



SURFACE VEHICLE RECOMMENDED PRACTICE

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Definition and Measurement of Beam Axle Efficiency

RATIONALE

New government regulations that raise automotive fuel economy requirements and change the methods by which vehicle level fuel economy is measured drive the need for improved methods to measure component level efficiency. The intent of this SAE Recommended Practice is to provide the method to generate consistent component level efficiency data in support of modeling and analysis of vehicle-level emissions and fuel economy.

1. SCOPE

This SAE Recommended Practice covers beam axles utilizing hypoid gear final drives. It is a component level test, performed with three dynamometers in a "T-cell" arrangement. It includes both an efficiency characterization method, as well as a break-in method to support efficiency characterization. It was developed for beam axles used in light truck applications but may be extended to other hypoid gear drive systems.

1.1 Purpose

To provide a common method to consistently measure and quantify the efficiency characteristics of beam axles.

2. REFERENCES

2.1 Related Publications

The following publications are provided for information purposes only and are not a required part of this SAE Technical Report.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

SAE J1952	All-Wheel Drive Systems Classification
SAE J2059	All-Wheel-Drive-Drivetrain Schematic Symbol Standards
SAE J2263	Road Load Measurement Using Onboard Anemometry and Coastdown Techniques
SAE J2985	Definition and Measurement of Transfer Case Speed-Dependent Parasitic Loss
SAE J3039	Definition and Measurement of Power Transfer Unit Speed-Dependent Parasitic Loss
SAE 2020-01-1413	Predictive Break-In and Rapid Efficiency Characterization of Beam Axles

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Documents

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2.1.2 Other Publications

United States Code of Federal Regulations, Title 40 - Protection of Environment [40 CFR], Part 86 - Control of Emissions from New and In-Use Highway Vehicles and Engines [40 CFR 86]

United States Environmental Protection Agency, Emission Standards Reference Guide

3. DEFINITIONS

3.1 BEAM AXLE

For the purposes of this standard, a beam axle is a fully enclosed drive system consisting of a center section with a hypoid gear reduction and differential, and two tubes housing axle shafts and wheel bearings. It transfers torque from a longitudinal driveshaft attached to the hypoid pinion to left and right side wheels and supports the vehicle as an integral part of the suspension.

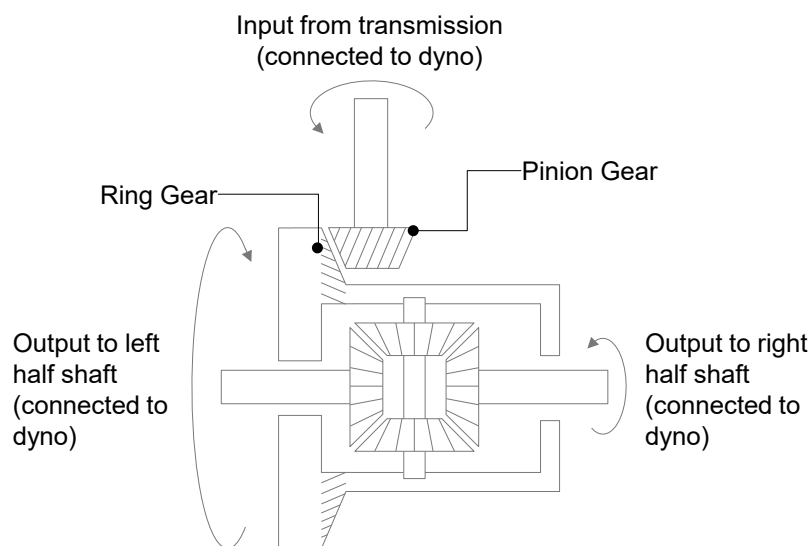


Figure 1 - Beam axle

3.2 LOADED EFFICIENCY

Efficiency of the beam axle when a driving load is applied to the input, or pinion, and a braking torque is applied to the outputs

3.3 SPIN LOSS

Torque required to turn the input of a beam axle at a constant speed when there is nothing connected to the outputs.

