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DC MOTOR SPEED MEASUREMENT BASED ON BRUSH EFFECTS

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Abstract- This paper presents a new method for measurement speed of DC motors without using any speed sensor such as speedometer, tachometer, encoders, and so on. This method uses of the effects brushes on the current motor. A new approach based on improved zero detecting method is presented for detecting effects of the brushes on current motor. The presented approach has been done on a case study and results of experiments show that the presented method is able to get the precision measurement speed of DC motor instantaneously. Thus, it can be used to online speed control of DC motor.

Keywords: Sensorless Speed Measurement, DC Motor, Zero Level Crossing Detecting.

I. INTRODUCTION

DC motors are used in many industrial applications. Direct current motors are used in many industrial applications that require adjustable speed. In uses requiring quick stops, a DC motor can minimize the size of a mechanical brake or make it unnecessary. This is done by dynamic braking (motor generated energy fed to a resistor grid), or by regenerative braking (motor generated energy returned to the ac supply). DC motor speed can be controlled smoothly down to zero, followed immediately by acceleration in the opposite direction (without power circuit switching).

In addition, due to high torque to inertia ratio, DC motors respond quickly to control signal changes. Infinite range (smooth control down to zero speed) for short durations or reduced load is also common [1, 2]. The introduction of DC motors to run machinery eliminated the need for local steam or internal combustion engines, and line shaft drive systems. DC motors can operate directly from rechargeable batteries, providing the motive power for the first electric vehicles. Today DC motors are still found in applications as small as toys and disk drives, or in large to operate steel rolling mills and paper machines [1].

The speed of a DC motor can be controlled by changing the voltage applied to the armature or by changing the field current. The introduction of variable resistance in the armature circuit or field circuit allowed speed control. Modern DC motors are often controlled by power electronics systems called DC drives [2]. Calculation of the speed in motors is important.

It can be used in control processes. Measurement speed is requiring for control processes, monitoring, testing, etc [3]. Conventional approaches for speed measuring are speedometers, such as encoders, tachometers, and so on. The working principles of Hall sensor has been introduced in [1]. To the defects of traditional methods, it proposed the designing strategy of motor speed measurement system based on single chip microcontroller with integrated chip [2]. The hardware circuits including power module, data processing module and data display module have been described and it focuses on the analysis speed measurement module.

The speed data can be obtain through counting impulse signals and displayed on LCD. Experience shows that the system have high stability, it can meet the needs of DC motor speed measurement. References [3, 4] present an approach sensorless measurement speed for induction motors based on Hilbert transform and Interpolated Fast Fourier Transform (IFFT). Ildarabadi [5] presents measuring speed of DC motor based on effect of brush and commutation in DC motor. Max level of current waveform detection in [5].

However, this approach is complicate and sensitive to noise. Using of effect of brush and commutation in DC motor is used for measuring speed of universal motor in [6]. In this paper, a new approach is presented for measuring speed of DC motors without using of speed sensors. This method can be used for any typical DC motors such as the PM DC motor, the series DC motor, the shunt DC motors and the compound DC motor.

Section 2 describes the principal of DC motor. In this Section also is introduced the effects brushes on the current of DC motors. Section fourth presents the approach of sensorless speed measurement based on effects brushes on the current. The case study and simulations have been presented in fifth section. Calculation of this work presents in sixth section.

II. DC MOTOR

The DC motors are the electrical motors that work with DC voltage. These motors are used in industry application that requires speeding control process. DC motors are in form of the series DC motor, the shunt DC motor and the PM DC motor. Their core rotor is laminated until the loss of eddy current is reduced [7, 8].

A DC motor is a mechanically commutated electric motor powered from direct current (DC). The stator is stationary in space by definition and therefore the commutator to also be stationary in space [9] switches the current in rotor. The brushed DC electric motor generates torque directly from DC power supplied to motor by using internal commutation, stationary magnets (permanent or electromagnets), and rotating electrical magnets.

Advantages of a brushed DC motor include low initial cost, high reliability, and simple control of motor speed. Disadvantages are high maintenance and low life span for high intensity uses. Maintenance involves regularly replacing the brushes and springs, which carry the electric current, as well as cleaning or replacing the commutator. These components are necessary for transferring electrical power from outside motor to the spinning wire windings of the rotor inside motor. Brushes are made of conductors.

A commutator is the moving part of a rotary electrical switch in certain types of electric motors or electrical generators that periodically reverses the current direction between the rotor and the external circuit. The commutators have two or more softer metallic brushes in contact with them to complete the other half of the switch. In a motor, it applies power to the best location on the rotor, and in a generator, picks off power similarly. As a switch, it has exceptionally long life, considering the number of circuit makes and breaks that occur in normal operation [9].

