SURFACE VEHICLE RECOMMENDED PRACTICE

J2817™ FEB2025

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Superseding J2817 AUG2019

(R) Definition and Measurement of Torque Biasing Differentials

RATIONALE

This document is being updated to include all types of differentials and to include lessons learned from recent test developments completed in late 2014.

SAE J2817 has been reaffirmed to comply with the SAE Five-Year Review policy.

1. SCOPE

This SAE Recommended Practice covers passive torque biasing axle and center differentials used in passenger car and light truck applications. Differentials are of the bevel gear, helical gear, and planetary types, although other configurations are possible.

1.1 Purpose

To provide a common means to define, measure, and quantify the operating characteristics of torque biasing for all differentials.

2. REFERENCES

There are no referenced publications specified herein.

3. DEFINITIONS

3.1 TORQUE BIAS RATIO

Given a differential where one full turn of a first output shaft results in one full turn in the opposite direction of a second output shaft (1:-1 ratio across outputs):

Torque bias ratio is defined as the ratio of the output torques when differentiating under load.

$$\text{Torque Bias Ratio (TBR)} = \text{Torque High/Torque Low} \quad \text{(Eq. 1)}$$

(Expressed as N:1)

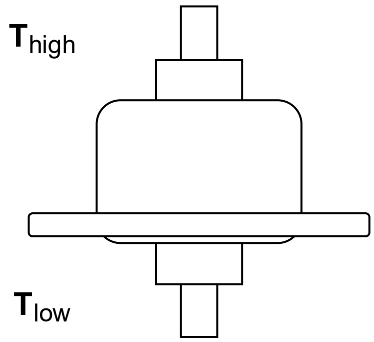


Figure 1 - Differential outputs showing high and low torque

3.2 LOCKING EFFECT

Locking effect (LE) is an alternate means of expressing torque imbalance supported by the differential. It is the relationship between torque difference and input (total) torque. It is useful when defining the performance of a torque split differential (ratio across outputs other than 1:-1). The relationship between locking effect and bias ratio is shown in Figure 2.

$$\% \text{ Locking Effect} = 100 \times \Delta T/\text{Ttotal} \quad \text{(Eq. 2)}$$

$$\% \text{ LE} = 100 \times (\text{Torque High} - \text{Torque Low})/(\text{Torque High} + \text{Torque Low})$$

