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The report will include: static and dynamic test of the actuator, test in different ranges of its operational range and comparison of two actuators.
One of the important fact that is discovered is that the actuator response has a clear hysteresis loop. This fact must be taken into account when using the actuator as trailing edge geometry on the wind turbine wing.

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Contents

1 Introduction

In this report a measurement study of the actuator TH-6R from Face International Corporation [1] is described. This work is part of the project ADAPWING carried out at Risø National Laboratory partly funded by the Danish Research Council. The ADAPWING project aims at developing a method to alleviate some of the fluctuating response of a wind turbine by using Adaptive Trailing Edge Geometry (ATEG). Different ATEG designs has been investigated, however, the most suitable found was the TH-6R actuator manufactured by Face International Co.

The project does not aim at making a system that can be sold to the wind turbine manufactures, but instead developing a prototype that can be tested in a wind tunnel and hence demonstrate the potential shown in earlier work [2]. The goal of this report is therefore not to investigate wether this actuator can be use in a closed loop controller system, but rather to uncover the potential of the actuator in a test environment.

Three major questions must be answered in this report to conclude wether the mentioned actuator is usable for this application.

- Static loading response.
- Dynamic response.
- Reproducibility of response for different actuators of same kind

The static loading response is important since the aerodynamic loading of the trailing edge will be non-zero and change with angle of attack and flap deflection. It is important to estimate how much deflection the aerodynamic loading causes since there will be no feedback control loop in the wind tunnel tests.

The dynamic response will be used to estimate the response of the actuator for intermediate fluctuations. It will provide results that can be used to estimate errors and lags in the actuators.

In the wind tunnel test the profile will be a 2 meter section with actuators along the full width of the profile demanding about 40 actuators. It is therefore important to investigate if the output response of one actuator is equal to that of another actuator or estimate the margin of error.

2 Test stand

The actuator is fabricated such that it can either be clamped or act as a cantilever beam supported at one end. For the purpose of an ATEG, the actuator will be acting as a cantilever beam, hence the test is rigged as shown in Figure 1.

The actuator is fitted with two strain gauges as seen in Figure 2; one at the root and one at the middle. Furthermore, a laser distance measurement device is setup to give an indication of the real displacement.

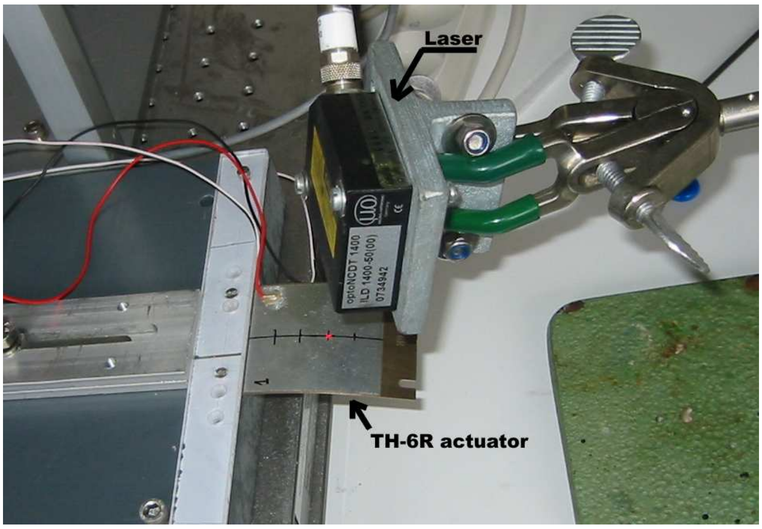

Figure 1. A picture of the test stand with the laser distance measuring device.