3.4 UNIT UNDER TEST (UUT)

This term and its associated acronym are used to describe the test article (beam axle) undergoing the tests outlined herein.

3.5 MAXIMUM OUTPUT SPEED (MOS)

This term and its associated acronym refer to the maximum output speed to be characterized. MOS does not necessarily reflect the maximum speed capability of the axle, but instead the highest speed at which efficiency data is to be collected. For light-duty truck applications, a maximum output speed of 1400 rpm is recommended. Note: It is recommended to standardize on axle output speeds, not an equivalent vehicle speed. During development of the standard, it was discussed that this is an axle test on an axle dyno. The same axle is often sold with different tire sizes, so it is recommended to standardize on axle output speeds, not an equivalent vehicle speed, then add in the uncertainty from tire size.

3.6 MAXIMUM COMBINED OUTPUT TORQUE (MCOT)

Maximum Combined Output Torque (MCOT) is the highest torque at which efficiency data will be collected. It is defined as the sum of the two output shaft torques.

MCOT should approximate the highest torque the axle is capable of sustaining for extended periods. Guidelines for setting MCOT are provided in Table 1.

Table 1 - Recommended MCOT

Axle Application	MCOT	Note
Light Truck (Full Size)	4200 Nm	GVWR 2722 kg - 3856 kg
Light Truck (Mid-Size)	3100 Nm	GVWR Less than 2722 kg
Other	$MCOT (Nm) = GVWR (kg) * 1.24$	MCOT in Nm, GVWR in kg

3.7 UUT TEMPERATURE

UUT temperature is the temperature of the lubricating oil as measured by a thermocouple in the oil drain plug, or if no drain plug is present, in the lowest point of the oil sump (as shown in Figure 2).



Figure 2 - Thermocouple for UUT temperature measurement

3.8 MAXIMUM SUMP TEMPERATURE

The maximum sump temperature is the highest oil temperature at which data will be collected. Maximum sump temperature should be decided before starting tests and set low enough to avoid damaging the UUT.

3.9 STEP

A step is a single operating condition consisting of a constant speed and torque. Temperature may change within a step.

3.10 STEP AVERAGED

Data collected throughout the standard is measured and reported as “step averaged.” A given parameter will change over the duration of a step due to measurement noise, drift, transient effects in the UUT, or other factors. To account for this noise, data for the parameter is averaged over the entire duration of the step, and then reported or used for other calculations.

3.11 CYCLE

A cycle is a series of steps tested in a predetermined order. There are three cycles in this standard: break-in, loaded efficiency, and spin loss.

3.12 EQUILIBRIUM TEMPERATURE

Define with equation (see 6.3.5).

3.13 SOAK

Soak refers to conditioning the axle to a desired temperature by holding it in a temperature controlled chamber until all components are near the target temperature.

3.14 DRIVE AND COAST

For loaded testing, the input dynamometer should be set to control speed, while the output dynamometers are set to control torque.

All testing (drive, coast, and spin loss) is conducted in the forward vehicle driving direction. For drive testing (loaded), the input torque is applied in the forward vehicle driving direction, simulating load from the transmission, while the output torque is applied opposite to the spin direction, simulating reaction forces from the road. For coast testing (loaded), input and output torque application is reversed, simulating a coasting load on the transmission. Spin direction remains in the forward vehicle driving direction. During spin-loss testing (unloaded), the driveshaft outputs are allowed to spin unconstrained and unloaded.

Drive and coast definitions are shown schematically in Figure 3.

