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SURFACE VEHICLE RECOMMENDED PRACTICE

SAE J1540

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Manual Transmission Efficiency and Parasitic Loss Measurement

1. ***Scope***—Because of the intense focus on fuel economy and fuel emission standards, it has become imperative to optimize vehicle drivetrains. In light of this, component efficiencies have become an important factor in the drivetrain decision-making process. It has therefore become necessary to develop a universal standard to judge transmission efficiency.

This SAE Recommended Practice specifies a test procedure which maps torque transmittal efficiency and parasitic losses for manual transmissions. The application of this document is intended for manual transmissions used in light (class 4) through heavy truck applications with both simple and compound ratio structures.

This document is separated into two parts. The first compares input and output torque throughout a specified input speed range in order to determine the overall transmission efficiency. This test is used to evaluate all forward gears; testing in reverse is optional. The second procedure measures parasitic losses experienced at zero output torque over a range of operating speeds. A procedure for further reduction of this data into a loaded efficiency from gear and bearing systems is also provided.

2. ***References***

2.1 **Related Publication**—The following publication is provided for information purposes only and is not a required part of this document.

SAE Paper 840054—Measurements of Power Losses in Automotive Drive Train

3. ***Definitions***

3.1 **Manual Transmission**—The assembly exclusive of the clutch which is driven by the engine and used, through manual interface, to effect a ratio change in transmitting power to the final drive system.

4. *Equipment*

4.1 Test Cell—Efficiency tests require a prime mover and absorption unit with torque and speed capability beyond that required for test data points. Motors with either hydraulic or electric drives are ideal for this type of test due to their relatively precise torque and speed control although diesel dynamometers may be used if necessary. The recommended procedure for this test is unique compared to more conventional load/speed tests in that it requires two transmissions, mounted output shaft end to output shaft end in order to isolate true system losses. This requirement may be satisfied by either a Four Square type test cell or Dynamometer whose bed plate length will accept the length of the back to back units between the drive unit and absorber. Either cell type must be supplemented by the following mounting and measurement hardware; Figure 1 provides a simplified diagram of the test setup:

a. Trunnion Bearing Mounts—Both test transmissions must be supported at their input and output shafts by a trunnion type bearing mount. This will permit the installed transmission(s) to rotate freely about their axis.
b. Torque Reaction Arm—A torque reaction arm is installed between the drive and coast transmission cases. An additional moment arm is mounted to, and extends out from the drive unit's case on a horizontal plane and then attached to a calibrated load cell at a known length from the mainshaft centerline. This load cell is in turn mounted to ground to permit measurement of the linear force component of the combined torque losses from each unit. Transmission losses are converted into a torque moment by calculating the product of the reaction arm length and the load cell reading and then dividing by two to reflect the average loss per unit.
c. Mounting Orientation—The cell must be capable of mounting the transmissions at the production intent inclination and roll angles. It is also desirable to test at zero degrees inclination for comparison to competitive test data.
d. Torque Measurement—Proper load cell selection is critical for test accuracy. A precision linear load cell transducer is required accurate to within 0.25% of full scale. This potential error is acceptable if the unit's full-scale reading is closely matched to the peak expected measured value. A Torque Transducer is used at the input side of the drive unit. This transducer should also be selected to minimize measurement error by selection of a cell with minimal error (<1% of full scale recommended) and again matching its maximum value to desired test points. Steps should be taken on both torque and linear load measurement systems to minimize or eliminate any additional accuracy losses due to signal conditioning, filtering, etc.
e. Speed Control—The cell must be capable of maintaining speed within ±5 RPM of the specified speed throughout the test torque range.
f. Temperature Controls—Supplemental sump lubricant cooling or heating may be required to maintain sump temperatures of 82 °C ± 2 °C.
g. Calibration—Calibration curves should be performed for all equipment and instrumentation after every test ratio to assure data accuracy.