A commutator is a common feature of direct current rotating machines. By reversing the current direction in the moving coil of a motors armature, a steady rotating force (torque) is produced. Similarly, in a generator, reversing of the coils connection to the external circuit provides unidirectional (i.e. direct) current to the external circuit [9]. A commutator consists of a set of contact bars fixed to the rotating shaft of a machine, and connected to the armature windings as has been shown in Figure 2. As the shaft rotates, commutator reverses the flow of current in a loop rotor winding every 180 electrical degree or (180×2/*P*) mechanical degree.

Therefor direct of rotor current remains fix under every poles [7]. For a single armature winding, when the shaft has made one half complete turn, the winding is now connected so that current flows through it in the opposite of the initial direction. In a motor, the armature current causes the fixed magnetic field to exert a rotational force, or a torque, on the winding to make it turn. In a generator, the mechanical torque applied to the shaft maintains the motion of the armature winding through the stationary magnetic field, inducing a current in the winding.

In both the motor and generator case, the commutator periodically reverses the direction of current flow through the winding so that current flow in the circuit external to the machine continues in only one direction. Small DC motors are used where light weight is important and usually operate at high speed (500 to 8000 RPM (revolutions per minute)). The DC motors provide the highest horsepower per dollar in fractional horsepower range, at the expense of nose, relatively short life, and high speed [8].

Rotor of DC motors is consist of iron soft Ferro-magnetism core because reduction reluctance of magnetic path and it has been laminated because reducing of core losses.

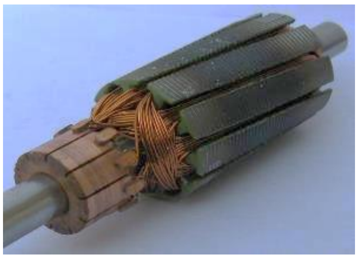

Figure 1. Rotor of the DC motor

The waveform of DC motor is not perfectly DC. It has a ripple that is created by effect of brush and collector (or commutator) in rotor. Figure 2 shows the waveform of induced DC motor on one coil winding in rotor.

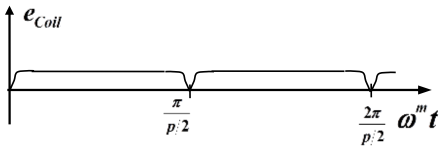

Figure 2. Induced voltage waveform on each coil of the DC motor

If it be supposed there are 10 blades collector, then the waveform of induced on DC motor terminals will be as Figure 3.

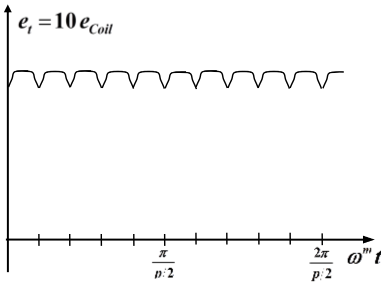

Figure 3. Induced voltage waveform of the DC motor

Therefore it is expected that waveform of current machine is also similar to induced voltage waveform. Another factor affecting the motor current waveform, which is seen as a partial commutation sparks at the brushes. Figure 4 shows the actually waveform of DC motor current.

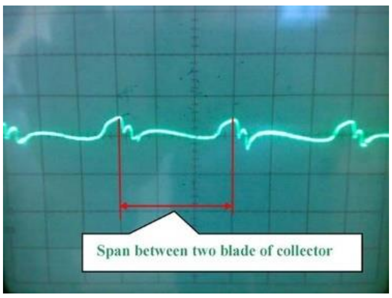

Figure 4. Current waveform of the DC motor in slow speed

III. DETECTION EFFECT OF BRUSHES IN CURRENT WAVEFORM AND SENSORLESS SPEED MEASUREMENT

In this section presented the new approach for detecting effects of brushes. It is based on detecting zero level crossing. For this purpose, in first it is removed DC section of current waveform, and then calculated time between two zero level crossing rising. As can be seen from Figure 4, the current waveform has confusion created by current commutation effect. Thus, if these confusions are not omitted then determining the zero level crossing will not be possible. In this paper without disturbance crossing is characterized by elevated levels.

