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Speed Measurement Method for Digital Control System

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Abstract

In the paper a modified digital speed measurement method is proposed. The method has a good static accuracy, like well known other measurement procedures, but its advantage consists in a constant sampling period. The method is implemented on single chip microcontroller. Experimental results proved good properties of the proposed concept.

I. Introduction

A tachometer is an important part in design of feedback loop in adjustable speed drives. Many industrial drives use a DC tachometers due to their good dynamic performance and low cost. Rapid development of microprocessor speed control systems encouraged to apply digital tachometers because of such their significant advantages like:

- good accuracy,
- lack of A/D converters in the case of microprocessor control system,
- noise immunity,
- no maintenance.

Digital speed measurement methods, based on pulse train coming from a shaft encoder, are reviewed in several papers [2,4,5]. Two elementary methods which are widely known base on counting a number of encoder pulses in a fixed period (method M) or measurement of the elapsed time between successive pulses (method T). Well known disadvantages of these methods, which are low accuracy in the range of small speed for method M and poor accuracy in the range of high speed together with variable counting (sampling) time for method T, led to development of new measurement concepts.

In [2,6] a modified measuring concept called method M/T was presented. This new method combines advantages of both mentioned methods; its idea consists in counting pulses from the shaft encoder during a period, which is synchronised with these impulses. Some exemplary realisation on 16-bit microcontroller SAB 80C166 is shown in fig. 1 [3].

A reversible counter T2 counts impulses coming from encoder (C) meanwhile timer T3 measures time of their duration by clock impulses counting (L). After passing reference sampling period, measured by timer T1, the first impulse coming from encoder ends measurement period. This process is illustrated in fig. 2.
The speed is calculated according to formula:

$$\omega(k) = \frac{2\pi \cdot C(k)}{N \cdot L(k) \cdot T_{clk}} \tag{1}$$

Where

- C(k) is a number of encoder pulses counted by T2,

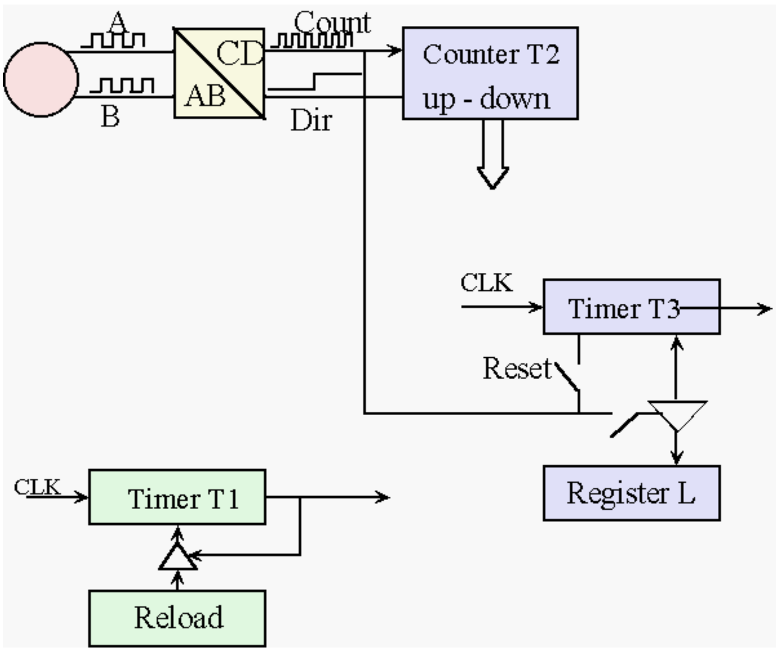

Fig. 1: Block diagram of speed measurement system - method M/T

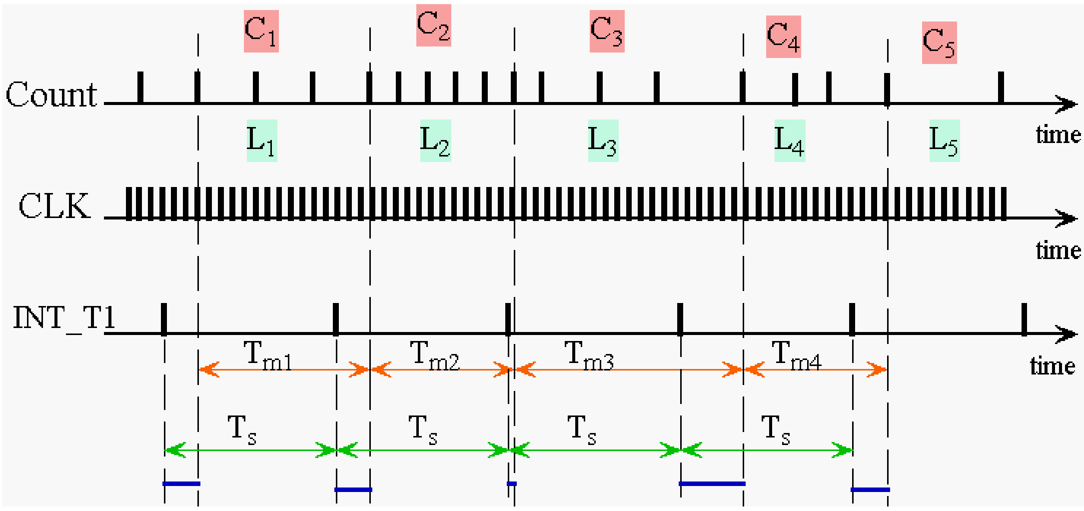

Fig. 2: Principle of speed measurement method M/T

- L(k) is number of clock system pulses counted by T3,
- N is a number of encoder impulses per rotation,
- T_{clk} is a period of clock impulses.

Measurement of small speed values (C(k) = 1) consists in counting a time distance between successive impulses like in the method T. Disadvantage of method M/T is variable measurement time, which varies between:

$$T_S \le T_m \le T_S + \frac{2\pi}{N \cdot \omega} \qquad (2)$$

where T_S is desired sampling period.

The formula (2) shows that the measurement time T_m depends on actual value of measured speed so the worst case appears for the smallest speed value.

In literature some modification of method M/T are described [1,2,4], which ensure constant sampling period, what is of importance in case of speed control realisation.

In the paper some modification of a concept CSDT (Constant Sampling period Digital Tachometer) [5] is proposed, which ensures constant sampling period with measurement accuracy equal to M/T. The proposed approach eliminates disadvantage of M/T method, which is variable measurement period, and can be realised on 16-bit microcontroller SAB 80C166.

II. Description of proposed measurement method

In the proposed method like in the original one a variable measuring period, synchronised with encoder impulses, is used. The method guarantees constant sampling period - after each sampling

