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Manual Transmission and Transaxle Efficiency and Parasitic Loss Measurement

RATIONALE

The technical report covers technology, products, or processes which are mature and not likely to change in the foreseeable future.

STABILIZED NOTICE

This document has been declared "Stabilized" by the SAE IC Powertrain Steering Committee and will no longer be subjected to periodic reviews for currency. Users are responsible for verifying references and continued suitability of technical requirements. Newer technology may exist.

Foreword—This SAE Recommended Practice standardizes a method of transmission and transaxle efficiency determination that involves the measurement of input and output torques. This method is extremely sensitive to the accuracies of the torque measurement transducers, particularly if transmission losses are being determined. For example, if the actual efficiency of a transmission under a particular test condition is 95% and both the input and output transducers have 1% error, the resulting calculation of efficiency from the data measurements could range from 93.1% to 96.9%. The same data used to show transmission losses would yield losses between 3.1% and 6.9%. In order to obtain meaningful results with this method, all of the procedures outlined in 4.1, Transmission Dynamometer, particularly in regards to the accuracy of the torque transducers, must be followed.

An alternate method of measuring transmission efficiency is the heat loss method. This method is based on the measurement of temperature rise of lubricant due to the friction in the drivetrain. Improved accuracy (0.5% error maximum) over a large range is easily obtained. This method is explained in detail in SAE Paper 840054.

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1. *Scope*

Scope—Because of the intense focus on CAFE and fuel emission standards, optimization of the automobile drivetrain is imperative. 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 the dynamometer test procedure which maps a manual transmission's efficiency. The document is separated into two parts. The first compares input and output torque throughout a specified input speed range in order to determine "in-gear" transmission efficiency. The second procedure measures parasitic losses experienced while in neutral at nominal idling speeds and also churning losses while in gear.

The application of this document is intended for passenger car and light truck.

All references to transmissions throughout this document include transaxles.

2. *References*

2.1 Applicable Publications—The following publications form a part of this specification to the extent specified herein.

SAE Paper 840054—"Measurements of Power Losses in Automotive Drive Train," Yoshiyuki Ko and Kenzo Hosoi

SAE Paper 820741—"Efficiency Characteristics of Manual and Automatic Passenger Car Transaxles," Leo A. M. van Dongen

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 or halfshafts (in the case of a transaxle).

4. *Equipment*

4.1 Transmission Dynamometer—The transmission dynamometer must be capable of the following parameters.

a. Mounting the transmission at zero degrees inclination and production representative roll angle. Mounting the transmission in this manner will limit the torque fluctuations associated with coupling angles.
b. Capable of transmission input and output torque measurement within 0.2% of full scale or best available.
c. Allow for changing both input and output torque transducers during the test, so that the expected torque to be measured will always fall within 75% to 100% of the full rated torque capacity of the transducer.
d. Capable of maintaining speed within 5 rpm of the specified speed throughout test torque range.
e. Measuring and maintaining fluid sump temperatures of 65° C ± 2° C (149° F ± 1 °F) and 90° C ± 2° C (194 °F ± 1 °F).

NOTE—SAE Paper 820741 recommends using several combinations of torque transducers at both the input and the output. Doing this, "the torque sensors are mainly used at loads higher than 15 to 20% of the maximum allowable load, so that the deviation varies from 0.2% (high torques) to 1.3% (low torques)." Figure 1 is a graphical representation of the variance of accuracy with load from this paper. The committee recommends the tighter specification shown in 4.1c. Using this recommendation, the expected transducer error will be within 0.25%.

