



SURFACE VEHICLE RECOMMENDED PRACTICE

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Electric Motors for Driveline Actuation Standard
Terminology, Test Parameters, and Equipment Requirements

RATIONALE

This SAE Recommended Practice covers electric motors used for activating/modulating driveline disconnects and torque transfer devices on passenger (car and light truck) vehicles. This document provides the driveline industry with a common terminology and best practices for the most common types of electric motors, used in all-wheel drive (AWD) and four-wheel drive (4WD) vehicles where an electric motor may be used for drive line activation.

SAE J3104 has been reaffirmed to comply with the SAE Five-Year Review policy.

INTRODUCTION

The document describes the most common types of electric motors used for driveline actuation.

These devices generally consist of permanent magnet direct current (PMDC) electric motors. The motor output is rotary, although the actuator may use mechanisms to provide linear output. The actuator may often provide a mechanism for increased (multiplied) torque output or increased linear force output. PMDC motors can be of a brushed or brushless configuration. (N.B. Other types of motors such as wound field motors, stepper motors, AC induction motors, and switched reluctance motors may be used, but are not common.) As such, this specification will focus on PMDC motors.

Relays and Solenoids

In some instances, relays and solenoids may be used for actuation. These actuators are typically solenoid-type devices. A solenoid coil is energized and a moving iron-based element (armature) is drawn into the magnetic field, often against the tension of a spring. These devices are not part of the scope of this documentation.

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1. SCOPE

This document will apply to the most common applications of electric motors, used for activating all-wheel drive (AWD) and four-wheel drive (4WD) disconnect systems as used in passenger (car and light truck) vehicles. The standard will provide consistent definition, terminology, tests, and reporting methods.

2. REFERENCES

2.1 Applicable Documents

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

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 J3011 Measurement and Characterization of Electronically Controlled All-Wheel Drive/Driveline Coupling Systems

3. ACTUATOR TYPES

Electric motors provide the driving mechanism for actuators, which control the driveline to either connect or disconnect engine power from the driving wheels. As such, they will be defined as electric motor drives, which, in most cases, connect to an actuator. The actuator typically increases the torque or force output in order to move the driveline mechanism. The electric motor and actuator can be:

3.1 Defined Position Actuators

The motor moves an actuator mechanism to engage or disengage different driveline features such as 2WD, 4WD, high-, or low-drive positions. The design may be such that the motor and actuator need to hold in the engaged or disengaged positions. However, the motors generally engage different functions from one end of the cycle to the other. Often, an encoding device or position sensor is included to allow the controlling device to determine the motor position and thus ensure the stop is at the correct location. Motors for these actuators generally have short duty cycles.

3.2 Active Device Actuators (Mechanical or Hydraulic)

The motor applies a varying torque output to the actuator or hydraulic pump in order to provide a varying load to the driveline. These are often more demanding devices, as the motor may need to be powered for longer periods of time. These motors generally have longer duty cycles and often require more complex design and control configuration.

3.3 Motors with Electric Brakes

Motors may include electric brakes to provide adequate locking of the device and are often used to provide hold engagement. These components are unique items and are not part of this document.

4. ELECTRIC MOTORS DESCRIPTION

4.1 Brushed Motors

Brushed motor drives incorporate a rotating element defined as an armature. The armature consists of a series of coil windings wrapped around an iron core. The coil windings are electrically connected to a commutator which interfaces with a brush holder. The brush holder incorporates motor brushes, which contact the commutator and allow electrical current to transfer to the armature coil windings in appropriate sequence. The magnetic field is produced by the permanent magnets in the stationary part (housing) of the electric motor, defined as the stator assembly. (N.B. In a PMDC brushless motor, the permanent magnets rotate, whereas in a PMDC brushed motor, the permanent magnets remain stationary.) All brushed motors operate as synchronous motors, meaning that the electrical current through the armature winding are switched off and on and are commutated in direct relationship with the position of the permanent magnets.

Detailed explanation of motor theory and operation is beyond the scope of this standard.

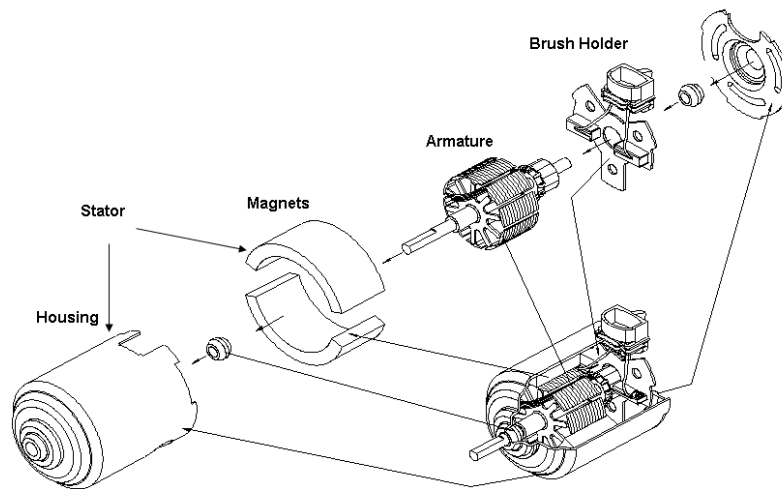


Figure 1 - Brushed motor exploded view showing armature, stator, and brush holder

