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THE POSITION SENSOR IMPERFECTIONS AND ITS INFLUENCE ON BRUSHLESS DC MOTOR MOTION PROPERTIES

Summary. The paper presents the influence of position sensor (PS) imperfections on brushless DC motor (BLDC) motion properties. The following cases were considerate: improper location of the PS, asymmetrical construction and incorrect selection of the Hall sensors. The consequence of those foulest is: deterioration of motion properties, an electromagnetic torque decrease, increase of source current consumption and loss of the power.

WPŁYW WAD CZUJNIKA POŁOŻENIA WIRNIKA NA WŁAŚCIWOŚCI RUCHOWE BEZSZCZOTKOWEGO SILNIKA PRĄDU STAŁEGO

Streszczenie. W artykule omówiono wpływ czujnika położenia wirnika (PS) na właściwości napędu z bezszczotkowym silnikiem prądu stałego (BLDC). W pracy rozpatrzono następujące przypadki: czujnik położenia jest umieszczony w niewłaściwym miejscu, czujnik ma niesymetryczną budowę oraz wadliwy dobór sensorów hallotronowych tworzących czujnik położenia wirnika. Konsekwencją nieprawidłowej identyfikacji położenia wirnika może być pogorszenie właściwości ruchowych, wzrost prądu pobieranego ze źródła, obniżenie momentu rozwijanego przez silnik, a także wzrost strat.

1. INTRODUCTION

The main advantages of brushless DC motor (BLDC) over other motors include improved reliability, high efficiency, high power density, and an overall better dynamic performance. Those features of permanent magnet motors cause that other motors could be replaced by brushless dc motor and this contributes to increase industrial applications. In many publications referring to BLDC motor there are a lot of control systems description and electronic commutator control method. Currently vector control and sensorless control are very popular. However, in many industrial solutions often it is required to apply a simple, reliable and cheap control system. In most cases it is classical control system which uses information of rotor position. The block diagram of brushless DC motor in classical configuration is shown on fig. 1. For easy rotor position identification position sensor is used. The PS is consisted of three Hall sensors (rather optical sensors). The typical construction of position sensor based on hall sensors is shown in fig. 2b.

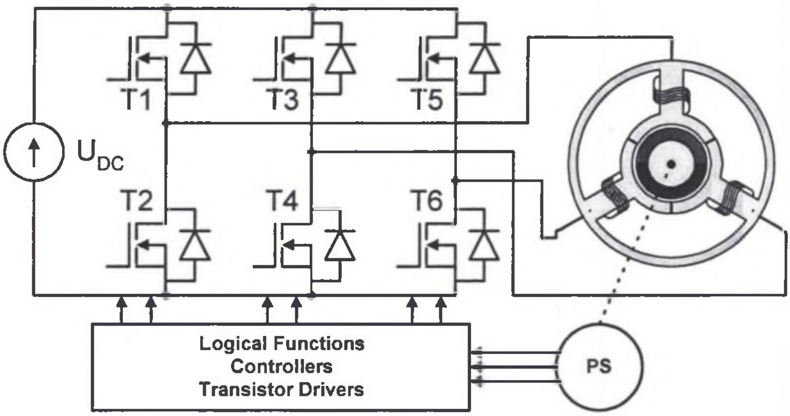

Fig. 1. Block diagram of brushless DC motor drive
Rys. 1. Schemat napędu z silnikiem bezszczotkowym prądu stałego

a) b)

