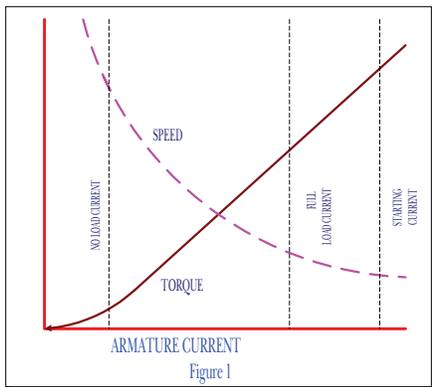


Section 1. INTRODUCTION

Section 1.1 Motor Characteristics

The level of sophistication in the controllability of traction motors has changed greatly over the past several years. Vehicle manufacturers and users are continuing to expect more value and flexibility in electric vehicle motor and control systems as they are applied today. In order to respond to these market demands, traction system designers have been forced to develop new approaches to reduce cost and improve functions and features of the overall system. Development is being done in a multi-generational format that allows the market to take advantage of today's technology, while looking forward to new advances on the horizon. GE has introduced a second generation system using separately excited DC shunt wound motors. The separately excited DC motor system offers many of the features that are generally found on the advanced AC systems. Historically, most electric vehicles have relied on series motor designs because of their ability to produce very high levels of torque at low speeds. But, as the demand for high efficiency systems increases, i.e., systems that are more closely applied to customers' specific torque requirements, shunt motors are now often being considered over series motors. In most applications, by independently controlling the field and armature currents in the separately excited motor, the best attributes of both the series and the shunt wound motors can be combined.

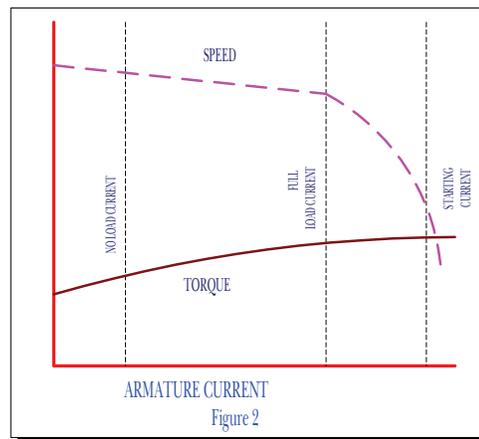


As shown in the typical performance curves of Figure 1, the high torque at low speed characteristic of the series motor is evident.

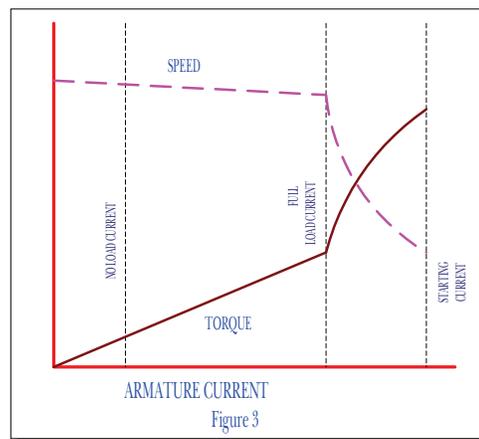
In a shunt motor, the field is connected directly across the voltage source and is therefore independent of variations in load and armature current. If field strength is held constant, the torque developed will vary directly with the armature current. If the mechanical load on the motor increases, the motor slows down, reducing the back EMF (which depends on the speed, as well as the constant field strength). The reduced back EMF allows the armature current to increase,

providing the greater torque needed to drive the increased mechanical load. If the mechanical load is decreased, the process reverses. The motor speed and the back EMF increase, while the armature current and the torque developed decrease. Thus, whenever the load changes, the speed changes also, until the motor is again in electrical balance.

In a shunt motor, the variation of speed from no load to normal full load on level ground is less than 10%. For this reason, shunt motors are considered to be constant speed motors (Figure 2).



In the separately excited motor, the motor is operated as a fixed field shunt motor in the normal running range. However, when additional torque is required, for example, to climb non-level terrain, such as ramps and the like, the field current is increased to provide the higher level of torque. In most cases, the armature to field ampere turn ratio can be very similar to that of a comparable size series motor (Figure 3.)



Aside from the constant horsepower characteristics described above, there are many other features that provide increased performance and lower cost. The

following description provides a brief introduction to some of these features.