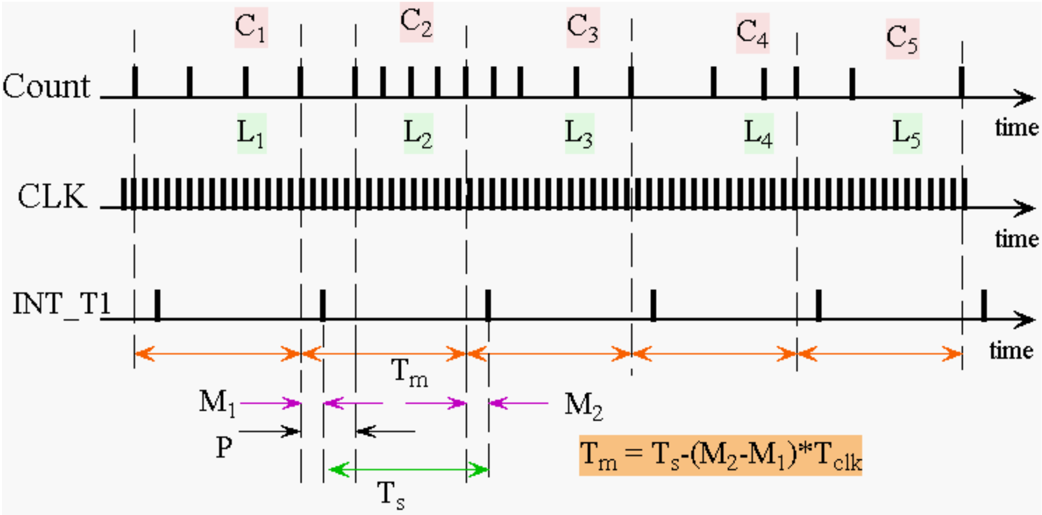

Fig. 3: Principle of modified speed measurement method

pulse the last measured value of speed is accessible. In opposition to the M/T method the measurement period (measurement window) can be not only longer but also shorter of desired value of sampling period. The minimum value of this measurement window is limited to a half of the sampling period and its maximum value is shorter or equal to double sampling period value. The principle of the method operation is shown in fig. 3.

A single chip microcontroller SAB80C166. contains 16 bit microprocessor equipped with such peripherals like counters and timers concatenated with compare and capture modules, controlled by external signals. Important feature of applied microcontroller is its hierarchical interrupt system. Block diagram of proposed measurement system is shown in fig. 4.

Timer T0 generates periodically interrupt impulses INT_T0 with proper sampling periods T_s. Signals A/B from the encoder are converted to form C/D (counting impulse/direction) by external electronic module and are send to the input of reversible counter T3. Simultaneously this input impulses comes to the CAPREL register and are used to control of counter T5 operation. The T5 counts clock impulses of frequency 5 MHz (T=200 ns). The first encoder impulse coming after sampling impulse generates interrupt signal INT_CR, reload actual value of counter T5 to the register CAPREL and resets T5. Interrupt procedure (INT_CR) blocks itself starting till the end of running sampling period, captures an actual value of T5 and stops reloading the value of counter T5 to the CAPREL. Interrupt procedure INT_T0, generated with constant period, initiates algorithm of speed calculation described by following formula:

$$\omega(k) = \frac{2 * \pi * C(k)}{N \cdot T_m(k)} \quad (3)$$

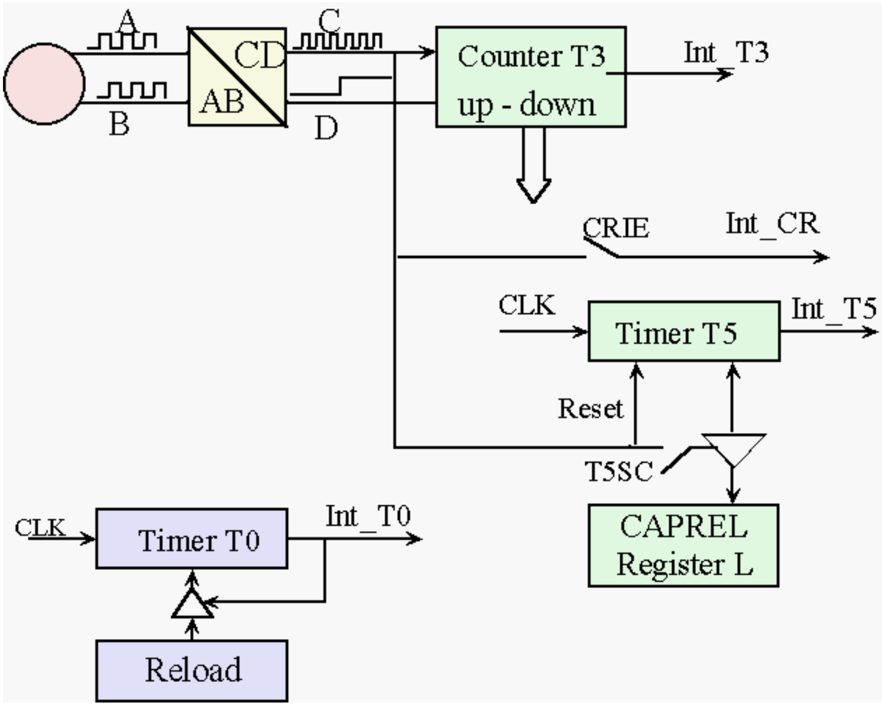

Fig.4: Block diagram of measurement system

where C(k) is a number of encoder pulses counted in $T_{m,}$ and T_m is

$$T_m(k) = T_s - T_{clk} * (M(k) - M(k-1)) \tag{4}$$

For very small values of speed the timer T5 can be overflow what is not accepted in the algorithm. This situation is avoided due to interrupt procedure INT_T5, which is generated when T5 reaches its maximum state. This interrupt procedure stops T5 counting and generates the output signal of measured speed with information that speed is equal zero. This means that measurement procedure reaches its minimum value of measured range. For example if overload time of T5 is 13 ms and N=4000 ppr then the minimum speed is 1.2 rpm. The new coming encoder impulse starts counting process of T5. Algorithms of interrupt procedures are presented in fig. 5.

III. Experimental results

The proposed measurement method was tested on a laboratory stand, which block diagram is shown in fig. 6. During the experiment the speed of permanent magnet synchronous motor, supplied from frequency converter, was measured in digital and analogue way. The digital measurement bases on proposed method and applies shaft encoder with N=4096 ppr. The sampling period of speed measurement was assumed equal 0.25 ms.

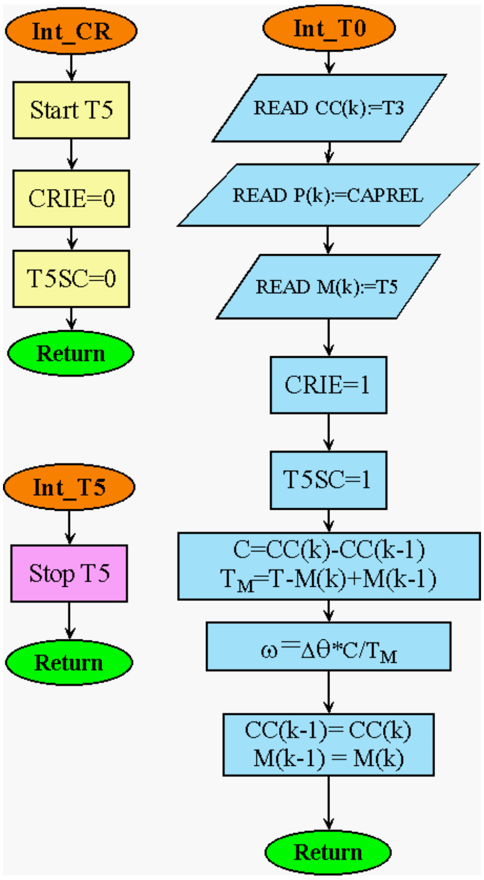

Fig. 5: Algorithms of interrupt procedures

During tests the proposed method was compared with measurement obtained by means of analogue tachometer. Analogue signal of measured speed sent by tachometer installed on the motor shaft was converted to digital form by 10-bit ADC included in microcontroller structure. Results of digital and analogue measurement were registered in digital form in memory of microcontroller. After tests the registered values were converted by the additional DAC to the voltage and plotted on the screen of oscilloscope.

First tests showed that tachometer voltage contains significant value of high harmonic distortion (noise) so a simple low pass filter was needed.

Fig. 7 shows waveforms of speed measurement during motor reverse from -500 rpm till 500 rpm. The waveforms confirm correct dynamic properties of digital measurement. Its signal