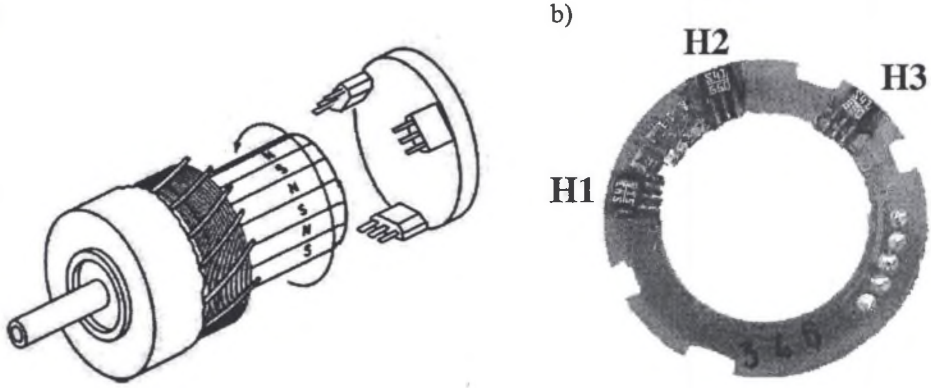

Fig. 2. BLDC motor: a) location of the position sensor and
b) construction of PS with 3 hallotronic sensors
Rys. 2. Silnik BLDC: a) umiejscowienie czujnika położenia wirnika oraz
b) konstrukcja czujnika z trzema czujnikami Halla

During motor drive parameters determination, the influence of position sensor on motion properties is often passed over. Usually it is assumed that position sensor matches well and always, under any condition it works correctly and reliably. But what can happen when position sensor is working incorrectly?

In the paper the authors describe three types of Position Sensor (PS) imperfections which can have significant influence of drive motion properties. There are as follows:

- improper location of PS,
- asymmetrical location of Hall sensors on PS surface,
- incorrect selection of hallotronic sensors.

The aim of the performed research was to determinate which construction imperfections of position sensor have essential influence on BLDC drive motion properties. The analysis in this paper concerns only PS with hall sensors.

2. IMPROPER LOCATION OF POSITION SENSOR

The brushless DC motor works correctly when PS is located in neutral position. The term neutral means that transistors are switched on only when electromotive force (EMF) has constant (maximum or minimum) value. It gives the constant level of machine torque. Proper location of position sensor and phase current (result of simulations) are shown in fig. 6.

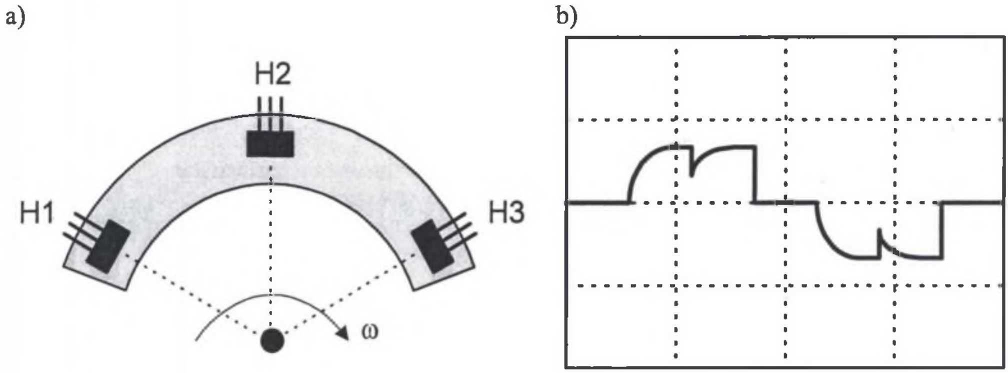

Fig. 3. The position sensor: a) in neutral position and b) waveform of phase current
Rys. 3. Czujnik położenia wirnika: a) w położeniu neutralnym i b) kształt prądu fazowego

Shift the position sensor from neutral position to new position in negative direction (under-commutation) always lead to increase phase current in the end of cycle (large impulse). This fact is cause that transistors of electronic commutator are not switching on at the moment when EMF has constant value. Switch transistors on with delay cause decrease velocity, electromagnetic torque, increase torque ripple and considerable increase loss of power in commutator and motor. The PS in under-commutation position and phase current (result of simulations) are shown in fig. 4.

