SURFACE VEHICLE RECOMMENDED PRACTICE	J3053	JUL2015
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Heavy Duty Truck and Bus Electrical Circuit Performance Requirement for 12/24 Volt Electric Starter Motors

RATIONALE

This document is intended to give the industry a design standard to define the design of the electrical circuits used in conjunction with 12/24 volt electric starting motors. The document will include all elements of the Electric Starter system main cranking and control circuits.

1. SCOPE

The scope of this SAE Recommended Practice is to describe a design standard to define the maximum recommended voltage drop for starting motor main circuits as well as control system circuits for 12V through 24V starter systems.

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 publications 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.

SAEJ544 Electric Starting Motor Test Procedure

2.1.2 ISO Publications

Available from International Organization for Standardization, ISO Central Secretariat, 1, ch. de la Voie-Creuse, CP 56, CH-1211 Geneva 20, Switzerland, Tel: +41 22 749 01 11, www.iso.org.

ISO 8856 Amendment 1 Road Vehicles-Electrical Performance of Starter Motors-Test Methods and General Requirements

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3. DESCRIPTION

The electrical cranking system components in a heavy duty truck and bus include batteries, cabling, master disconnects, switches, control switches, relays, terminations and cranking motor. The starting system shall be designed in a fashion to provide the necessary engine RPM to start an engine under the most severe climatic conditions for which the system is intended. This SAE Recommended Practice is focused on the starter motor electrical circuit and its corresponding circuit components (Shown in Figure 6 - Diagram of Crank Circuit Main Cables), but engine cranking has many other variables as shown in Figure 1 that will also influence engine cranking and starting performance.

Engine manufactures may have minimum electrical system design guidelines defined to meet their engine starting requirements. These engine manufacture guidelines shall be considered by the truck and bus OE when designing the electrical crank system.

Truck and bus OE's may also incorporate a holistic electrical cranking system design. For example, by reviewing the minimum operating temperature, minimum required engine cranking speed, circuit components, starting aids, and recommended oil type, the OEM may choose to deviate from recommended circuit voltage drops:

- Battery Internal Resistance (Rbatt) may be reduced by applying a battery pack with a lower internal resistance, or by using ultracapacitors, or other alternative power sources (reference Fig. 6)
- A starting aid such as a block heater may allow the engine to crank at an internal temperature that greatly exceeds cold climate ambient.
- Temperature aids such as an air preheater and low viscosity oil may be used.

If a truck or bus OE electrical cranking system design deviates from the defined component VD's found in table shown in Figure 7, explicit service literature shall be provided by the truck or bus OE defining the proper electrical crank system test procedure and a list of any specialized components such as specific battery chemistry.

