ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 9, Issue 6, June 2022

Intellectualization of Control Systems of a Metal-cutting Machine using Optoelectronic Sensors

Sayfulin Ramil Rashidovich

Doctoral student of the Navoi State Mining and Technology University of the Republic of Uzbekistan

ABSTRACT: The article discusses the modelling and simulation of an incremental encoder and associated units for processing the information provided by the encoder in metal cutting machine. The proposed mathematical model of the incremental encoder and present incremental measuring method are important design considerations for the incremental encoder interface. For the speed determination different methods are modelled and simulated: for high speed region the frequency measurement is used and for low speed domain the period measurement is appropriate. The presented simulation subsystems of the encoder, position and speed computation may be integrated in any Matlab-Simulink structure.

KEY WORDS: Incremental encoder, position, speed, method, measurement, simulation, device, system, counter, signal, measuring.

I.INTRODUCTION

An incremental encoder is an electromechanical device that generates pulses on A and B (aka "clock") outputs in response to incremental mechanical movements. Two basic types of incremental encoders are available: linear incremental encoders, which detect linear motion; and rotary incremental encoders which detect movement of a rotating shaft. In either case, when an encoder is moving at a constant speed, the output pulses take the form of quadrature-encoded square waves. As an encoder moves faster, the pulse frequency increases accordingly. Since the relationship between pulse frequency and velocity is linear, it's a simple matter to use the pulse frequency as an indication of speed. The output pulses can be transformed into speed units by measuring their frequency, and then multiplying the frequency by an appropriate scale factor.

II. SIGNIFICANCE OF THE SYSTEM

Incremental encoders are used in measurement and control systems, and such systems are usually controlled by a CPU. Since the encoder counter is typically sampled by a CPU, and CPUs have other responsibilities besides sampling encoder counts, there are some special considerations to take into account when designing incremental encoder interfaces.

III. LITERATURE SURVEY

There has been extensive research over the past few decades in order to provide accurate and delay-less smooth velocity information over a wide speed range from a digital incremental encoder. An excellent survey is provided in [1,2]. The simplest velocity estimation approach is based on counting encoder position pulses within a sampling period, as is the case in the well-known M-method. However, the M-method produces highly noisy output, especially at high sampling rates, due to the spatial position quantization inherent to incremental encoders. The alternative T-method can be utilized instead, in which the time interval between two adjacent encoder pulses should be measured by counting high-frequency clock pulses. The velocity information is then obtained by the reciprocal of the measured time interval, i.e., by arithmetic division. Though the method can provide fine velocity estimation at low speed, it is prone to errors at high speed. Thus, the main stream of the velocity measurement methods combine the M-method and the T-method. Since the pioneering work by Ohmae [3], the MT-method has been applied widely, because it works well in wide speed ranges and also has a high accuracy in the low speed range. Some variations of the MT-method appeared in [4–6]. They can be classified as the MT-type methods which may provide highly smooth velocity with no phase lag in a wide speed range. Further research deals with performance improvement of the MT-method and its enhanced robustness to the hardware inaccuracies [7-8]. Time stamping of encoder pulses presents a generalization of the MT method [9-10]. Here, the velocity is estimated by a polynomial fitting through a number of time-stamped encoder counts, which increases computation complexity significantly. On the other hand, Zhu

ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 9, Issue 6, June 2022

[11] proposed an MT-type method with an efficient processing algorithm in order to simplify the required real time computation effort.