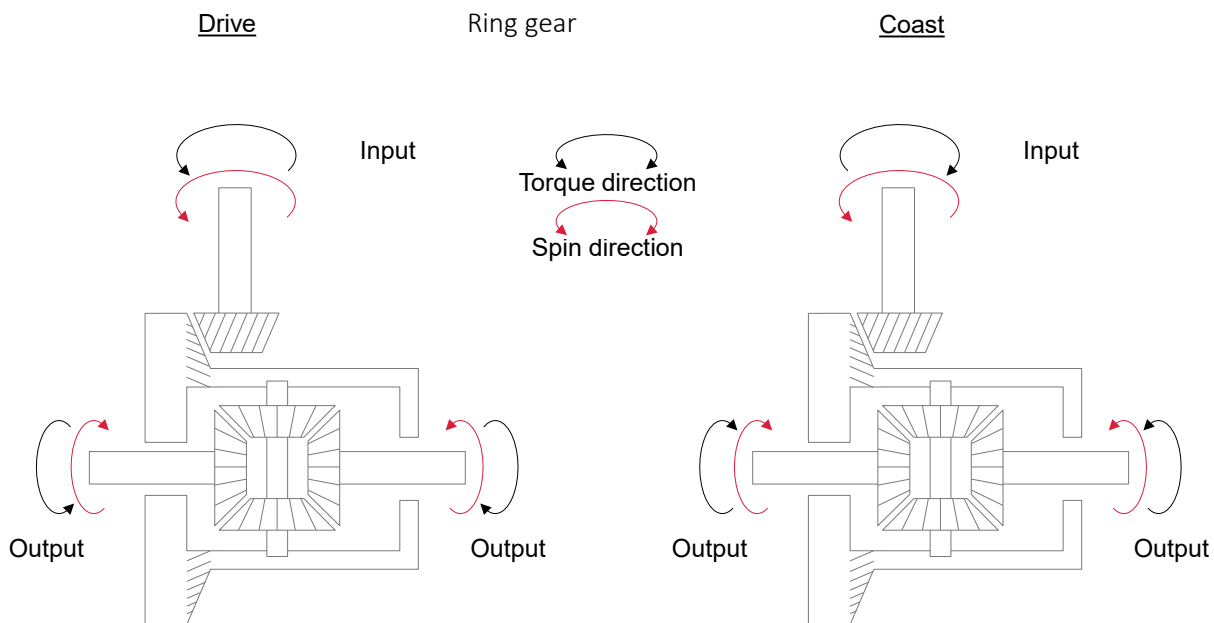


Figure 3 - Drive and coast definitions

4. EQUIPMENT REQUIREMENTS

Measurements should be performed on a standard horizontal axis test stand, with dynamometers driving the beam axle input and both outputs. Precision torque measurement devices should be mounted between the motors and UUT, as shown in Figure 4. If a link shaft or gearbox is utilized, it should be located between the drive motor and the torque meter, with the torque meter closest to the axle flange. The test stand should have a means for disconnecting both output dynamometers from the UUT in under 15 minutes.