5. *Test Procedure*

5.1 Preparation and Set-Up—Ideally, the test transmission should be randomly selected from normal production. When a test unit must be built specifically for efficiency testing, any design features (surface finishes, selective fits, coatings, etc.) which may effect efficiency should be representative of production intent and set as close to nominal conditions as possible. Inclusion of any optional accessories (PTO, pumps, brakes, etc.) which may effect test results is the decision of the tester but should be noted in test documentation. It is recommended that the base version be tested in all cases to permit future comparisons and determine accessory impact on results.

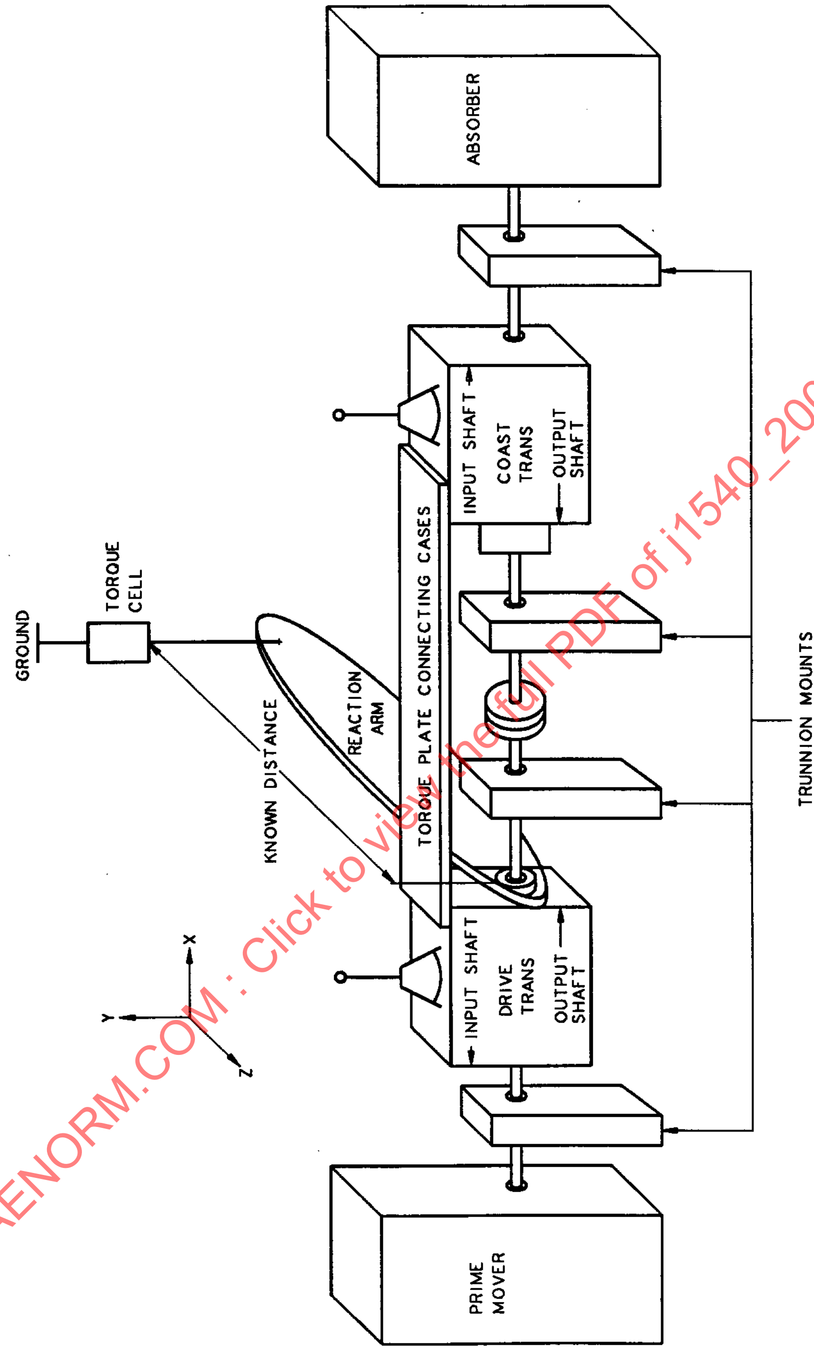

FIGURE 1—SIMPLIFIED DIAGRAM OF THE TEST SETUP

The test should begin with the transmission filled with lubricant to the manufacturer's specifications for type and volume. It may be necessary to add lubricant during the test to maintain normal operating levels. The transmission must be run through a break-in period, specified in Table 1, prior to any data acquisition. The transmission must be run in each forward gear for the specified duration.

TABLE 1—TRANSMISSION BREAK-IN PERIOD

Time	Input Torque	Input Speed
0.5 h	10% of Maximum Rating	50% of Maximum Rating
1.5 h	25% of Maximum Rating	100% of Maximum Rating
1.0 h	50% of Maximum Rating	100% of Maximum Rating

5.2 Test #1—Transmission Efficiency at Constant Input Speed—This test provides efficiency data for all drive conditions. The sump temperature should be maintained at 82 °C ± 2 °C throughout testing.

The schedule in Table 2 must be run for each forward gear.

TABLE 2—SCHEDULE FOR EACH FORWARD GEAR

Input Speed (RPM) % of Maximum Rated	Input Torque as % of Rated Unit Torque 25%	Input Torque as % of Rated Unit Torque 50%	Input Torque as % of Rated Unit Torque 75%	Input Torque as % of Rated Unit Torque 100%
40%	XX	XX	XX	XX
60%	XX	XX	XX	XX
80%	XX	XX	XX	XX
100%	XX	XX	XX	XX

XX - Measured Torque Loss Values

5.2.1 PROCEDURE

a. Install transmissions on test fixture.
b. Check lubrication level, correct to manufacturers specifications. Provide seal lubrication, if required.
c. Check the following instrumentation for proper set-up and calibration.
    1. Input torque meter
    2. Load Cell
    3. Input RPM tachometer