IV. METHODOLOGY

Incremental encoders are used in measurement and control systems, and such systems are usually controlled by a CPU. Since the encoder counter is typically sampled by a CPU, and CPUs have other responsibilities besides sampling encoder counts, there are some special considerations to take into account when designing incremental encoder interfaces.
Incremental encoders have three output signals as standard:

- a signal A consisting of n pulses per revolution (this signal can be a block or sine-wave)
- a signal B, identical to A but 90° displaced
- a signal Z (= zero marker output)

From the combination A, B and Z we can:

1) determine the shaft position. For this the Z pulse, the initialisation pulse, is used and there after the pulses A or B are counted;
2) determine the direction of rotation (comparing A with B)/
The rotating code disc of an incremental encoder consists of a disc that allows light through and which has a number of darkened strips to prevent light shining through. Fig. 1 shows what this involves. Notice also how A and B channels and the Z pulse are formed with the transparent parts. The code disc can be made of glass, metal or plastic.

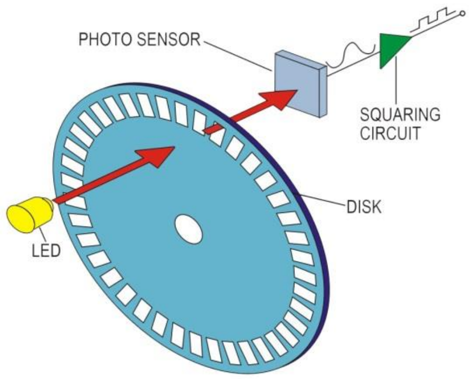

Fig. 1. Code disc of incremental encoder together with the resulting waveforms

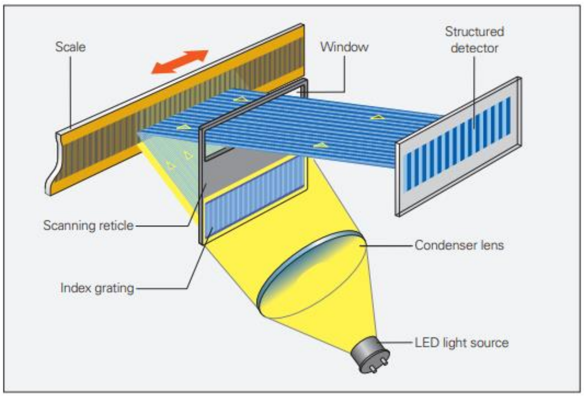

Fig. 2. Principle configuration optical encoder HEIDENHAIN

If the resolution has to be increased (more pulses per revolution) then the diameter of the disc (and thus the encoder) must be larger by necessity.A standard "trick" to increase the number of pulses per revolution involves differentiating the block wave. Take an encoder with 500 pulses per rev. Differentiation of the positive flank of the block wave in fig. 18-15 results in 1000 pulses per rev, and differentiation of the positive and negative flanks results in 2000 pulses per rev.The encoder is usually specified as : n pulses per rev with the options x2 and x4. The photo below from the firm Heidenhain shows once again the transparent principle of an optical encoder.

The input signal of the incremental encoder is the angular position θ of its shaft with respect to the fixed reference axis. The output signals are the two pulses shifted by a quarter angular step $A(\theta)$ and $B(\theta)$, respectively the marker signal $Z(\theta)$. If θp is the angular step of the encoder, the outputs may be described by the following equations :

ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 9, Issue 6, June 2022

$$A(\theta)=\begin{cases}1 & \text{if} \quad 0\le(\theta \bmod \theta_p)\le\theta_p/2;\\ 0 & \text{if} \quad \theta_p/2<(\theta \bmod \theta_p)\le\theta_p;\end{cases}$$
$$B(\theta)=\begin{cases}1 & \text{if} \quad 0\le((\theta-\theta_p/4)\bmod \theta_p)\le\theta_p/2;\\ 0 & \text{if} \quad \theta_p/2<((\theta-\theta_p/4)\bmod \theta_p)\le\theta_p;\end{cases} \qquad (1)$$
$$Z(\theta)=\begin{cases}1 & \text{if} \quad \theta \bmod(2\pi)=0;\\ 0 & \text{if} \quad \theta \bmod(2\pi)\ne 0.\end{cases}$$

