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ROBUST CONTROL ALGORITHM FOR PMSM MOTOR WITH HALL POSITION SENSORS

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Abstract: *The paper deals with a development of robust control algorithm for electro-mechanical actuator, which is intended to delivery of fuel to Auxiliary Power Unit APU in an aircraft. Contemporary technological developments within the all-electric aircraft concept lead to replacement of existing hydraulic-mechanical circuits by intelligent actuators based on electrical servo drives which increase overall reliability and utility value, decrease operating costs, dimensions and weight. The aims of the development were to design a model of control algorithm for Electrically Driven Fuel Pump EDFP in accordance with rigid aviation standards and to verify this algorithm on a test bench that simulates a real fuel circuit. A Permanent Magnet Synchronous Motor PMSM is used as actuator and low-cost Hall position sensors are selected for sensing rotor position.*

Keywords: PMSM, EDFP, APU, Hall sensors, PWM.

1. Introduction

The EDFP is a part of APU and is composed of a fuel pump, Stop Valve (SV), PMSM with Hall sensors and Control System CS. The APU is a bleed-less turbine essentially supplying mechanical and/or electrical power to the A/C. The system architecture block diagram is depicted in the Fig. 1. The aim of this paper is focused only on design and verification of model of a complex control algorithm for the EDFP. The models of the other parts of this system were detailed described in papers (J. Toman et al., 2012; V. Hubík et al., 2008).

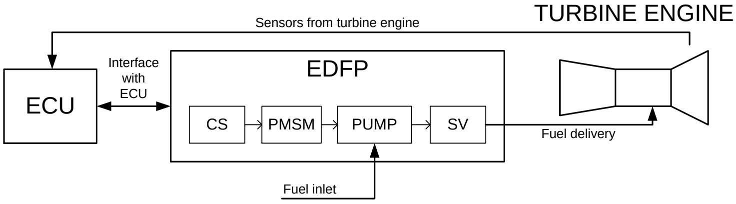

Fig. 1: EDFP system architecture.

The main problem of the control algorithms is to determine the position of the rotor with the accuracy needed for effective and safe operation. There are two well-known ways to determine the rotor position: a usage of common sensors like incremental encoder and resolver or a usage of Hall sensors. The usage of Hall sensors is advantageous because it does not require a mechanical coupling and the cost is low. The speed measurement and prediction algorithms can be used to solve the problem of a lack of information obtained from the sensors. This solution is effective when the speed changes of the rotor are negligible or at least are slow. If significant dynamic changes are present in the system, more complex control algorithms are needed to handle the obstacles caused by these changes. In addition, the reliability of algorithms will be guaranteed even if the sensor is faulty. This control strategy approach was inspired by papers (S. B. Ozturk et al., 2006; A. Lidozzi et al., 2007)

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The designed control algorithm shall ensure safe and reliable control of the PMSM motor that drives the EDFP. EDFP operation shall be ensured under various external conditions, including harsh environments and unknown initial states such as fuel pressure in the system, position of the rotor or necessary starting torque of the PMSM motor.

Requirements for the control system were defined during the early stage of the project by consultation with external aviation specialists. These requirements include electrical characteristics, reaction of the control system to defined incidents, start-up characteristics, control commands, environmental etc. From the control algorithm design point of view, the following main requirements shall be taken into account:

- The maximum underflow should be less than 2% at $\Delta\omega > 40\%$ and the fuel flow should stabilize in 240 ms.
- In case of stop command the EDFP shall stop in less than 100 ms

2. Control System Modeling and Simulations

The control algorithm was designed to improve the performance of a standard low-cost sensor control solution with three Hall sensors, without adding other demands on computational power. The main idea is to estimate the actual rotor position between sensed changes of the Hall sensors outputs by measuring the time period of a full electrical revolution and assuming that the next period has approximately the same length. This enables the estimation of the rotor position within one electrical revolution.

The whole control is realized by the Commutation&Control module inside the Control Electronics model. This model is shown in Fig. 2 with several external modules which give the necessary data, such as a timer, speed calculation and interrupt requests IRQA.

