EXPERIMENTAL STUDY OF PRECISION ANGLE ENCODER

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Abstract

The application of new and advanced production processes plays an important role in the development of the manufacturing industry. This trend is especially relevant to the automotive industry, where each element must ensure high quality requirements. Therefore, automating the automotive manufacturing process is necessary to ensure the highest level of control methods. For this purpose, various sensors are used, the signals of which are analyzed and the control plan itself is adjusted. Experimental investigations of a precision angle encoder were performed in the work. During the research, the dynamic characteristics of the created stand were determined. Experimental studies yielded the results of an experimental study of a precision angle encoder when the system is subjected to shock and harmonic excitation. In order to elucidate the effect of oscillations on the accuracy of a high-resolution coded precision angle encoder, primary electrical signals and their change under oscillations were recorded. Studies have shown that high-resolution code-precision angle encoders have different design responses to dynamic effects depending on the direction of the vibrations acting.

Keywords: precision encoder; measuring system; dynamic characteristics; dynamic characteristics; angle encoder; shock and harmonic excitation

1. Introduction

Ensuring the application of modern production methods in the automotive industry is essential to ensure an automated, flexible concept of production processes, in which process control is perhaps the most important element. The years of process control ensure

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the quality of the product, so measurement accuracy is an integral part of the manufacturing industry, especially in the automotive industry. CAM/CAE processes are widely used in the automotive industry, with measurement tools and technologies playing a key role. Therefore, the use of various optical encoders and the study of their applicability is an important process in ensuring the final quality of the product. Optical encoders play an important role in computer-controlled systems (CNC) [1], coordinate measuring machines (CMM), robotics [11], positioning systems [7], tracking systems [2] and other precision positioning systems [4].

The precision instruments uses feedback systems [15, 17], their errors can be divided into several groups: geometric and kinematic errors; thermal errors; dynamic and interpolation errors [5, 13, 16]. Under real operating conditions, dynamic devices using feedback systems develop dynamic factors that cause dynamic errors [3, 6, 8]. In most cases, high-precision systems (CNC or CMM) [9, 10, 18] are used dynamic factors are compensated by evaluating the entire system with integrated precision instruments using feedback systems [12, 14]. For this type of compensation, precision instruments using feedback systems are accepted as ideal measurement systems that operate without dynamic errors.

Speed/position sensors are most commonly used in the control of electrical machinery, the military industry, avionics, and more. These sensors are key components of variable speed drives. They provide information that can be used to adjust speed, position, or torque. The control of systems is highly dependent on the measured variables using sensors. In the event of sensor failures, these sensors cannot perform measurements properly. Sensor measurements can often be affected by temperature, vibration, or electric field.

Among the types of sensors suitable for measuring the change in angle, optical and capacitive encoders are most commonly used. Both optical and capacitive encoders are lattice displacement sensors that use repetitive periodic structure and incremental measurement techniques to perform position measurements. Due to their high resolution, accuracy and long service life, optical encoders are widely used as angular displacement sensors. However, optical sensors are not suitable for use when the system loses power, and when their operation is stopped, the angle position is reset to the original, even though the angle of the system itself has already changed. Therefore, even more sophisticated optical sensors have been developed - absolute angle change sensors. These sensors use a coded plate with light and dark strips that the system scans as the angle changes. Although absolute optical sensors work flawlessly when the system is disconnected from the power supply, the accuracy of these optical sensors is lower compared to traditional optical sensors.

2. Methodology of experimental studies of a precision angle encoder

Experimental tools allow to evaluate the properties of real objects and give the final characteristics of these objects, eliminating simplifying assumptions. With the development of increasingly complex structures, the number of design parameters that affect the properties of these structures and the specifics of their production is increasing. In realizing such constructions, both theoretical and experimental models are equally important and necessary. While numerical models allow the properties of systems to be modelled accurately, simple engineering models are sometimes more desirable to gain an intuitive understanding of the behaviour of systems.

In the experimental studies, studies were performed on different external excitations and the studies consisted of two parts:

a) when the measuring system of the angle encoder was stationary (the main shaft of the encoder was rigidly attached to the housing);
b) when the angle encoder measuring system has taken measurements, at constant speed.

The aim of the first studies is to determine whether the external excitation affects the subtraction accuracy of the angular encoder, the aim of the other studies is to evaluate the performance of the angular encoder at different external excitations. The scheme of the stand is shown in Figure 1.

