FOSWEC2 Repair and Upgrade

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# Introduction

This report documents the efforts in repairing and upgrading the FOSWEC2 device. Major efforts include:

* Replacement of motor encoders from analog to digital based design
* Pendulum testing of motors and new encoders to establish torque constants
* Comparison of encoder noise pre and post encoder swap
* EtherCAT network definition and motor checkout without flaps
* Dry swing tests of flaps in an upside-down configuration of the FOSWEC2
* Repair of 6DOF load cell whose cable was compromised
* Complete update to MATLAB/Simulink operating software to update to new Speedgoat operating system and user interface
* Wave basin testing of the FOSWEC2 to verify all changes

# Encoder swap

A feedback stability issue with the FOSWEC2 deployment in February 2020 was identified and potential solutions explored. One issue identified was encoder noise. The original absolute encoder used on the FOSWEC2 was the Sick SKS36-HFA0-K02 with Hyperface interface. The encoder specs include 128 sine/cosine periods per revolution and 4096 total number of steps. As this is a hybrid analog/digital transducer, it is possibly susceptible to noise from the surrounding environment.

The Heidenhain ECN 1123 512 with EnDat2.2 interface was chosen as a fully digital replacement absolute encoder. This encoder has 23 bits per revolution or 8388608 position values per revolution. Custom adapter pieces were designed and fabricated by Sandia National Laboratories to allow for integration of the new encoder. A cad rendering of these pieces is shown in Figure 1

Logo

Description automatically generatedA picture containing telescope

Description automatically generated

Figure : Custom adapter parts for new encoders

# Pendulum tests

Pendulum tests were used to verify functionality of the new encoders and verify the torque constant for the motors. These tests are designed to determine the relationship between torque and current. This is necessary and relevant because most motor drives have current as their input and a relationship between commanded current and actual torque measured is desired. For these tests a custom coupler needed to be fabricated connecting the motor to the torque transducer. The rest of the test stand was repurposed from another project. The bench test setup is shown in Figure 1.

A picture containing text, floor, indoor, wooden

Description automatically generated

Figure : Bench setup of pendulum tests

Ramp tests were conducted to estimate the torque constant with a maximum current of 20A achieved. The test consisted of four ramp events two clockwise and two counterclockwise alternating as shown in Figure 2.

Chart, line chart

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Figure : Torque vs. Time for pendulum ramp tests

The torque-current relationship was plotted for each ramp segment as shown in Figure 3.

Chart, line chart

Description automatically generated

Figure : Torque vs. Current relationship used to estimate torque constant

and the MATLAB polyfit command was used to estimate the torque constant. This was done for the four ramp segments and the Kt values averaged. This was then repeated for the Bow motor and the results are summarized in Table 1.

Table : Kt estimates from pendulum tests

|  |  |
| --- | --- |
| Motor | Kt (Nm/A) |
| Aft | 0.9636 |
| Bow | 0.9438 |

The datasheet for the motor (MF0150025 with the 300V winding) lists a torque constant of 1.021 Nm/A +/- 10%, which gives limits of 0.9189 Nm/A and 1.1231 Nm/A. The measured torque constants for the bow and aft motors fall within these limits.

# Encoder Comparison

Initial evaluation of the noise characteristics comparing the old and new encoders position is detailed in this section. Ten seconds of data from dry testing on 12/18/2019 at 12:32:30 was used for the old encoder data. A section of test period where no commands were being issued to the drive was used. For the new encoders a pendulum bench test (aft20amps.mat and bow20amps.mat) from 9/1/2022 and 8/29/2022 respectively was used. Comparison of the time series of the two encoder signals are shown in Figure 5. Time from the two tests have been shifted to be on the same axis. Also, the means have been subtracted from both signals to be on the same rotation scales.

A picture containing graphical user interface

Description automatically generated

Figure : Comparison of old and new FOSWEC encoders

Comparison of the variance of the signals is shown in Figure 6. While this result is very encouraging, the true test will be when we are applying feedback in an in-water test.

