SAE International	SURFACE VEHICLE RECOMMENDED PRACTICE	J3011 OCT2012 Issued 2012-10

Measurement and Characterization of Electronically Controlled All-Wheel Drive/Driveline Coupling Systems

RATIONALE

To recommend test configuration parameters, procedures, and analysis techniques of electronically controlled all-wheel drive (AWD)/driveline coupling system for measurement of specific performance characteristics.

FOREWORD

The intended scope of this SAE Recommended Practice is to encompass all types of electronically controlled driveline coupling devices including active on-demand (AOD) and cross axle devices. This practice is not intended for launch devices and transmission related systems.

1. SCOPE

This SAE Recommended Practice covers the most common applications of electronically controlled on-demand AWD couplings used in passenger (car and light truck) vehicle applications.

2. PURPOSE

The purpose of this SAE Recommended Practice is to provide a means to define, measure, and quantify the operating characteristics of electronically controlled on-demand AWD coupling systems.

3. REFERENCES

3.1 Applicable Documents

The following publications form a part of this specification to the extent specified herein. Unless otherwise indicated, the latest issue of SAE publications shall apply.

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

SAE J1952 All-Wheel Drive Systems Classification

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4. DEFINITION

Electronically-controlled coupling systems consist of a mechanical coupling device controlled by an electronic control unit (ECU). The ECU contains control algorithms and the communication interface to allow access to key vehicle information as well as for communication with such systems as anti-lock braking systems (ABS), electronic stability control (ESC) systems, etc., (please reference J1952 for further definitions). As a result of this level of vehicle system integration, the performance of the coupling may be assessed either with or without an ECU.

In order to reduce the fuel consumption of passenger vehicles, AOD coupling systems may incorporate a driveline disconnect or two-wheel drive (2WD) mode that substantially reduces drag torque, (typically at the expense of response time). The unique usage of these devices makes it important to distinguish between standard couplings and couplings with disconnect capability. Except where noted, all test procedures outlined in this document should be made and measured while in the AWD mode. Notable exceptions to this include the measurement of drag torque losses in section 11.

The rated torque capacity of the device shall be defined by the device supplier.

5. SYSTEM CONTROL METHODOLOGY

A vehicle representative ECU or other electronic control method may be used to control the coupling. In any case, coupling performance will be assessed based on when a commanded input is first received by the coupling or ECU, as shown in Figure 1. The particular system control methodology used must be defined and documented as part of the data reporting process.

