**INTRODUCTION**

The neutral and ionized gas mass spectrometer (NIM) built by the University of Bern for the Jupiter Icy Moons Explorer (JUICE) mission has two inlets. Depending on the operation mode, the gas either enters the instrument via an antechamber or directly via a radial slit. In order to shut off the entry via the antechamber the instrument contains a shutter mechanism driven by a brushless direct-current (BLDC) motor.

The scope of this work is the implementation of a control for this brushless motor, the characterization of the mechanism under different conditions and the validation that the proposed solution is reliable.

**BLDC MOTOR CONTROL**

The BLDC motor of the shutter mechanism is operated in open loop mode. A more complex control mode is not viable due to the mission related constraints:

- A vacuum and instrument compatible position sensor is not available.
- Detection of the BEMF is not viable due to the motor size and operation speed.
- PCB space constraints do not allow to measure the current of each motor phase individually.

These points make an operation in sensor based or sensorless mode impossible.

The implemented prototype controller generates the three necessary sine waves without any feedback. The model is implemented using the Simulink/Simscape environment which is part of the Matlab-software package.

- The model of the motor driver logic is equivalent to the prototype VHDL implementation.
- The switching PWM motor phase driver was modeled approximately using an average circuit approach.
- The remaining electronic circuits were modeled exactly.
- The BLDC motor model is based on the torque and BEMF constants.
- The mechanical models of the motor and gear were tuned based on physical measurements.

**FAILURE CASES ANALYSIS**

Based on a system decomposition of the shutter subsystem a failure mode and effects analysis (FMEA) was carried out.

The identified failure modes where grouped into failure cases with identical effects. These failure cases were individually analyzed via simulation. The analysis was focused on the visible effects on the available housekeeping values:

- Motor supply current
- Motor supply voltage
- Motor phase voltages

It was shown, that each case could be identified based on the available data. Especially the motor supply current is very rich in information with respect to the system condition. The following are some examples.

**Friction increase**

The next figure shows the standard deviation of the supply current during the constant speed phase for different amount of friction increase in the system. The optimum power operation point can be identified by the sharp drops in the curves.

**TEST SETUP**

An automated test setup was elaborated, controlled by a collection of python scripts and classes. It includes the following functionality:

- Configuration and data acquisition via lab instruments.
- Execution of test movements using the motor control prototype implementation.
- Execution of a list of test cases with different parameters.
- Centralized storage of the acquired data.

The setup allowed for the execution of fully autonomous multi-day test campaigns.

**SIMULATION SETUP**

A simulation model of the shutter subsystem was implemented using the Simulink/Simscape environment which is part of the Matlab-software package.

- The model of the motor driver logic is equivalent to the prototype VHDL implementation.
- The switching PWM motor phase driver was modeled approximately using an average circuit approach.
- The remaining electronic circuits were modeled exactly.
- The BLDC motor model is based on the torque and BEMF constants.
- The mechanical models of the motor and gear were tuned based on physical measurements.

The model is implemented to show a general equivalent behavior as the physical shutter setup. It is not tuned to give exact numerical values. The model is implemented for the following use cases:

- Analysis of the influence of numerical parameters of the VHDL controller implementation.
- Verification of the phenomena observed on the physical test model.
- Simulation of possible error cases, which would be impossible to replicate without destroying a physical model.
- Complementary use with the ground reference model during the mission.

**SHUTTER BLOCKED**

The following figure compares the nominal operation case with the case of a blocked shutter. The supply current vs time is plotted. In the case of a blocked shutter we can see the high oscillations of the current.

**Phase open circuit**

The next figure shows the case of an open circuit on one of the motor phases. Again a very distinctive behavior of the motor supply current can be seen.

**High speed housekeeping recording**

Based on the simulated observations we propose an additional feature for the implementation of the housekeeping recording in the flight instrument. In order to reproduce plots as presented above, the system needs to support recording the housekeeping data at a rate of at least 1kSps. This should be achieved via one or more dedicated block RAM storage elements and a synchronization of the recording with the motor movement.