Assessment of the influence of interference on the sliding mode observer

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Abstract. The article presents the results of studying the effect of interference on the sliding mode observer. The effect of interference in the lines feeding the engine is evaluated. The measured interference is present in the current signal. The operation of a sliding observer of the position and speed of the rotor of a permanent magnet synchronous motor is described. This observer is used as part of a sensorless vector drive control system. The presented version of the motor state observer is implemented by creating a model in the Matlab Simulink software package and tested on the bench using a 200W motor. The aim of the work is to develop an observer who is resistant to drive parameter changes.

1. Introduction
The use of permanent magnet synchronous motors (PMSM) has recently become increasingly common [1-5]. At the moment, the most widely spread systems are vector control PMSM. Vector control is widely used in processes where precise maintenance of speed or moment is necessary and ensures the absence of moment ripple, unlike DTC systems (direct torque control). A feature of this work is also the use of state observers based on the sliding mode. They have a number of attractive properties in terms of building automatic control systems. Vector control is quite demanding - current sensors, rotor position sensors are needed. For tasks where it is not possible to measure the speed and position of the rotor, sensorless control is used. To do this, an observer is added to the classical vector control structure, whose task is to calculate the position of the PMSM rotor from the measured currents in the lines feeding the motor. The data line is influenced by electromagnetic interference.

2. Model of the sliding mode observer
The considering the processes occurring in the PMSM, these equations should be used [6-10]:

\[ \Psi_d' = \Psi_r + L_s \cdot i_d \]

\[ \Psi_q' = L_s \cdot i_q \]

\[ U_d = R_s \cdot i_d + L_s \frac{di_d}{dt} - \omega \Psi_q \]
\[ U_q = R_s \cdot i_q + L_s \frac{di_q}{dt} + \omega \Psi_d \]  
(4)

Electromagnetic moment in axes «\( \alpha, \beta \)»:

\[ M = \Psi_\alpha \cdot i_\beta - \Psi_\beta \cdot i_\alpha \]  
(5)

in axes «d,q»:

\[ M \left[ (\Psi_d \cdot i_q - \Psi_q \cdot i_d) \right] = \Psi_r \cdot i_q + L_s \cdot i_d \cdot i_q - L_s \cdot i_q \cdot i_d = \Psi_r \cdot i_q \]  
(6)

One of the most common methods for calculating the position of the rotor is the method of determining the back-EMF [11, 12]. This approach uses the relationship between back EMF and the position of the rotor. Its essence is to calculate the spatial vector of back-EMF, which will allow to determine the angle of the rotor position. In the dq reference system, which is connected with the rotor, the rotor flux linkage vector is aligned with the d axis, and the back-EMF is always co-directed with the q axis [12-21]. Thus, the rotor positions can be calculated by projecting the back-EMF vector from the dq-system into the stationary reference system (\( \alpha \beta \)-axis). According to expressions (1) - (6), the projections on the \( a \) and \( b \) axes of the back-EMF vector can be defined as:

\[ e_a = \omega \Psi_m \sin \theta = -U_a + R_i a + L \frac{di_a}{dt} \]

\[ e_b = \omega \Psi_m \sin \theta = -U_b + R_i b + L \frac{di_b}{dt} \]  
(7)

Accordingly, the position of the rotor can be calculated from the formula:

\[ \theta = \arctan \frac{e_a}{e_b} \]  
(8)

We presume that the voltage on the stator is known. It is formed in the control system of the reference signals, and fed to the motor by means of an autonomous voltage inverter (AIN) with pulse-width modulation (PWM). Currents in the lines supplying the motor and stator voltages can be converted to a fixed coordinate system using the Clark transformation. We will form an observer in axes \( \alpha, \beta \), from equations 3,4,7 we can write the following expressions:

\[ \frac{d}{dt} i_{s\alpha} = \frac{R_s}{L} i_{s\alpha} + \frac{1}{L} (v_{s\alpha} - e_{s\alpha}) \]

\[ \frac{d}{dt} i_{s\beta} = \frac{R_s}{L} i_{s\beta} + \frac{1}{L} (v_{s\beta} - e_{s\beta}) \]  
(9)

The switching surface will represent a rich or sigmoid function.
Figure 1. Switching surfaces a) - linear function with saturation, b) – sigmoid.

Linear function with saturation is described by the relations:

\[
s = \begin{cases} 
  \frac{s}{\varepsilon}, & \text{if } |s| \leq \varepsilon \\
  \text{sign}(s), & \text{if } |s| > \varepsilon 
\end{cases}
\]

(10)

3. Analysis of the simulation results

Let us make a simulation of the operation of the control system in the presence of noise in the measured signals of the current of the lines feeding the engine. To do this, we simulate the presence of interference by adding white noise to the signals of the motor phase phases at a level of 10% of the amplitude value of the current. In Figure 2 shows the oscillograms of currents in the fixed coordinate system α, β.

Figure 2. Oscillograms of currents in axes α, β in the presence of white noise at the level of 10%.
In the presence of white noise in the measuring channels, an increase in the error in the calculation of the rotor position angle is observed. The error in calculating the rotor angle in the presence of white noise at a level of 10% is shown in Figure 3.

Figure 3. Oscillogram of the error of calculating the rotor angle in the presence of white noise in the signals of the motor stator currents.

4. Conclusion
Based on the existing theory of sliding modes, the observer state structure of a synchronous motor with permanent magnets has been developed. Based on the structure obtained, a model of a state observer in Matlab Simulink was developed. The results presented in Figure 2, Figure 3 allow us to conclude about the possibility of using this observer in robustness problems to the parameters drift in a wide range - the range shown in the figures covers the possibility of changing the specified parameters in the practical application of the algorithm.

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