$$\% \text{ LE} = 100 \times (\text{TBR} - 1)/(\text{TBR} + 1)$$

$$\text{TBR} = (1 + \%\text{LE})/(1 - \%\text{LE}) \quad \text{(Eq. 3)}$$

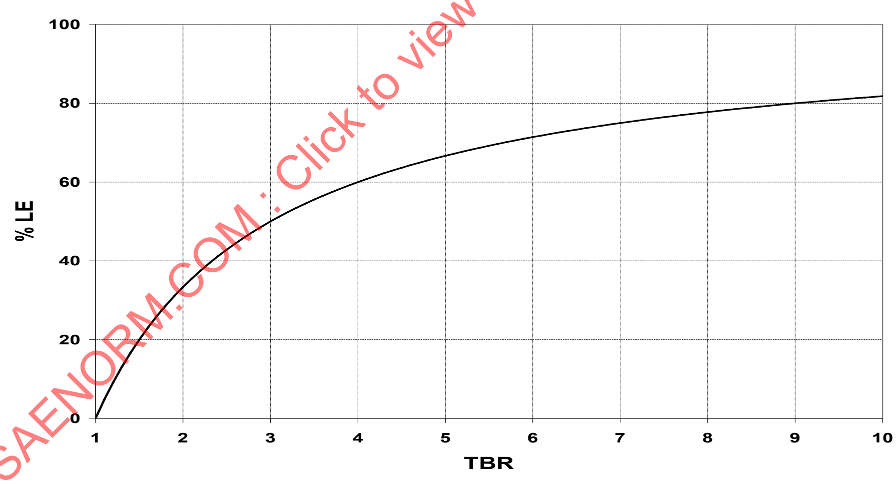


Figure 2 - Plot of locking effect versus torque bias ratio

3.3 TORQUE SPLITTER

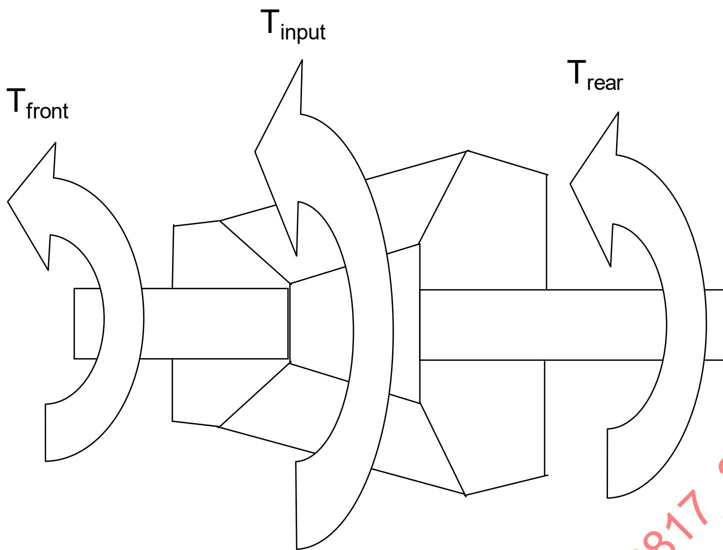


Figure 3 - Diagram of torque splitter

$$\text{T Input} = \text{T Front} + \text{T Rear} \quad \text{(Eq. 4)}$$

Torque split ratio (TSR) is the gear ratio of the two output shafts.

where:

Nf = number of teeth on front output gear

Nr = number of teeth on rear output gear

$$\text{TSR} = \text{Nf/Nr} \quad \text{(Eq. 5)}$$

Example:

12 teeth on front output gear.

18 teeth on rear output gear.

$$\text{TSR} = \text{Nf/Nr} = 12/18 = 0.667$$

Torque distribution (front:rear) assuming a “frictionless” open differential is always fixed at a certain ratio determined as follows:

% Torque to front output: Tf = 100 x Nf/(Nf + Nr)

% Torque to rear output: Tr = 100 x Nr/(Nf + Nr)

Example #1:

12 teeth on front output gear.

18 teeth on rear output gear.

%Tf = 100 x 12/(12 + 18) = 40%

%Tr = 100 x 18/(12 + 18) = 60%

This is normally expressed as a 40/60 (front/rear) nominal torque split.

When biasing capability is added, torque is distributed over a range around the nominal split ratio. Torque distribution ratio (TDR) is the ratio of the output torques when biasing. It is expressed as the ratio of the high torque output to the low torque output and may also be shown as percent torque to front and rear. It is a combined effect of TSR and TBR.

When biasing to the front, TDR = TBR * TSR

When biasing to the rear, TDR = TBR/TSR

Example #2: 12/18 tooth combination gearing, 30% locking effect:

TSR = Nf/Nr = 12/18 = 0.667

LE = 0.3

TBR = (1 + 0.3)/(1 - 0.3) = 1.86

When biasing to front, TDR = 1.86 * 0.667 = 1.24 (1.24:1 ratio front to rear).

%Tf = 100 x TDR/(TDR + 1)

%Tf = 100 x 1.24/(1.24 + 1) = 55.4% (55% front, 45% rear)

When biasing to rear, TDR = 1.86/0.667 = 2.78 (2.78:1 ratio rear to front).

%Tr = 100 x TDR/(TDR + 1)

%Tr = 100 x 2.78/(2.78 + 1) = 73.5% (74% rear, 26% front)

In Example #2, the nominal 40:60 torque split will send up to 55% of the torque to the front or 74% to the rear due to the biasing capability. Within the defined limits of torque distribution, differential gearing remains static relative to the differential housing in a vehicle application. When torque distribution reaches either the bias to front or bias to rear limit, differentiation will occur with torque distributed at the limit. Torque distribution is shown graphically in Figure 4.