Chart, bar chart

Description automatically generated

Figure : Variance comparison

# EtherCAT network definition

Because of changes in the Beckhoff module configuration due to changes in encoder needs and redundant modules, the EtherCAT network needed to be redefined. Additionally, addition of the Mini-DAQ to the EtherCAT network will require re-definition. This proved to be a challenge as getting the TwinCAT software to recognize the network with the two motor drives present was a challenge. Furthermore, attempts to customize the signals in and out of the motor drives failed and the default values was the only configuration shown to work. AMC\_AppNote\_017.pdf was used as a guide, but ultimately unsuccessful in customizing the network. Eventually a configuration was found that combines the two motor drives and two Beckhoff EtherCAT slave nodes.

# Motor checkout with flaps disconnected

Simulink model was created that configures and sends commands to the motors. Timeout errors were present when trying to set the operation mode of both motors at the same time through Simulink, so configuration was set to operation mode 10 which is cyclic torque mode through the DriveWare software. Code was left in Simulink model but commented out. A sinusoidal torque signal of 1A at 1s was sent to both motors with oscillating motion on both motors confirmed. Scaling on motor position was confirmed by commanding zero and manually rotating each motor one rotation and recording position data.

# Flap Load cell checkout

Checkout of FT30648 on the bow flap indicated a large negative offset in z (~-2500N). The flap and FOSWEC was disconnected from the load cell. While recording, compression force was applied by hand and the offset flipped to positive (~700N). Known weights were applied to the load cell on the bench and reasonable readings around this positive offset were observed. Flap was reconnected and similar positive offset was observed. Simulink model was updated to translate the coordinate system of the load cell into HWRL basin coordinate system.

FT17382 was returned to ATI for repair and calibration and will be integrated when returned.

# Flap SSI encoder checkout

Efforts to incorporate the Flap SSI encoder outputs in the model failed. Configuration in TwinCAT failed to create a scenario where the LED’s indicating valid data on the EL5002 module would light up. Many different configurations were attempted without satisfactory results. I hooked up an oscilloscope to the clock and data signals and they are both showing signals, however movement of the encoder does not induce changes in the count values. Needs further evaluation or change of sensor.

# Pressure sensor checkout

Nominal gains and offsets were used for the pressure gauges due to lack of factory calibration data. A pressure gauge calibration study was undertaken to get an understanding for these nominal gains and offsets.

There is one absolute pressure gauge inside the submerged enclosure. The main purpose of this gauge is monitoring and maintaining pressure inside the submerged enclosure and providing a reference for the gauge sensors in the enclosure. Its model number is TD1200BBA005003D002X and the range is 0-50psi. It is connected to a Beckhoff module EL3154, 4-20mA input. The EL3154 outputs a 16-bit integer. The sign bit is ignored and the range of 0-2^15 corresponds to 4-20mA. Therefore, the conversion from counts to psi is 50/2^15 with no offset.

There are four gauge style pressure sensors measuring the pressure between the inside and outside of the enclosure. These have a model number TDH41BGV01503Q005. Despite the data sheet indicating a range of Vac-15psi for this model number, the range listed on the sensor is -14.7-15 psi. These are connected to a Beckhoff module EL3154, 4-20mA input. The EL3154 outputs a 16-bit integer. The sign bit is ignored and the range of 0-2^15 corresponds to 4-20mA. To verify proper scaling for the sensors a study was conducted. First the performance of the EL3154 was tested. A decade resistance box was connected to the input of the EL3154 and was changed to input a 4-20mA input. The signal read in TwinCAT3 was then verified to be in the range of 0-2^15-1 for this current range as shown in Figure 7.

Next we hooked up one of the pressure sensors to a Fluke 2700G Series Reference Pressure Gauge and a pump and increased the pressure to 15 psi. Pressure was read into Simulink via the EL3154 and displayed in real-time on the screen. A video was taken of both the calibration and Simulink screen as shown in Figure 8. Appendix A gives a summary of the data analyzed. It was determined that using nominal gains was good enough at this time and were assumed as a slope of 29.7/2^15-1, and offset of -14.7.

A computer on a desk

Description automatically generated with low confidence

Figure : Testing the EL3154 by inputting 4-20mA and verifying output in TwinCAT3.

A desk with a computer and other objects on it

Description automatically generated with low confidence

Figure : Recording pressure on calibrator and with Simulink to verify scaling and offset values.

# Motor temperature checkout

Motor temperature was logged using the Beckhoff EL3692 modules and values seemed in a reasonable range and increased when the motor was loaded.

# VRU accelerometer checkout

VRU unit was disconnected from enclosure housing and manually rotated to verify angular motions.