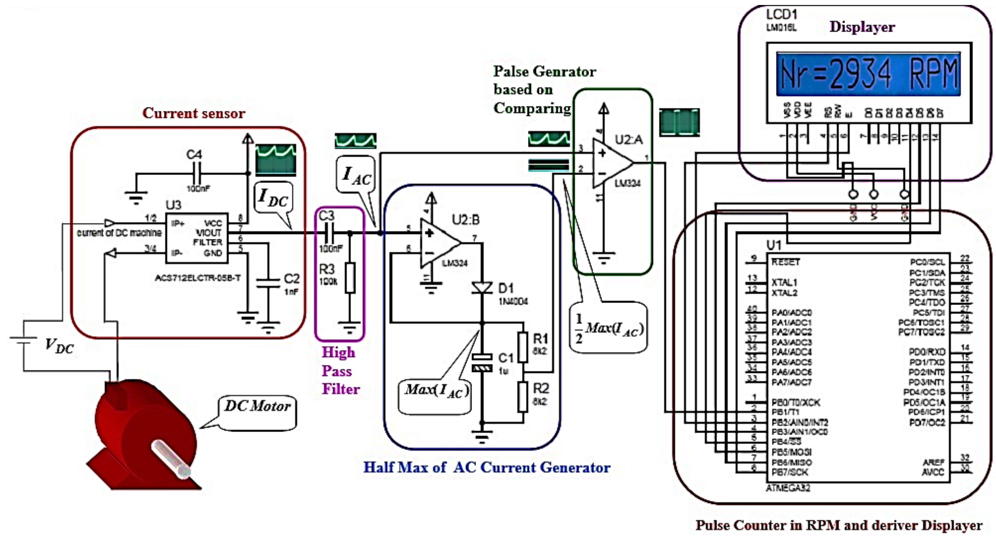

Figure 6. Current waveform of the DC motor in high speed

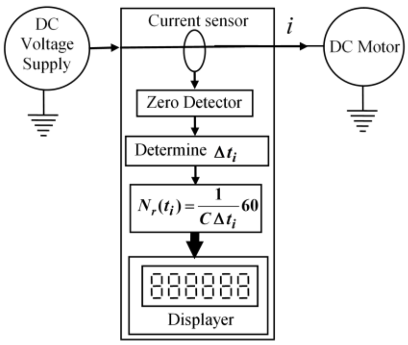

Figure 5. Sensorless speed measurement system

When DC motor is running, the blades of collector installed on the rotor pass under brushes. Because of current is chapping in this time, therefore the current of motor is chapped and it creates ripples in current of DC motor. Figure 5 shows the flowchart of presented approach that realized by the circuit be shown in Figure 6. In this flowchart, we have:

1- Omitting DC level of current waveform by passing current through high pass filter and call it I_{AC}.

2- Determining time passes through zero of I_{AC} and calls its t_i.

Determining of t_i is difficult, because of the effect of current commutation. The current has turbulence when crossing the zero level. For solving this problem, in this paper the presented new approach. For this means, in first calculated the maximum of the I_{AC} and call it max (I_{AC}). Then divide it to two and compare it with I_{AC} as shown in Figure 6.

3- Compute the difference between two consecutive times and call it $\Delta t_i = t_i - t_{i-1}$ by microcontroller as shown in Figure 7.

4- The instantaneous speed of motor in RPM is as follows:

$$N_r(t_i) = \frac{1}{C\,\Delta t_i} 60 \text{ (RPM)} \quad (1)$$

where, C, N_r (t_i) are the number of blades of commutator and online speed of motor in RPM in t_i, respectively.

It is note that instantaneous speed is not able to represent because it have quick variations. The flowchart of computing DC motor speed by microcontroller is shown in Figure 7. The pseudopod for this work is as follows:

-Start

Lable1: k=1

    Reset Timer
    While (k equal or less than of 50)
    Start timer

Lable2: If; Input change one to zero;

    Comment: I in flowchart
    After the input (I) change to one again;
    k=k+1
    Goto Lable 2
    End
    Stop timer and call time of timer; T
    Comment: T is 50 times of time passing brush from one blade
    commutator and next blade commutator (Δt_i in flowchart).
    Compute the (60×1/$C\Delta t_i$) and call N_r
    Comment: N_r is rotation speed per minute
    Display N_r
    Goto Lable1

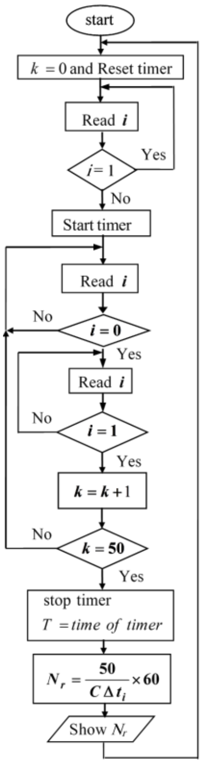

Figure 7. Compute the DC motor speed by microcontroller

IV. CASE STUDY

This section presents the case study for showing ability of the presented approach. For this purpose, it has been used DC motor applied in lifting window of Pride cars. This DC motor has 10 blades over commutator is used as has been shown in Figure 1. Figure 9 to 12 shows current waveform of the DC current. Those figures show recorded in 1 ms per division (ms/div). This ripple waveform on current of motor is obvious and by passing of wavelet transform, one can separate this ripple of the original current signal. According to Figure 8 for this purpose current is measurement by doing series a resistance with DC motor and sampling of current waveform.