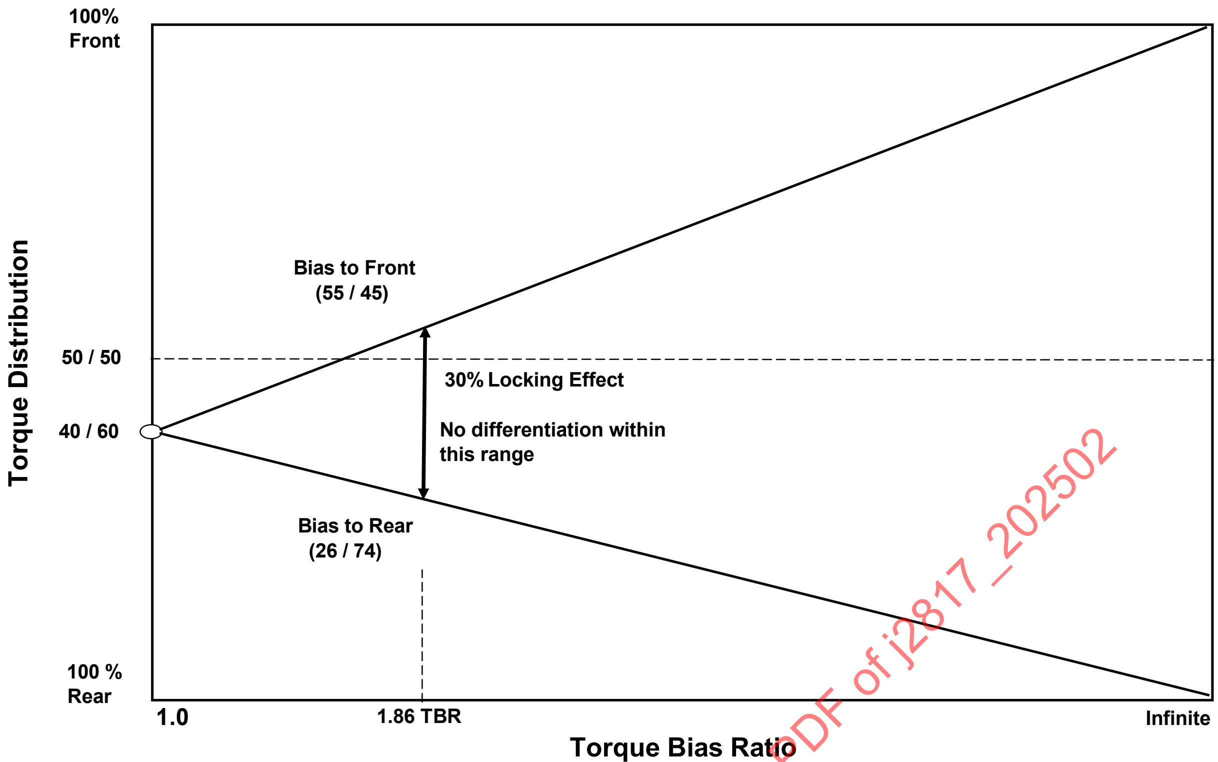


Figure 4 - Torque distribution at 30% LE

Example #3: 18/12 tooth combination gearing, 30% locking effect.

TSR = Nf/Nr = 18/12 = 1.50

LE = 0.3

TBR = (1 + 0.3)/(1 - 0.3) = 1.86

When biasing to front, TDR = 1.86 * 1.50 = 2.78 (2.78:1 ratio front to rear).

%Tf = 100 x TDR/(TDR + 1)

%Tf = 100 x 2.78/(2.78 + 1) = 73.5% (74% front, 26% rear)

When biasing to rear, TDR = 1.86/1.50 = 1.24 (1.24:1 ratio rear to front).

%Tr = 100 x TDR/(TDR + 1)

%Tr = 100 x 1.24/(1.24 + 1) = 55.4% (55% rear, 45% front).

3.4 Preload

Torque biasing properties of bevel, helical, and planetary gear differentials are commonly achieved by using gear thrust forces to generate friction within the differential, and thereby resistance to differentiation. Spring thrust may also be added to generate additional friction.

Without the addition of spring thrust, there is generally negligible resistance to differentiation when input torque is equal to zero. With the addition of spring thrust, an initial preload is generated which creates resistance to differentiation when input torque is equal to zero.

The effect of preload can be seen in Figure 5 by examining Δ torque versus total torque.

