AN EFFICIENT DRIVE CIRCUIT FOR SWITCHED RELUCTANCE MOTOR

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Abstract The purpose of this paper is to present an efficient converter circuit used to drive switched reluctance motors. It uses the C-dump topology in which the trapped energy in the phase windings is returned to the supply capacitor to be used in the following strokes. In addition to the C-dump topology, it uses two extra feedbacks. One comes from a governor mounted on the shaft of motor which controls the proper advancement of the firing time for each power transistor in different speeds, and the other, gets pulses from the shaft sensors in order to keep the motor speed constant under different loads. A Spice simulation has been performed on the drive circuit to see the current waveforms under different firing time advancements. Finally the test results of the converter circuit driving an isolated phase reluctance motor are presented.

Key Words Switched Reluctance Motor Drive and Converter Drive for Reluctance Motor, SRM Drive Circuit

چکیده این مقاله، یک راه انداز موتور رلوکتانس با ساخت C-dump را با استفاده از دو فیدبک مختلف برای بالا بردن سرعت و بهتر نمودن راندمان موتور معرفی می کند. نامگذاری برای این مبدل ها از آنجا صورت گرفته که انرژی ذخیره شده در هرفاز در خازنی انباشته می گردد و در حرکت بعدی موتور در روی فازهای دیگر از آن استفاده می شود. برای بالا بردن سرعت موتور و همچنین راندمان بهتر بایستی که در سرعت های مختلف شروع پالس گیت ترانزیستورهای قدرت هر فاز کمی زودتر اعمال گردد تا جریان، زمان لازم را برای افزایش داشته باشد، لذا یک فیدبک، فرمان خود را از روی فرمانه (Governor) نصب شده بر روی شفت موتور برای انجام این عمل می گیرد. فیدبک دیگر، فرمان خود را از سنسورهای نصب شده برروی شفت موتور برای ثابت نگه داشتن سرعت موتور در زیر بارهای مختلف می گیرد. با استفاده از نرم افزار Pspice افزایش جریان در این نوع موتور برای زمان های مختلف پالس گیت شبیه سازی شده است. بالاخره مدار راه انداز فوق بر روی یک موتور رلوکتانس با فازهای ایزوله تست شده است.

INTRODUCTION

The widespread interest in the switched reluctance motors in the recent years increases the need for more efficient drive circuit for the motor [1-2]. The essential features of the power switching circuit for each phase of reluctance motor comprises two parts:

1. A controlled switch to connect the voltage source to the coil windings to build up the current.

2. An alternative path for the current to flow when the switch is turned off, since the trapped energy in the phase winding can be used in the other strokes. It also protects the switch from the high current produced by the energy trapped in the phase winding.

Figure 1 shows a simple form of switching circuit for a switched reluctance motor [3-4].

The general equation governing the flow of stator current can be wrirtten for Figure 1 as:

$$V = Ri + \frac{d\lambda}{dt} \tag{1}$$

where, V is the voltage applied across the winding and λ is the flux linking the coil.

Considering a linear magnetic circuit and negligible resistance, Equation 1 can be rewritten as:

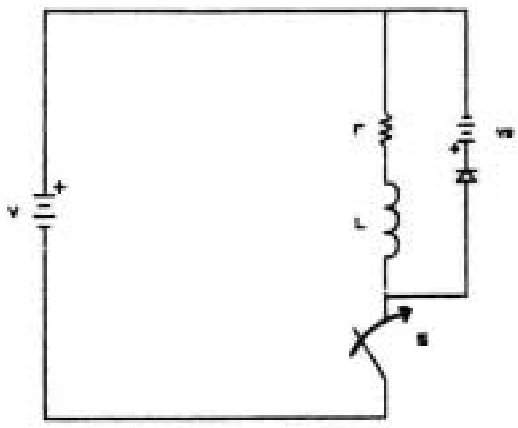

Figure 1. A simple switching circuit.

$$V = L\frac{di}{dt} + i\frac{dL}{d\theta}\frac{d\theta}{dt} \qquad (2)$$

therefore, the rate of energy flow is given by:

$$vi = \frac{d}{dt}\left(\frac{1}{2}Li^2\right) + \frac{i^2}{2}\frac{dL}{d\theta}\omega \qquad (3)$$

Equation 3 indicates that for a reluctance motor the input electrical power goes partly to increase the stored mangetic energy ($1/2Li^2$) and partly to provide mecanical output power ($i^2/2\ dL/d\theta\omega$).