4.2 Brushless Motors

PMDC brushless motor drives incorporate a rotating element defined as a rotor. In a PMDC motor, the rotor houses the permanent magnets and, as such, creates the permanent magnetic field which reacts with the stator winding field.

(N.B. In a PMDC brushless motor, the permanent magnets rotate, whereas in a PMDC brushed motor, the permanent magnets remain stationary.) The stator windings consist of a series of coils wrapped around an iron core. The stator windings are electrically switched in correct sequence to the moving magnetic field of the rotor. All brushless motors require a method(s) to define rotor position and switch coils off and on in the appropriate timing sequence. Descriptions of the different methods of sequencing used are beyond the scope of this document. Electronic switching is used to appropriately sequence or commutate electrical current to the stator winding. This is done by the electronic controller. Electronic switching is generally accomplished by an array of conventional transistors or metal oxide field effect transistors (MOSFET)s. PMDC brushless motors are synchronous motors.

Detailed explanation of motor theory and operation is beyond the scope of this document.

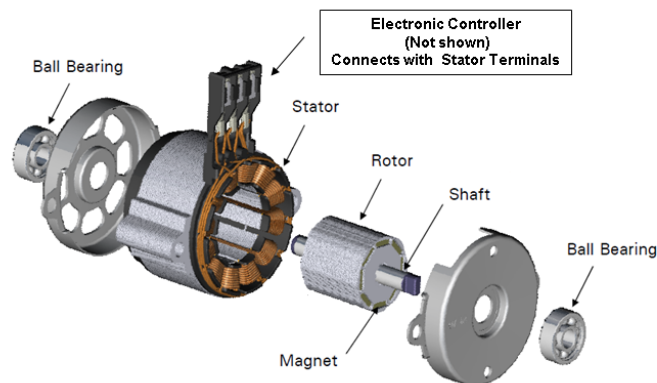


Figure 2 - Brushless motor exploded view showing stator and rotor

5. BRUSHED MOTOR TERMINOLOGY AND GUIDELINES

5.1 Ambient Temperature (Units - Celsius, °C)

The ambient temperature is the environment temperature that the motor operates within. An example of an environment temperature would be the air surrounding the actuator device. If the actuator is internal to the driveline component, then the environment could be the fluid or lubricant temperature. In most cases, the components will operate at higher temperatures than the environment due to internal heating effects.

5.2 Motor Terminal Voltage (Units - volts, V)

The motor terminal voltage is applied to the motor terminals, typically at the connector or lead interface, or as close to the motor body as possible. It is important to consider that the voltage often changes during motor operation, even though the supply voltage remains constant. Open circuit voltage will generally be higher than the motor operating voltage due to the ohmic resistance of the conductors leading from the battery (power supply) up to the motor. As such, when testing motors, it is important to define the proper method for measuring and recording motor voltage.

It is recommended that the wiring harness up to the brushed motor have a resistance of 20% or less of motor internal resistance.