During a rotation angle of the shaft, equal to the angular step of graduation θp, there are four switching events in the output pulses; therefore the minimal rotation-angle-increment detectable by the encoder is θp/4. The number of pulses, generated by the encoder in the course of a rotation, is equal with the number of angular steps of the graduation on the circular track on the rotor.

$$N_r=\frac{2\pi}{\theta_p} \qquad (2)$$

The speed calculation structure based on frequency measurement is presented in Fig. 3. In order to enhance the precision, the "Logic x4" block multiplies by 4 the frequency of the encoder signals. Two, alternatively resetted and enabled counters count the number of pulses. The content of the just disabled counter is used for speed computation. The speed identification based on frequency measurement produces relatively small errors at high speed because the number of pulses from the encoder in the measurement-time interval is high.

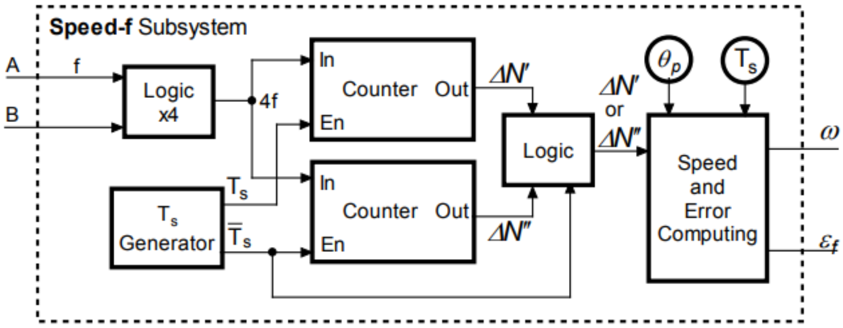

Fig. 3. The simulation structure of the speed computing subsystem based on frequency measurement.

The conventional MT-method for velocity measurement can be described as [8]:

$$v_k^{MT}=\frac{x_k-x_{k-1}}{T_s+\delta t_{k-1}-\delta t_k}, \qquad (3)$$

where x_k , δt_k and ν_K^{MT} are the acquired encoder positions, the elapsed time interval since the recent encoder pulse (sampled in the k-th sampling instant), and the estimated velocity calculated by the formula, respectively.

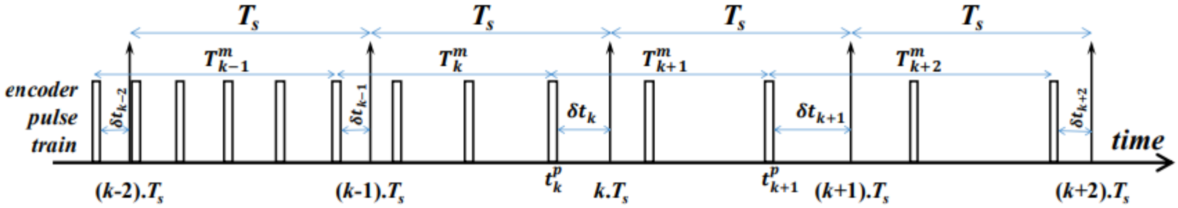

Figure 4. The timing diagram of encoder pulse train with sampling periods.

Though the sampling period is normally fixed, the measurement time interval T m, which extends between the edges of the first and the last position pulse captured in the measurement window, varies accordingly. Thus, smooth velocity output can be obtained that actually represents accurate velocity on the measurement interval. However, at low velocity, it may happen that encoder pulses may not occur in every sampling interval, but a single blank sampled period or a series of blank sampling

ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 9, Issue 6, June 2022

periods may appear before the next encoder pulse occurrence. Then, the previous formula can be rewritten as:

$$v_{k_i}^{MT} = \frac{x_{k_i} - x_{k_i - m_{i-1}}}{m_{i-1}T_s + \delta t_{k_i - m_{i-1}} - \delta t_{k_i}}, \quad (4)$$

where $m_i = 1 + n_i$, and n_i determines the number of blank sampling intervals. It means that if some encoder pulses appear in the k_i -th sampling interval, then this is followed by n_i blank sampling intervals, such that:

$$k_{i+1} = k_i + n_i + 1, \quad (5)$$

Thus, between the sampling intervals with encoder pulse occurrence there are n_i blank sampling intervals. The measurement interval is then extended for the same number of intervals. Note that the velocity estimation formula is calculated at the non-blank sampling intervals only.