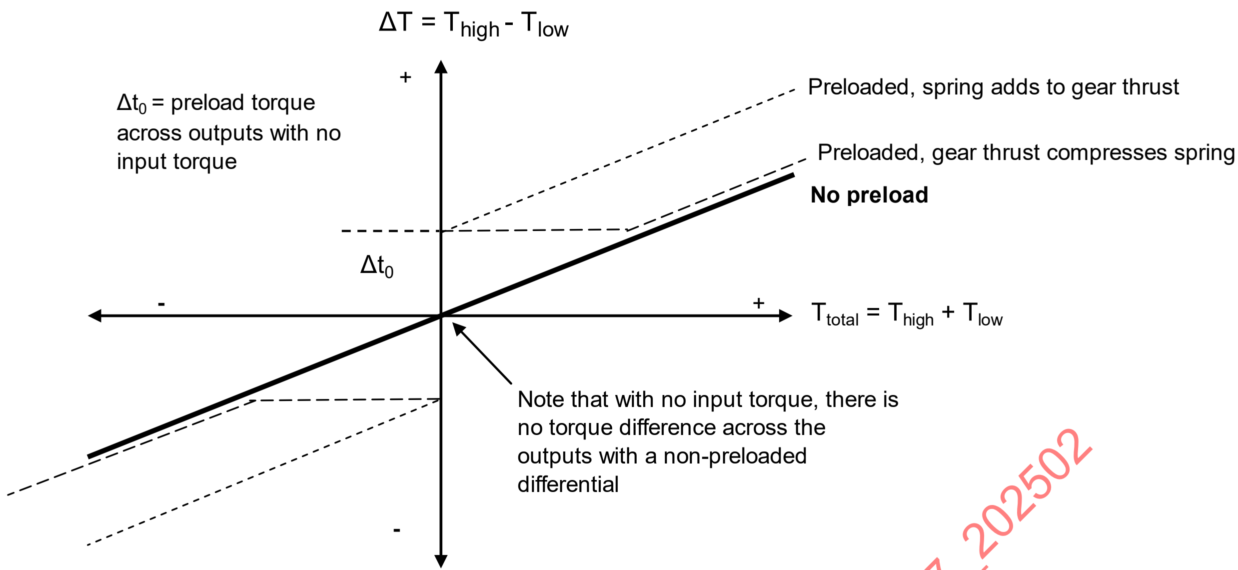


Figure 5 - Plot of Δ torque versus total torque

In the typical case where spring preload adds to gear thrust, Δ torque created by spring preload increased torque on the highly loaded output and decreases torque on the opposite output.

Example #4: 2.5 TBR + 100 N*m Preload in an axle differential

Thigh = Ttotal * TBR/(TBR + 1) + 100

Tlow = Ttotal * 1/(TBR + 1) - 100

Figure 6 shows a comparison of output torques in an axle differential having 2.5 TBR with no preload and with 100 N*m preload.

where:

TL = torque left, Nm

TR = torque right, Nm

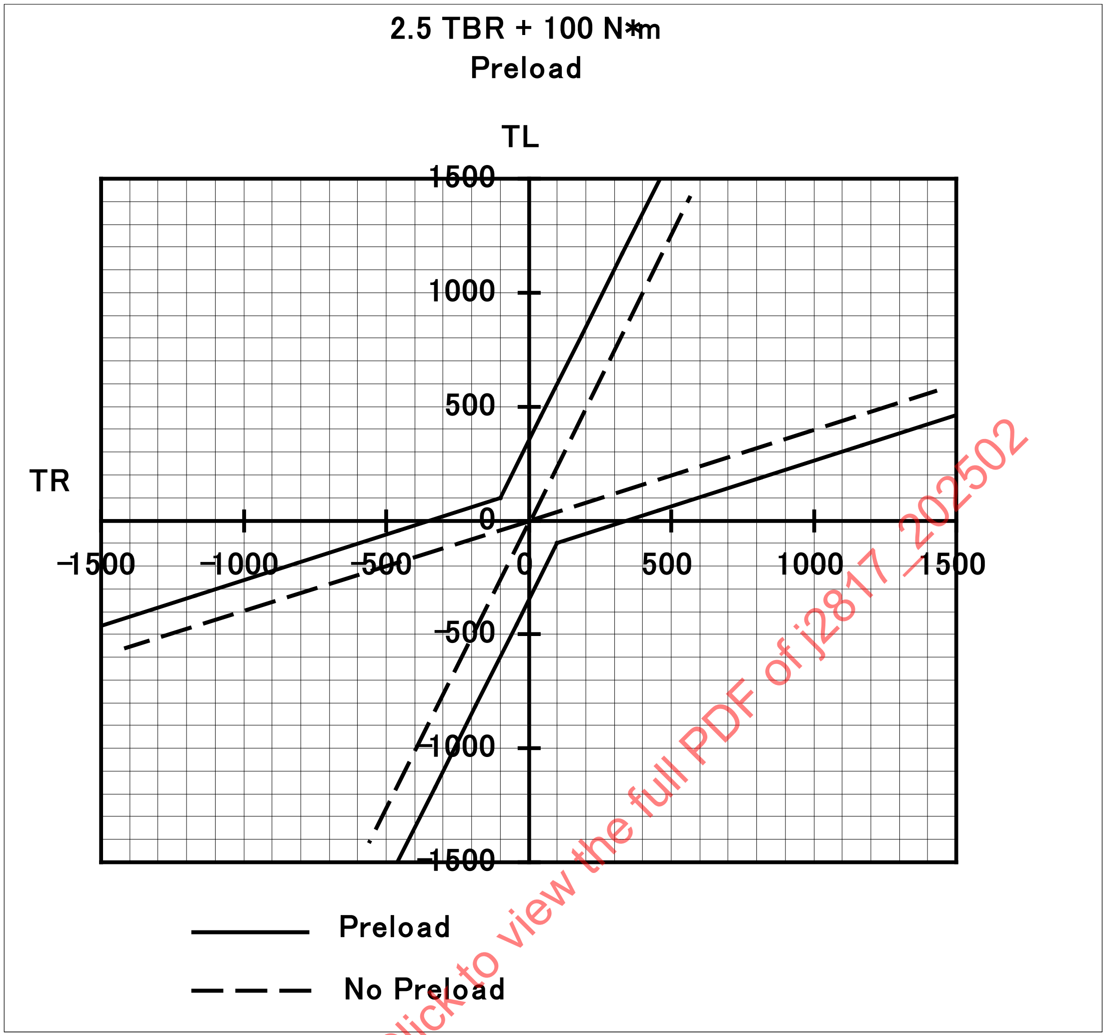


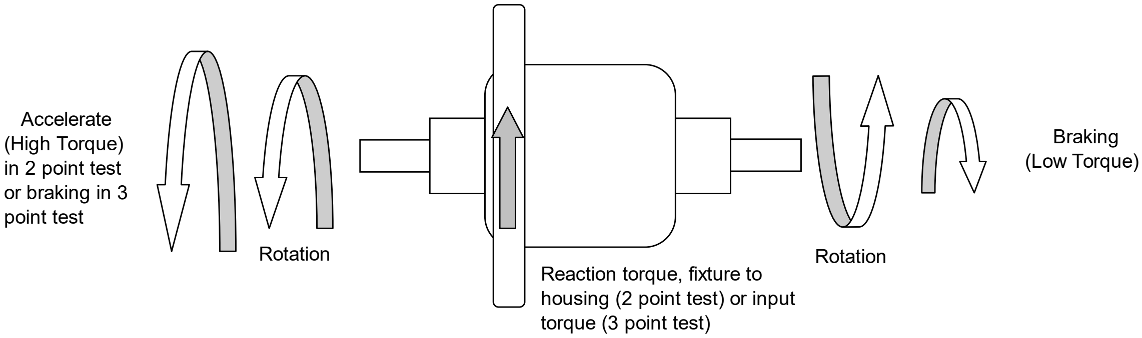
Figure 6 - 2.5 TBR with and without preload

3.5 Backlash

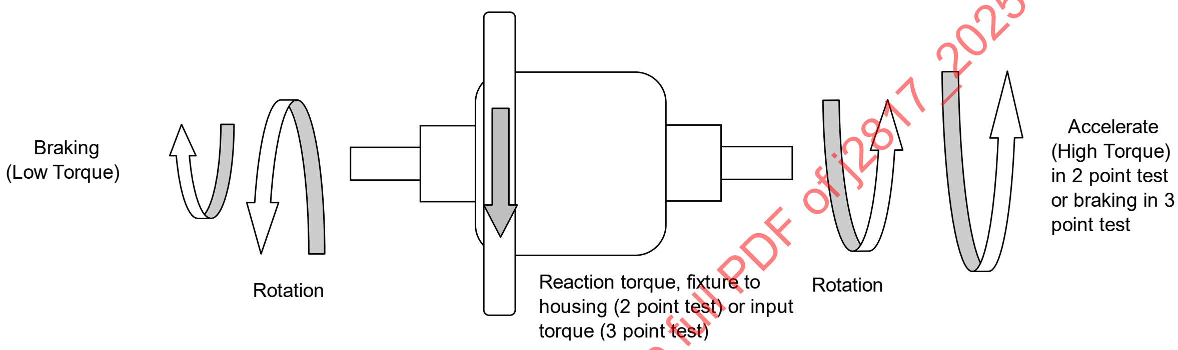
Backlash is normally found in any bevel, helical, or planetary geared differential as a result of necessary manufacturing tolerances and operating clearances between internal components. It is evident during a load reversal as a rotational movement of the input or outputs which occurs before torque is transmitted. It should be noted that preload (e.g., spring) will increase the amount of input torque required before this rotational movement can be detected.