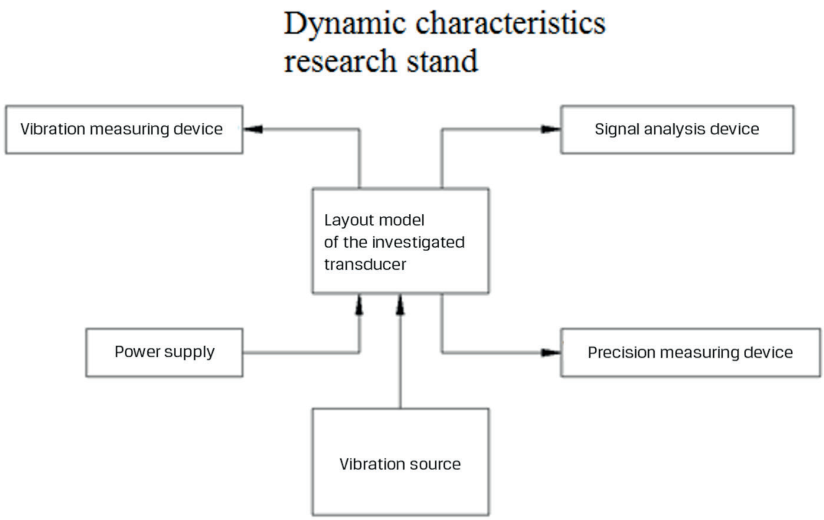

Fig. 1. Schematic of a research stand for the dynamic characteristics of a high-resolution coded precision angle encoder

Objectives of the study of the dynamic characteristics of the high-resolution coded precision angle encoder: To perform measurements of the axial and radial oscillations of the encoder coded disk and indicator grid and to determine the influence of various factors on the dynamic properties of the encoder; To perform measurements of the encoder output signals (analog and digital) and to determine their dependence on the parameters of the dynamic mode; To perform measurements of digital encoder output signals and to determine the influence of dynamic effects on the stability of the scanned signal.

Vibration measuring instruments from the Danish company Brüel & Kjær were used to measure the vibration parameters. The stand consists of an angle encoder system, data acquisition and processing equipment 3660D with a computer DELL, accelerometers and a signal generator and amplifier for a vibrator.

Description of research tools and methods. Brüel & Kjær measuring instruments were used to measure the vibration parameters. Figure 2 shows a block diagram of the determination of the dynamic characteristics of the system of a high-resolution coded precision angle encoder together with the mounting structure. Figure 2 shows the vibration measuring instruments: three-axis accelerometer 4506; portable measurement result processing equipment "9727" with computer DELL, alarm vibrator (Brüel & Kjaer 4811) with the control and amplifier. Accelerometers 4506 were mounted on the appropriate points on the encoder.

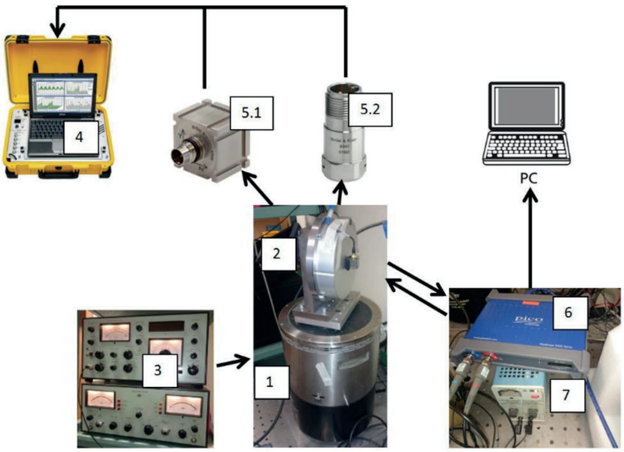

Fig. 2. High-resolution code precision angle encoder system with the mounting structure for determining the dynamic characteristics of the system

PicoScope 3203 measuring instruments were used to obtain data from the high-resolution coded precision angle encoder.

3. Research results

Experimental studies were performed in two stages: shock excitation, during which the aim is to determine the resonant frequencies of the system; forced excitation to investigate the operating parameters of the encoder at different excitation variants. Bench oscillation measurements were performed in three directions (X, Y, and Z directions in Figure 2) when there was shock excitation and vertically when there was forced excitation. When shock-excited system response results were used, Figure 3 shows a temporal plot of the system 2-point Y-direction acceleration in part a, part 3 b, c and d show the system 2-point (vibrator base and encoder housing) frequency plots, respectively. X (Figure 3d), Y (Figure

3b) and Z (Figure 3c). In the graphs in Figure 3, the notations next to the numbers "m" and "u" correspond to the multipliers 10^{-3} and 10^{-6}, respectively (see Figure 3). The results show the resonant frequencies of the system, and based on these results the operation of the system at resonant frequencies dangerous to the system was simulated.