As discussed above, feedback from an incremental encoder or other pulse sensor is the most common method of position and speed measurement in processor systems, with the output from an opto-detector or magnetic sensor converted to a TTL signal. The speed can be calculated from the pulse frequency or period.

The MCU timer can be used as a counter by connecting it to an input pulse stream. The pulses must be counted over a known time period, so a second timer is used to generate an interrupt after a suitable interval, which causes the MCU to read the counter. The final count must be high enough (within the maximum count available) to obtain a reasonably precise result, since the minimum error is ±1 bit. For example, if the count is 100, the minimum error is, by definition, 1%. With a count of 1000, it is only 0.1%.

V. EXPERIMENTAL RESULTS

In order to investigate different position and speed determination algorithms an experimental set-up is under construction (see Fig. 5). The incremental encoder (type 1XP8001-1) is mounted on the shaft of an induction motor driven by a static frequency converter. The encoder signals are processed by an experimental board built around a DSP based development board from Spectrum Digital. Storage Scope TDS3014 Experimental Board A,B,Z Ua,b,c IE IM Micromaster Frequency Converter PC Incremental Encoder Induction Motor Figure 5: Block scheme of the experimental rig.

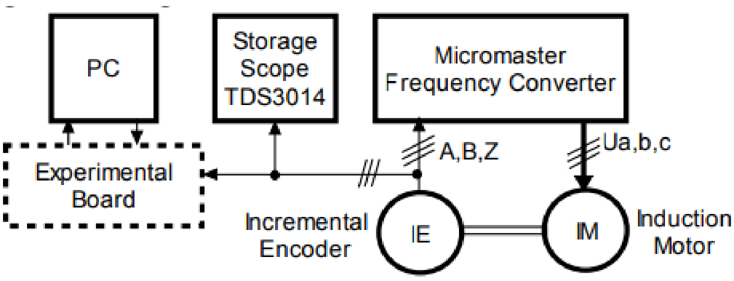

Figure 5: Block scheme of the experimental rig.

ISSN: 2350-0328

International Journal of Advanced Research in Science, Engineering and Technology

Vol. 9, Issue 6, June 2022

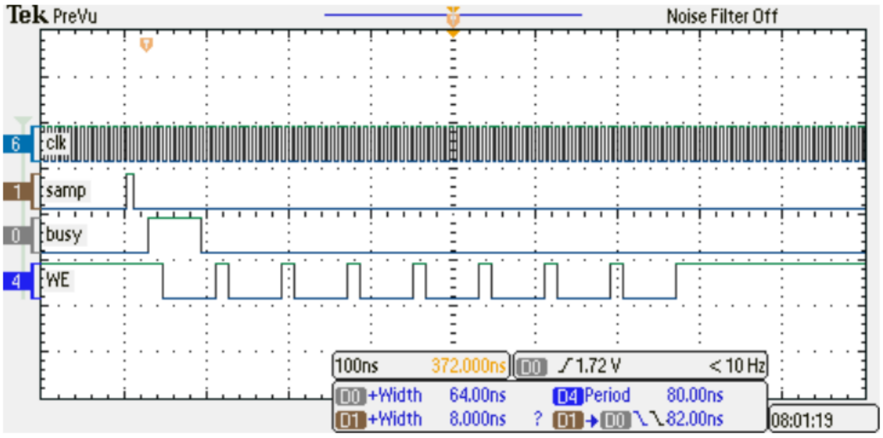

Figure 6: Captured encoder output signals

The consumption of the FPGA resources for the experimental design solution presented above is relatively small. For the calculation process, we used 5 dedicated 18 × 18 hardware multipliers, two blocks of RAM, and the total number of occupied logic cells was less than 5%.