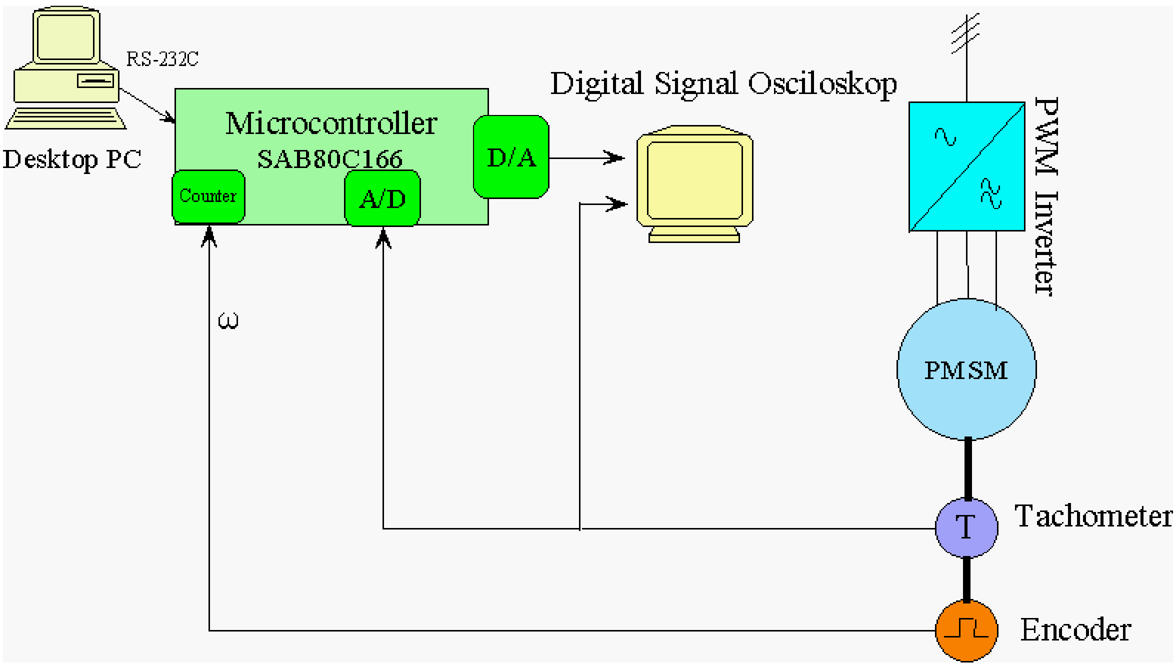

Fig. 6: Block diagram of a laboratory stand

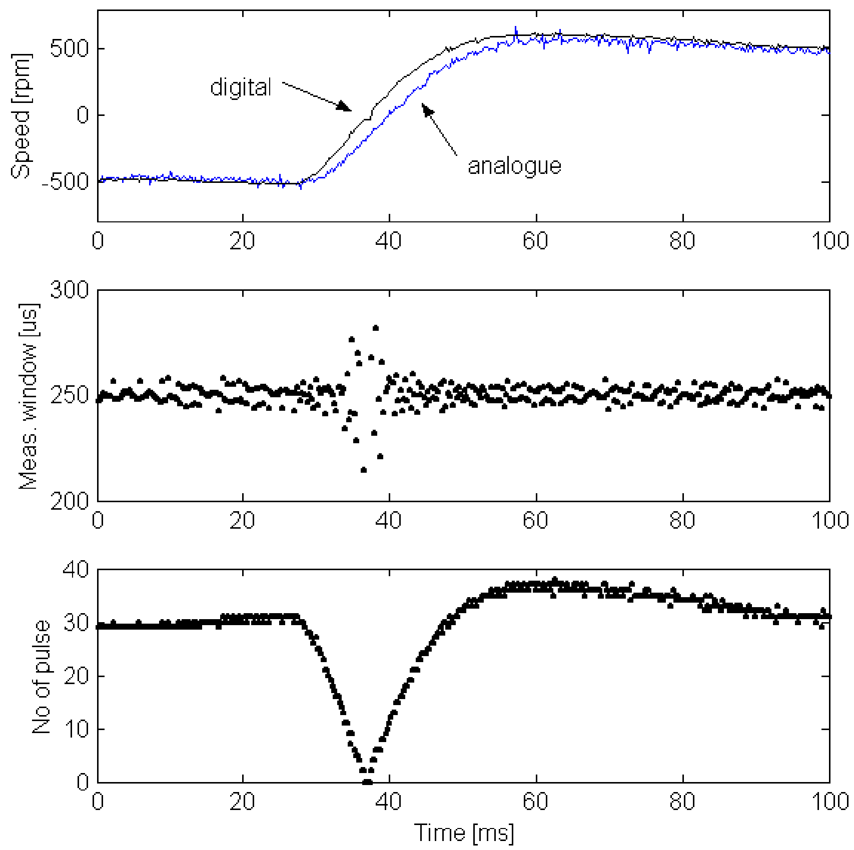

Fig. 7: Waveforms of digital and analogue measurement signals during motor reverse (-500 rpm → 500 rpm)