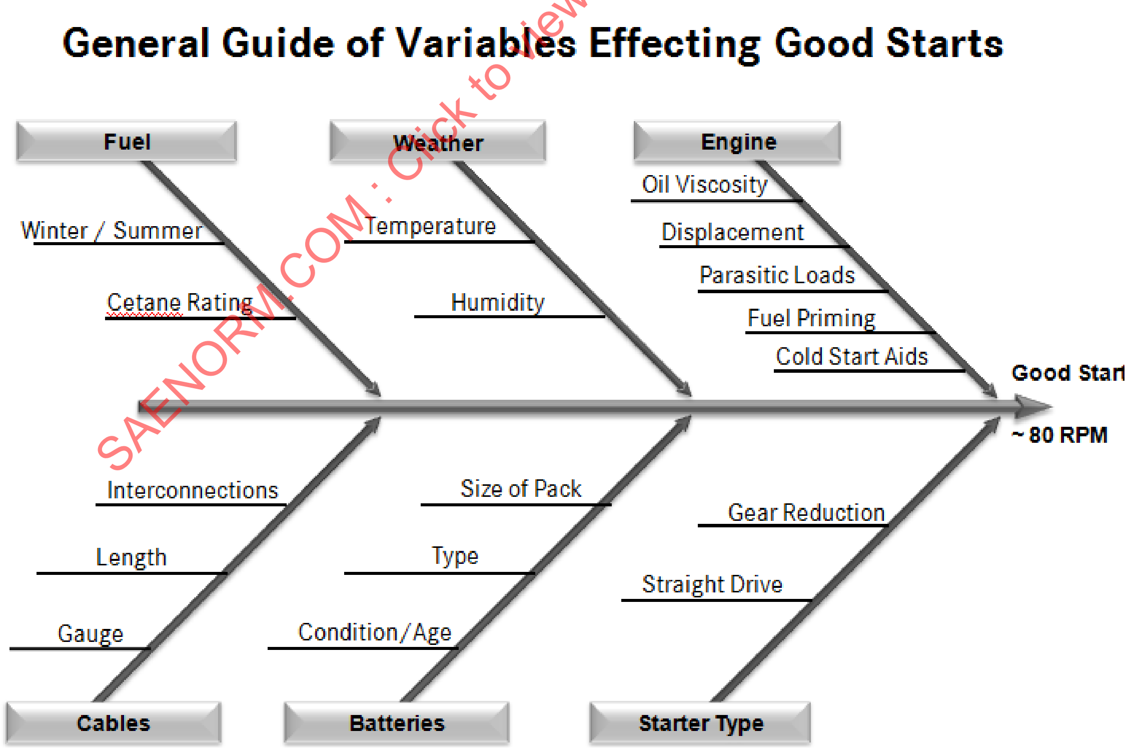

Figure 1 - Fishbone diagram

4. COMPONENT – STARTER MOTOR – STRAIGHT DRIVE VS. GEAR REDUCTION & STARTER EFFICIENCY

- **Torque per Amp** - The gear reduction starters have the advantage of producing more torque for a given amount of current (see Figure 2- Chart of Torque vs. Current). So in this regard, gear reduction is "more efficient".

- **Efficiency** - True efficiency is defined as Power Out /Power In. Gear reduction starters are more efficient than straight drive starters in the desired working range of the starter (see Figure 3 - Chart of Efficiency vs. Cranking speed)

- **Speed vs. Voltage** - For a given steady state current, **speed is proportional to voltage**. Both straight drive and gear reduction motors are affected nearly equally in this regard. As shown in Figure 4 – Chart of Engine RPM vs. Starter Voltage, the slope is basically the same for straight drive and gear reduction.

Figures 2 thru 4 were created from starter performance test data. The test method used to generate this data conforms to SAE J544 and ISO 8856. (All data shown is relative to a 12 V Electrical System)