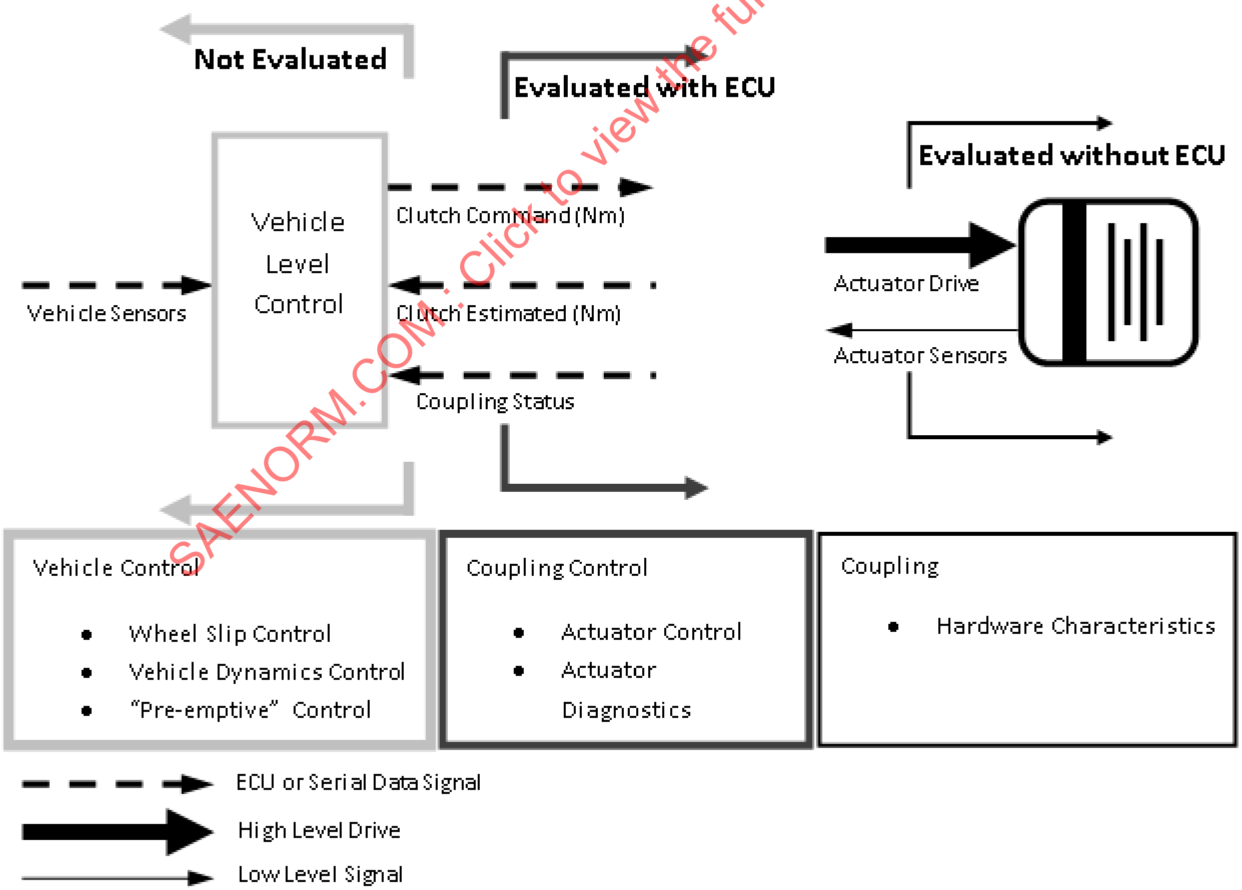

FIGURE 1 - COUPLING TEST CONTROL METHODOLOGY

6. TEST RIG SET-UP

Coupling output is to be grounded (stationary) with an inline torque transducer recommended on the grounded side, as shown in Figure 2 (optionally, the torque transducer may be located on the rotating input side or in a reactionary torque arm, so long as all accuracy and system requirements are achieved).

Two fixturing options are acceptable.

1. Grounding the clutch housing.

2. Grounding the main shaft.

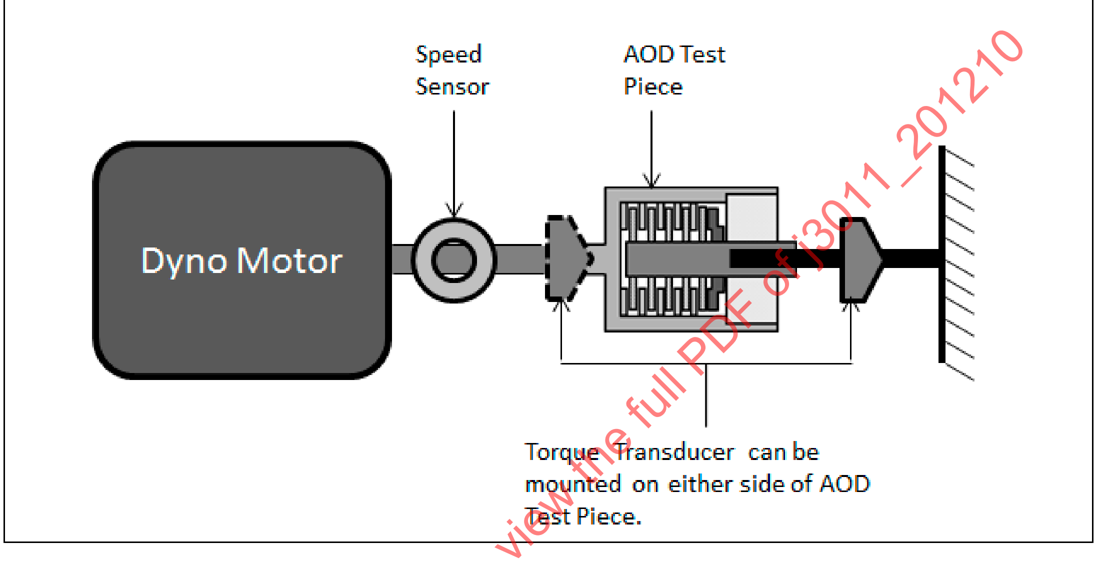

FIGURE 2 - TEST RIG SET UP

Basic test rig capabilities should include the following:

- Maximum torque capacity shall be a minimum of 10% above the test requirements.
- Torque transducer resolution shall be ± 0.50% of full scale based on 150% of the rated clutch torque capacity for all testing except Section 11. For drag torque in connected mode, measurement resolution shall be ± 0.75 Nm, and for disconnect capable couplings, the resolution shall be ± 0.05 Nm.
- Maximum speed capacity should be a minimum of 10% above test requirements.
- The measured speed sensor shall be mounted to the unit under test, where the dyno output stiffness shall be ten times the theoretical torsional stiffness of the coupling.
- Speed shall be controlled to within ± 0.5 RPM or 0.50% of max RPM, whichever is greater.
- Minimum and maximum speed requirements:
    - Connected mode: 2 - 200 RPM
    - Disconnected mode: up to 3000 RPM
    - If ramp up rates indicated in section 11 cannot be achieved, please indicate actual rates used for the test.