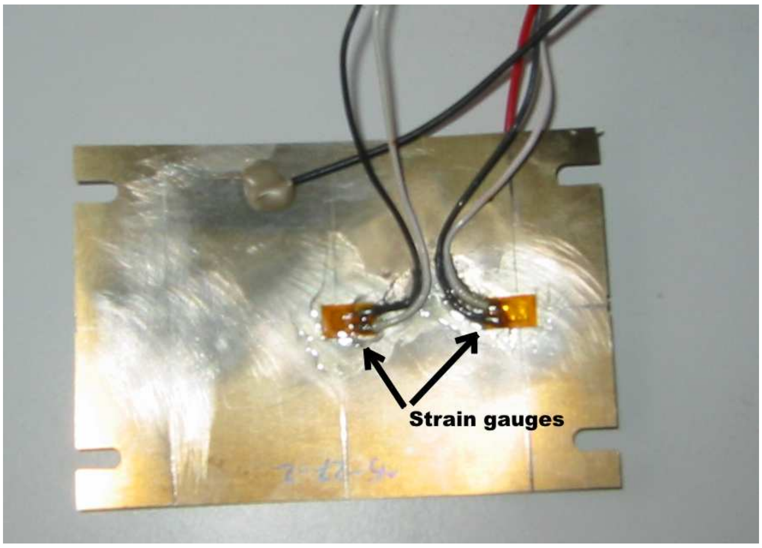

Figure 2. A picture of how the strain gauges are fitted the TH-6R actuator.

Figure 3. A picture of the amplifier use in the tests.

3 TH-6R data sheet

Face International Co. produces a number of different actuators in various sizes of with different response. For the test in the wind tunnel the airfoil section will be a 2 meter section with a chord of 60 cm. Earlier work show that a trailing edge flap of 10% of the chord length is sufficient to get a force response large enough without having a too large flap displacement. This result in an actuator with a length of about 6 cm. The TH-6R actuator is shown in Figure 4 and the properties are shown in Table 1 and Table 2.

Mass	16.3 g
Footprint (domed)	75.82 mm x 51.82 mm
Footprint (flat)	76.20 mm x 51.82 mm
Piezo Thickness	0.38 mm
Total Thickness	0.71 mm
Dome Height	4.24 mm
Capacitance	77 nF

Table 1. TH-6R Dimensions and Physical Properties.

Max. Voltage	
-	+
450V	900V

Table 2. TH-6R Specifications: Electrical Properties.

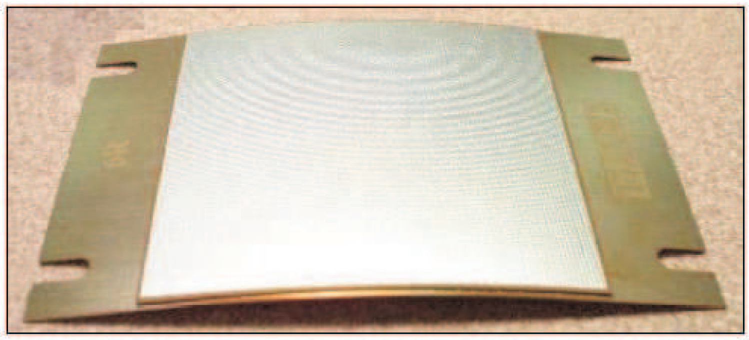

Figure 4. A picture of the TH-6R actuator.

4 Measurements

In this section the most important results from the tests are shown and commented. The tests chosen are selected to get the best overview of the response of the actuator in different configurations.

4.1 Static test

For the purpose of an ATEG the actuator needs to have a certain stiffness to carry the aerodynamic forces on the trailing edge of the airfoil. These forces are estimated using a attached flow code and for worst case scenario corresponding to a case where the angle of attack is 10 degrees and the angle of the flap is 10 degrees. Figure 5 shows the forces on the ATEG. Converting this distributed aerodynamic force to a single load such that it can be tested in the test stand results in a 50 g mass at the end of the actuator. The 50 g gives a displacement of 1.4 mm which is equivalent to about 1.4 degrees. This error must be taken into account in the wind tunnel tests. This is one of the reasons for the strain gauges which will be used as a check.

4.2 Full peak-to-peak (-450 to 900 V) at 0.45 Hz

In this section the actuator is tested in its full range. The peak-to-peak voltage values are from -450 V to 900 V. This is tested at 0.45 Hz in 600 s.

In Figure 6 the displacement of the actuator at 54 mm is shown as a function of the voltages applied to the actuator. It can be seen that there are some hysteresis in the actuator, as the response is a loop.