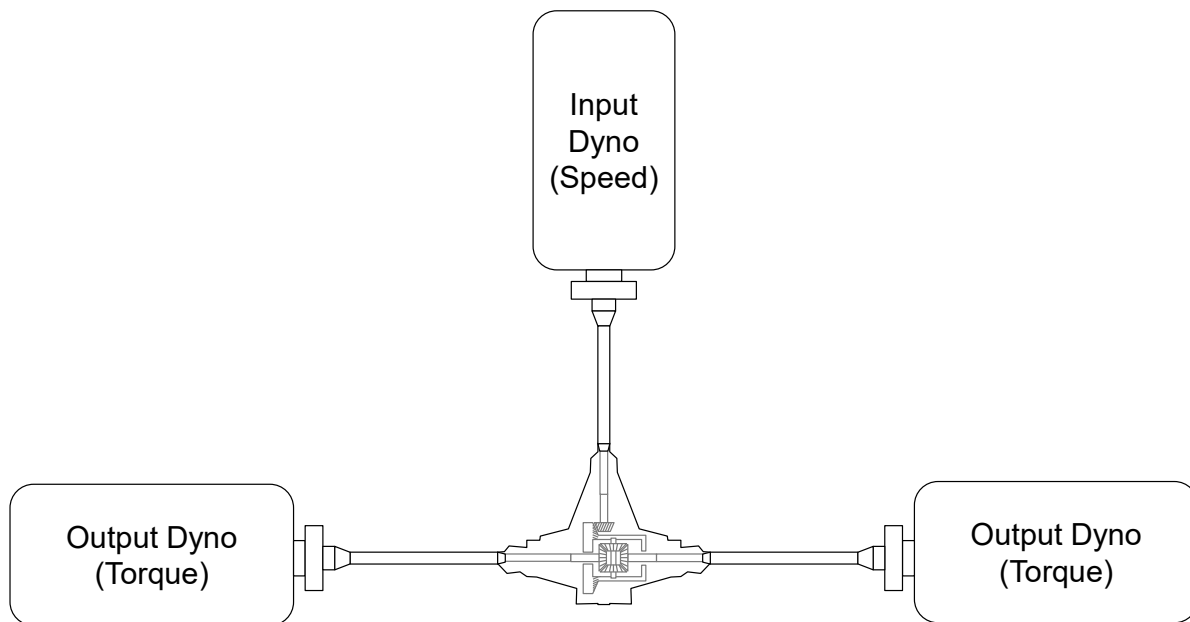


Figure 4 - Dynamometer setup

UUT temperature is controlled by either direct oil conditioning or by an environmental chamber, depending on which portion of the test is being run. For break-in, a “Shark Gill” cover described in 5.2.1 is used in conjunction with direct oil conditioning to control UUT temperature. Ambient air temperature is not controlled during break-in. For the loaded efficiency and spin loss portions of this standard, the Shark Gill cover is removed, and temperature is controlled by an environmental chamber as described in 6.2.1. Power capability of the input dynamometer should be adequate to maintain MCOT continuously at $0.5 \times \text{MOS}$, and MOS at $0.5 \times \text{MCOT}$. Output dynamometers power capability should be at least half the input dynamometer power capability. Torque meters should be sized close to MCOT and have $\pm 0.05\%$ full scale accuracy or better. Speed measurements are to be accurate to within ± 2 rpm of actual speed.

Table 2 - Test setup

Description	Break-In	Loaded Efficiency	Spin Loss
Input Dyno	Drive (speed control)	Drive (speed control)	Drive (speed control)
Output Dynos	Absorb (torque control)	Absorb (torque control)	Disconnected
Rear Cover	“Shark Gill”	Unmodified	Unmodified
Environmental Chamber	Not used	Installed	Installed
Preconditioning	Direct oil conditioning	Soak	Loaded efficiency

Table 3 - Dynamometer requirements

Criteria	Input Dynamometer	Output Dynamometers
Dynamometer Speed Capability at MCOT	$0.5 \times \text{MOS}$	$0.25 \times \text{MOS}$
Dynamometer Torque Capability at MOS	$0.5 \times \text{MCOT}$	$0.25 \times \text{MCOT}$
Minimum Torque Meter Sizing	MCOT	$0.5 \times \text{MCOT}$
Minimum Torque Meter Accuracy	0.05% Full scale	0.05% Full scale
Minimum Speed Measurement Accuracy	± 2.0 rpm	± 2.0 rpm

4.1 Stabilization

For all cycles in this standard, torque loss should be allowed to stabilize between steps. This is achieved by using a 5 second ramp and minimum 3 second stabilization period between steps in a cycle.