Section 1. 2 Solid-State Reversing

The direction of armature rotation on a shunt motor is determined by the direction in which current flows through the field windings. Because of the shunt motor field, typically only requires about 10% of the armature current at full torque, it is normally cost effective to replace the double-pole, double-throw reversing contactor with a low power transistor H-Bridge circuit (Figure 4).

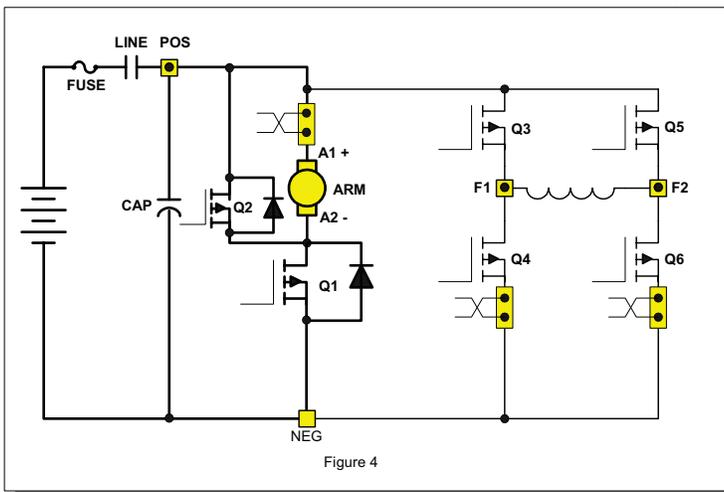


Figure 4

By energizing the transistors in pairs, current can be made to flow in either direction in the field. The field and armature control circuits typically operate at 12KHZ to 15KHZ, a frequency range normally above human hearing. This high frequency, coupled with the elimination of directional contactors, provides for very quiet vehicle operation.

The line contactor is normally the only contactor required for the shunt motor traction circuit. This contactor is used for both pre-charge of the line capacitors and for emergency shut down of the motor circuit, in case of problems that would cause a full motor torque condition. The line can be energized and de-energized by the various logic combinations of the vehicle, i.e. activate on key, seat or start switch closure, and de-energize on time out of idle vehicle. Again, these options add to the quiet operation of the vehicle.

Section 1. 3 Flexible System Application

Because the shunt motor controller has the ability to control both the armature and field circuits independently, the system can normally be adjusted for maximum system efficiencies at certain operating parameters. Generally speaking, with the ability to independently control the field

and armature, the motor performance curve can be maximized through proper control application.

Section 1. 4 More Features with Fewer Components

Field weakening with a series wound motor is accomplished by placing a resistor in parallel with the field winding of the motor. Bypassing some of the current flowing in the field into the resistor causes the field current to be less, or weakened. With the field weakened, the motor speed will increase, giving the effect of "overdrive". To change the "overdrive speed", it is necessary to change the resistor value. In a separately excited motor, independent control of the field current provides for infinite adjustments of "overdrive" levels, between the motor base speed and maximum weak field. The desirability of this feature is enhanced by the elimination of the contactor and resistor required for field weakening with a series motor.

With a separately excited motor, overhauling speed limit, or downhill speed, will also be more constant. By its nature, the shunt motor will try to maintain a constant speed downhill. This characteristic can be enhanced by increasing the field strength with the control. Overhauling load control works in just the opposite way of field weakening, as armature rotation slows with the increase of current in the field. An extension of this feature is a zero-speed detect feature

which prevents the vehicle from free-wheeling down an incline, should the operator neglect to set the brake.

Regenerative braking (braking energy returned to the battery) may be accomplished completely with solid-state technology. The main advantage of regenerative braking is increased motor life. Motor current is reduced by 50% or better during braking while maintaining the same braking torque as electrical braking with a diode clamp around the armature. The lower current translates into longer brush life and reduced motor heating. Solid state regenerative braking also eliminates a power diode, current sensor and contactor from the circuit.

For GE, the future is now, as we make available a new generation of electric traction motor systems for electric vehicles having separately excited DC shunt motors and controls. Features that were once thought to be only available on future AC or brushless DC technology vehicles systems are now achievable and affordable.

Section 2. FEATURES OF SX FAMILY OF TRANSISTOR MOTOR CONTROLLERS

Section 2.1 Performance

Section 2.1.1 Oscillator Card Features