In Figure 7 a small section of the time series is shown for the voltage and displacement response. The red curve is the input voltage to the actuator while the blue curve is the laser measured displacement. It can be seen that there is a phase difference between the input voltage and the displacement output. The phase difference is larger for intermediate voltage and become less at the peaks. This fact could also be seen in Figure 11 where the loop is a ellipse with "sharp

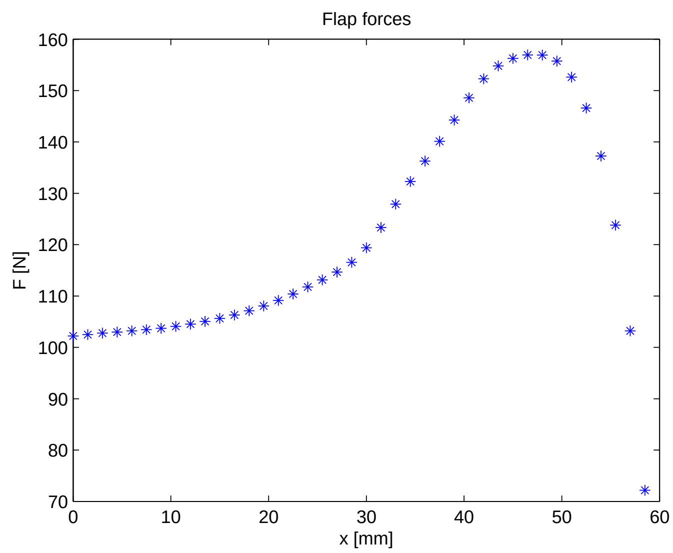

Figure 5. Forces on the last 10% of the airfoil when angle of attack is 10 degrees and the flap angle is 10 degrees.

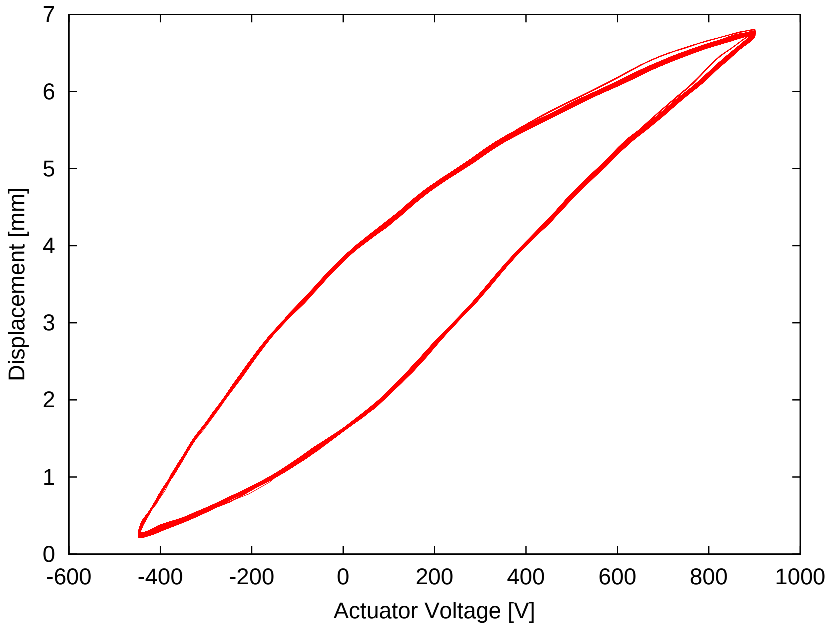

Figure 6. Displacement as a function of actuator input voltage.

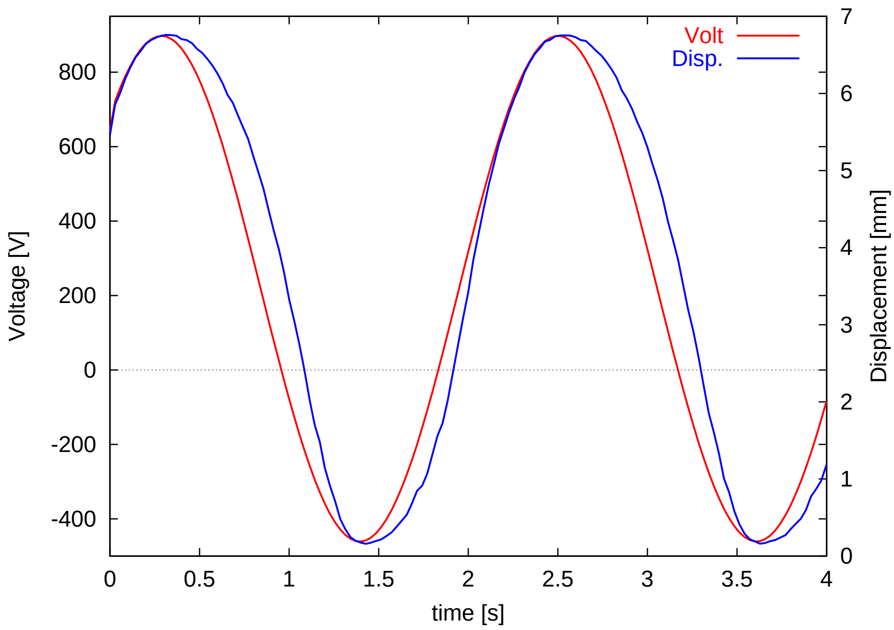

Figure 7. Voltage on y1 axis and displacement on y2 axis as a function of time.

ends". The more open the loop is the bigger the phase difference is.