- Minimum and maximum temperature respectively: (-40 to 150 °C)
- Clutch initial condition temperature shall be measured at either: (as shown in Figure 3)

  1. Clutch reaction plate by grounding the clutch housing and spinning the main shaft.
  2. Core of the main shaft by grounding it and spinning the outer housing.

If the temperature sensor is located in the main shaft, it is unacceptable to run more than one cycle before thermally reconditioning (cold soaking) the test unit since the difference in temperature between the clutch housing and the main shaft may be significant, as shown in Figure 4. This graph demonstrates the thermal deviations between the clutch plates, sump, inner shaft, and skin of the coupling, thus requiring special cooling practices in between sections and cycles. It also shows why clutch housing surface temperature cannot be used for control temperature.

Coupling testing shall be performed in two phases.

1. As shipped – new coupling intended for installation in a production vehicle.
2. Target Life – coupling which has completed the life cycle durability testing.

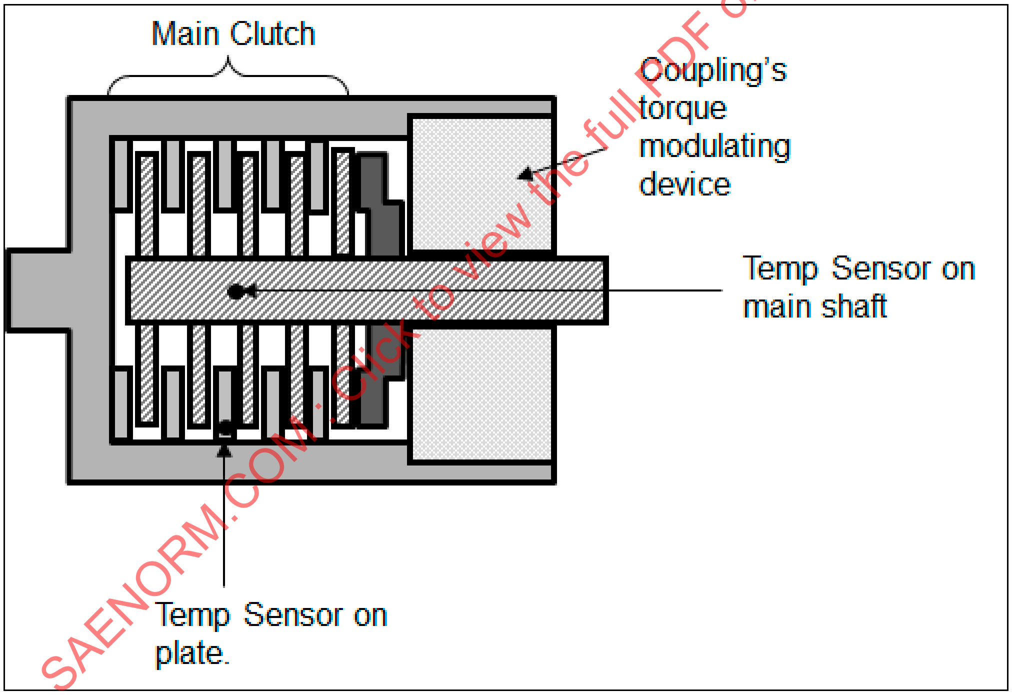

FIGURE 3 - TEMPERATURE SENSOR LOCATION OPTIONS

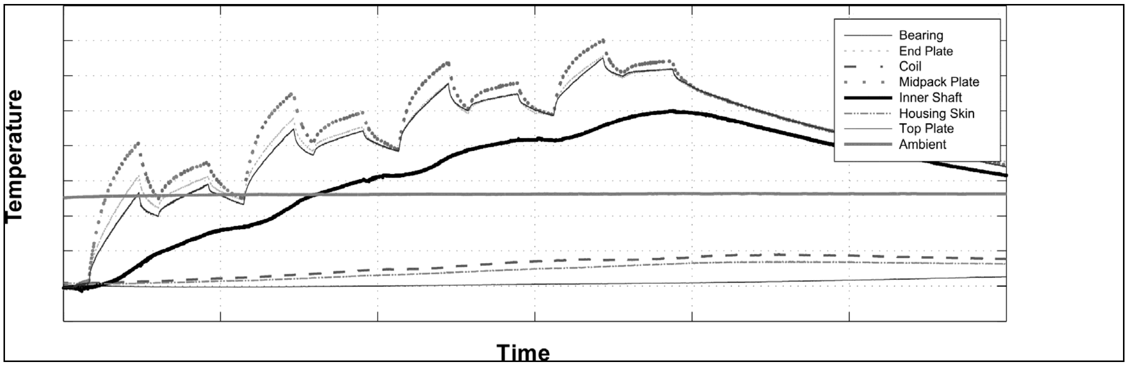

FIGURE 4

7. TESTING AND ANALYSIS

For the purpose of characterizing the system performance, the recommended tests for the full coupling assembly will consist of:

Step Input – Section 9

Dynamic Response Profile – Section 10

Drag Torque Behavior – Section 11

Mu-V characteristics – Section 12

8. GENERAL TEST REQUIREMENTS

All single point data collection shall be run a minimum of three times for all test sections. The data shall be tabulated for the three sets and averaged as a final graph.