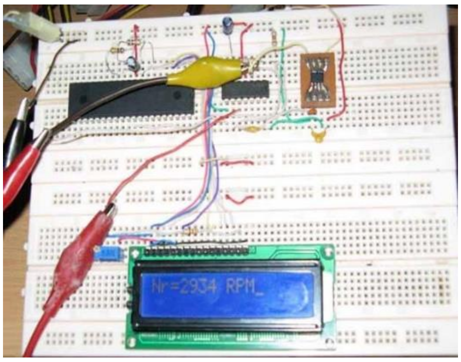

Figure 8. Sensorless speed measurement system

After sampling and passing waveform of aliasing filter, it has been passed of Maximum detector and is determined the time between two sequence maximum detecting of waveform (Δt_i). Now speed of DC motor calculates. In the following, module of sensorless measurement is presented.

This module includes a linear current sensor with part number ACS712ELCTR-05B-T for acquisition current of DC motor, an operational amplifier with part number LM324, ATmega32 that is a micro controller and LCD for displaying of DC motor speed. Figure 6 shows the module of sensorless speed measurement of DC motor, the senility of this approach to one of defect in this approach.

Figure 9. Current waveform of the DC motor in slow speed

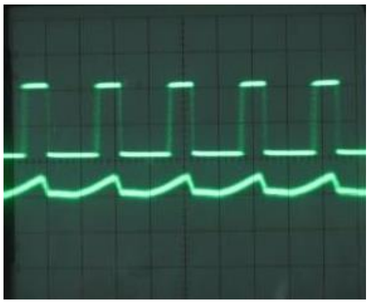

Figure 10. Current waveform of the DC motor in medium speed

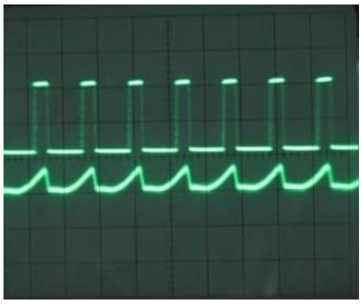

Figure 11. Current waveform of the DC motor in high speed

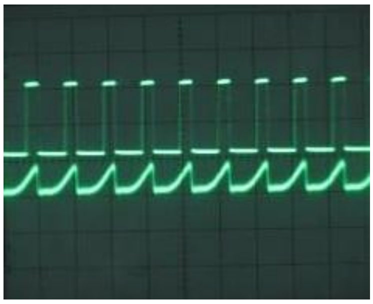

Figure 12. Current waveform of the DC motor in the highest speed

Figures 2 to 4 shows current waveform of this DC motor in 20 ms. If the current signal is passed of the maximum detector, then the time between maximum of ripple of current (Δt_i) can be calculated. The amount of Δt_i for Figures 2 to 4 is as follows:

$$\Delta t_{i\text{, Fig. 9}} = 3.548 \times 1 = 3.548 \text{ ms} \tag{3}$$

$$\Delta t_{i\text{, Fig. 10}} = 2.045 \times 1 = 2.045 \text{ ms} \tag{4}$$

$$\Delta t_{i\text{, Fig. 11}} = 1.285 \times 1 = 1.283 \text{ ms} \tag{5}$$

$$\Delta t_{i\text{, Fig. 12}} = 1.05 \times 1 = 1.05 \text{ ms} \tag{6}$$

Therefore, the speed of motor in time, every figure is as follows:

$$N_r(t_i)_{\text{Fig. 9}} = \frac{1}{10 \times 3.548 \times 10^{-3}} \times 60 = 1691 \text{ RPM} \tag{7}$$

$$N_r(t_i)_{\text{Fig. 10}} = \frac{1}{10 \times 2.045 \times 10^{-3}} \times 60 = 2934 \text{ RPM} \tag{8}$$

$$N_r(t_i)_{\text{Fig. 11}} = \frac{1}{10 \times 1.283 \times 10^{-3}} \times 60 = 4676 \text{ RPM} \tag{9}$$

$$N_r(t_i)_{\text{Fig. 12}} = \frac{1}{10 \times 1.05 \times 10^{-3}} \times 60 = 5714 \text{ RPM} \tag{10}$$

V. CONCLUSIONS

A new method of improved detective crossing the zero level of waveform analysis based sensorless speed detection of DC motor is presented in this paper. Speed is detected by sampling of current, passed of zero level crossing detector then calculation of time between two sequence zero level crossing waveforms and the speed of motor calculation based it instantaneous in RPM. Therefore, the presented approach has high accuracy and can be use to online control application.

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BIOGRAPHIES

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