    4. Lubricant sump temperature thermocouple

    NOTE—Compound transmissions having separate main and auxiliary sumps may require supplemental cooling systems to maintain desired temperature range within each sump.
d. Manually rock the transmissions about their mounting to assure free rotation and the absence of any unusual residual torque.
e. Drive the transmission in top gear at rated speed and bring the torque level up to the first test parameter. All transmission to reach an equilibrium temperature. Adjust cooling of lubricant to target temperature, 82 °C ± 2 °C.

f. Adjust the cell inputs to obtain the first test ratio, input speed, and torque level. When the transmission has stabilized at the specified lubricant sump temperature, take input torque and load cell readings and record.
g. Proceed to the next test parameter.

5.2.2 DIAGRAM OF SET-UP—Figure 1 is a generic schematic of the transmission efficiency test. Figures 2 and 3 describe the recommended data log and graph formats for this test.

5.3 Test #2—Parasitic Losses—This test is intended to measure the parasitic losses, primarily from sump oil churning. This test requires the removal of the coupling between the two unit's output shafts so that the only torque transmitted and measured is from system drag. Losses are then measured at each of the desired test gear and input speed conditions while maintaining sump temperature at 82 °C ± 2 °C.

Input RPM—600 to Maximum Rated in 100 RPM increments.

5.3.1 PROCEDURE

a. When possible, the transmissions used in Test #1 should be utilized for this test for consistency.
b. Install transmission on test fixture.
c. Check lubrication level. Correct to manufacturer's specifications. Provide seal lubrication if required.
d. Check the following instrumentation for proper set-up and calibration.

1. Input torque meter
2. Input RPM tachometer
3. Lubricant sump temperature thermocouple (See note on compound transmissions in Test #1.)

e. Drive transmission at reasonable input speed to permit transmission to reach the desired test temperature. Adjust cooling system as required to maintain a stabilized sump temperature of 82 °C ± 2 °C.
f. When the transmission has reached the specified lubricant sump temperature, set RPM to first test parameter and take the input torque reading and record.
g. Proceed to the next test parameter.