These studies (Figure 3) highlight the significantly occurring resonant zones of (500-550) Hz, (800-900) Hz, (1100-1200) Hz and (1300-1350) Hz of angular encoder systems.

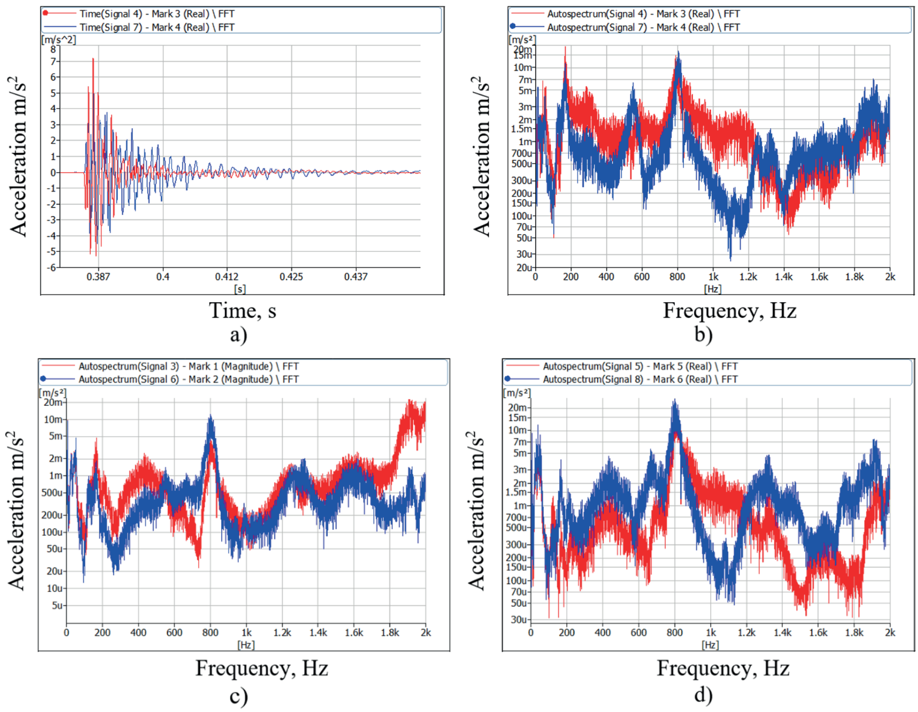

Fig. 3 Time-domain a) (Y-direction) acceleration and frequency acceleration curves of the 2-point high-resolution coded precision angle encoder system (Figure 2b vibrator base red curve and encoder body blue curve): b) – Y direction, c) – Z direction and d) – X direction

Evaluating the results in Figure 3, were followed by additional experimental studies using forced excitation using sinusoidal and random white noise generation signals. During this test, the values of the resonant frequencies were corrected, and at the same time the measurements of the angular encoder were performed. The main purpose of this test is to determine the effect of external excitation on the subtraction accuracy of an angular encoder. The results of the experimental results are presented in Figure 4, where parts a and c show the temporal graphs of the acceleration of the system at 2 points (Figure 2 vibrator base and encoder housing) in the Z direction, and parts b and d, respectively.

Figure 4 The temporal and frequency plots of vibration base and encoder housing acceleration in parts a and b show the system response to a resonant frequency of 1322 Hz, and it can be seen that the oscillation level of the angular encoder housing at this frequency is 7 times higher than the incoming oscillation level. Assessing Figure 4. The graphs in c and d show a series of resonant zones when the system is excited by a white noise signal. As with shock excitation, (500-550) Hz, (800-900) Hz and (1100-1200) Hz resonant zones occur, and in addition, this type of excitation highlights additional (1400-1500) Hz, (2200-2300) Hz, (2400-2500) Hz and (2800-2900) Hz resonant zones.

In order to elucidate the effect of oscillations on the accuracy of the High Resolution Code Precision Angle Encoder, the primary electrical signals and their change under oscillation were recorded. Studies have shown that a change in signals occurs.