Dislocation position sensor in positive towards (over-commutation) leads to earlier switching on the transistors. Generally over-commutation cause that in the moment when transistors are switched on appear high impulse in waveform of phase current. This impulse came from the same reason as in under-commutation – phase current appear not exactly in intervals of EMF constant value. Shift the PS to over-commutation position and phase current (result of simulation) is shown in fig. 5. In this case amplitude of impulse is smaller, because phase current starts from zero. In under-commutation impulse of current starts from constant value (deferent from zero), so its amplitude on the end of conducting cycle is higher. In narrow range of over-commutation angle it is possible to improve motion properties of the motor. The correction of PS position brings the reduction of torque ripple, increase torque and speed of the machine. The angle of over-commutation, which is leading to motor motion properties improvement, is variable value. It is a function of load torque, velocity and motor parameters. The mentioned problems are subject of the authors' separate research.

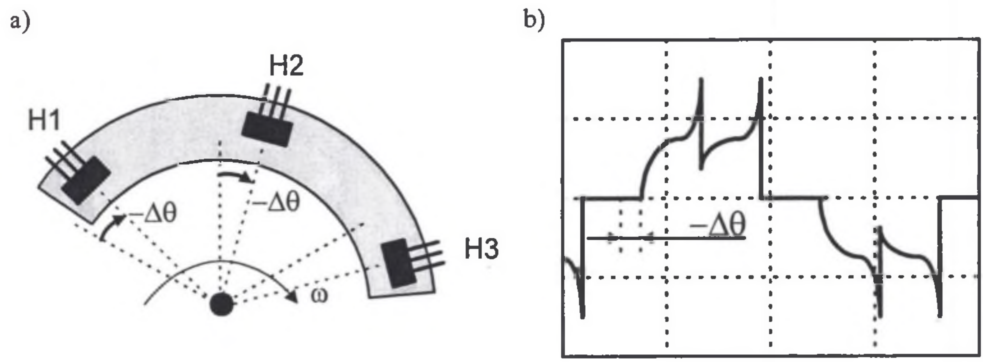

Fig. 4. The position sensor: a) in under-commutation position and b) corresponding waveform of phase current
Rys. 4. Czujnik położenia wirnika: a) przesunięty do warunków komutacji przyspieszonej, b) przebieg prądu fazowego

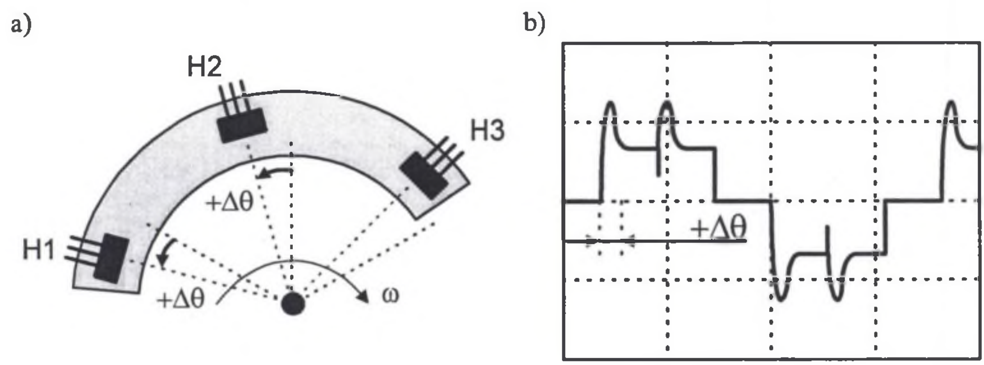

Fig. 5. The position sensor: a) in over-commutation position and b) waveform of phase current
Rys. 5. Czujnik położenia wirnika: a) przesunięty do warunków komutacji opóźnionej, b) przebieg prądu fazowego