# Inverted dry flap checkout

# Summary of FOSWEC2 updates

* Encoders were changed from Sick to Heidenhain
* Scaling was changed on gauge pressure sensors
* Simulink model was redesigned and updated
* Graphical User Interface was developed to interact with FOSWEC2
* Motor operation mode changed from “profile torque” (ID4) to “cyclic torque” (ID10)

# Appendix A

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | cts | psi meas | psi assumed  slope&offset | absolute error | psi meas  slope&offset | absolute error |
|  | 16225 | 0.0087 | 0.0063 | 0.0024 | -0.0674 | 0.0761 |
|  | 17504 | 1.1262 | 1.1656 | 0.0394 | 1.0919 | 0.0343 |
|  | 18775 | 2.3068 | 2.3177 | 0.0109 | 2.2439 | 0.0629 |
|  | 19949 | 3.1199 | 3.3818 | 0.2619 | 3.3079 | 0.1880 |
|  | 21156 | 4.4818 | 4.4758 | 0.0060 | 4.4019 | 0.0799 |
|  | 22506 | 5.575 | 5.6994 | 0.1244 | 5.6255 | 0.0505 |
|  | 23644 | 6.603 | 6.7309 | 0.1279 | 6.6569 | 0.0539 |
|  | 24737 | 7.5827 | 7.7216 | 0.1389 | 7.6476 | 0.0649 |
|  | 25686 | 8.6265 | 8.5818 | 0.0447 | 8.5077 | 0.1188 |
|  | 26936 | 9.6087 | 9.7148 | 0.1061 | 9.6407 | 0.0320 |
|  | 28030 | 10.5172 | 10.7064 | 0.1892 | 10.6322 | 0.1150 |
|  | 29160 | 11.6502 | 11.7306 | 0.0804 | 11.6564 | 0.0062 |
|  | 30170 | 12.5754 | 12.6461 | 0.0707 | 12.5718 | 0.0036 |
|  | 31273 | 13.5546 | 13.6458 | 0.0912 | 13.5716 | 0.0170 |
|  | 31838 | 14.2776 | 14.1580 | 0.1196 | 14.0837 | 0.1939 |
|  | 32565 | 14.7419 | 14.8169 | 0.0750 | 14.7426 | 0.0007 |
|  | 31238 | 13.5133 | 13.6141 | 0.1008 | 13.5398 | 0.0265 |
|  | 30152 | 12.5157 | 12.6298 | 0.1141 | 12.5555 | 0.0398 |
|  | 29029 | 11.5022 | 11.6119 | 0.1097 | 11.5377 | 0.0355 |
|  | 27921 | 10.4957 | 10.6076 | 0.1119 | 10.5334 | 0.0377 |
|  | 26838 | 9.4909 | 9.6260 | 0.1351 | 9.5519 | 0.0610 |
|  | 25573 | 8.5142 | 8.4794 | 0.0348 | 8.4053 | 0.1089 |
|  | 24467 | 7.5073 | 7.4769 | 0.0304 | 7.4029 | 0.1044 |
|  | 23539 | 6.5044 | 6.6357 | 0.1313 | 6.5618 | 0.0574 |
|  | 22296 | 5.5083 | 5.5091 | 0.0008 | 5.4352 | 0.0731 |
|  | 21316 | 4.5018 | 4.6208 | 0.1190 | 4.5469 | 0.0451 |
|  | 20194 | 3.5017 | 3.6038 | 0.1021 | 3.5300 | 0.0283 |
|  | 18971 | 2.4999 | 2.4953 | 0.0046 | 2.4215 | 0.0784 |
|  | 17987 | 1.5046 | 1.6034 | 0.0988 | 1.5296 | 0.0250 |
|  | 16885 | 0.5062 | 0.6046 | 0.0984 | 0.5308 | 0.0246 |
|  | 16331 | 0.0036 | 0.1024 | 0.0988 | 0.0287 | 0.0251 |
|  |  |  |  | mean abs error | | mean abs error |
|  |  |  |  | 0.0897 |  | 0.0603 |
| slope | psi/cts | 9.0636E-04 | 9.0640E-04 |  | 9.0636E-04 |  |
| offset | psi | -14.7731 | -14.7000 |  | -14.7731 |  |
|  | rsq | 0.999716984 | 1.0000 |  | 0.99971698 |  |