REVIEW OF DRIVE CIRCUITS

Some of the proposed practical drive circuits for reluctance motor are: a two switch per pole circuit in which for each phase one transistor is used to control the amount of current through the winding, while the other transistor synchronizes the operation of that phase with the rotor position by the utilizing a sensor [5-7].

In N+1 transistors converter circuit for N-phase motor, only one transistor is common to all phases for the control of current [8-9].

In Bifilar winding converter configuration the number of switches and diodes per phase is reduced by introducing a Bifilar winding for each stator pole [10].

In the C-dump topologies, the energy stored in the winding is dumped on the capacitor and used again in the next stroke [11]. Finally, in regenerative single switch per phase converter the source voltage is connected to the phase winding by switching two transistors. When these transistors are off, the energy stored in the phase winding is released to a capacitor and used in the next stroke [12-13].

THE DRIVE CIRCUIT

In order to produce torque at all rotor positions, the entire 360 degrees must be covered by segments of the rising inductance from different phases as shown in Figure 2a, and currents must be commutated and sequenced to coincide with appropriate segments as shown in Figure 2b.

The practical phase current waveform at low and high speeds, controlled by chopping or PWM are shown in Figure 3a and 3b, respectively.

As seen in Figure 3b, the lower solid curve is at higher speed than the upper solid curve, because the current at high speed can not build up quickly, hence

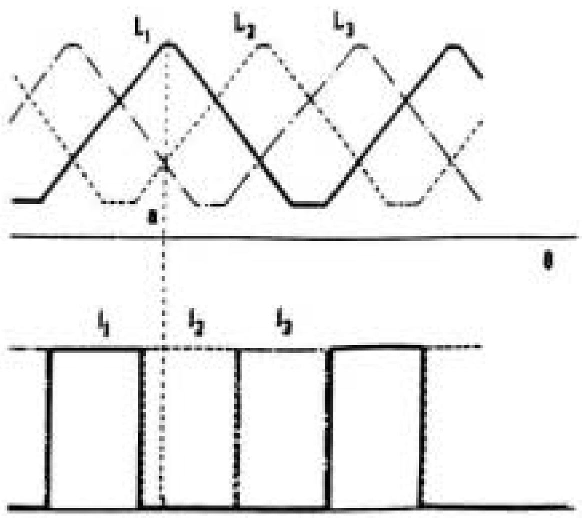

Figure 2. a) Inductance profiles of three phases. **b)** Ideal current waveform of three phases.

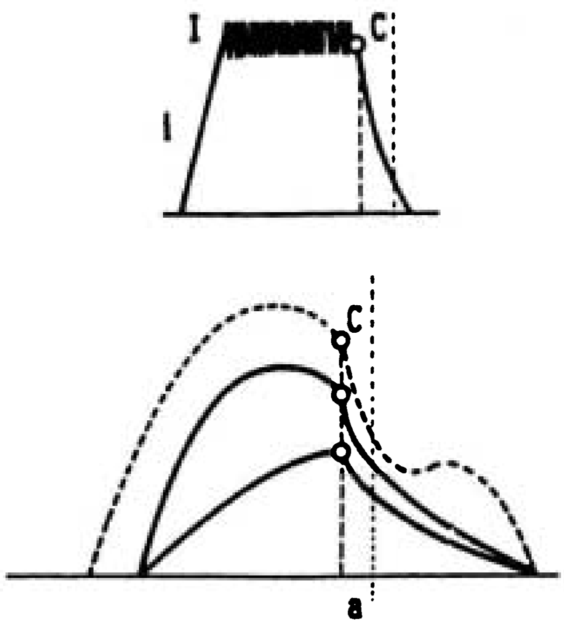

Figure 3. a) Practical phase-current waveform at low speed. **b)** Practical phase-current waveforms at high speed.

the current magnitude is much lower and the torque produced falls off at high speed. If it were possible to advance the turn on angle, the current waveform would be as shown in Figure 3b by the dotted curve which shown higher current magnitude hence, higher torque produced. In order to change the conduction angle just enough for different speeds, a governor is mounted on the shaft of the motor. The opening of the goernor arms is directly proportional to the speed of the motor which controls the positioning of the shaft decoder with respect to the shaft sensors. As the speed goes up so does the advancement of the shaft decorder. A picture of the governor is shown in Figure 4.