3.6 Modes of Operation

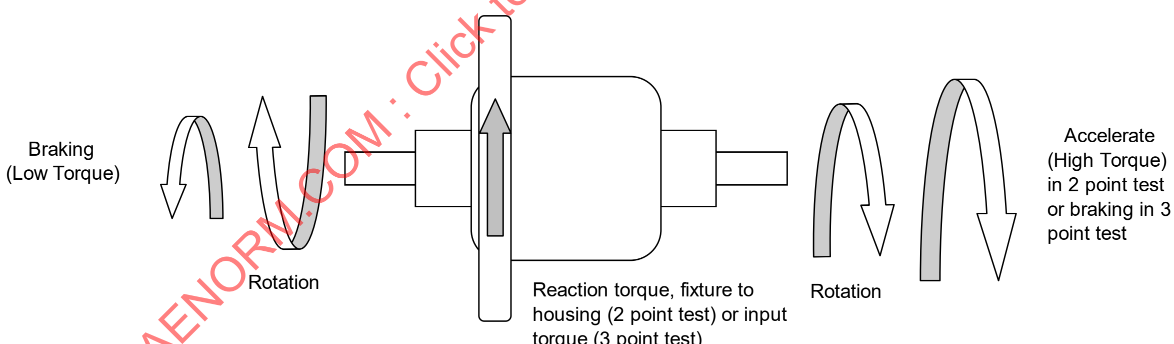
Torque bias can be measured in four modes of operation as shown in Figure 7. These modes apply to both axle and center differentials.



Typical of drive mode, left turn in a rear axle

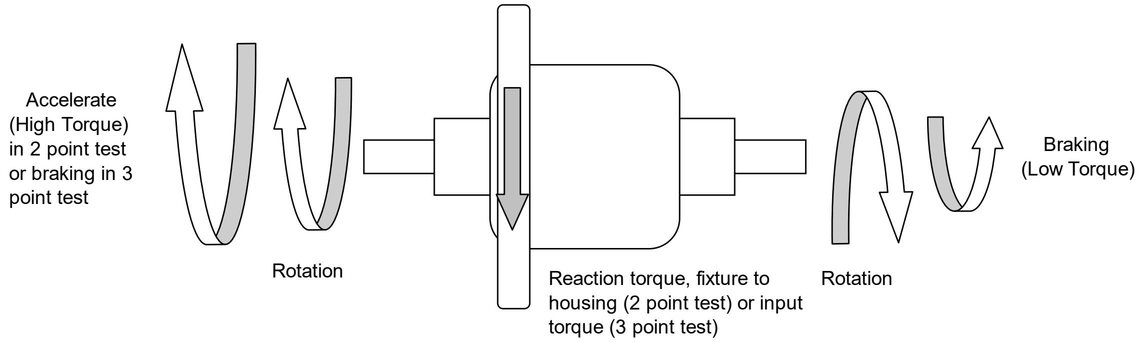


Typical of coast mode, left turn in a rear axle



Typical of drive mode, right turn in a rear axle

Figure 7 - Four modes of operation



Typical of coast mode, right turn in a rear axle

Figure 7 - Four modes of operation (continued)

4. PROCEDURES

The significance of torque-to-turn (TTT) measurement is to determine the relative nature of the overall natural "stiffness" of the differential. Even non-preloaded differentials have some natural stiffness built in; this test is to determine the quantity of the initial break away torque and differentiation torque measured in both low bias and high bias mode.

4.1 Preload Measurement

4.1.1 Torque-to-Turn (TTT) Procedure (Low Bias/Output to Output Measurement)

a. Lubricate all sliding surfaces with the application specific lubricant. Note certain clutch materials may need to be soaked for an extended period of time.

b. Assemble suitable output shafts to differential.

c. Lock one output shaft from rotation.

d. Allow input member to rotate freely.

e. Turn opposite output shaft a minimum of three full clockwise rotations at 3 rpm speed.

f. Record peak (breakaway torque) reading as well as average (rolling torque) reading. An example is shown in Figure 8.

g. Repeat steps e. and f. in the reverse direction.

Note this method can be used to measure an in-vehicle axle differential by raising one wheel off the ground and placing the transmission in neutral.