Due diligence shall be taken to stabilize the coupling temperature between runs for at least 30 minutes or as required to ensure the desired core temperature has been reached. Stabilized temperature is defined by the temperature fluctuating less than two degrees once it is within the required temperature range.

9. STEP INPUT TEST

The purpose of this test is to characterize the torque engagement and release response of the system at various delta speeds and start temperatures whilst at various requested torque levels (see Figure 5).

9.1 Minimum level of parameters to be monitored and recorded:

- Coupling reacted torque.
- Coupling temperature (measured according to the options outlined above).
- Delta speed.
- Coupling input current, voltage and pressure (where applicable).

9.2 Coupling Torque Measurement Procedure:

- Document 100% and 50% of the coupling's rated torque capacity.

- Supply a report on two couplings.

    1. As shipped – new coupling intended for installation in a production vehicle.

    2. Target Life – coupling which has completed the life cycle durability testing (such as from Design Validation testing). NOTE: The total energy profile showing, load vs. speed vs. time and Joules exerted during the test shall be provided with the test report.

- The results should be tabulated in the matrix shown in Table 1.

- Torque evaluation with and without ECU (if applicable).

    - With ECU: Response time to be measured from the input of the Clutch Command torque request (Nm) into the actuator controller (see Figure 1) to the measured reacted torque of the coupling. ECU processing time is included in the total response time.

    - Without ECU: Response time to be measured from the initial application of actuator power (see Figure 1) to the final reacted torque of the coupling.

- Test conditions:

    - Controlled power source capability for the ECU (12 V ± 3 V)

    - Sampling rate: 1024 Hz (to capture 100 ms response time)

    - Coupling start temps: -20 °C, 0 °C, +20 °C, +50 °C, +100 °C, (±2 °C)

        - 5 RPM

        - 10 RPM – Steady state

        - 20 RPM – Dynamic event

        - 50 RPM – Homogeneous launch

        - 100 RPM – Step Mu. Curb

        - 150 RPM – Step Mu. Curb + 50% (GVWR - Curb)