In order to keep the speed constant as much as possible for different loads, another feedback control

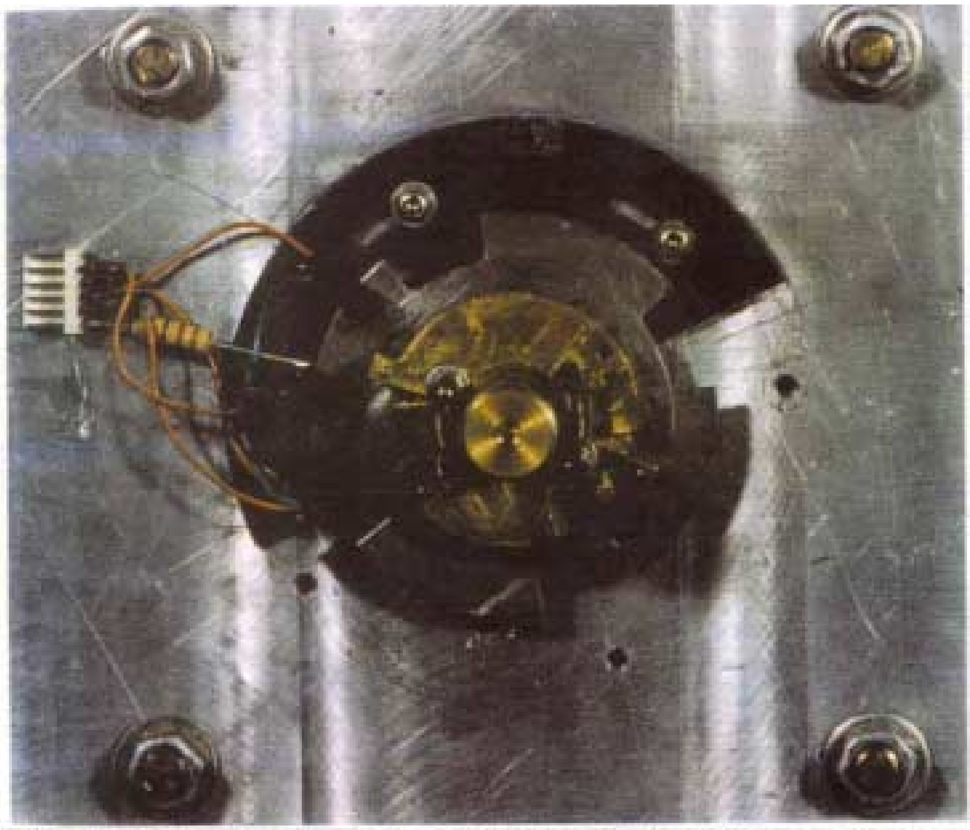

Figure 4. The governor on the motor shaft.

system has been installed inside the converter circuit. This control system gets its feedback pulses from the shaft position sensors and then turns them into voltage (i.e. more pulses means higher voltage production). Then this voltage is fed into the PWM circuit to change the width of voltage pulses controlling the motor current, the complete converter circuit is shown in Figure 5.

The circuit in Figure 5 provides a means of recovering the trapped energy and still permanently maintaining the dump capacitor voltage above the supply voltage. In order to keep the voltage on the dump capacitor high enough, a comparator circuit is used on the gate of transistor, Q_5, which provides a low-loss means of recovering the stored energy while permanetly maintaining the capacitor above the supply voltage.

The speed control feedback get its pulses from the motor shaft sensors and then, turns them into a voltage proportional to the frequency of the pulses coming from the shaft sensors which is, in turn, proportional to the speed of motor. The voltage is then fed into an error amplifier which controls the width of pulses out of the PMW unit.

In order to see the behavior of the current wave form under different advancements for the conduction angle, a Spice simulation has been performed for the drive circuit shown in Figure 5. In this simulation the inductance of the motor is considered to be linear and to change from a minimum of 50 mH to a maximum of 200mH with no overlapped area (dead zone) between stator and rotor poles. The supply voltage is 100V and motor speed is considered to be 300 rpm. The motor inductance profile for one, the motor phases, L_1, and the gate pulses for the transistor Q_2 without any time advancement as well as the resulting current waveform are shown in Figures 6a, 6b, and 6c, respectively. The maximum current build up is about 900mA. In Figure 7 and 8, a 0.2$msec$ and a 0.4$msec$ time advancements are made on the gate pulses of transistor Q_2 respectively. Comparing the three resulting current waveforms, one can see that it is possible to achieve higher current magnitudes as the turn on angles for the transistors are advanced.