changed even faster the analogue one because of a delay caused by inserted filter. The digital signal smoothly passes through the most difficult measurement region near zero speed, what is significant advantage of proposed method. Two additional waveforms show inner signals, which represent number of counted encoder impulses (C) and a length of measurement window T_m - expressed by equation (4). Both signals well illustrate principle of measurement method - the number of counted encoder impulses increases simultaneously with speed value and measurement window length varies correctly around sampling period (0.25 ms) in assumed range.

Fig. 8 presents waveforms for starting and fig. 9 for breaking process of the motor. These two tests are more difficult because of steady state at standstill of motor (with zero speed). Signal of digital measurement presents correct behaviour at zero speed. Once more two additional signals illustrate method operation. Better illustration is given in fig. 10, which presents clearly individual samplings values. Visible small distortions appearing from time to time in measured signal are involved by overlap of two interruptions; one from timer T0 (Int_T0) and second from encoder impulse (the first after sampling - Int_CR), what makes some delay in measurement procedure.

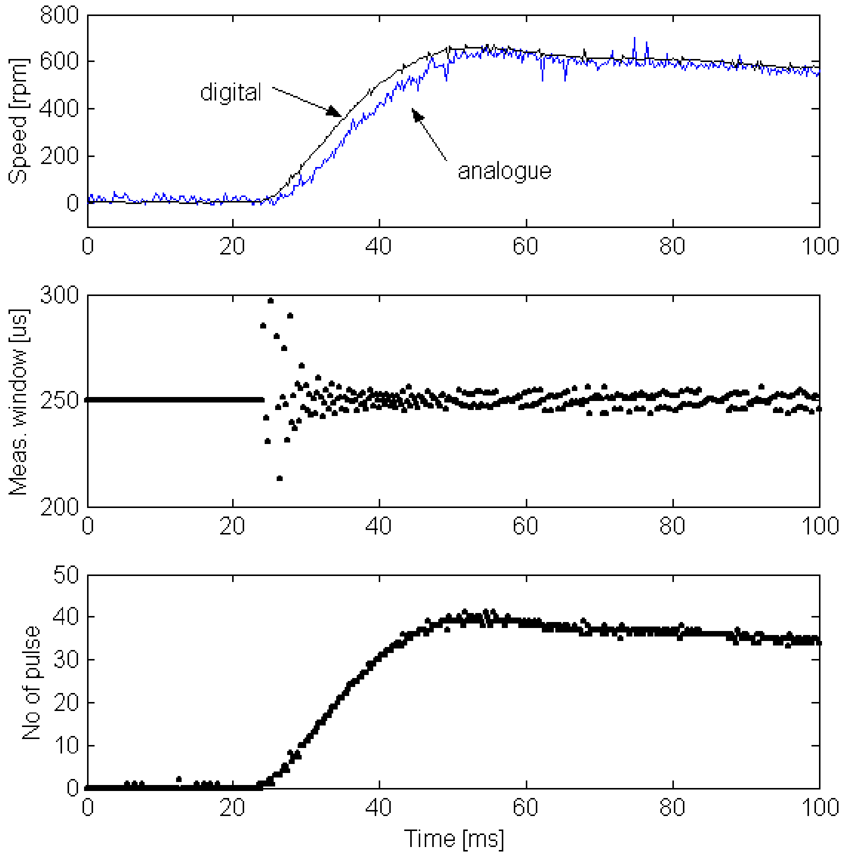

Fig. 8: Waveforms of digital and analogue measurement signals during motor starting (0 rpm → 600 rpm)

In all presented waveforms of analogue measurement signal some distortion are visible in spite of inserted filter. This is one more argument for applying proposed digital tachometer instead of analogue one.