Experimental results show that forced excitation affects the operating parameters of a high-resolution code precision angle encoder. Table 1 below shows the statistical characteristics of the angular sensor A and B signals at different excitation states.

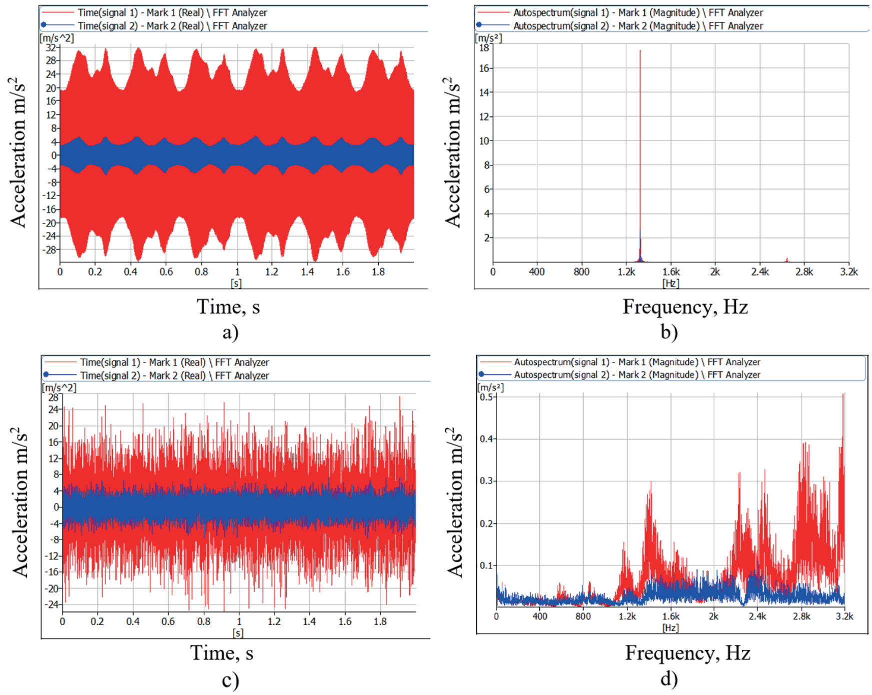

Fig. 4 Temporary (Z-direction) acceleration curves of the acceleration of the high-resolution coded precision angle encoder system at 2 points (Figure 2: red curve of the vibrator base and blue curve of the encoder housing) a) for sinusoidal excitation 1322 Hz; c) for random excitation, i.e. white noise and corresponding frequency acceleration plots; b) for 1322 Hz sinusoidal excitation; d) for white noise)

The Table 1 shows the statistical characteristics of the angular sensor A and B signals at 50 Hz, 500 Hz and 1322 Hz sinusoidal excitation, as well as white noise and when there was no forced external excitation. The output signals A (sine) and B (cosine) of the high-resolution coded precision angle encoder are presented as a function of time and in the form of a Lissajous curve in Figure 5.

Tab. 1. Statistical characteristics of the angular sensor A and B signals

Excitation frequency	Angle encoder output signal	Average	Standard deviation	Min	Max	Scatter
50 Hz	A	0.38017	0.15139	0.15693	0.59787	0.44094
50 Hz	B	0.39562	0.14886	0.18047	0.59614	0.41567
500 Hz	A	0.38034	0.14988	0.15970	0.58477	0.42507
500 Hz	B	0.37923	0.14956	0.17188	0.59705	0.42517
1322 Hz	A	0.37128	0.15099	0.16713	0.58925	0.42212
1322 Hz	B	0.39034	0.14429	0.18286	0.60118	0.41832
White noise	A	0.38619	0.13360	0.18908	0.57040	0.38132
White noise	B	0.39508	0.12893	0.20658	0.57600	0.36942
No vibrations	A	0.46294	0.16177	0.23906	0.69766	0.45860
No vibrations	B	0.48098	0.15502	0.26174	0.70842	0.44668