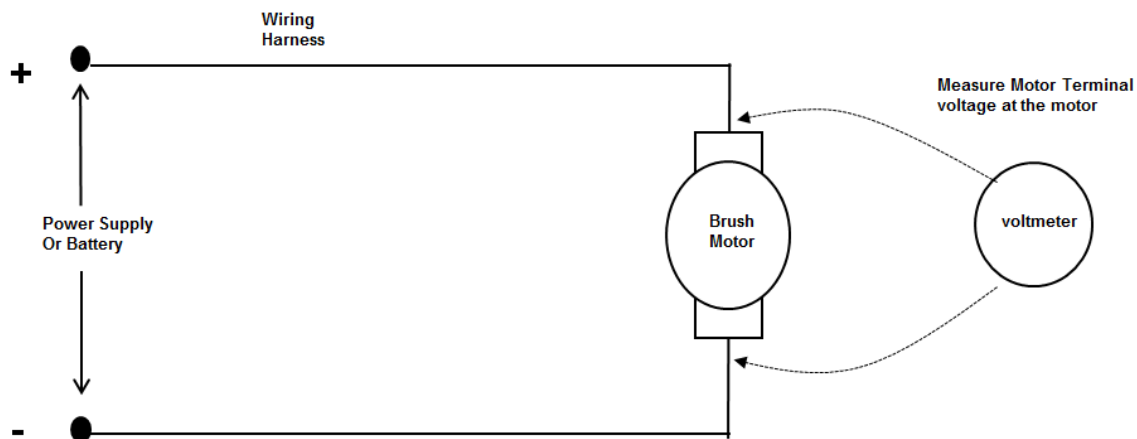


Figure 3 - Pictorial brush motor and voltmeter leads close to motor connector

5.3 Generated Voltage (BEMF) (Units - volts, V)

A motor will act as a generator and a motor at the same time while in operation. The generated voltage (back electromotive force, BEMF) is always opposite to the applied voltage, and, as such, will reduce the current through the motor. Generated voltage is directly proportional the operating speed. As the motor increases in speed, the generated voltage increases and correspondingly reduces the motor current. If the motor speed is further increased, there will be a point when the generated voltage becomes equal and opposite to the operating voltage. The two equal and opposing voltages cause the current to go to zero. This is a theoretical point only (when the generated voltage equals the operating voltage), but is used in the design of electric motors.

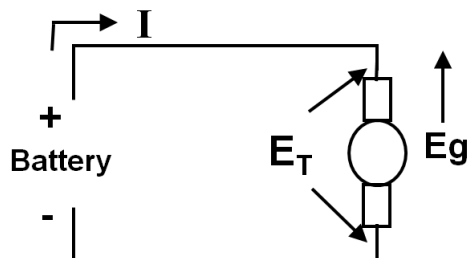


Figure 4 - Schematic showing generated voltage in opposite direction to applied voltage and current

If the motor shaft is driven externally, generated voltage can be measured and is used for establishing the motor electrical properties.

5.4 Brush Voltage Drop (Units - volts, V)

The brush voltage drop, or brush drop, is the reduction in voltage at the contact between the brush and commutator interface. Brush drop is used when considering or measuring such parameters as true no-load speed and generated voltage. In automotive 12-V DC systems, typical brush drops range from 0.5 to 1 V.

5.5 Motor Internal Resistance (Units - ohms, Ω)

The motor internal resistance (measured in ohms) consists of the sum of the internal resistances of the motor electrical connections, brushes, and armature. It is often difficult to get a direct reading from an ohmmeter across the motor terminals, as the brush-to-commutator resistance varies significantly. As such, it is obtained by measuring the components individually, or it is taken by dividing the input voltage by stall current as taken from the dynamometer test. (Typical resistances for drive train actuators can range from 80 to 500 m Ω .)

$$\text{Motor Internal Resistance} = \text{Motor Terminal Voltage} / \text{Stall Current}$$

5.6 Stall (Starting) Current (Units - amperes, A)

The stall current in a brushed motor is defined as the steady-state current that flows through the motor under a locked rotor condition when motor terminal voltage is available and the current rise time has been overcome. At this point, the motor is not developing any generated voltage (BEMF). See Generated Voltage (BEMF).

Often the stall current is referred to as starting current of a brushed motor (it is higher than operating current).

5.7 Operating Current (Current at Commanded Conditions) (Units - amperes, A)

As current is directly proportional to the torque in a motor, the current will vary depending on the motor torque requirement. There is generally a desired or commanded torque, and, as such, there will be a defined operating or commanded current. The command or operating current is often specified by the driveline system developer and is provided to the motor supplier in order to allow them to suitably size the motor.

5.8 No-Load Current (Units - amperes, A)

The no-load current is the current that the motor draws when the external torque load on the rotor is zero and the motor is only overcoming its own internal losses. See Internal Loss Torque.

5.9 Operating Speed (Speed at Commanded Conditions) (Units - revolutions per minute, rpm)

There is generally a desired or commanded speed which corresponds to the operating torque. The command or operating speed is often specified by the driveline system developer and is provided to the motor supplier in order to allow them to suitably size the motor.

5.10 No-Load Speed (Units - revolutions per minute, rpm)

The no-load speed is the speed at which the motor operates at if the torque load at the motor output shaft is reduced to zero at the motor shaft and the full line voltage is present at the motor terminals. The no-load speed of the motor is one of the parameters used by the motor designers to suitably size the motor.

5.11 True No-Load Speed (Units - revolutions per minute, rpm)

The true no-load speed is a speed at which a motor would operate at for a given terminal voltage if all internal motor losses are reduced to zero. True no-load speed is a hypothetical or theoretical point, but is used by motor designers for setting design parameters. Theoretically, at true no-load speed, the generated voltage is equal and opposite to the terminal voltage. However, in practice, at true no-load speed, the generated voltage is slightly less, due to the brush drop.

Theoretically, at true no-load speed:

$$\text{Generated Voltage} = \text{Terminal Voltage (equal magnitude but opposite direction)}$$