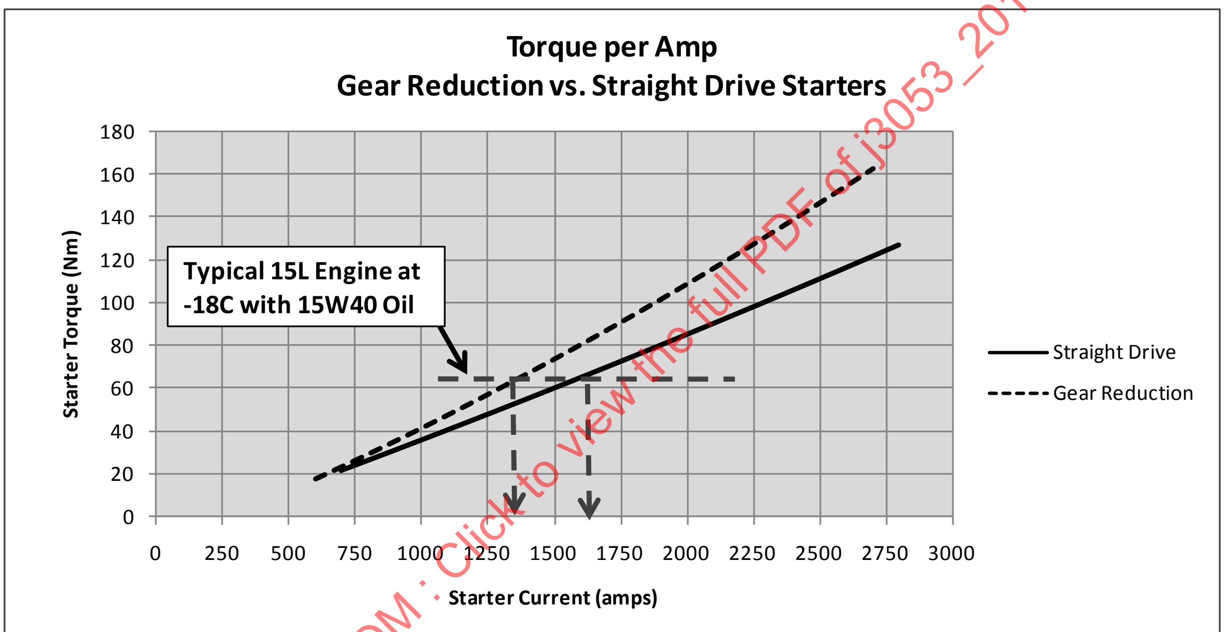

Figure 2 - Chart of Starter Torque vs. Current

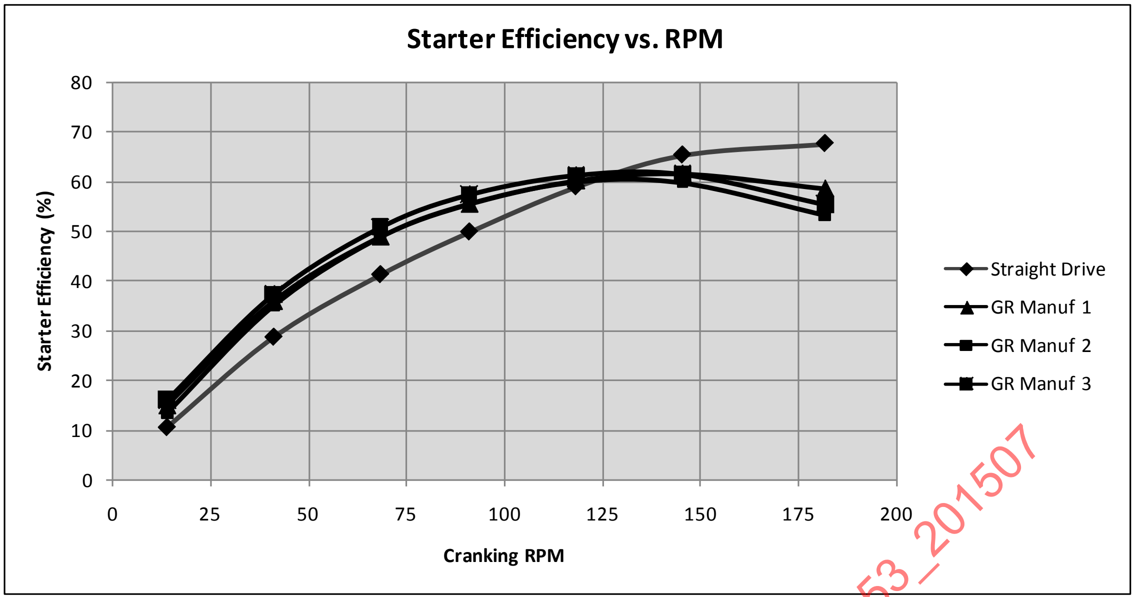

Figure 3 - Chart of Starter Efficiency vs. Cranking RPM

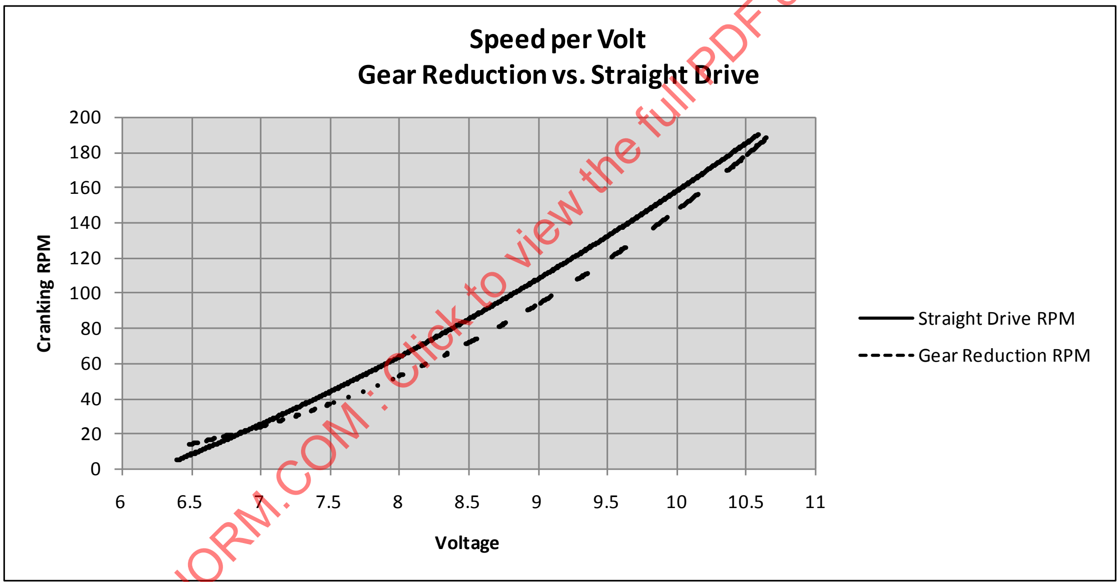

Figure 4 - Chart of Cranking Speed vs. Voltage

5. COLD CRANKING – ENGINE RPM /VOLTAGE / CURRENT

The bar charts in Figure 5 below are based on actual data from a cold crank test of a 13L engine with 15W40 oil at -18^{o}C fitted with a gear reduction starter motor. The crank data is based on 20 second continuous crank events. Fuel was disabled to prevent engine starting. Four different lead-acid battery packs were tested and all were conditioned to 70% state of charge. Since temperature and oil weight were held constant for all tests, the cranking torque demanded by the engine was also constant for each test. This cold crank data clearly demonstrates that:

A. Cranking speed is proportional to voltage..- voltage is relative to battery chemistry (battery internal resistance, Rbatt), but not necessarily a direct correlation to Cold Cranking Amps (CCA). As battery internal resistance increases, starter RPM will decrease as a result of lower available voltage at the starter.

B. Current is proportional to torque - required cranking torque was constant for each test, therefore current remained constant despite the different battery packs and resulting voltages during cranking.