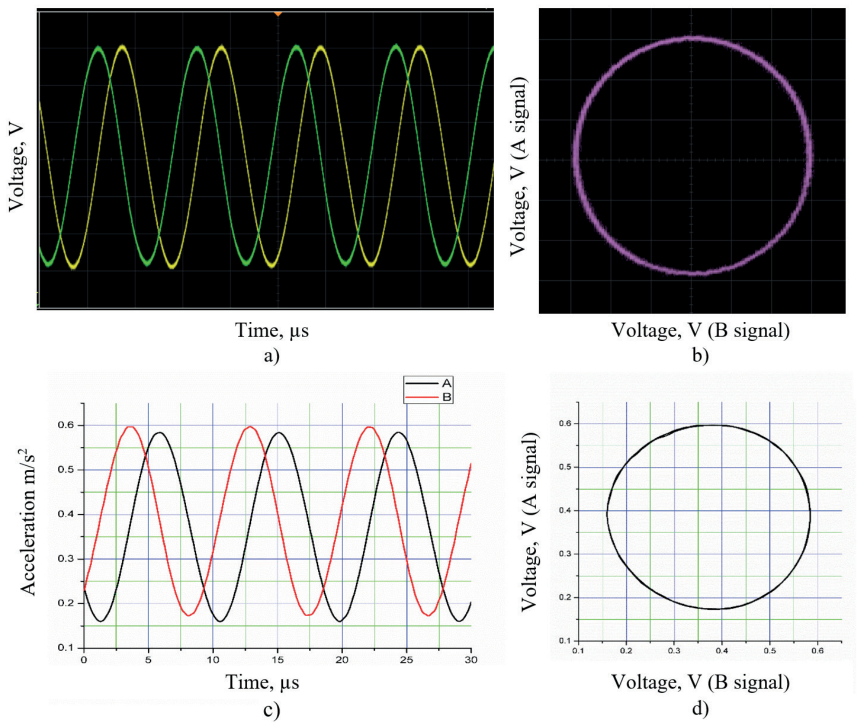

Fig. 5 The output signals A (sine) and B (cosine) of the high-resolution coded precision angle encoder are presented as a function of time and in the form of a Lissajous curve: a) when the encoder shaft rotates at a constant speed and has no vibration effect; b) when the sensor is subjected to random excitation and white noise; c) presented in the acceleration curves at the same conditions as a); d) presented in the voltage signals influence at the same conditions as b)

Assessing the statistical characteristics of the angular encoder A and B signals at different excitation states, it can be seen that the effect of external excitation is manifested by reducing the voltage values of minimum and maximum A and B signal voltages from 22.5 (signal A) to 52.2 (signal B), respectively. when evaluating the scattering of A and B signals, the effect of external excitation is manifested by reducing voltages from 7.45% (signal B) to 20.3% (signal A).

The performed researches of dynamic properties of high-resolution code precision angle encoder allow to evaluate the operating parameters that affect the qualitative properties of the encoder (accuracy and stability). Based on the obtained research, the design of a high-resolution coded precision angle encoder (optocouplers, scales, bearing mounting) can be optimized to reduce the influence of oscillations and increase the reliability / stability of the encoder operation in dynamic mode.

Axial and radial measurements of the high-resolution coded precision angle encoder code disk and indicator grid oscillations were performed and the influence of various factors on the dynamic properties of the encoder was determined.

Measurements of the encoder output signals (analog and digital) were performed and their dependence on the dynamic mode parameters was determined. Measurements of digital encoder output signals were also performed and the influence of dynamic effects on the stability of the read signal was determined.

The performed studies showed significantly resonant zones of (500-550) Hz, (800-900) Hz, (1100-1200) Hz and (1300-1350) Hz of the angle encoder system.

4. Conclusions

The performed researches of dynamic properties of high-resolution code precision angle encoder allow to evaluate the operating parameters that affect the qualitative properties of the encoder (accuracy and stability). Based on the obtained research, the design of a high-resolution coded precision angle encoder (optocouplers, scales, bearing mounting) can be optimized to reduce the influence of oscillations and increase the reliability / stability of the encoder operation in dynamic mode.

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Experimental investigations of a high-resolution code-precision angle encoder were performed in the work. Experimental studies were performed to determine the dynamic parameters of a high-resolution code-precision angle encoder under various internal and external conditions. The research framework can predict the regularity of changes in the dynamic parameters of analogous systems. The performed studies showed the occurring resonant zones of (500-550) Hz, (800-900) Hz, (1100-1200) Hz and (1300-1350) Hz of the angle encoder system.

In order to check the influence of the determined resonant frequencies on the accuracy of the high-resolution code-precision angle encoder, the electrical output signals A and B generated by the high-resolution code-precision angle encoder were analysed. The obtained values of signals A and B of the high-resolution code-precision angle encoder for various excitation variants show that the external excitation affects the accuracy of the high-resolution code-precision angle encoder and the given angular error.

5. References

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