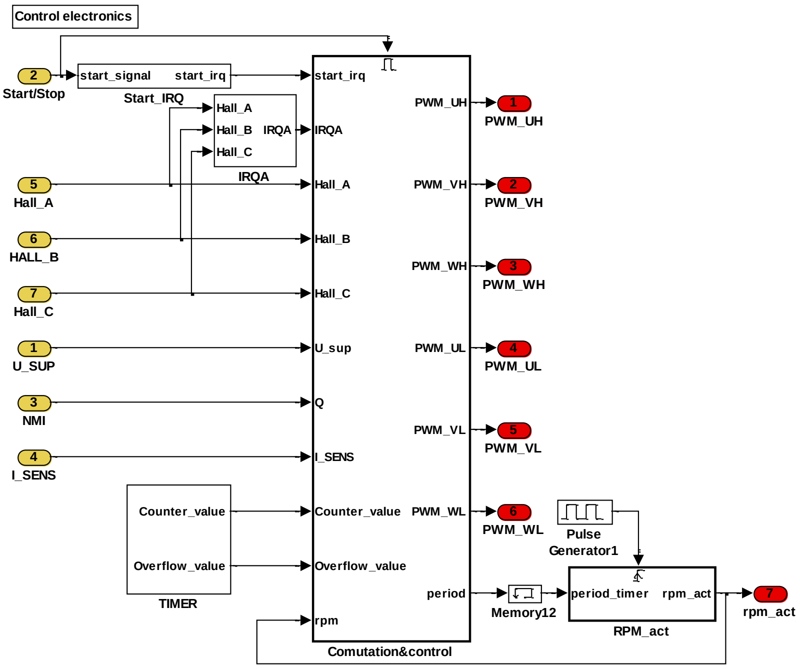

Fig. 2: Overall view of control electronics module with external speed estimation module, timer and interrupt generators.

Commutation&Control is the main module, which includes most of motor control procedures. Its operation is enabled by receiving the start signal. This subsystem and its modules are responsible for the following tasks: *IRQA_USR* - determining actual rotor position, computing revolution period, *Control_system* - speed and current control, generating PWM duty signal, *Period_correction* – correcting revolution period in case of sudden rotor stop, *TimerA* – generating interrupts to trigger function of *Sin_commutation* block, *Sin_commutation* - creating sinusoidal waveforms from PWM duty, *PWM* - generating pulse width modulated signal to drive power transistors, *Startup_timer* – aligning rotor into desired starting position, *Hall_interrupt* – generating interrupts based on Hall sensors output change. The model structure of this module is shown in Fig. 3.

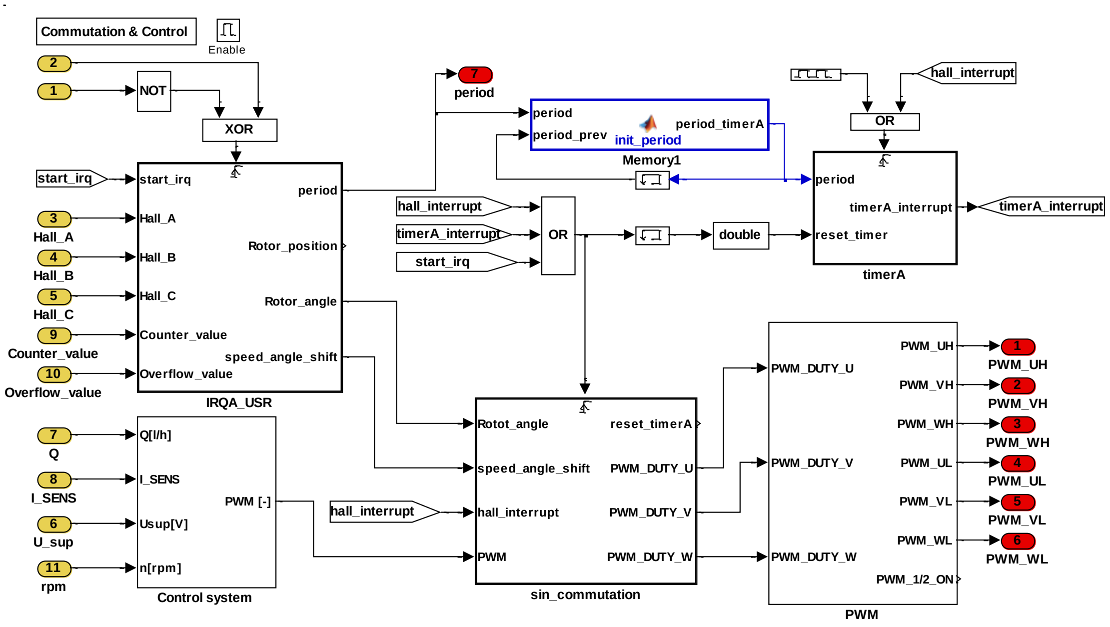

Fig. 3: Commutation & Control module.

2.1. Control system

Current and speed control system consists of two regulators, connected into the cascade. The difference is in the integrator limiting, which sets not only the limit for the maximum regulator output but also for the maximum increment in one computing step. The regulators are preceded by a switch disabling their function (and thus preventing them from integrating the regulation error) during the initial rotor positioning phase. PWM signal is connected to the Sin_commutation subsystem, its magnitude is corrected to cover a potential supply voltage drop. The anti-windup block and output saturation is implemented in the classic digital proportional-integral-derivative controller.