In order to test the performance, this converter circuit is used to drive an isolated-phase switched

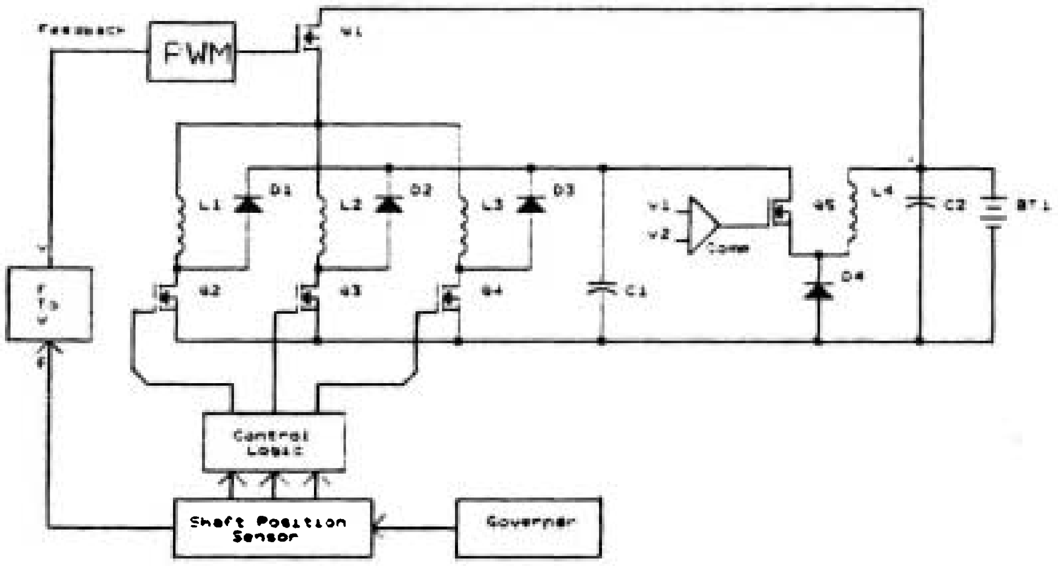

Figure 5. Complete converter circuit for operating SR motor.

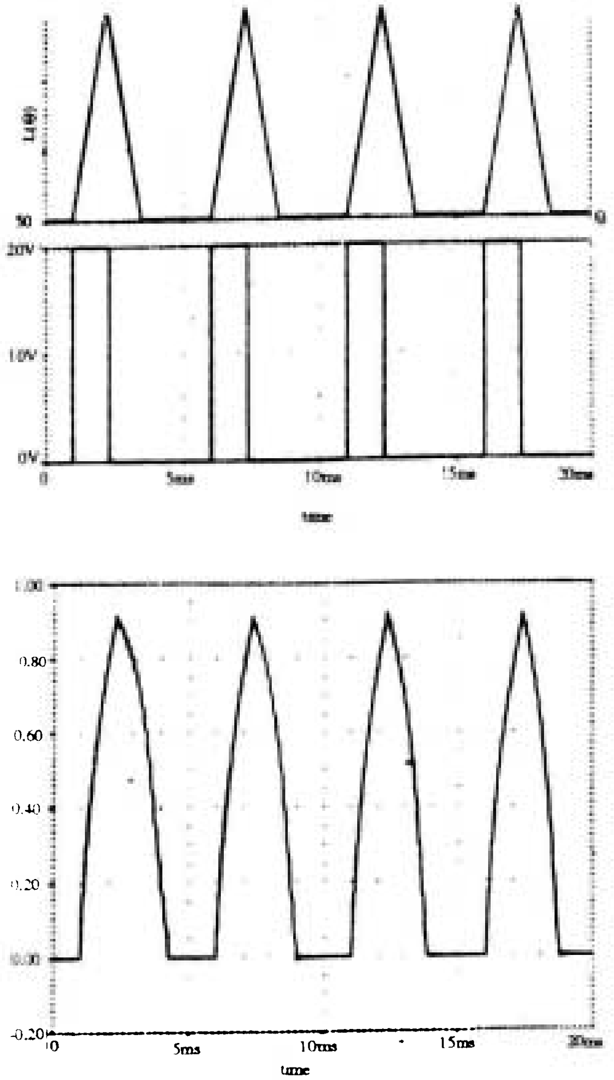

Figure 6. a) Inductance profile, **b)** Transistor gate pulses, **c)** Resulting current waveform.