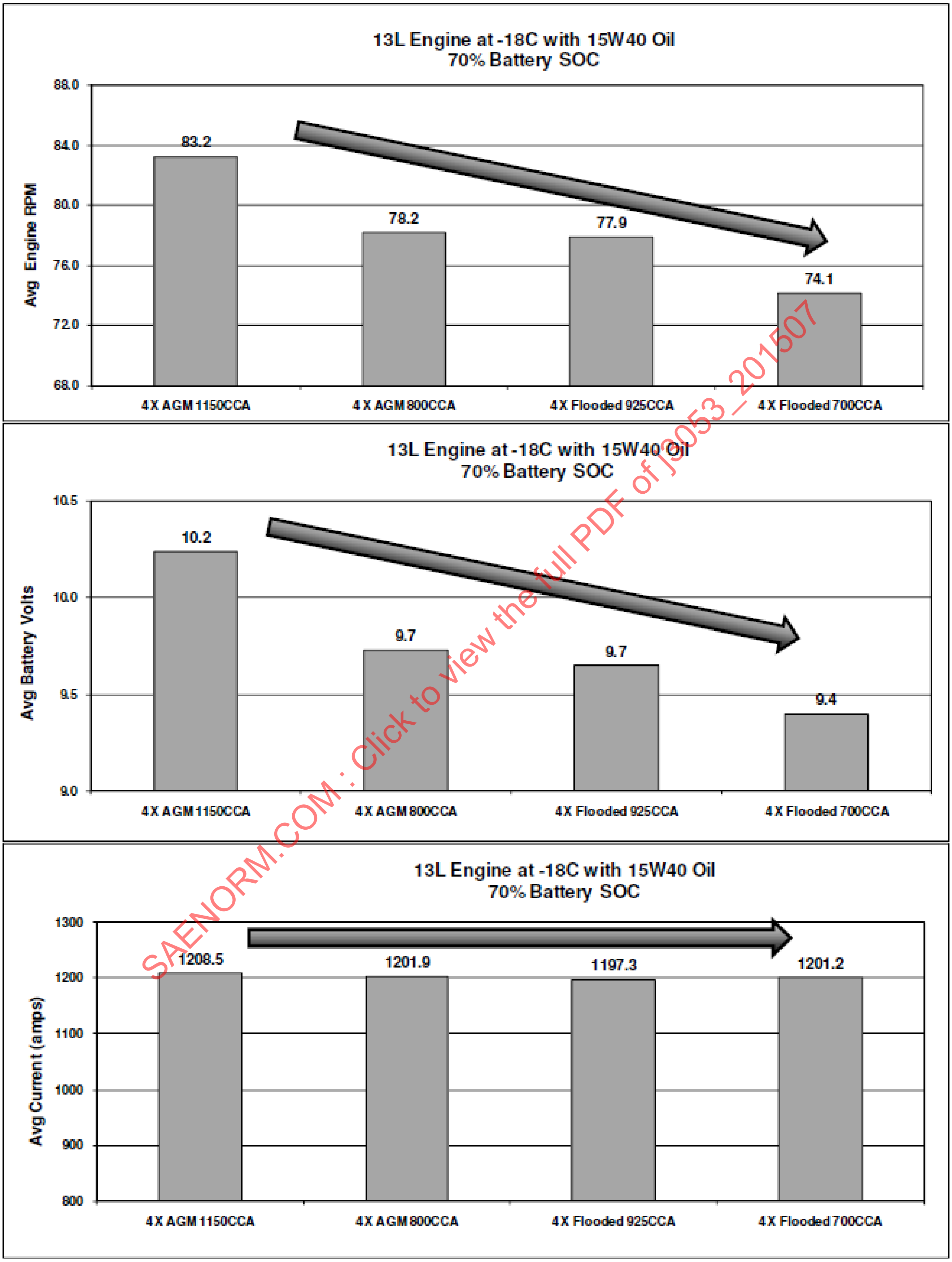

Figure 5 - Charts of cold crank data

6. STARTER ELECTRICAL CIRCUIT – MAIN CRANKING CIRCUIT

The main cranking circuit consists of the positive and negative cables, master disconnect switch and all circuit terminations (Figure 6 - Crank Circuit Diagram, Main Cables).

- Voltage drop measurement shall be performed by applying the highest reasonable current load to the circuit to minimize the signal to noise ratio. Measurements should be performed quickly to minimize changes in circuit resistance due to $I^2 \times R$ heating affects. 120 amps is the minimum recommended load to be applied for measurement purposes. Figure 7 provides recommended values for VDROP/120AMPS, VDROP/500AMPS, as well as the equivalent resistance in Ohms.

- The starting motor circuits in motor vehicles shall be designed so that the difference between the voltage at the battery terminals and the starting motor terminals (including connections and disconnect switch) shall not exceed those values shown in Figure 7 - Table of Main Cranking Circuit Recommended Maximum Voltage Drop. The voltage drop values are defined with a normal circuit temperature of 20 °C (68 °F).