        - 200 RPM – Step Mu. GVWR

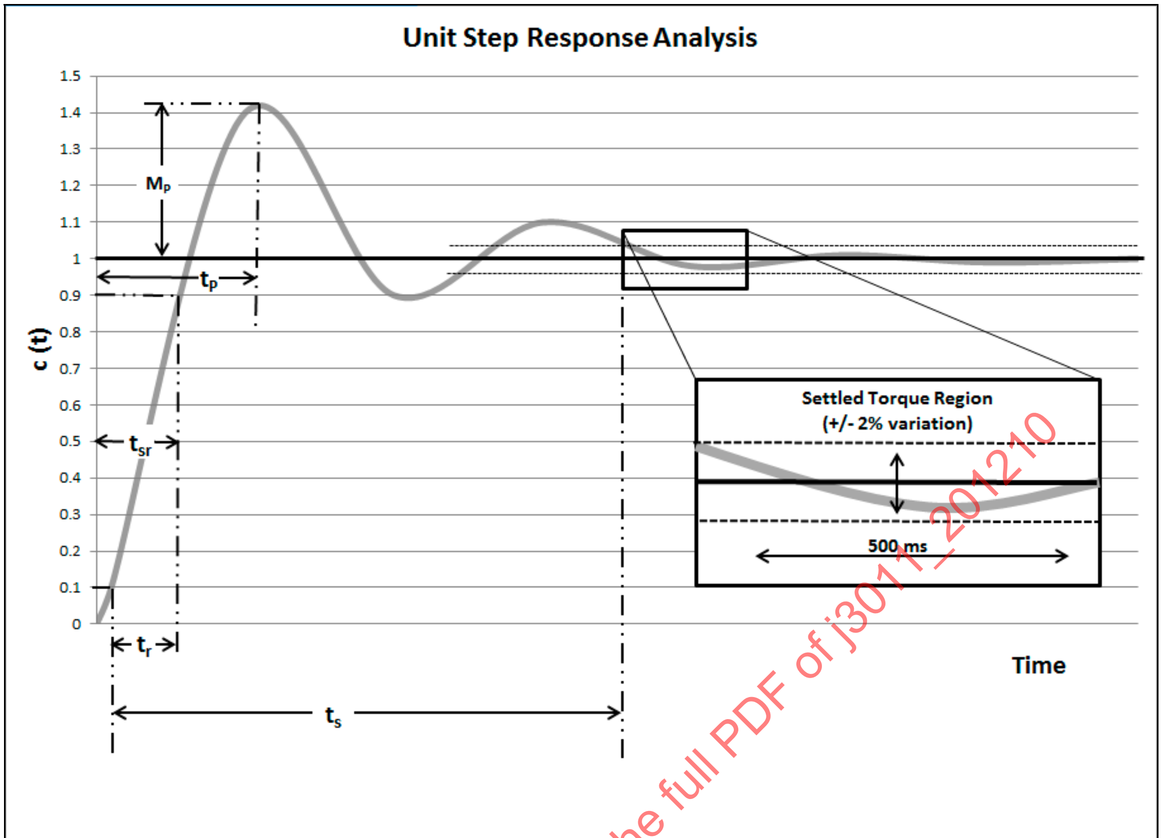

FIGURE 5

9.2.1 Step Input Data Analysis Characterization:

- Command Torque: c(t): Commanded torque expressed in terms of target torque percentage.
- Target Torque (T_t): The desired torque value commanded by the control system
- Settled Torque (T_s): Defined after the torque has settled and reached the steady state region (after t_s). Point with the greatest deviation shall be picked as the result. Note: also known as "actual torque"
- Torque Accuracy (T_a): The greatest difference between the target torque (T_t) and the (T_s) settled torque. $T_a = (T_t - T_s)/T_t$
- Peak Overshoot (M_p): Defined as the percentage difference between the peak measured torque and the settled torque value (If target torque value is not reached, then there is no peak overshoot)
- Engagement Rise Time (t_r): Defined as the time from 10% torque, to when the actual measured torque level has reached 90% of the target torque value
- System Engagement Response time (t_{sr}): Defined as time from receipt of target torque request, to when the torque level (measured) has reached 90% of the target torque value. Initial target torque value = 0 Nm
- Time to Peak Torque (t_p): Defined as the time from the digital request to when peak torque occurs

- Settling Time (t_s): Defined as the time from 10% torque to the time to reach and stay within ±2% of the settled torque for 500 ms
- Fall Time (powered): Defined as the time required from the command of 0 Nm within the settled torque region to when the torque level has reached 75 Nm
- Fall Time (loss of power): Defined as the time required from the initialization of loss of power within the settled torque region to 75 Nm. Applicable when there is a loss of power and active torque control is not possible

TABLE 1

Step Input Results Matrix

Test A = With ECU
Test B = Without ECU
Perform test series at -20, 0, 20, 50 and 100 °C
Enter reacted torques in Nm: (50 and 100 % of max torque)

NOTE: Coupling test shall be performed in two phases:
1.) As shipped
2.) Target Life

		Delta Speed, RPM						
Test	Units	5	10	20	50	100	150	200
Rise Time (tr):	sec.							
System Response time(tsr)	sec.							
Peak Overshoot (Mp)	%							
Time to Peak Torque (tp):	sec.							
Torque Accuracy:	%							
Settling Time (ts):	sec.							
Fall Time (powered)	sec.							
Fall Time (loss of power)	sec.							

10. DYNAMIC RESPONSE PROFILE

The purpose of this test is to characterize and assess the coupling system's capability to respond to a rapidly changing request signal. The data will define the system's frequency response performance.

The **Swept Sine** method facilitates the calculation of a transfer function for the AWD coupling to be used in conjunction with simulation programs by OEM's/suppliers to aid in system specification and coupling selection.

10.1 Swept Sine:

This test is related to non-homogenous vehicle surfaces such as transitioning from ice to snow to pavement. It also encompasses the interaction of the vehicle's stability system with AWD function (request for torque).

When reacting to a swept sine input coupling request function, the coupling test rig set up shall be configured as outlined in Figure 2, as described above. Due to high energy exerted during this test, thermal compensation is required to keep the results consistent. The test shall consist of calculating a transfer function of the coupling, and the reacted torque phase angle. The Transfer Function is defined by dividing the FFT of the delta torque by the FFT of the coupling request message, as shown in Equation 1.

$$TransferFunction = \frac{fft(OutputTorque)}{fft(Coupling\,\mathrm{Re}\,quest)} \qquad \text{(Eq. 1)}$$

- The test shall conform to the following system control response characteristics:
- Exponential frequency sweep from 0.2 - 5Hz
- Report data in Table 2 up to 3Hz, and graph up to 5 Hz.
- Average torque target to be 55% of rated torque capacity
- Range of torque request to be 30-80% of rated torque capacity
- Delta speeds: 5, 50 and 100 RPM.
- Operating coupling temperatures (0, 20, 100 °C.)

10.2 Parameters for Testing

The exponential frequency input parameters required to conduct the testing are listed. The swept sine coupling request function will rise according to the exponential instant frequency equation as shown below in Figure 6.