3. THE ASYMMETRICAL LOCATION OF HALL SENSORS ON THE PS SURFACE

For proper work of the brushless DC motor it is also required the symmetrical construction of PS. What means, that hall sensors have to be placed on surface of PS with the 120° electrical interval. The mechanical angle between each hall sensors depends on the motor pole number. The symmetrical construction of the position sensor is shown in fig. 5a. Asymmetrical location of the Hall sensors at the PS surface (fig. 6b) has influence on the each transistor switch on/off moments. The described situation leads to change the conducting time of each phase, so it is possible to occur simultaneously under-commutation and over-commutation states in one phase current pulse. It means that in waveform of phase current two large impulses may appear - one at the beginning and one at the end of transistor conducting time. Of course in this case, the conducting time for one transistor is different than conducting time for the other one.

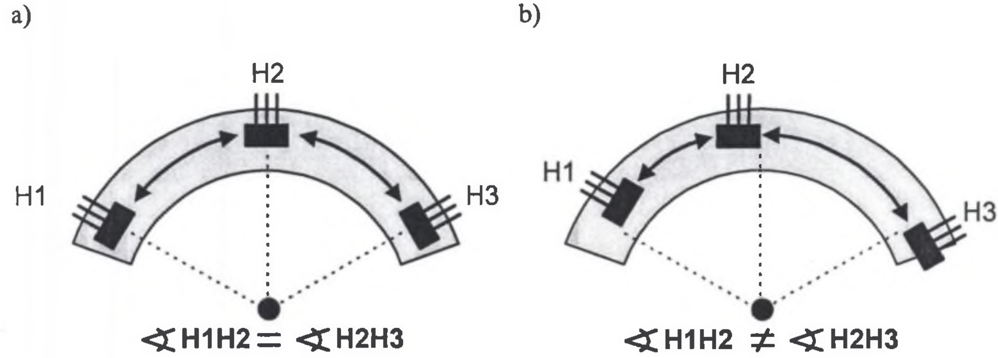

Fig. 6. The construction of position sensor: a) symmetrical and b) asymmetrical
Rys. 6. Konstrukcja czujnika położenia wirnika: a) symetryczna i b) asymetryczna

4. THE INCORRECT SELECTION OF HALL SENSORS IN PS

Additional condition for proper work of BLDC motor is correct selection of hallotronic sensors in the PS. Those Hall sensors should always work in state of saturation for both of magnetic air gap flux direction. It is strongly recommended to avoid linear operational range of hallotronic sensors.

