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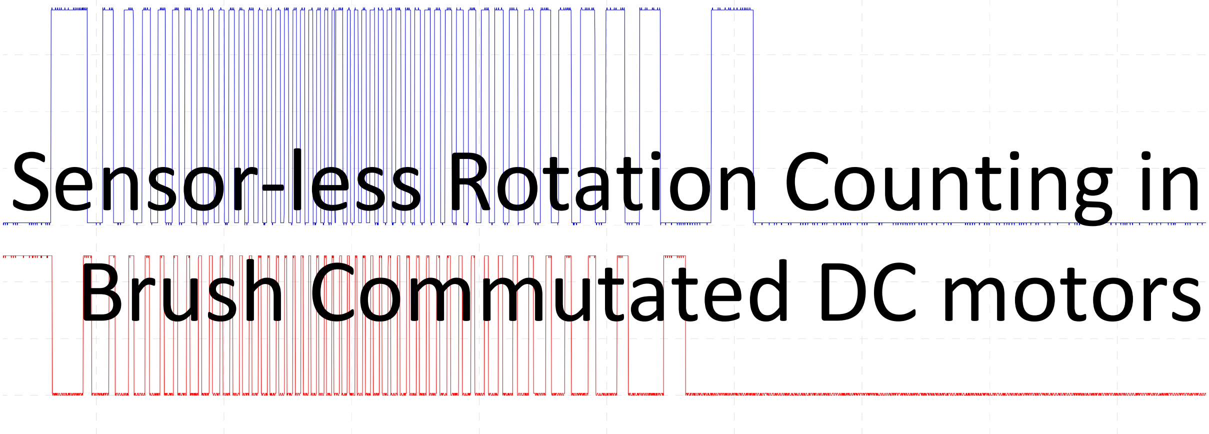

Sensor-less Rotation Counting in Brush Commutated DC motors

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This paper describes two sensor-less rotation counting methods for brush commutated (BDC) electric motors.

The first method, Ripple Counting, is a known counting method in the industry. The method relies on measuring the current fluctuations in one of the power supply wires to the motor.

The second is a new method, Transient Counting, which is based on measuring the voltage transients generated by the rotating motor. This transient detection forms the basis for a new sensor-less electric motor detection, control and monitoring technology, DCM-MotionTechnology[1], invented by IDEAdvance Ltd.

The paper describes the two methods and how they compare.

INTRODUCTION

In many BDC electric motor applications, e.g. automotive actuator systems, it is essential to keep track of the motor rotations in order to implement precise and reliable motion control. Traditionally this is done with optical sensors with photodiodes or Hall effect sensors both which pick up counting pulses from the rotating motor shaft or from the movements of the load attached to the motor shaft. These counting pulses are then sent back to the motor controller.

In order to reduce implementation complexity and cost in electric motor applications it is attractive to use sensor-less rotation counting methods, i.e. methods where sensors and feedback wires with fragile connectors are not required.

Ripple Counting is a known sensor-less counting method [1]. This method is based on measuring the fluctuations in the supply current to the motor as it rotates. However, a number of problems are associated with Ripple Counting making it difficult and less attractive to replace traditional counting methods in many applications.

DCM-MotionTechnology offers a new and unique sensor-less signal detection of the voltage transients generated by a BDC motor when it rotates. The signals can be detected anywhere on the power supply wires to the motor and as such the technology can be fully integrated in the motor control system.

[1] Patent WO2010/040349A1 (pending)

RIPPLE COUNTING

Ripple Counting works on the 'law of induction', or more specifically Lenz' law, which says that the magnetic field of any induced current opposes the charge that induces it. This so-called Back Electromotive Force (BEF) (sometimes called the counter electromotive force) can be detected by measuring the current flowing through each coil as the motor rotates.