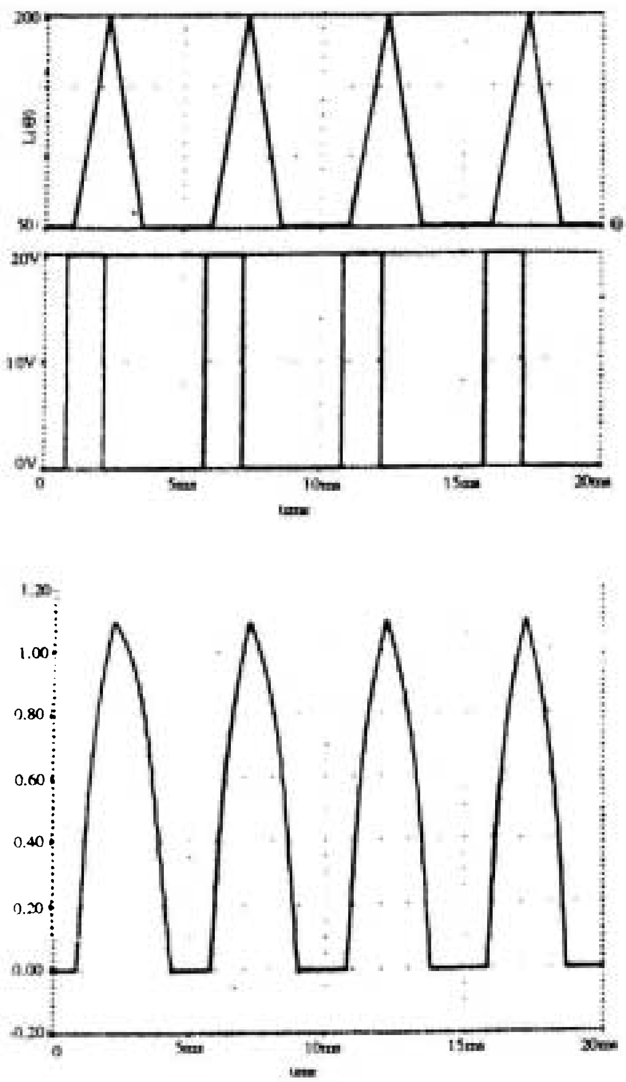

Figure 7. a) Inductance profile, **b)** Transistor gate pulses, **c)** Resulting current waveform.

reluctance motor. Figure 9 shows a plot of speed versus current under light load, one with the governor presented and acting, and the other without any govenor action.

Comparing the motor speed and current under light load with and without the governor action in Figure 9, one can see higher motor speed and lower motor current in the case where the governor is working. This shows that the governor has caused a definite improvement in the motor performance, including efficiency.

The following plot shows motor normalized torque versus speed. In Figure 10, curve A is with the governor action and speed feed back control presented. Curve B is with governor action but no speed feedback control is used. As seen from these two curves the one with speed feedback control has much smaller speed regulation.