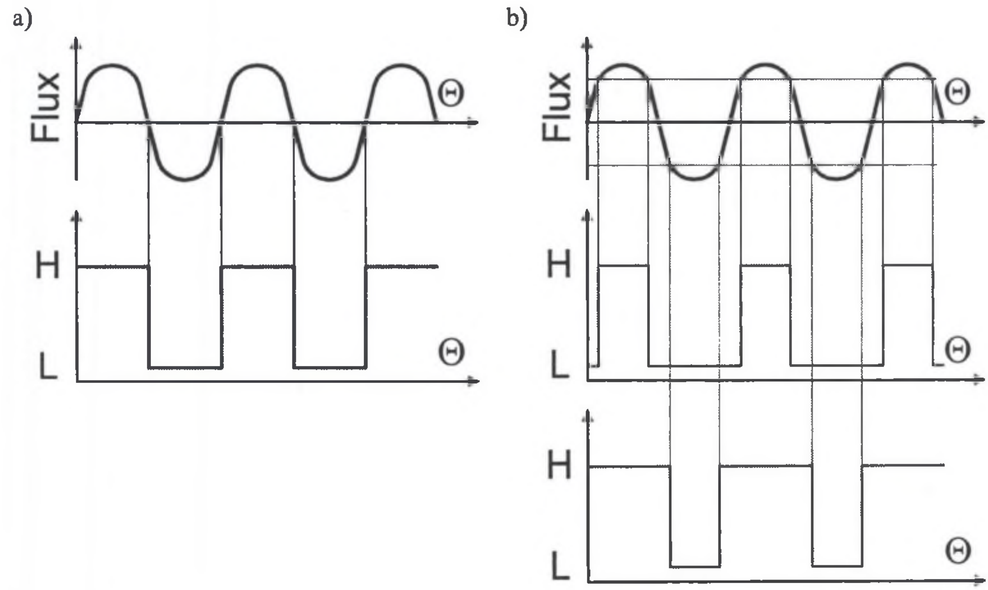

Fig. 7. Effects of the selection of Hall sensor: a) proper and b) incorrect
Rys. 7. Skutki doboru czujnika hallotronowego: a) właściwego, b) niewłaściwego

When Hall sensors work in the linear operational range the rotor position can be estimated inaccurately. The errors in conversion process are caused by the difference in the conducting times of transistors. Another imperfection, which can appear in hall sensors, is specific output voltage level for a given sensor. That manifest in different output voltage level for each hall sensor within framework of one PS.

The result of this error is the same as in the case of work in linear operation range. The incorrect selection of hallotronic sensors gives effect closed to the asymmetrical construction of Hall sensors on PS surface.

5. THE LABORATORY TEST

In the BLDC motor (under 1,2 kW) not large defects in construction and location of position sensor have lower influence on motion properties than in the motors of higher nominal power. For this reason in authors' research 3.6 kW brushless DC motor supplied with 24 V was used. The parameters of the motor are as follow: nominal current $I_n = 265$ A, rated speed $n_n = 2860$ min^{-1}, winding resistance $R_t = 0{,}94$ mΩ, and self-inductance $L_t = 3{,}66$ μH. The motor is equipped with PS based on three Hall sensors (A16L). Those sensors are mounted on a rotary ring, which allows for change the position of the PS and distance between two different hall sensors. For the purpose of project realisation the authors have made a special electronic commutator (fig. 8b). The construction of the converter is compact. Thanks that, the factor of power density (1,6 W/cm^3) and load-current (350 A) carrying capacity of the converter is relatively high.

a) b)

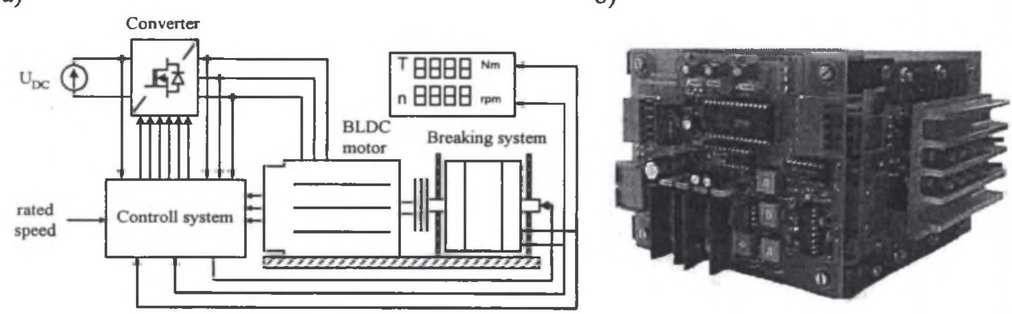

Fig. 8. The laboratory tests system: a) block diagram and b) the view of electronic commutator made by authors
Rys. 8. Stanowisko badawcze: a) schemat blokowy, b) widok komutatora elektronicznego skonstruowanego przez autorów

As a result of the laboratory tests waveforms of phase and DC-link currents are presented. Figure 9a shows the case of proper PS construction, and fig. 9b shows the same waveforms in case of asymmetrical PS construction. Next figure (10a) shows the reason of appearing the over-commutation and under-commutation - transistors are switched on and switched off when EMF has not constant value. Differences in conducting periods of each transistor are shown in fig. 10b.