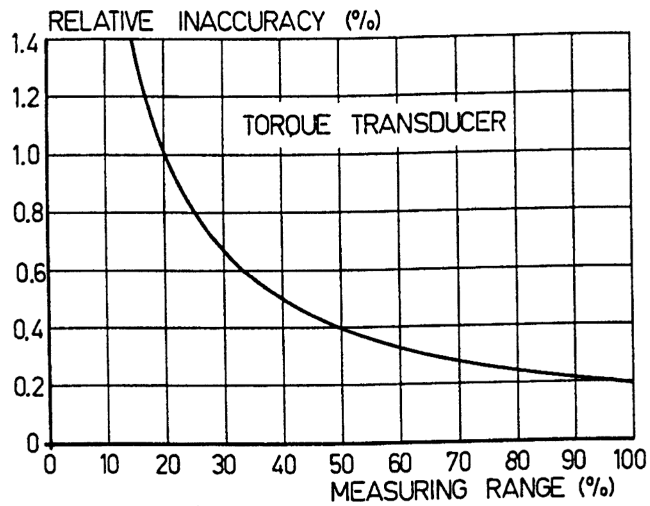
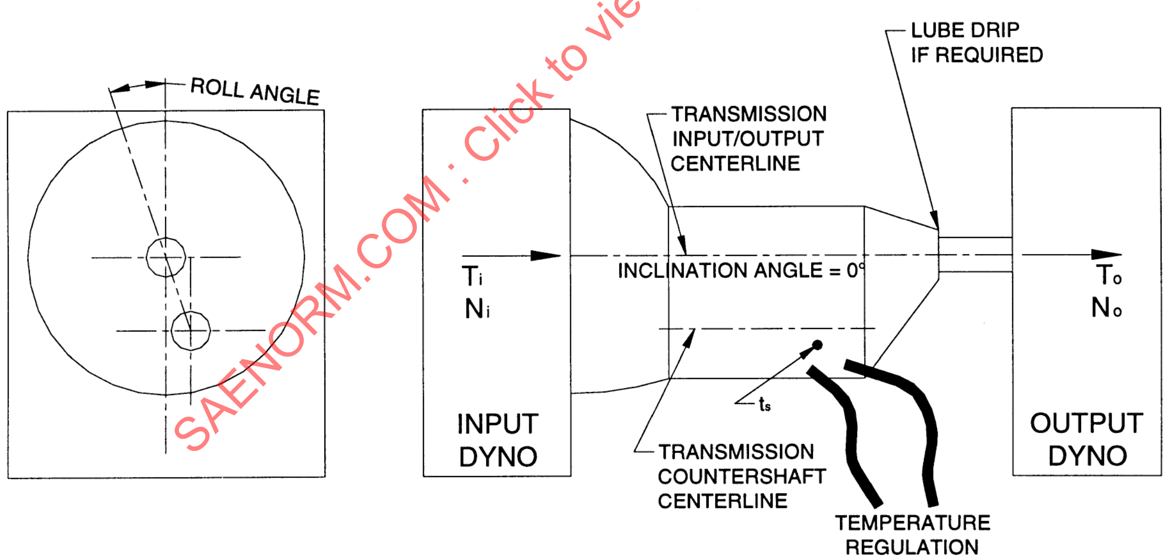


FIGURE 1—REPRODUCTION OF FIGURE 5 FROM SAE 820741

5. *Test Procedures*

5.1 Preparation and Set-Up—If the intent of the obtained values is to advertise the efficiency of a production unit, the test must begin with a new production unit. However, for comparative purposes or as insight to a new transmission program, a used or prototype unit may be evaluated. The published results should reflect the level of the unit (i.e., prototype, production, extended mileage, etc.).

A typical RWD transmission dynamometer schematic is included in Figure 2.



SPECIFY:

T_i -- Input Torque (N-m)
N_i -- Input Speed (RPM)

RECORD:

T_o -- Output Torque (N-m)
N_o -- Output Speed (Ref) (RPM)
t_s -- Sump Lubricant Temperature (°C)

FIGURE 2—TYPICAL RWD MANUAL TRANSMISSION DYNAMOMETER SCHEMATIC

The unit is to be filled with lubricant of the transmission manufacturer specifications for type and volume. It may be necessary to add lubricant during the test to maintain normal operating levels.

New transmissions must be run through a break-in period, specified as follows, prior to any data acquisition. The transmission must be run in each forward gear for the specified duration.

a. Input RPM—1000
b. Input Torque—13.6 N-m (10 ft-lb)
c. Duration—20 min

5.2 Test #1—Transmission Efficiency at Constant Input Speed—This test provides efficiency data for operating conditions similar to those encountered in CAFE cycle testing. Two temperatures will be run in this test, 65 and 90 °C (149 and 194 °F).

NOTE—If a transaxle is to be run, provisions must be made to lock the differential. To accomplish this, it is suggested that a specialized halfshaft be installed which would lock the differential. Other means to lock the differential are acceptable as long as the design does not impair or improve the function of the unit. Disassembly of the unit to lock the differential then rebuilding is not recommended except as a last resort as this would disrupt the production assembly integrity of the unit. The design should be such to withstand the maximum torque anticipated during the test.

The schedule in either Table 1A or 1B must be run for each forward gear.