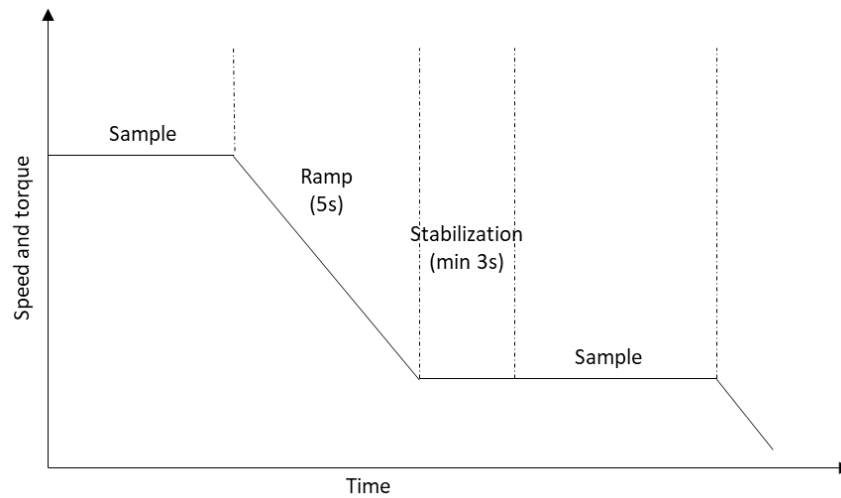


Figure 5 - Stabilization between steps

4.2 Run-to-Run Repeatability

In order to verify representative results are being achieved, it is important to establish reasonable run-to-run repeatability. The dynamometer, torque measurement, and temperature control system should have a run-to run repeatability of 0.5 Nm or better for a given UUT and operating condition.

5. BREAK-IN

5.1 Introduction

In order to achieve repeatable and comparable results, test axles must undergo a break-in procedure before efficiency characterization.

This break-in procedure is based on the idea that for a hypoid gear axle, where the primary mode of break-in is the wearing down of asperities between the ring and pinion gears, the surface finish of the gears will eventually cease changing as break-in progresses. For a given speed, load, and temperature, the efficiency of an axle will eventually reach an asymptotic limit over time. This asymptotic behavior can be modelled for a given UUT, enabling prediction of changes in that UUT's efficiency over time, as well as its eventual efficiency if the break-in process were to continue indefinitely.

For computational expedience, this standard uses torque loss, defined as input torque, multiplied by gear ratio, minus output torque, instead of efficiency.

$$\begin{aligned} &\text{Torque loss} \\ \tau &= (m_{in} \times r) - m_{out, total} \end{aligned} \quad (\text{Eq. 1})$$

Torque loss is continually modeled as both a polynomial and exponential function, and the function with the better fit is used to assess level of break-in of the UUT. These two functions are:

Polynomial function

$$\tau = \frac{M}{n+A} + T \quad (\text{Eq. 2})$$

Exponential function

$$\tau = Mn^{-A} + T \quad (\text{Eq. 3})$$

where:

τ = torque loss for a given step

m_{in} = torque at the input for a given step

$m_{out,total}$ = combined torque at the output for a given step

r = axle gear ratio

n = repeat number of the break-in cycle

M and A = shape-factors determined by least-square regression

T = estimated fully broken-in torque loss of a given step, determined by least-square regression

Many data points are required to perform a reliable regression, and in a vehicle application, break-in does not occur at only one torque. To collect many points over a wide range of torque conditions, the break-in cycle moves continuously between several torque levels (steps), and a step-averaged torque loss measurement is recorded at each. These steps are arranged into a cycle, which is repeated to generate a family of torque loss versus time curves for the UUT. These curves are assessed against a set of mathematical criteria, and when all the curves (each representing a step in the cycle), meet the break-in criteria, the axle is considered broken-in.

There are two parts to the break in criteria. The first part ensures that the regression is stable, i.e., the predicted asymptotic torque loss is not changing significantly between cycles. The second part assesses whether the UUT is broken in by ensuring that either the torque loss of the UUT is within 0.5% of the torque loss asymptote, or the UUT torque loss is changing by less than 0.5 Nm/h at all operating points. The UUT is considered broken in when both parts of the break in criteria are met for either the polynomial or exponential regression, whichever is a better fit.

5.2 Break-in Equipment Setup

Table 4 - Break-in equipment setup

Function	Version
Temperature Control	Oil Sump Thermocouple
Axle Conditioning	Direct Oil Conditioning
Rear Cover	"Shark Gill"
Sump Temperature	80 °C ± 2 °C
Max Permissible Temperature	125 °C