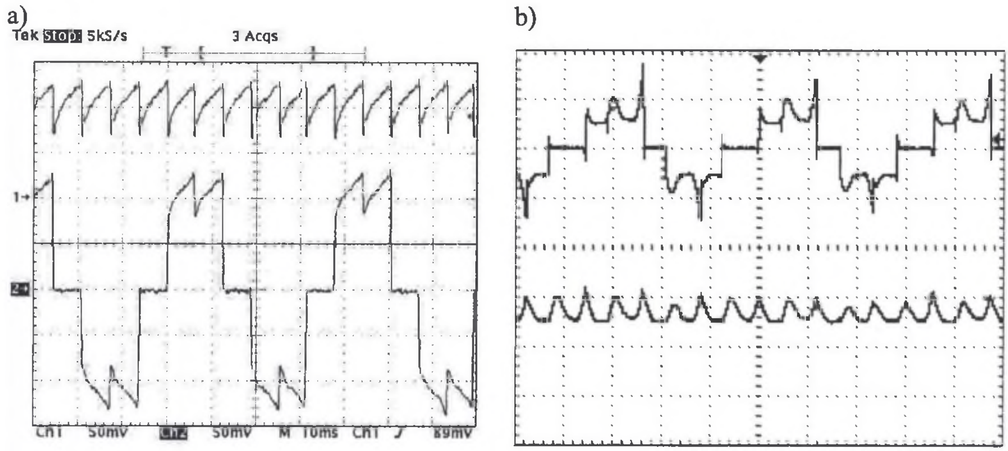

Fig. 9. The waveforms of phase and DC-link currents: a) in case of proper work of the PS and b) the same waveforms in case of asymmetrical construction of the PS
Rys. 9. Prąd fazowy i całkowity silnika w przypadku: a) poprawnej pracy czujnika położenia wirnika, b) te same przebiegi w przypadku jego asymetrycznej konstrukcji

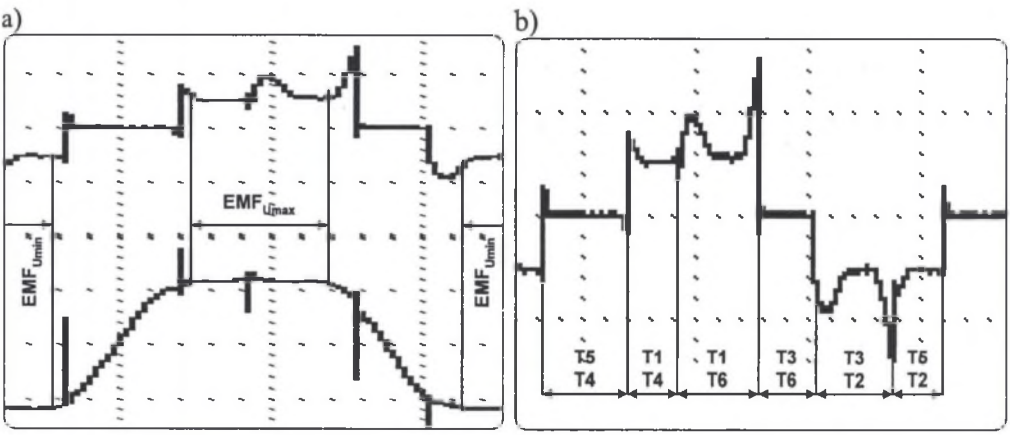

Fig. 10. Effects of improper work of the position sensor
Rys. 10. Skutki niewłaściwej pracy czujnika położenia wirnika

6. CONCLUSION

Motion properties of each drive depend on motor construction and control method. But in case of brushless DC motor these motion properties depend also on the position sensors. Improper position, asymmetrical structure or incorrect selection of Hall sensors gives defects in operation of the motor. The deterioration of motion properties can be the consequence of the rotor position incorrect identification. That means on the one side an increase the ripples of torque and DC-link current. On the other side it means the decrease of the electromagnetic torque. Finally the position sensor imperfections can even lead to the damage an electronic commutator.

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