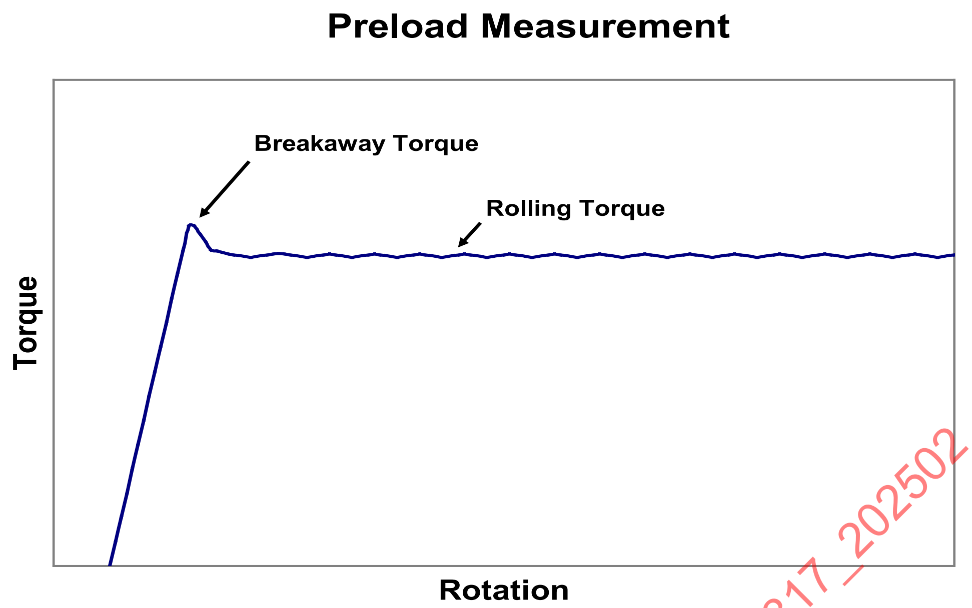


Figure 8 - Example of breakaway torque and rolling torque

4.1.2 Torque-to-Turn (TTT) Procedure (High Bias/Output to Input Measurement)

a. Lubricate all sliding surfaces with the application specific lubricant. Note certain clutch materials may need to be soaked for an extended period of time.

b. Assemble suitable output shafts to differential.

c. Lock input member from rotation.

d. Turn one output shaft a minimum of three full clockwise rotations at 3 rpm ± 1 rpm of speed while allowing the opposite output to rotate freely.

e. Record peak (breakaway) reading as well as average (rolling torque) reading.

f. Repeat steps d. and e. in the reverse direction.

g. Repeat steps d. through f. with the opposite output shaft.

Note this method can be used to measure an in-vehicle axle differential by raising both wheels off the ground and placing the transmission in park. TTT will change over life; suggest that it be measured green and after break in called out in 4.3.2. If measuring a plate style LSD, do not run TBR first, since it will affect the clutch surface due to the high load place on the surfaces during the TBR test.

4.2 Backlash Measurement (Applies to Differentials without Preload)

4.2.1 Measurement at One Output

a. Lubricate all sliding surfaces with the application specific lubricant. Note certain clutch materials may need to be soaked for an extended period of time.

b. Assemble output shafts equipped with expanding arbors to differential. This is intended to measure backlash of the differential assembly only and does not include splines.

c. Lock one output shaft from rotation.

d. Lock input member from rotation.

e. Turn opposite output shaft in both clockwise and counterclockwise directions under a torque load of ±15 N·m.

f. Measure and record total rotational movement of the output shaft to which torque was applied.

NOTE: If testing a differential in an assembly (such as an axle), be aware that other components will contribute to measured backlash.

4.2.2 Measurement at Input (High Torque)

a. Lubricate all sliding surfaces with the application specific lubricant. Note certain clutch materials may need to be soaked for an extended period of time.

b. Assemble output shafts equipped with expanding arbors to differential. This is intended to measure backlash of the differential assembly only and does not include splines.

c. Lock both output shafts from rotation.

d. Rotate the input in one direction to a torque of 100 N·m.

e. Rotate the input in the opposite direction to a torque of 100 N·m.

f. Rotate the input back to the original position (zero torque).

g. Referring to Figure 9, draw the best-fit lines (labeled) tangent to the curves. This separates wind up from lash.