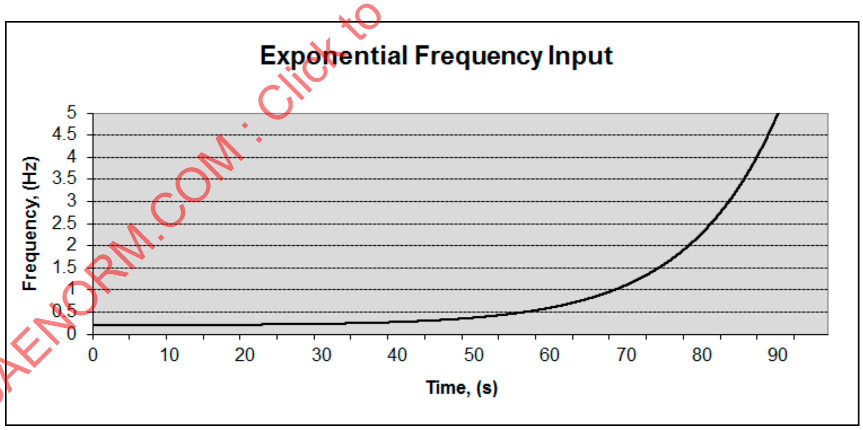

FIGURE 6

- Sampling rate: 256 Hz
- Length of test: 90 sec

- Start Frequency: 0.2 Hz
- End Frequency: 5.0 Hz
- Sweep rate: 12
- Time(x) = 1 / Sampling Rate: 90 s
- Constant, (a) = (End Freq-Start freq) / (exp (Length of test / Sweep rate))
- Inst Frequency = a*(exp(Time(x)/Sweep rate)) + Start frequency

The equations governing the coupling torque request are outlined below. Figure 7 shows the graphical representation of the requested torque.

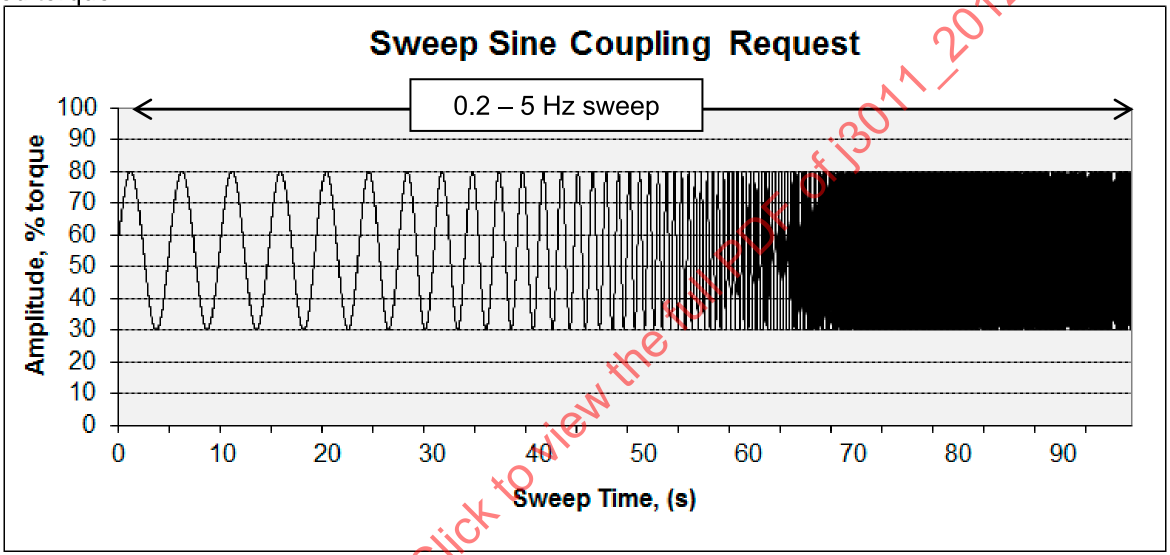

FIGURE 7

- Frequency Response f(x) = Sine Amplitude*(Sine((Time (x)*2Pi * Instant frequency)))
- Maximum sine signal: 80%
- Minimum sine signal: 30%
- Sine Amplitude = (Max sine signal - Min sine signal) / 2

The results of the test shall be reported as outlined below. The results shall be tabulated in a matrix shown in Table 2 as well as in a graphical form in Figure 8.

Please note, the data is to be run at three rotational speeds, 5, 50 and 100 rpm. The data is then entered into one graph up to 5 Hz.

TABLE 2 - TRANSFER FUNCTION RESULTS

DeltaN	Temp.	Frequency(Hz)	TF(dB)
5rpm 50rpm 100rpm	0 °C	0.2	
		2	
		3	
	20 °C	0.2	
		2	
		3	
	100 °C	0.2	
		2	
		3	