IV. Conclusions

The proposed digital method of speed measurement has a good static and dynamic properties and operates correctly at zero speed so can be successfully applied in feedback loop of speed control systems. The obtained feedback signal does not require any filter and is much more accurate than signal from ordinary analogue tachometer. The presented system guarantees constant sampling period, what is its significant advantage. The method can be applied on single chip 16-bit microcontroller as well as on FPGA modules.

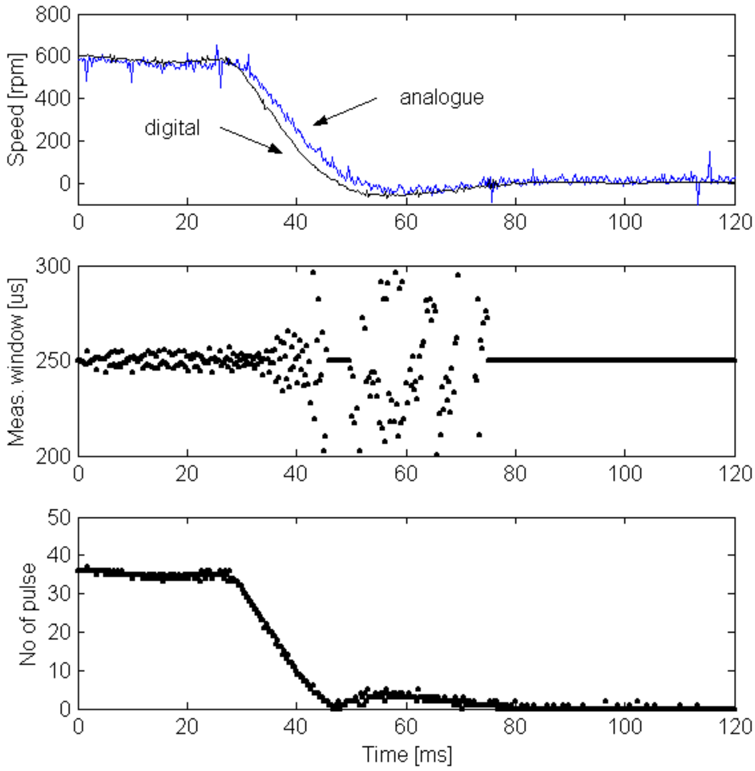

Fig. 9: Waveforms of digital and analogue measurement signals during motor braking (600 rpm → 0 rpm)

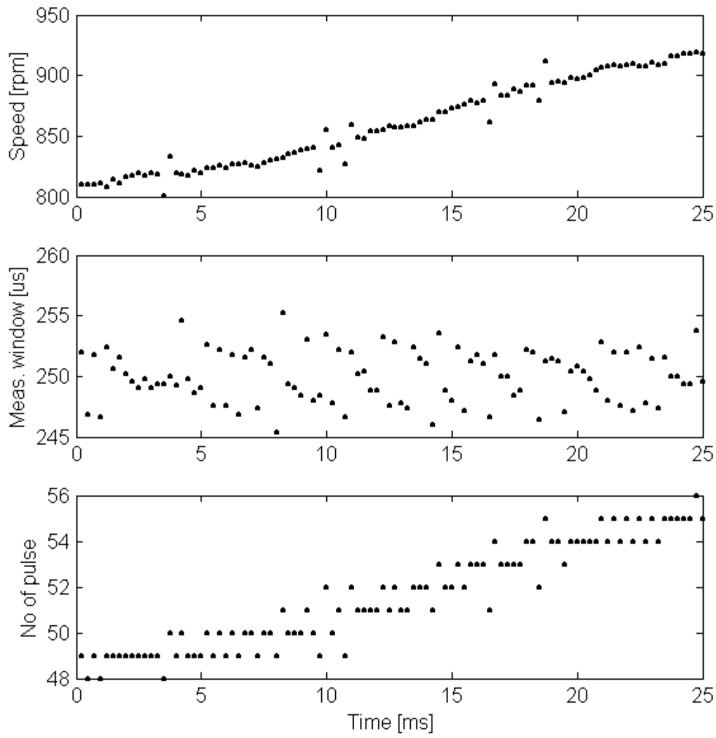

Fig.10: Illustration of speed measurement method - individual sampling values

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