6. Presentation of Results

6.1 Identify the transmission unit completely and record test conditions on all data and curve plot sheets.

6.2 Loss Calculations—Transmission losses are normally expressed in components of parasitic, loaded, and the summation or total efficiency. Equation 1 is used to calculate the individual loaded loss components (expressed as percentage):

$$\text{Loaded Loss} = (1 - (\text{total torque loss} - \text{chum loss}) / \text{input torque}) * 100 \quad \text{(Eq. 1)}$$

6.3 Develop the desired performance curves. Examples of typical plots are shown on Figures 2 and 3. The plots shown provide an example of a fictitious 5-speed medium truck transmission.

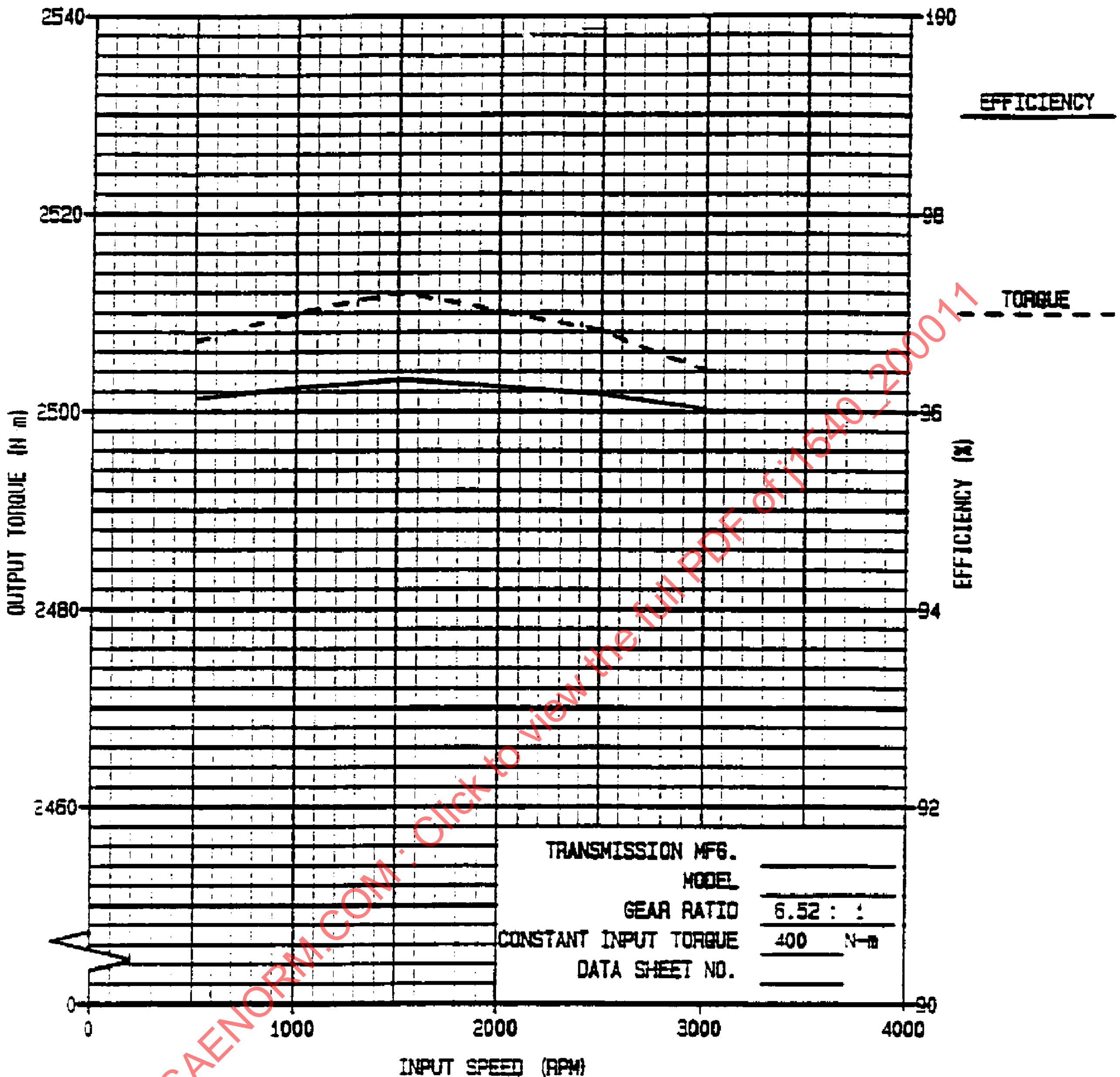

FIGURE 2—TEST #2—TYPICAL INPUT SPEED PLOT OF TRANSMISSION LOAD EFFICIENCY AT A CONSTANT INPUT TORQUE FOR A MANUAL TRANSMISSION