In a fully encapsulated motor and particularly a multi pole motor this is difficult to measure. Therefore Ripple Counting usually relies on measuring the voltage variations over a small resistor inserted in one of the power supply wires to the motor. The result is a voltage curve representing the *accumulated* currents running through the coils of the motor assembly as the motor rotates.

The figure below shows the current ripple (blue curve) that can be measured over a small series resistor inserted in one of the power lines for a typical 8 pole BC DC motor used for automotive applications.

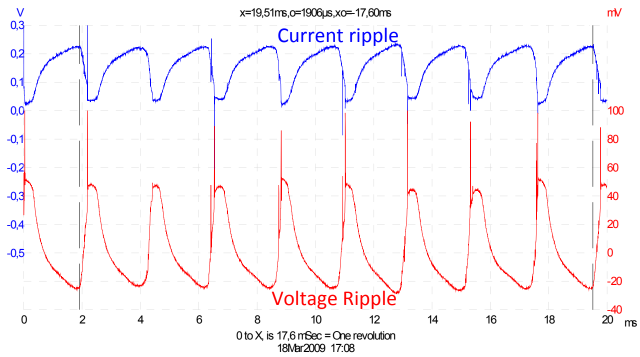

Figure 1 - Current and voltage ripples for a typical 8 pole BC DC motor. One full revolution of the motor is shown between the dotted vertical lines.

Due to the current ripple being measured as the voltage over a shunt resistor (0.1Ω in this case) the units on the blue y-axis are V. The red voltage ripple curve shown in the figure is not relevant for Ripple Counting, but will be explained on page 3.

The current ripples as shown in this simple measurement are easily distinguished and therefore suitable for counting commutations. However, a number of problems have been experienced when adopting this method in practice.

The problems all arise from the fact that the current ripple waveform characteristics are highly dependent of a number of factors such as the supply voltage and the actual load, speed, direction and temperature of the motor. Other factors such as the in-rush current, ageing of motor parts and electromagnetic interference can also influence the ripple waveform [2]. The amplitude and the shape of the waveform can vary significantly due to these factors. In other applications noise transients superposed onto the ripple current waveform can generate false counting pulses.

It has proven difficult to design a detection system based on Ripple Counting that can be used to precisely and reliably count the number of commutations of a rotating motor from start to stop. Numerous attempts to seek to improve the reliability of Ripple Counting have been described in the literature, see examples in [3-5].

DCM MOTION TECHNOLOGY

DCM-MotionTechnology is a new detection, control and monitoring method for BDC electric motors. The method relies on signals detected by the DCM-TransientDetector.

The DCM-TransientDetector works on the basic principle of Ohms law and the behavior of a *collapsing magnetic field* in which a Back-Fire or Kick-Back Transient is generated whenever the power to a coil is instantaneously switched off.

At each commutation point, when the brush breaks contact with a commutation segment, the energy stored in the motor winding as a magnetic field causes an arc or voltage spike between the brush and the commutator segment. This occurs not only during normal commutation but also in situations where the brushes bounce on the rotating commutator.

The method relies on the physical behavior of a coil when a current running through it is disconnected ('Law of Induction'). The DCM-TransientDetector detects the Kick-Back Transient from the collapsing magnetic field in the coil when the power to the coil is turned off.

The Kick-Back Transient is a short duration event of a temporary excess voltage, which is proven absolutely stable by its nature and is seen as a spark generated between the breaking contact points. This is similar to the spark generated by an ignition coil.

The Kick-Back Transient triggers the modulation of an electronic encoder signal for each of the motor commutations. Thus an N pole motor will encode N signals per rotation. The Kick-Back Transient can be measured anywhere on the power supply wires to the motor.

Now going back to figure 1 the red curve in the figure shows an example of the typical voltage signal waveform that can be measured between the power lines of a rotating motor. At first one will notice that for each commutation the signal shows some of the same waveform characteristics as the ripple current waveform (the blue curve). It is however not the overall waveform characteristics within each commutation that is of interest here.