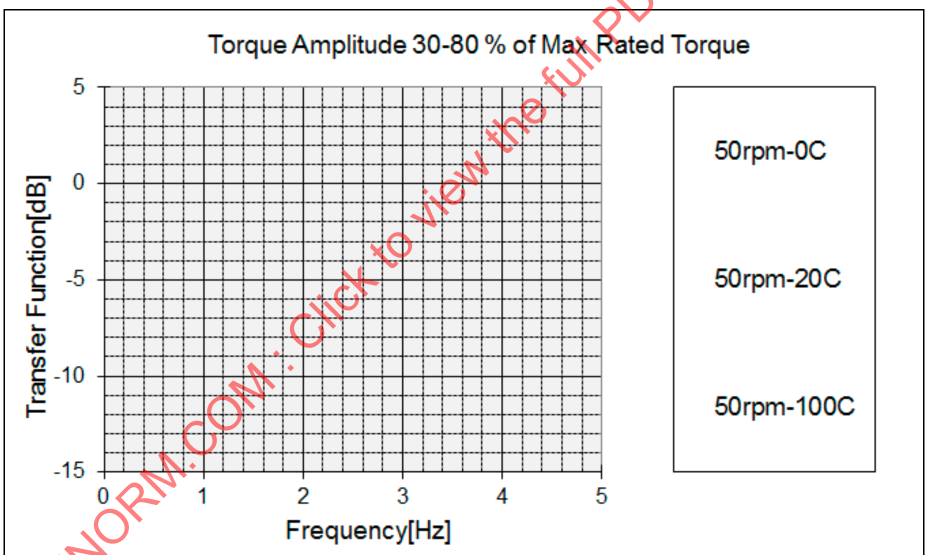

FIGURE 8

10.3 Phase Angle Measurement:

Phase angle measurement is defined by a phase shift between the commanded sinusoidal input and the reacted torque. Typically with increased frequency, the reacted torque phase angle will lag the command input. The amount of lag (measured in degrees) is the resulting measured parameter. The example is presented in Figure below.

TABLE 3 - REACTED PHASE ANGLE RESULTS

DeltaN	Temp.	Frequency(Hz)	RTPE(deg)
5rpm 50rpm 100rpm	0 °C	0.2	
		2	
		3	
	20 °C	0.2	
		2	
		3	
	100 °C	0.2	
		2	
		3	

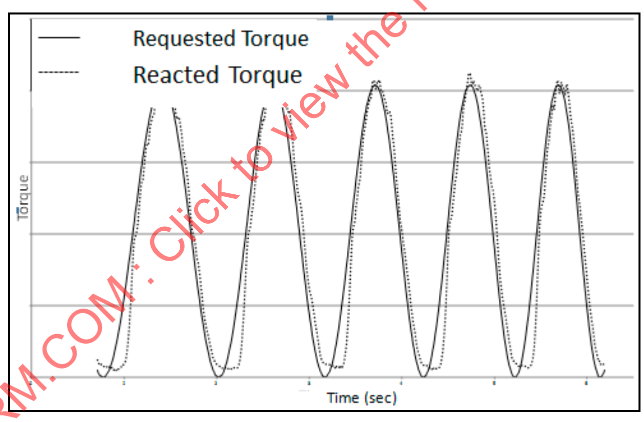

FIGURE 9

The measured data is to be tabulated in the matrix shown in Table 3 and graphed as shown in Figure .

Please note that the data is to be run at three rotational speeds, 5, 50 and 100. The data is then entered into one graph.

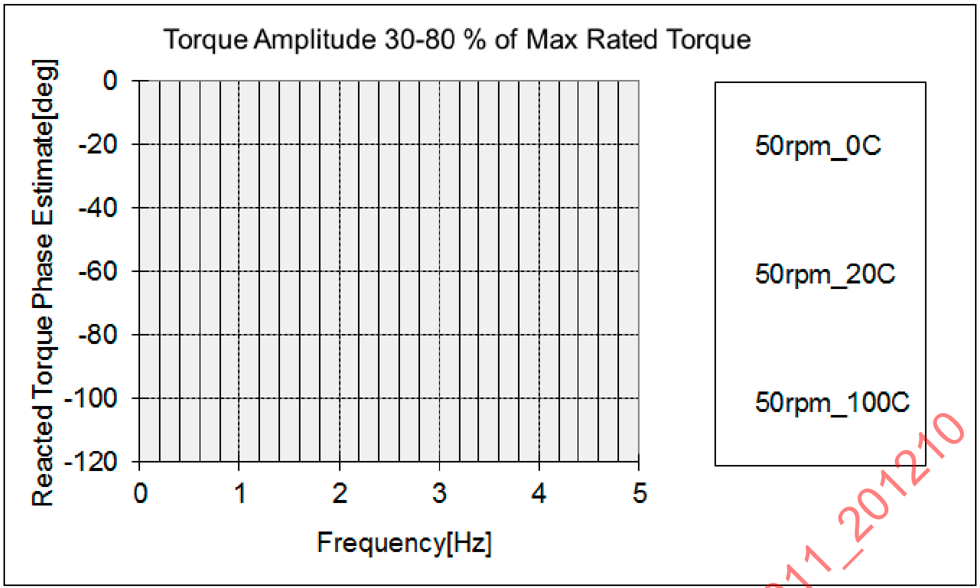

FIGURE 10

11. DRAG TORQUE BEHAVIOR

The purpose of this test is to characterize the minimum level of torque that is transmitted by the coupling during the unpowered state. This test is significant in determining the parasitic loss of the coupling which is part of the driveline. As mentioned in the Definition Section, section 4, at the beginning of the document, the supplier shall perform the test according to the type of AWD system that is under test. Depending on the type of device being tested (see definition in the test conditions for the step input test), the tested speed intervals will vary.