TABLE 1A—SCHEDULE RUN FOR EACH FORWARD GEAR—ALTERNATIVE #1—AS PERCENTAGE OF MAXIMUM INPUT TORQUE

Input Speed (RPM)	Specified Input Torque N-m (lbt-ft) 25% * YY	Specified Input Torque N-m (lbf-ft) 50% *YY	Specified Input Torque N-m (lbf-ft) 75% * YY	Specified Input Torque N-m (lbf-ft) 100% * YY
1000	XX	XX	XX	XX
2000	XX	XX	XX	XX
3000	XX	XX	XX	XX
4000	XX	XX	XX	XX

TABLE 1B—SCHEDULE RUN FOR EACH FORWARD GEAR—ALTERNATIVE #2—IN 20 N-M (15 LBF-FT) INCREMENTS UP TO MAXIMUM INPUT TORQUE

Input Speed (RPM)	Specified Input Torque N-m (lbt-ft) 20 (14.75)	Specified Input Torque N-m (lbf-ft) 40 (29.50)	Specified Input Torque N-m (lbf-ft) • • •	Specified Input Torque N-m (lbf-ft) YY
1000	XX	XX	• • •	XX
2000	XX	XX	• • •	XX
3000	XX	XX	• • •	XX
4000	XX	XX	• • •	XX

NOTE: The specified data points are the minimum to be run. More are desirable.
If an Input Torque exceeds the maximum anticipated input torque at a particular Input Speed, that data point need not be run.
YY — Maximum Input Torque, either the Transmission Rated Torque or the anticipated application engine torque
XX — Measured Output Torque at each data point

5.2.1 PROCEDURE

a. Randomly select production representative transmission.
b. Check the following instrumentation for proper set-up and calibration.
   1. Input torque meter
   2. Output torque meter
   3. Input rpm tachometer
   4. Lubricant sump temperature thermocouple
c. Install transmission on test fixture.
d. Lock the differential (Transaxles only).
e. Check lubrication level. Correct to manufacturer's specifications. Provide seal lubrication if required.
f. Drive the transmission in first gear at approximately the specified speed and bring the torque level up to the first test parameter. Allow transmission to reach the first test temperature and stabilize. Adjust cooling of lubricant to target temperature, 65 or 90 °C (149 or 194 °F).
g. Adjust to first input speed and input torque level. When the transmission has stabilized at the specified lubricant sump temperature, take required readings and record. Figure 3 can be used to record data.
h. Proceed to the next test parameter.
i. The number of replications shall be sufficient to satisfy the Statistical Validity requirements of Section 7.

5.3 Test #2—Parasitic Losses, Neutral and In-Gear—This test has two parts. The first part is conducted in neutral with the output shaft(s) blocked from rotating. This test simulates idling conditions of a vehicle. The second part is conducted in each of the forward gears with the output shaft(s) free to rotate. This determines the churning losses present in the transmission. The values obtained reflect the parasitic losses experienced in the transmission.

5.3.1 PROCEDURE

5.3.1.1 Part 1—Neutral Gear Parasitic Loss—This test is to be run with the transmission in neutral and the output shaft fixed. Because transaxles may have lubrication systems which depend on the output gear turning, it is advised that the transaxle be cycled through the gears to establish the lubricant flow before each point is recorded. Two temperatures will be run, 65 and 90° C (149 and 194° F).

a. Randomly select production representative transmission.
b. Check the following instrumentation for proper set-up and calibration.
   1. Input torque meter
   2. Input rpm tachometer
   3. Lubricant sump temperature thermocouple

NOTE—The user needs to determine the proper capacity of the input torque load transducer. One method is to examine the results from Test #1, Transmission Efficiency at Constant Input Speed, and determine losses at the input shaft at low torque levels by using Equation 3, Total Torque Loss. Parasitic losses will be less than this. Past experience may also be used.

c. Install transmission on test fixture.
d. Lock the transmission output shaft(s) and place the transmission in neutral.
e. Check lubrication level. Correct to manufacturer's specifications. Provide seal lubrication if required.
f. Drive transmission at the first input speed. Allow transmission to reach the first test temperature and stabilize. Adjust cooling of lubricant to target temperature.
g. When the transmission has reached the specified lubricant sump temperature, take the input torque reading and record. Figure 4 can be used to record data.
h. Engage transaxle to establish lubricant flow before proceeding to the next input speed.
i. For the neutral portion of the parasitic loss test, evaluate at input shaft speeds between 600 rpm and 1200 rpm inclusive, in 100 rpm increments. The number of replications shall be sufficient to satisfy the Statistical Validity requirements of Section 7.

MANUAL TRANSMISSION EFFICIENCY TEST
SAE RECOMMENDED PRACTICE J-2453

MANUFACTURER: ______________________ PAGE _______ OF ________

MODEL NUMBER: ______________________ DATE: ____________

APPLICATION: ______________________ TEST NUMBER: ____________

LUBRICANT: ______________________ ROLL ANGLE: ____________

GEAR	RATIO	TRANS. SUMP TEMP. (°C)	INPUT SPEED (RPM)	INPUT TORQUE (N-m)	CALCULATED OUTPUT TORQUE * (N-m)	MEASURED OUTPUT TORQUE (N-m)	EFFICIENCY (%)

* — DETERMINE CALCULATED OUTPUT TORQUE FROM TOOTH NUMBERS, IF POSSIBLE.