3. Verification of the Design Control Algorithm on Real Target

The control algorithm was implemented to control unit and then mounted on the EDFP and performance tests were carried out on an evaluation mock-up platform that simulates a real fuel circuit. These tests were performed with particular emphasis on start and stop sequences of the EDFP.

The start sequence of the fuel pump, shown in Fig. 4, was verified for a step change request from 50 percent of the fuel flow. This means that the starting flow level was 43 l/h (3250 rpm of the BLDC motor) at 2 MPa of back pressure. The required flow after step change should be 92 l/h (7300 rpm of the BLDC motor) at 3.9 MPa of back pressure. Fig. 4 compares the optimized pump characteristic with the original values. With a precisely tuned motor controller it is possible to achieve a start time of less than 200 ms and to fulfill the requirements.

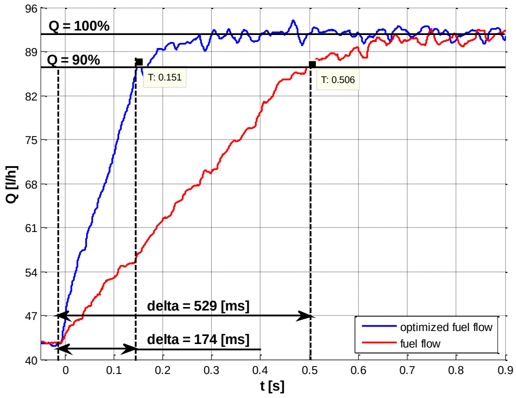

Fig. 4: The EDFP start sequence measurement.

The next important feature of the fuel pump is the stop time performance. This behavior is crucial for the turbine control system and dynamic of the whole hydraulic chain. According to the technical specification, the requirement is a stop time shorter than 100 ms when stop command received.

The stop time characteristic was much more difficult to measure. The directly connected speed or flow sensor to the fuel pump influences the stop time characteristic. The only way was to measure the speed from the motor’s internal Hall sensors. There are two graphs in Fig. 6 that represent the output signal from the position sensors. After a simple MATLAB post-process it is possible to evaluate the actual rotor speed.

The graph on the left side in Fig. 5 shows the stop time characteristic when the system is not perfectly optimized. The fuel pump should stop in this case from the nominal fuel flow of 92 l/h (7300 rpm of the BLDC motor) at 3.9 MPa of back pressure. It is obvious that the technical specification requirement has not been fulfilled. The stop time is more than 200 ms.

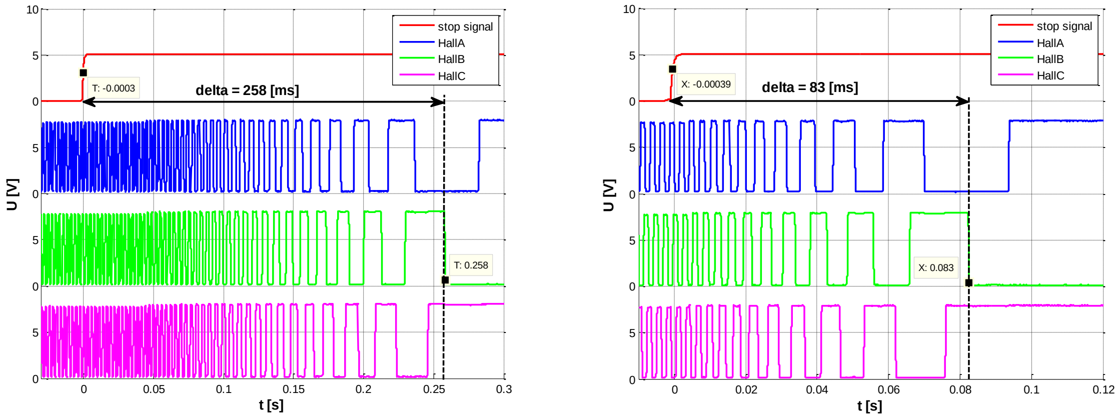

Fig. 5: The stop time characteristic with not optimized and optimized controller.

The second graph in Fig. 5 shows the stop time characteristic of the optimized controller. The same measurement method has been used in this case. The stop time has reduced to 83 ms which is acceptable.

4. Conclusions

Development and certification of any device in the aerospace industry requires a thorough approach, including definition of requirements, design of electronics, software coding and testing. In addition, very complex documentation must be maintained for the whole development and lifetime cycle.

The article describes the development of control algorithms to improve run-up performance and reliability of the EDFP with PMSM motor in actuating devices for safety critical applications. The development procedures described in this article indicate that they can bring about significant improvements in performance, safety and reliability of the control system along with reduction of development time and costs.

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