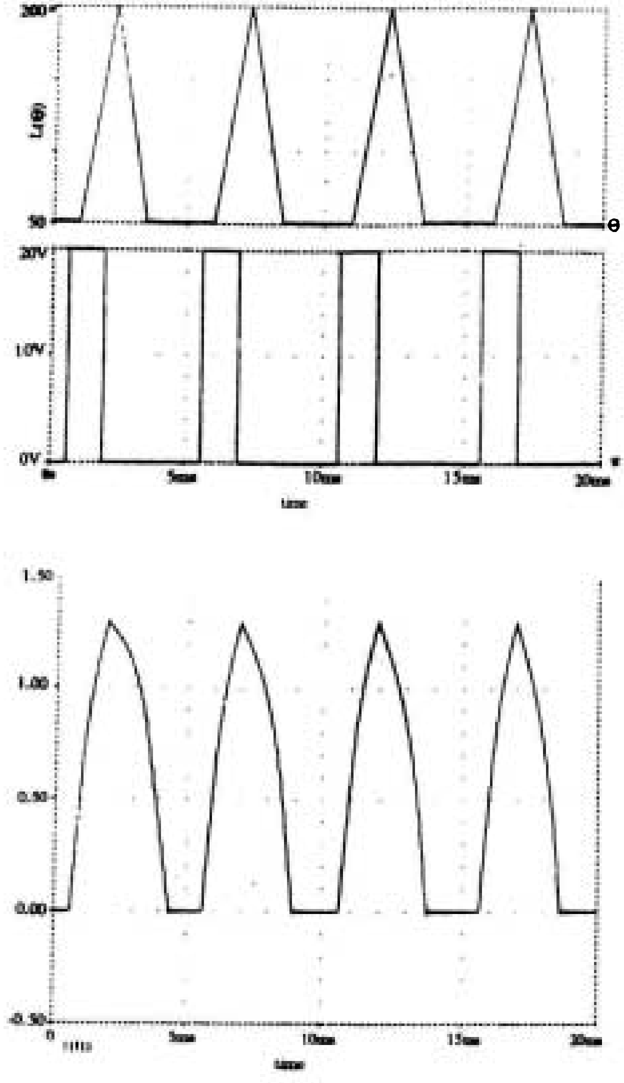

Figure 8. a) Inductance profile, **b)** Transistor gate pulses, **c)** Resulting current waveform.

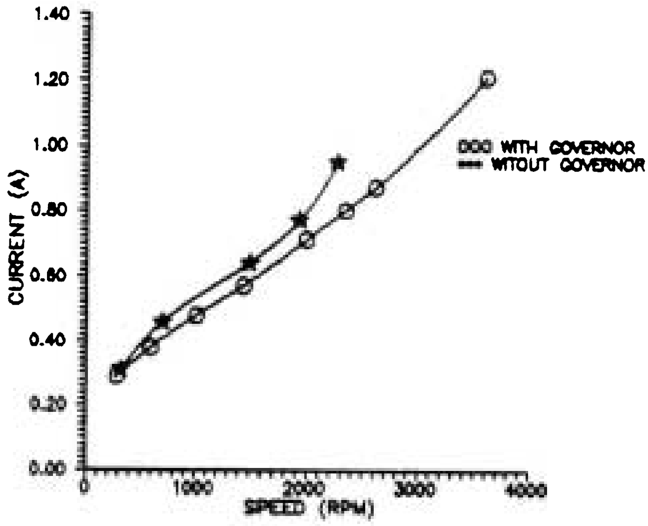

Figure 9. A plot of current versus speed for SR motor.

CONCLUSION

This converter circuit has been tested on an isolated phase switched reluctance motor and has shown to achieve efficient operation of the motor with only one switch perphase. This converter circuit has also all of the main advantages of other SR converter. It avoids the use of bifilar windings or split level DC supplies, and returns a high portion of the trapped energy to the source instead of dissipating it in a suppression resistor.

The governor on the shaft makes it possible for the motor current to build up more in high speeds and hence, higher torque for SR motor is obtainable. The current obtained by simulation is in very close agreement with the experimental results.

It is also noteworthy that the gain of speed feedback control is adjustable, therefore, the amount of speed drop under load can be controlled.

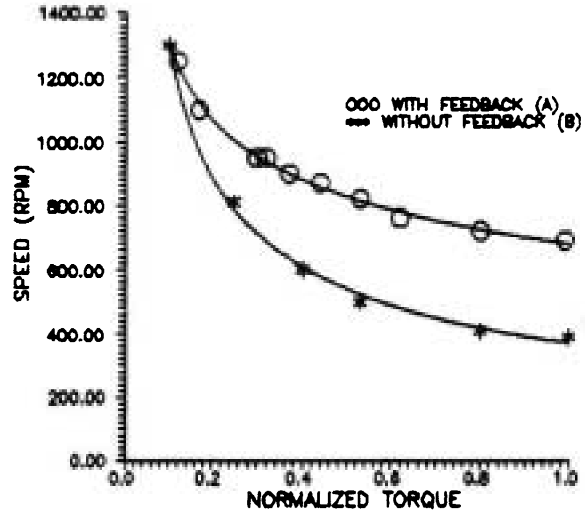

Figure 10. Motor normalized torque versus speed.

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