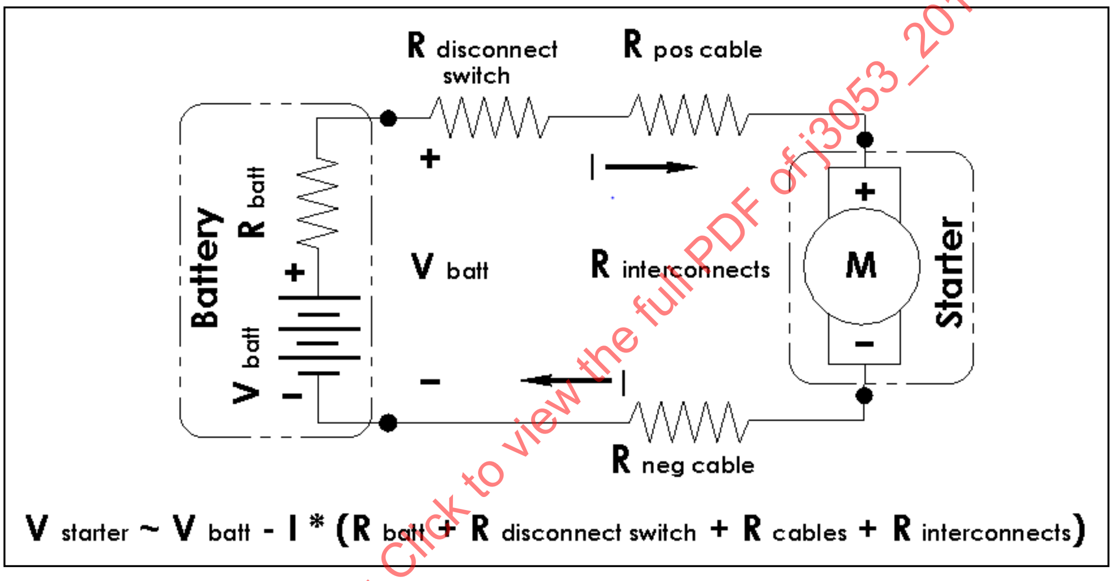

Figure 6 - Crank circuit diagram, main cables

Main Cranking Circuit Recommended Maximum Voltage Drop						
System Voltage	***Use***	***Total Circuit Resistance***	***V-drop/500 amps***	***V-drop/120 amps***	***Starter Output Range***	***Max Engine Displacement***
12 volt	Light Duty	0.003- 0.004Ω	---------	0.36 -0.48V	0.9kw - 2.5kw	8 liter gas 3.5 liter diesel
12 volt	Light / Medium Duty (LHDD)	0.002Ω	1.0V	0.24V	2.2kw - 3.3kw	6 liter
12 volt	Medium Duty (MHDD)	0.0012Ω	0.6V	0.14V	2.7kw – 6.8kw	9 liter
24 volt	Medium Duty (MHDD)	0.002Ω	1.0V	0.24V	4.5kw -7.3kw	13 liter
12 volt	Heavy Duty (HHDD)	0.001Ω	0.5V	0.12V	6.8kw - 8.5kw	16 liter
24 volt	Heavy Duty (HHDD)	0.002Ω	1.0V	0.24V	7.0kw - 13kw	30 liter

Figure 7 - Table of main cranking circuit recommended maximum voltage drop all exceptions to this requirement shall be defined as described in section 3.

6.1 Starter Electrical Circuit - Control Circuit

Starter solenoid current draw varies widely based on the type of starter engagement system. Robust control circuit design is critical to the starter engagement reliability and solenoid life. Although still important, the control circuit design for starters equipped with IMS (Integrated Magnetic Switch) is less sensitive to voltage drop based on the relatively low current draw of the IMS coil (~ 2 to 4 amps). For starters without IMS, the control circuit consists of the wiring from the battery power source to the magnetic switch, the magnetic switch contacts, and the wiring from the magnetic switch to the starter solenoid (see Figures 8 & 9 - Control Circuit Diagrams, with and without IMS). Vehicles with electronically managed starter controls shall consider protection for inductive voltage spikes resulting from de-energizing the starter solenoid. Likewise, the system design should ensure that (if) a control relay exist on the starter, that suppression is present on the coil of the relay which will ensure ample protection exist at the source where such inductive voltage spikes would be generated.