FIGURE 3—TRANSMISSION EFFICIENCY AT CONSTANT INPUT SPEED DATA COLLECTION CHART

MANUAL TRANSMISSION PARASITIC LOSS
SAE RECOMMENDED PRACTICE J-2453

MANUFACTURER: ______________________ PAGE ______ OF ______

MODEL NUMBER: ______________________ DATE: __________

APPLICATION: ______________________ TEST NUMBER: __________

LUBRICANT: ______________________ ROLL ANGLE: __________

GEAR	Input Speed RPM	Input Torque (N-m)					
		Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6

ENTER THE TORQUE, IN N-m, REQUIRED TO TURN THE TRANSMISSION IN NEUTRAL AND EACH OF THE FORWARD GEARS, AT THE SPECIFIED INPUT SPEEDS

FIGURE 4—TRANSMISSION PARASITIC LOSSES DATA COLLECTION CHART

5.3.1.2 *Part 2—In-Gear Parasitic Loss*—This test is to be run with the transmission in each of the forward speeds with the output shaft free to rotate. Part 2 measures $T_{loss\text{-}churn}$ — Torque Loss due to Oil Churning at Input. Two temperatures will be run, 65 and 90 °C (149 and 194 °F).

a. Use the same transmission as in Part 1
b. Check the following instrumentation for proper set-up and calibration.
   1. Input the meter
   2. Input rpm tachometer
   3. Lubricant sump temperature thermocouple

NOTE—The user needs to determine the proper capacity of the input torque load transducer. One method is to examine the results from Test #1, Transmission Efficiency at Constant Input Speed, and determine losses at the input shaft at low torque levels by using Equation 3, Total Torque Loss. Parasitic losses will be less than this. Past experience may also be used.

c. Install transmission on test fixture.
d. Check that the output shaft(s) are free to rotate.
e. Check lubrication level. Correct to manufacturer's specifications. Provide seal lubrication if required.
f. Drive transmission at the first input speed. Allow transmission to reach the first test temperature and stabilize. Adjust cooling of lubricant to target temperature.
g. When the transmission has reached the specified lubricant sump temperature, take the input torque reading and record. Figure 4 can be used to record data.
h. Proceed to the next input speed.
i. For the in-gear portion of the parasitic loss test, test in the same gears and input speeds as was done in Test #1 Transmission Efficiency at Constant Input Speed. The number of replications shall be sufficient to satisfy the Statistical Validity requirements of Section 7. It is recommended that the data for each of the input speeds and gears be recorded for the first trial before proceeding to take the data for the second trial, and so on.

6. *Presentation of Results*

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

6.2 Calculations

6.2.1 CALCULATED OUTPUT TORQUE

$$T_{out-calc} = T_{in} \times R_g \quad \text{(Eq. 1)}$$

where:

$T_{out\text{-}calc}$ = Calculated Output Torque
T_{in} = Measured Input Torque
R_g = Gear Ratio of selected transmission speed (use tooth counts if possible)

6.2.2 EFFICIENCY

$$E = \frac{T_{out-meas}}{T_{out-calc}} \times 100\% \quad \text{(Eq. 2)}$$

where:

E =Efficiency
$T_{out\text{-}meas}$ = Measured Output Torque

6.2.3 TOTAL TORQUE LOSS

$$T_{loss-total} = T_{in} \times \left(1 - \frac{T_{out-meas}}{T_{out-calc}}\right) \quad \text{(Eq. 3)}$$

where:

$T_{loss\text{-}total}$ = Total Transmission Torque Loss at Input

6.2.4 LOADED TORQUE LOSS

$$T_{loss-load} = T_{loss-total} - T_{loss-churn} \quad \text{(Eq. 4)}$$

where:

$T_{loss\text{-}load}$ = Transmission Torque Loss at Input due to Gearmesh Losses
$T_{loss\text{-}churn}$ = Transmission Torque Loss at Input due to Churning (Test #2, Part #2)

6.3 Graphical Presentation of Results—It may be desired to graphically present the results for the efficiency tests. Figure 5 shows one method of presenting the results. It is a copy of Figure 8 from SAE 820741. Please note that in order to get the level of detail shown in this figure, it will be necessary to obtain measurements at more data points than is shown in Tables 1A and 1B. Tables 1A and 1B are only intended to show the minimum requirements.