4.3 Mixed signal at 0.45 Hz

In this next test the input signal varied as follows: Full peak-to-peak the first 3 minutes, 400 V to 900 V the next 3 minutes, -450 V to 50 V next 3 minutes and the full peak-to-peak the last minute of the 10 minutes time series. This input signal is shown in Figure 10.

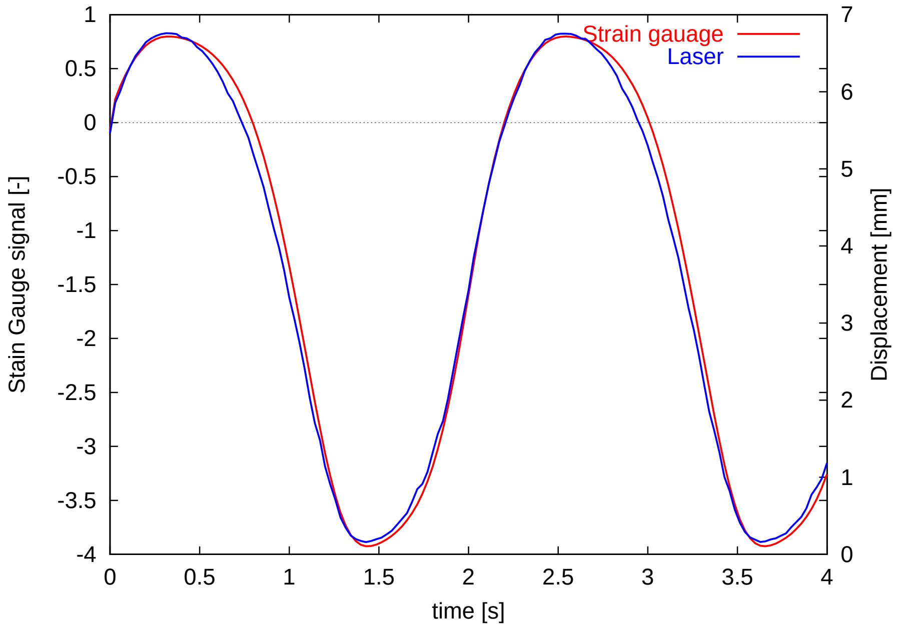

Figure 8. Strain gauge signal on y1 axis and displacement on y2 axis from the laser as a function of time.

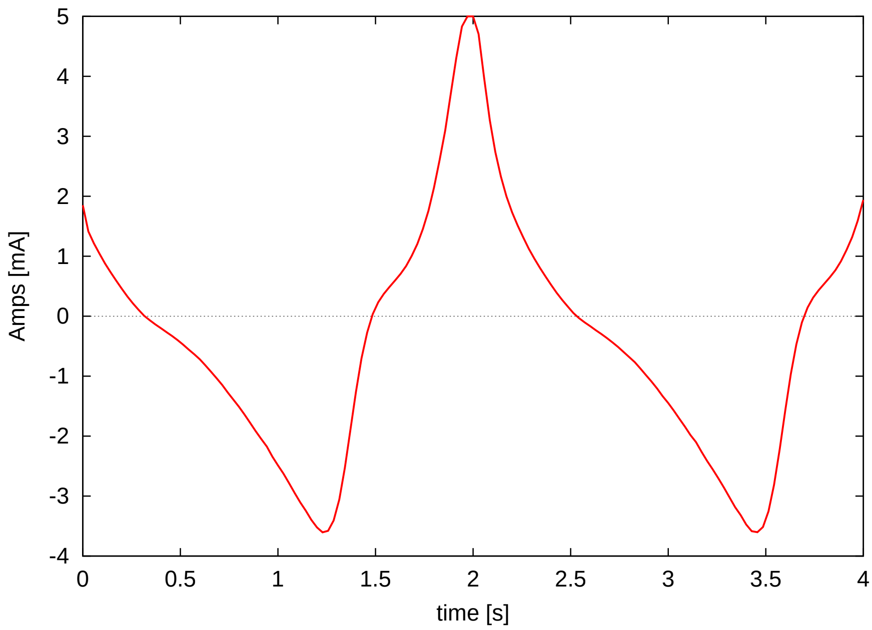

Figure 9. Amps as a function of time.