Typical Rotational Lash Graph

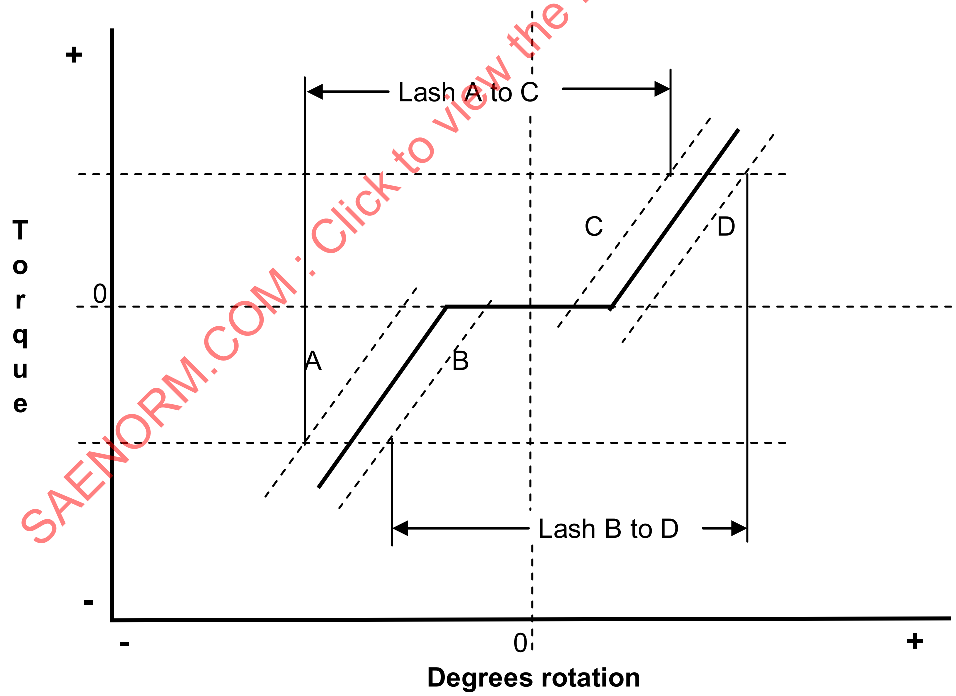


Figure 9 - Rotational lash

h. Measure the distance between lines A and C and B and D.

i. Average the distance.

j. Multiply this value by the graph scale to determine rotational lash value.

To eliminate variability due to interpretation of best fit lines, it is recommended to use a curve fitting technique.

4.3 Component Level Torque Bias Test

4.3.1 Equipment Requirements

Measurement at component level can be performed on a vertical or horizontal axis bench stand with two motor-brakes with the test differential secured to a fixture and provisions for lubricant flow to the differential. Temperature control is typically not required; however, temperature must remain below the maximum operating level as defined by the lubricant supplier. It should be noted that lubricant temperature may affect torque bias ratio. A provision to ensure removal of lubricant contaminants is required.

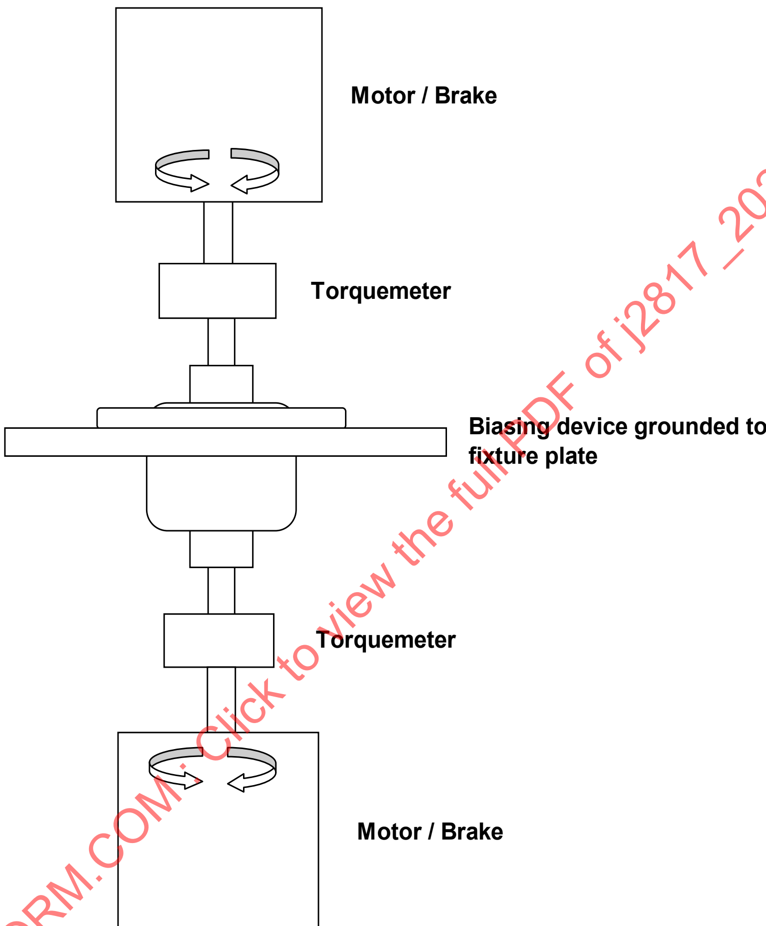


Figure 10 - Two point test rig

A diagram of the two point test rig is shown in Figure 10. Torque and speed capabilities are to be appropriately sized for the differential application. Torque meter accuracy is to be within ±0.5% of full scale. Output speed measurement is to be accurate within ±1% of actual speed.

4.3.2 Test Conditions

4.3.2.1 Break-In

Break-in is specified as a percentage of the total differential life, which is also the durability schedule to which the differential will be tested. It is assumed that the differential will be tested in the “as-shipped” condition recognizing that a change in bias ratio may be observed with extended operation at differentiation under load. This typically appears as a knee in the bias curve after which bias becomes stable as shown in Figure 11.