It is recommended to acquire the data as a 'stepped sweep' test series as shown in Figure . The stepped sweep test series is defined as a procedure whereby the dynamometer input motor is ramped to the target input speed and held for a fixed time interval.

Be sure to exclude any inertial influences during transitions between speed increments. It is recommended for the process to be automated in the test cell control system in order to minimize time between points and total time for the sweep (which can cause the unit to heat up beyond the target temperature if the sweep takes too long); such automation has also been shown to improve repeatability.

11.1 Parameters to be Monitored and Recorded:

- Coupling reacted torque.
- Coupling temperature measured according to the options outlined above. Be sure to note the location and type of temperature measurement.
- Coupling input current or voltage.

11.2 Coupling Torque Measurement Procedure:

- Test conditions:
    - Coupling Mode: Off (no power). If the coupling has a disconnect mode, ensure that the mode has been set prior to beginning the test.
    - Connected mode acceleration rate: 10 RPM / s.
    - Disconnected mode acceleration rate: 250 RPM / s.
    - Coupling start temps: -10, 0, 20, and 50 °C. (±2 °C)
    - Record the drag torque in terms of torque vs. delta speed (graph)
    - Speed should be controlled to within ± 0.5 RPM or 0.5 % from the target speed whichever is larger.
    - Delta Speeds:
        - Connected Mode: (5, 10, 25, and 50 RPM)
        - Disconnected Mode: (200, 350, 500, 1000, 1500, 2000, and 3000 RPM)
- In order to achieve repeatable results the coupling under test must be maintained at a target temperature.

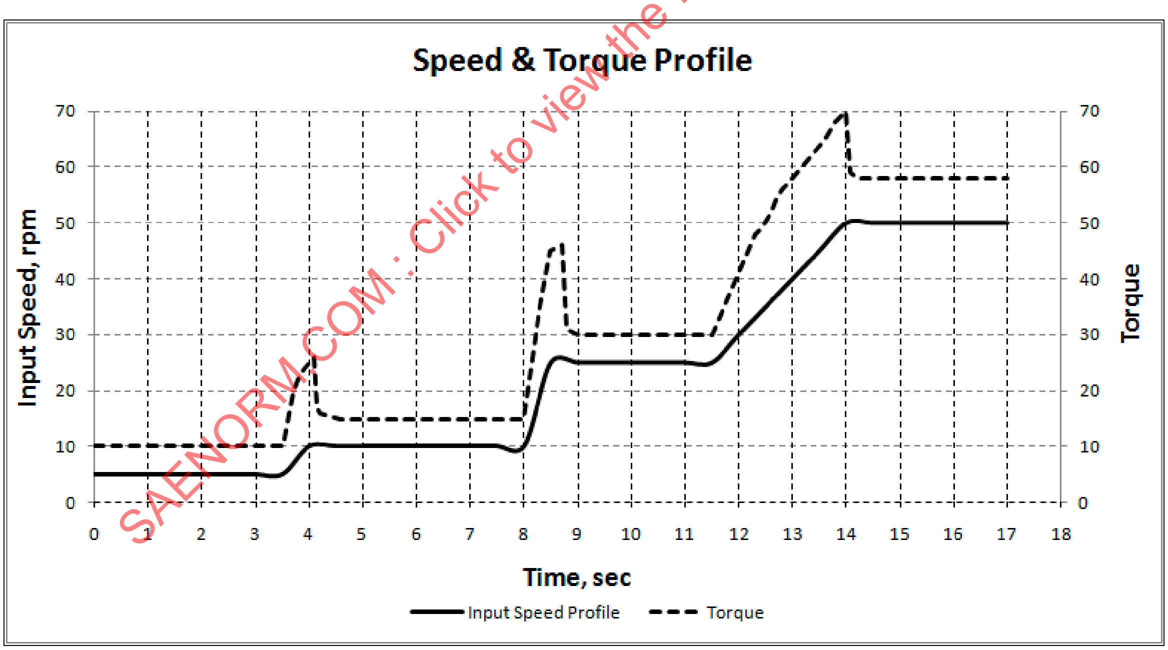

FIGURE 11

The most critical parameter to monitor during the test is the coupling temperature. Input torque must be stable and care taken to be certain the test stand controls and input electric motor inertia do not adversely influence the measurement. Ideally, all input speeds for a given run will be acquired as a continuous 'stepped sweep' test series to yield the most repeatable results.