Recent progressive variable speed drives are designed to increase product performance and system efficiency. One such motor type which can benefit from digital control is the switched reluctance (SR) motor. The SR motor brings advantages in both cost and reliability over other types of adjustable speed drives. These include its simple mechanical construction, high efficiency and high power density. On the other hand, large torque ripple, due to double saliency construction, limits usage of the SR motor in many applications.

Another advantage of an SR motor is its high-speed operation (> 50,000 RPM). This results in a smaller motor for a given output power and reduces the size and weight of the target application. A typical application that can benefit from this feature is the vacuum cleaner. The high-speed SR motor makes the vacuum cleaner smaller and lighter, and the noise generated by torque ripple is comparable to other types of motors.

**Application Requirements**

- Very high speed (>50,000 RPM)
- Open loop speed control
- Maximal speed limitation
- One direction of rotation
- Fast start up time (500–1000 ms)
- Full power in 2–3 seconds
- Small DC bus capacitor (<10 μF)

**Application Concept**

As noted in the “Switched Reluctance Motors” article on page 17, the SR motor requires position feedback for motor phase commutation. However, implementing mechanical sensors increases costs and decreases system reliability. Therefore, manufacturers of vacuum cleaners have attempted to eliminate position sensors for control of the SR motor. A variety of algorithms for sensorless control have been developed, most of which involve flux linkage estimation. These methods calculate the actual phase flux linkage and use its relation to the reference flux linkage for position estimation. The main disadvantage for these methods is that the estimation of the flux linkage is based on a precise knowledge of the phase resistance. The phase resistance varies significantly with temperature, which yields unwanted integration errors, especially at low speed. These integration errors create a significant position estimation error.

Another method for sensorless position estimation presented in this article is based on phase current peak detection. This control method allows SR motor operation at a very high speed, making this method useful for the vacuum cleaner application.

The principle of this method can be seen in figure 1. The phase starts to be excited at the moment corresponding to the desired current amplitude. The current begins to rise until the position where the stator and rotor poles begin to overlap. At this moment, the phase current reaches its maximum. In other words, the current peak determines the exact position of the rotor. Knowing the time of two consecutive current peaks, the commutation period and corresponding on/off times can be calculated. The current peak can be detected by external circuitry or by using a powerful DSC for direct software evaluation.
The advantage of this method is that it is independent of the motor parameters. All we need to know is the rotor position at the current peak. Another advantage is that the current peak detection algorithm is very simple compared to the estimation of the flux linkage method. Thus, this method can be used at very high speeds, whereas the low number of current samples for flux calculation limits the precision of the flux linkage estimation method.

Though the control technique is simple, it requires a powerful MCU if fully implemented digitally without any external components. This MCU has to be capable of very fast phase current sampling and current peak evaluation. For example, in a two-phase SR motor running at 60,000 RPM, the commutation period is only 250 μs. To gain sufficient precision in current peak detection, the phase current has to be evaluated at least every 5 μs.

**Implementation**

The MC56F8013 DSC is a good choice for this application. This device is a member of the MC56F80xx family, which is well suited for digital motor control, combining the DSP's calculation capability with the MCU's controller features on a single chip. These hybrid controllers offer many dedicated peripherals, such as pulse width modulation (PWM) modules, fast analog-to-digital converters (ADC), timers, communication peripherals (SCI, SPI, FC) and on-chip flash and RAM. The example of digital implementation of a current peak algorithm using the MC56F8013 DSC can be seen in figure 2. The example meets all requirements for vacuum cleaner application discussed above. Figure 2 illustrates the system concept, which incorporates a two-phase SR high voltage power stage, a two-phase SR motor and an MC56F8013 controller board, which executes the control algorithm. In response to the user interface and feedback signals, the system generates PWM signals for the two-phase SR high voltage power stage. High voltage waveforms generated by the DC-to-AC inverter are applied to the motor.

The state of the user interface is scanned periodically, while the DC bus voltage and the excited phase current are sampled. The SR motor starts on command from the start/stop switch. At first, the rotor is aligned to a known position. As soon as the rotor is stabilized, the startup algorithm begins to excite the phases to get the SR motor running. During startup, the rotor position is evaluated by an algorithm. Once the SR motor achieves a stable speed, the rotor position is evaluated from the peak current. After the startup sequence, the SR motor speed is increased to maximum by a speed ramp.

The phase current is sampled every 4.4 μs. The number of ADC samples taken during a PWM period is calculated at the beginning of every PWM cycle, according to the actual duty cycle. The current samples are evaluated by the peak detection algorithm. Once the peak has been detected, the actual commutation period and on/off times are calculated from the latest and previous peak times.

The application software is written in C language except for the current sensing, current peak evaluation and commutation event interrupt routines, since they are time critical. These routines are written in assembler.

**Freescale Enablement**

A full description of this application, including software and hardware resources, can be found in reference design DRM100 at freescale.com.
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