- Voltage drop measurement shall be performed by applying a current load suitable to the operating current level of the starter solenoid or IMS during the initial engagement phase.

- Magnetic switch shall be energized to perform total circuit voltage drop measurement. (Disconnect circuit from starter motor prior to performing measurement.)

- Measurements should be performed quickly to minimize changes in circuit resistance due to I^2 X R heating affects. Figure 10 describes several different engagement system types and provides recommended values for VDROP/100AMPS, as well as the equivalent resistance in Ω.

- The starting motor control circuits in motor vehicles shall be designed so that the difference between the voltage at the battery terminals and the starting motor control circuit terminals (including connections) shall not exceed those values shown in Figure 10 - Table of Recommended Control Circuit Voltage Drops. The voltage drop values are defined with a normal circuit temperature of 20 °C (68 °F).

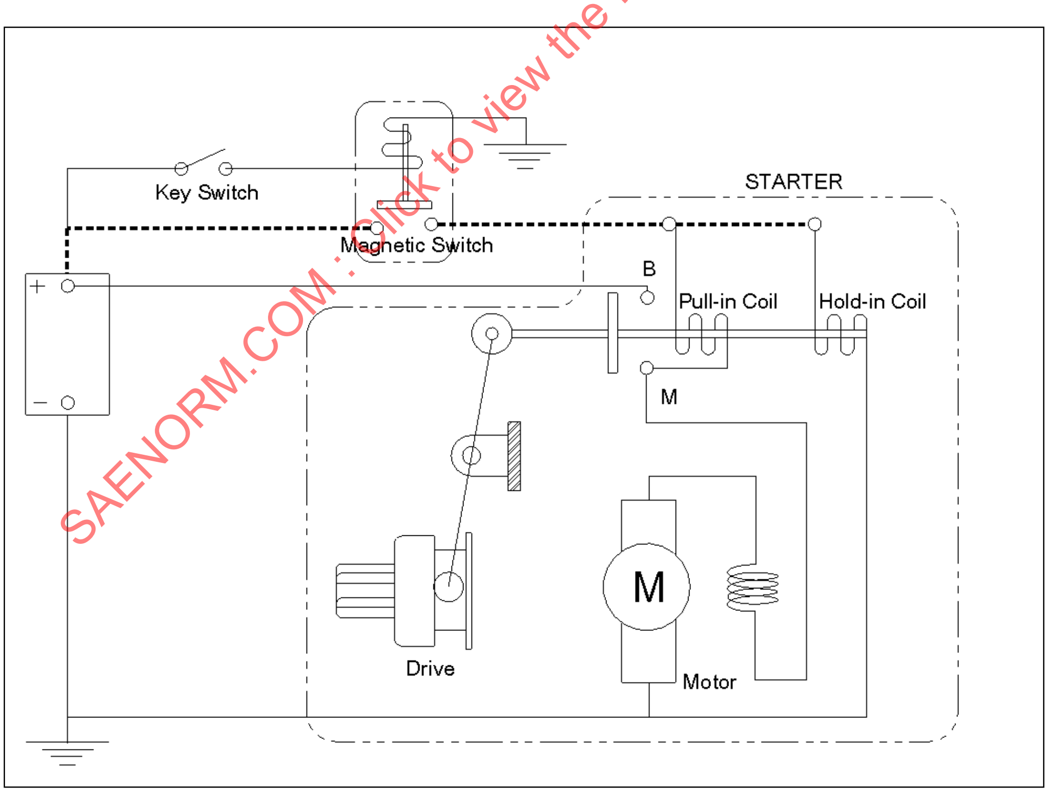

Figure 8 - Control circuit diagram, without IMS (Integrated Magnetic Switch)