The red curve clearly shows a significant short duration voltage transient for each commutation. This is the Kick-Back Transient which is the primary (but not the only) signal used for detection in this new method.

Let's now take a closer look at the characteristics of the signals that can be extracted on the power supply lines.

Fig. 2 illustrates a simulated simplified voltage curve for a 4 pole BDC motor.

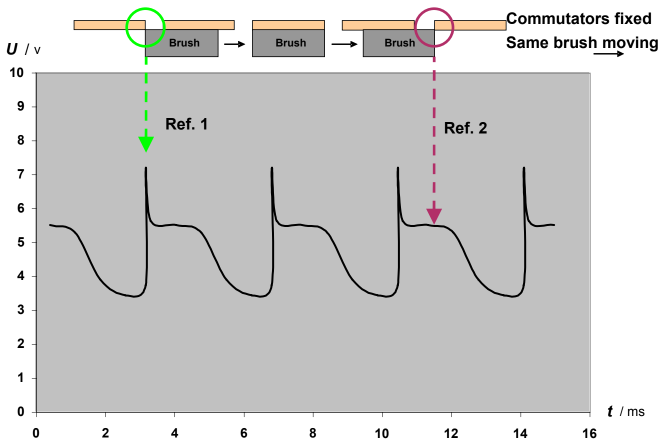

Figure 2 – Simulated, accumulated voltage curve for a 4 pole BDC motor

In the figure a simulated voltage curve is shown together with an illustration of a brush moving over the fixed commutators of the 4 coils.

Two points of interest are indicated by dotted vertical lines: Brush disengaging with commutator (Ref. 1, green), and brush engaging with a commutator (Ref. 2, purple).

The Kick-Back Transient is the narrow transient shown on the voltage curve (at Ref. 1) and is generated each time a brush disengages with a commutator from start to stop of the motor and whether the motor is powered or unpowered (i.e. whether the motor runs as a powered motor or is coasting in generator mode after the power has been turned off, driven by the inertia of the mass).

In addition to the detection of the Kick-Back Transient the DCM-TransientDetector extracts another signal from the power supply wires. This signal is called an Impedance Transient. (Note: the duration of this transient is too short to be visible in fig. 1 and 2).

The Impedance Transient is caused by the instant change of the impedance when a brush either engages or disengages with a commutator. For each commutation of the motor one Kick-Back Transient and two Impedance Transients are therefore generated. The Impedance Transients are usually of lover amplitude than the Kick-Back Transient and work in the opposite direction (negative voltage) but can still be detected with sufficient accuracy by the DCM-TransientDetector.

Figure 3 illustrates the signals the DCM-TransientDetector extracts.

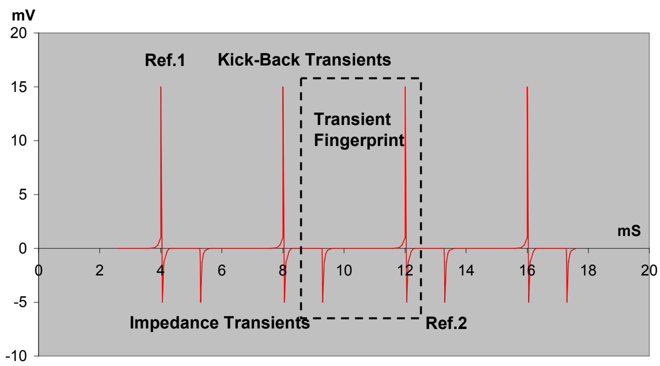

Figure 3 – Illustration of the bidirectional voltage signals that can be extracted from 4 commutations of a BDC motor. Ref. 1 and 2 refer to the points shown in figure 2. A Transient Fingerprint is shown within the dotted rectangular box.

STABLE AND RELIABLE COUNTING

DCM-MotionTechnology relies on the *combined information* or pattern, what we call the Transient Fingerprint, detected by the DCM-Transient-Detector to detect a commutation. This enables reliable counting even when one or more transients are missing, e.g. due to wear of a commutator.

