate a power map using the procedures this section specifies for torque maps. You may generate the power map directly or convert the torque map to a power map using engine speeds. The power map is also called a lug curve.

(f) *Cycles based only on torque/power at maximum test speed.* If the applicable test cycle for your engine does not require map information for engine speeds other than the maximum test speed, you may make the following simplifications:

(1) You need not perform the entire torque or power map, as long as you map the engines for speeds between 75 and 105 percent of the maximum test speed.

(2) You need not remap an engine according to paragraph (d) of this section. You need only verify the maximum torque or power at maximum test speed.

§ 1065.515 Test cycle generation.

(a) *Denormalizing test cycles.* The standard-setting parts establish the applicable test cycles consisting of second-by-second specifications for normalized torque and speed for transient cycles, or modal specifications for normalized torque and speed (or power and speed) for steady-state cycles. You must denormalize these values to get actual torque and speed for your engine.

(1) Torque is normalized to a maximum-torque value. Check the standard-setting part to see if it is normalized based on the maximum torque at the given speed or based on the maximum torque for all speeds. To denormalize the torque values in the cycle, use the engine's maximum-torque point or its torque map (§ 1065.510 describes how to generate the torque map).

(2) Power is normalized to a maximum-power value. Check the standard-setting part to see if it is normalized based on the maximum power at the given speed or based on the maximum power for all speeds. To denormalize the power values in the cycle, use the engine's maximum-power point or its power map (§ 1065.510 describes how to generate the power map).

(3) To denormalize speed, use the following equation:

Actual engine speed = (0.01) × (%engine speed) × (Maximum test speed—warm idle speed) + warm idle speed

(4) Paragraph (d) of this section describes how to calculate maximum test speed.

(b) *Example of denormalizing a test points.* For an engine with maximum test speed of 3800 rpm and warm idle speed of 600 rpm, denormalize the following test point: percent engine speed = 43, percent torque = 82.

(1) *Calculate actual engine speed.* The following equation applies for this example:

Actual engine speed = (0.01) × (43) × (3800 − 600) + 600 = 1976 rpm.

(2) *Determine actual torque.* Determine the maximum observed torque at 1976 rpm from the maximum torque curve. Then multiply this value (for example, 358 ft-lbs.) by 0.82. The resulting actual torque is 294 ft-lbs.

(c) *Cold-start enhancement devices.* If an engine has a properly operating automatic enhancement device for cold starts, let it override the zero-percent speed specified in the test cycles.

(d) *Maximum test speed.* For constant-speed engines, maximum test speed is the same as the engine's maximum operating speed in use. Maximum test speed for variable-speed engines occurs on the lug curve at the point farthest from the origin on a plot of power vs. speed. To find this speed, follow three main steps:

(1) *Generate the lug curve.* Before testing an engine for emissions, generate data points for maximum measured brake power with varying engine speed (see § 1065.510). These data points form the lug curve.

(2) *Normalize the lug curve.* To normalize the lug curve, do three things:

(i) Identify the point (power and speed) on the lug curve where maximum power occurs.

(ii) Normalize the power values of the lug curve—divide them by the maximum power and multiply the resulting values by 100.

(iii) Normalize the engine speed values of the lug curve—divide them by the speed at which maximum power occurs and multiply the resulting values by 100.

(3) *Determine maximum test speed.* Calculate the maximum test speed from the following speed-factor analysis:

(i) For a given power-speed point, the speed factor is the normalized distance to the power-speed point from the zero-power, zero-speed point. Compute the speed factor's value:

$$\text{Speed factor} = \sqrt{(\text{power})^2 + (\text{speed})^2}$$

(ii) Determine the maximum value of speed factors for all the power-speed data points on the lug curve. Maximum test speed is the speed at which the speed factor's maximum value occurs. Note that this maximum test speed is