VI. CONCLUSION AND FUTURE WORK

The information provided by the incremental encoders is inherently digital. The angular position of the encoder shaft is obtained by algebraic summing of the number of pulses provided by the encoder according to CCW and CW rotation. The direction of the rotation may be determined by a digital decoding scheme using the two quadrature signals. The direction changes are detected in an angular interval equal to a quarter of the angular step of the graduation. The frequency of the pulses generated by the encoder is proportional to the speed of the rotation. The error of the measurement is inversely proportional to the speed, therefore the procedure is appropriate for high speed region. At low speeds the measurement of the period of the encoder pulses is recommended. The measurement error is decreasing with the decreasing of the speed.

REFERENCES

[1] Kavanagh, R.C. Performance Analysis and Compensation of M/T-Type Digital Tachometers. IEEE Trans. Instrum. Meas. 2001, 50, 965–970. [CrossRef]

[2] Petrella, R.; Tursini, M.; Peretti, L.; Zigliotto, M. Speed Measurement Algorithms for Low-Resolution Incremental Encoder Equipped Drives: A Comparative Analysis. In Proceedings of the 2007 International Aegean Conference on Electrical Machines and Power Electronics, Bodrum, Turkey, 10–12 September 2007.

[3] Ohmae, T.; Matsuda, T.; Kamiyama, K.; Tachikawa, M. A Microprocessor-Controlled High-Accuracy Wide-Range Speed Regulator for Motor Drives. IEEE Trans. Ind. Electron. 1982, IE-29, 207–211. [CrossRef]

[4] Prokin, M. Extremely Wide-Range Speed Measurement Using a Double-Buffered Method. IEEE Trans. Ind. Elecron. 1994, 41, 550–559. [CrossRef]

[5] Kavanagh, R.C. An Enhanced Constant Sample-Time Digital Tachometer Through Oversampling. Trans. Inst. Meas. Control. 2004, 26, 83–98. [CrossRef]

[6] Pu, J.-T.; Wang, H. A Novel Variable M/T Method for Speed Measurement with High Precision. In Proceedings of the 2nd International Conference on Electronic & Mechanical Engineering and Information Technology (EMEIT-2012), Liaoning, China, 7–12 September 2012. [7] Hachiya, K.; Ohmae, T. Digital Speed Control System for a Motor Using Two Speed Detection Methods of an Incremental Encoder. In Proceedings of the 2007 European Conference on Power Electronics and Applications, Aalborg, Denmark, 2–5 September 2007.

[8] Lygouras, J.N.; Kodogiannis, V.; Pachidis, T.P.; Sirakoulis, G.C. A New Method for Digital Encoder Adaptive Velocity/Acceleration Evaluation Using a TDC with Picosecond Accuracy. Microprocess. Microsyst. 2009, 33, 453–460. [CrossRef]

[9] Chen, Y.; Yang, M.; Long, J.; Xu, D.; Blaabjerg, F. M/T Method Based Incremental Encoder Velocity Measurement Error Analysis and Self-Adaptive Error Elimination Algorithm. In Proceedings of the IECON 2017—43rd Annual Conference of the IEEE Industrial Electronics Society, Beijing, China, 29 October–1 November 2017. Sensors 2018, 18, 3250 28 of 28

[10] Merry, R.J.; Van de Molengraft, M.J.; Steinbuch, M. Velocity and Acceleration Estimation for Optical Incremental Encoders. Mechatronics 2010, 20, 20–26. [CrossRef]

[11].Zhu, W.-H. FPGA-Based Velocity Estimation for Control of Harmonic Drives. In Proceedings of the 2010 IEEE International Conference on Mechatronics and Automation, Xi'an, China, 4–7 August 2010.