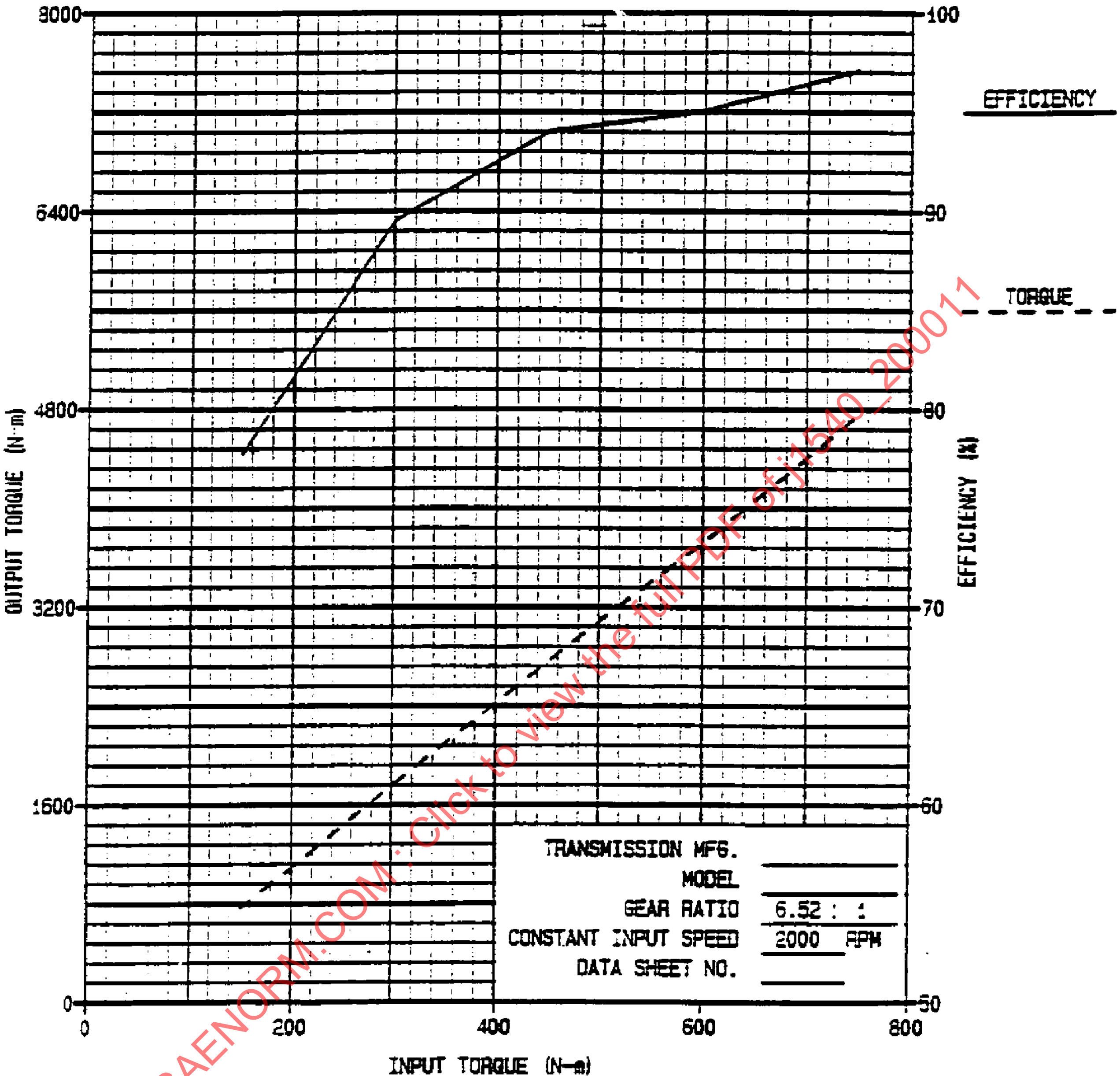

FIGURE 3—TEST #1—TYPICAL INPUT TORQUE PLOT OF TRANSMISSION LOAD EFFICIENCY AT A CONSTANT INPUT SPEED FOR A MANUAL TRANSMISSION

7. ***Statistical Validity*****—**A good experiment is one which provides the required information with the minimum amount of time and effort. Also, the conclusions drawn from the data and the decisions made based on these data must be valid. In order to meet these objectives, the test must be carefully designed and the results interpreted in a way such that statistically significant data are obtained. The following steps are recommended.

a. Samples should be taken so that they are fully representative of the parts being tested. This means the sample should be randomly selected in order to represent the true population.
b. The number of items being tested should be such that the final data are statistically significant. This is particularly important if you are seeking a small improvement of the order of 5 to 10%.
c. The final data must be properly systemized and analyzed for proper interpretation of the data.

The type of statistical distribution associated with this type of test is the normal distribution. Determination of whether the data is truly normal can be made by plotting results in histogram form. The confidence level required for the test results is influenced by the test objectives, cost, timing, accuracy of test equipment, number of samples available, degree of accuracy needed, and other such considerations. Normally one or more of these considerations needs to be traded off with the confidence level desired. It is recommended that a confidence level of 90% be used. The higher the confidence level, the less likely it is that the statistical inference from the data will be wrong. For experiments of evaluation where a normal distribution is selected as being representative, such as this, the sample size can be determined using Equation 2 and the procedure in 7.1:

$$n = \frac{z^{2*}\sigma^2}{E^2} \qquad \text{(Eq. 2)}$$

where:

n = Sample Size
E = Acceptable Error
σ = Estimate of Population Standard Deviation
Z = Standard Deviate

7.1 Procedure

a. Ideally, the tester will have valid historical data on similar products which can be used to develop an estimate of the expectant standard deviation and acceptable error terms. If this data is available, then the tester should determine a preliminary sample size using Equation 1, perform the tests, then recalculate the true population standard deviation. If the actual standard deviation is within the original estimate, then the test was valid and is complete. If the standard deviation was greater than the original estimate, than the sample size should be recalculated to determine if additional tests are required.
b. When historical data is not available, then the following assumptions can be used to determine the preliminary estimates of standard deviation and allowable error:

   $E = Z^{*}\,\sigma/\sqrt{n}$
   σ = Expected Range / 6
   Z = 1.65 (Table 3, 90% Confidence, Two-Sided)

   These terms are used with the sample size equation, Equation 1, to determine the preliminary sample size. Again, the test is then performed, the standard deviation of the test population is calculated and compared to the original estimate to determine if additional tests are required.
c. If a large sample size is not possible, the use of the student's “t” distribution is recommended. Table 4 provides the value of “t” versus test sample size and confidence for either one- or two-sided tests. The use of the “t” distribution will provide a more conservative estimate of the potential variance in the total population.