A large number of tests on a variety of odd and even poled electric motor types have shown that Transient Counting using DCM-MotionTechnology is a very stable and reliable counting method. It is now possible to precisely count the number of commutations from start to stop of the motor.

ADVANCED CONTROL AND MONITORING

Reliable rotation counting is however only one of the advantages of this new detection method. The distinct voltage transients and the Transient Fingerprint pattern enable a host of new control and monitoring possibilities for electric motors.

The precise physical detection of commutations per time unit enables advanced speed and torque control of electric motors.

The exact position of the Kick-Back Transient relative to the time line changes slightly whenever the power to the motor is turned on or off. It is therefore also possible to precisely detect this point with the DCM-TransientDetector.

The asymmetric appearance versus time of the secondary Impedance Transient opens for control of the motor whether it is pulling or braked by a load. As most motors are built with a lead in the primary rotation direction, the asymmetric pattern of the transients will depend on the rotational direction. This enables simple direction detection and direction control of such motors.

Further, it is possible to precisely control the power distribution to the motor *during each commutation.* This will reduce the arcing resulting in less wear and tear of critical motor parts and reduce the power consumption. DCM-MotionTechnology can thus extend the life time and provide significant energy savings for electric motors.

If the primary or secondary transient signals for one or more commutations are missing or 'ringing' or not within the expected sequence the motor may be worn, malfunctioning or badly constructed. Because more than one type of signal is used for detection in the DCM-TransientDetector, DCM-MotionTechnology can not only perform reliable rotation counting on malfunctioning motors but can also be used for in situ monitoring and quality control of electric motors.

ROBUSTNESS

The performance of the DCM-TransientDetector is by and large unaffected by the parameters which are influencing Ripple Counting. Whether the motor is powered or is coasting in generator mode driven by the inertia of the rotating mass has no influence on the counting reliability [6]. Successful testing has also been conducted with the DCM-TransientDetector on motors with build-in noise suppression circuits.

Experiments have shown that the amplitude of the Kick-Back Transients is mainly influenced by the conductivity of the surrounding air. This is because the intensity of the arc generated between a brush and a commutator depends on the air conductivity. Also if a very low voltage is supplied to the motor for a longer time, leaving the motor in a barely rotating state, the amplitude of the Kick-Back Transients is reduced.

For most applications the amplitude reduction of the Kick-Back Transients due to these factors will be so small that it has no influence on the counting reliability and the overall performance of DCM-MotionTechnology. For motor applications in critical environments it is possible to optimize the detection circuit to overcome the influence of reduced amplitude Kick-Back Transients.

SUMMARY

In this paper Ripple Counting and the newly invented DCM-MotionTechnology Transient Counting for sensor-less rotation counting in Brush Commutated DC motor applications have been explained.

It has been described how Ripple Counting relies on detecting the *current waveform fluctuations* per motor commutation. Some of the difficulties in obtaining reliable rotation counting using this method have been explained. In particular the performance can be degraded by the interference from transients generated by the motor and the surroundings.

IDEAdvance Ltd, the company behind the new DCM-MotionTechnology, has discovered that transients generated by the motor and detected as voltage transients between the power supply wires are in fact very useful signals, which can be used to precisely detect, control and monitor the rotation of brush commutated electric DC motors.

In a number of typical electric motor applications DCM-MotionTechnology's Transient Counting can thus replace more traditional and often expensive rotation counting systems based on optical sensors and Hall effect sensors, as well as obviating the sensor wiring, sensor power wiring and the often fragile connectors used to power the sensors and to feed the sensor information back to the motor controller.

In other applications the use of DCM-MotionTechnology to detect and control the rotation of an ordinary DC motor can replace more expensive servo motors and precision actuators.

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DCM-MotionTechnology covered by WO2010/040349 A1 and EP 1 929 623 B1 in EP, US, JP, CN, IN, KR, RU, BR.