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 really representative of the parts being tested. This means the samples 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 on the order of 5 to 10%.
c. The final data must be properly systemized and analyzed for proper interpretation.

The type of statistical distribution associated with this type of test is the normal distribution. 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 as follows:

$$n = \frac{Z^2 \times \sigma^2}{E^2} \quad \text{(Eq. 5)}$$

where:

n = sample size needed
E = acceptable error or width of interval estimate
σ = estimation of population standard deviation
Z = standard deviate (a function of the confidence level standard which can be found in the standardized normal tables, see Table 2 for a standardized normal or “Z” table).

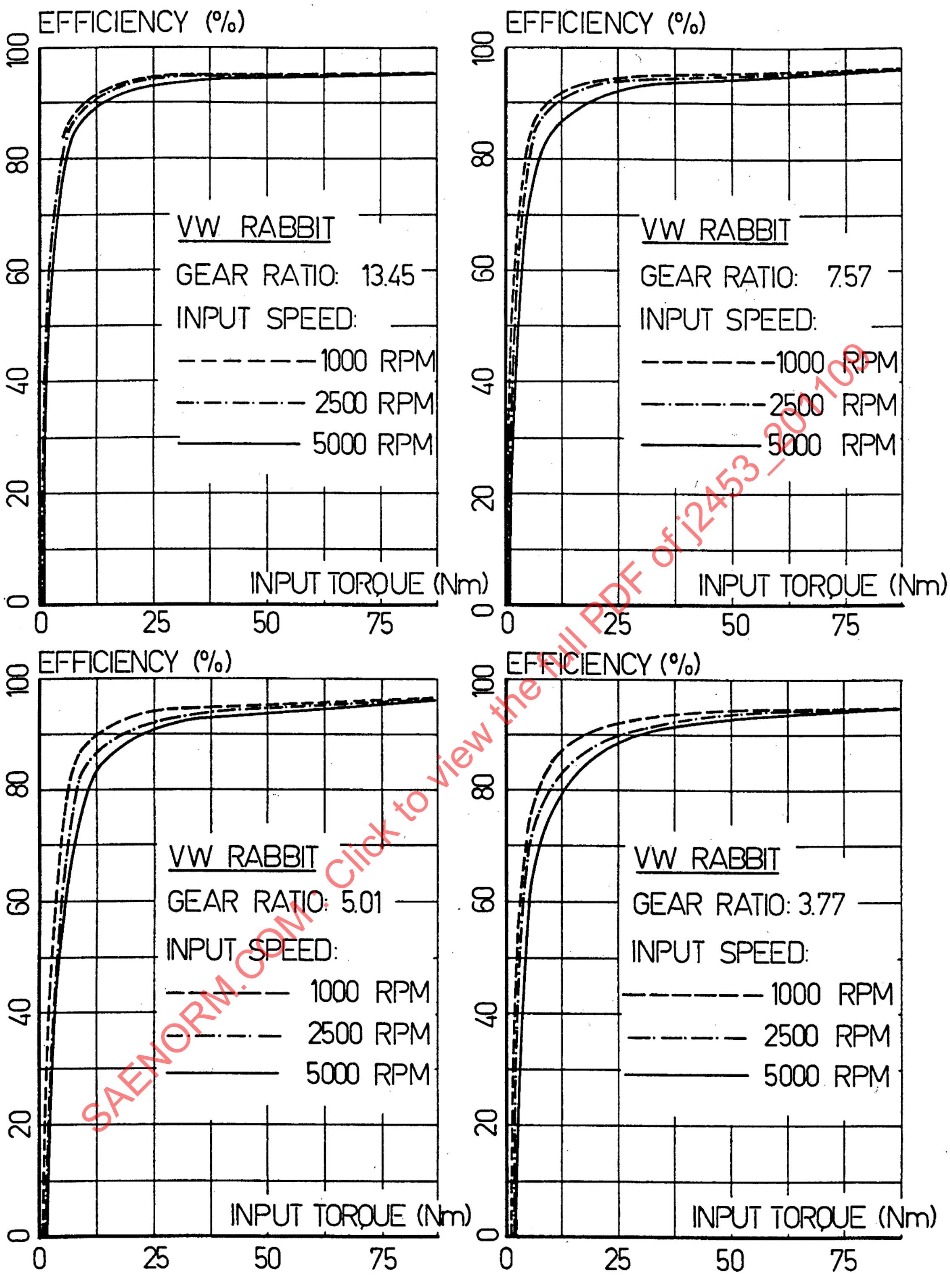


FIGURE 5—SAE 820741 FIGURE 8 SHOWING GRAPHICAL PRESENTATION OF RESULTS