In Figure 11 the displacement is shown as a function of the input voltage. Similar loop as seen in the previous test is seen.

The corresponding laser displacement output signal is shown in Figure 12 as a function of time. The full peak-to-peak input results in a displacement as expected from the previous test. For the next 3 minutes with 400 V to 900 V input a slight increase in the maximum output displacement of about 0.3 mm is seen, which is unexpected. The displacement amplitude is unchanged.

In the next 3 minute series with input voltage of -450 V to 50 V an ever worse

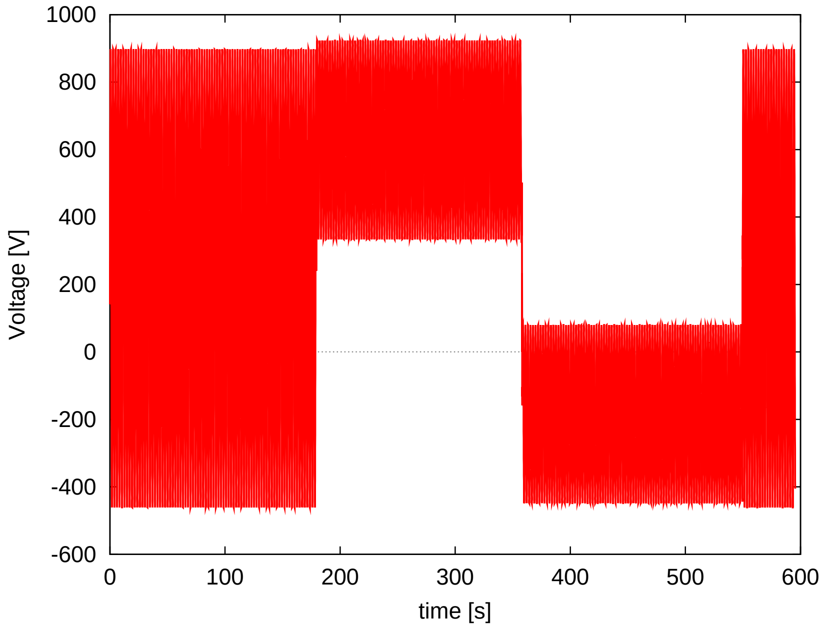

Figure 10. Voltage as a function of actuator input voltage.

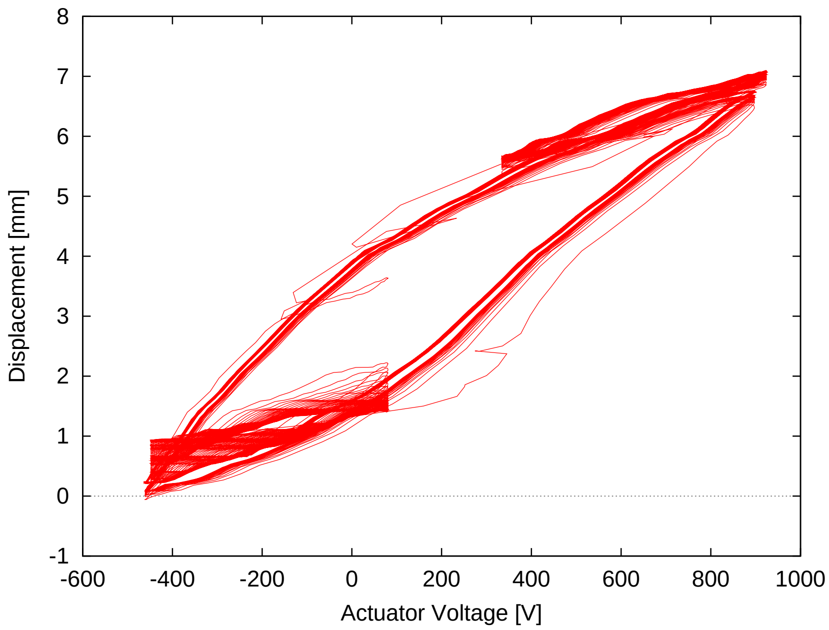

Figure 11. Displacement as a function of actuator input voltage.

characteristic is discovered. The displacement amplitude starts with an expected size, however, as time goes the amplitude decreases. A test is therefore run at this low voltage range during the whole 10 minute period. The time series can be seen in Figure 13. The amplitude in the beginning of the time series is about 1 mm, however, after about 4 minutes the amplitude is decreased to zero. Here after the amplitude increases again with a higher maximum value. This unpredictable behavior can be a huge problem for the wind tunnel application.

To further investigate this behavior a second actuator of the same kind is tested.

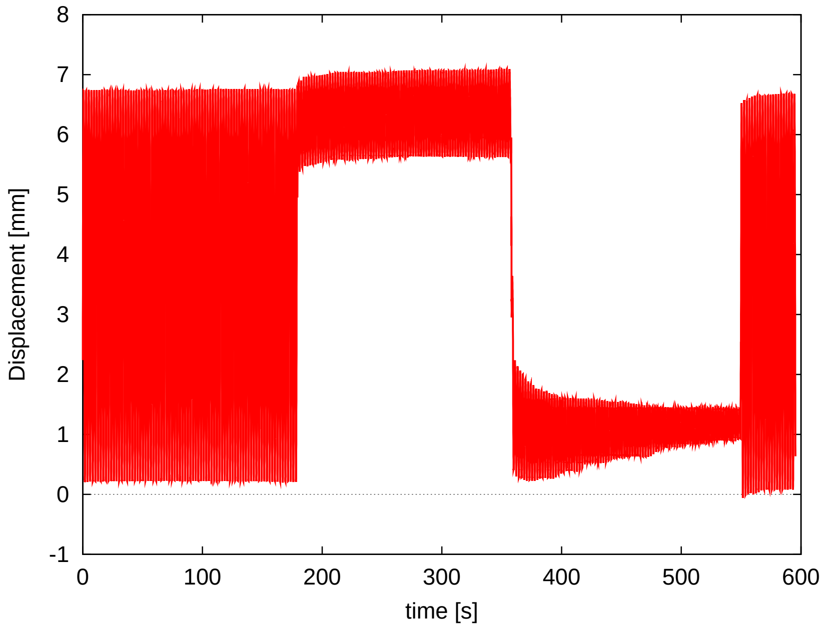

Figure 12. Displacement as a function of time for the mixed signal.

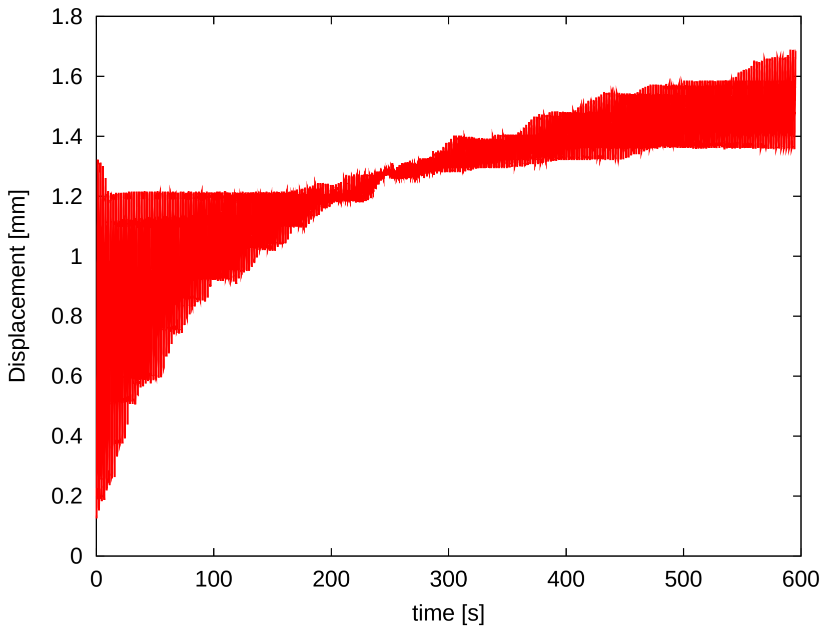

Figure 13. Displacement as a function of time for the signal -450 V to 50 V.

The displacement response for the second actuator is shown in Figure 14. The same behavior is not seen. The amplitude of the out decreases like in the last test as seen in Figure 15, however, after about 20 seconds the amplitude stabilizes at a given interval for a period of about 3 minutes as seen in Figure 16. After this period the amplitude again decreases (as seen in Figure 17) to settle at a constant level for the rest of the time series. This rather unpredictable behavior will result in a modified range of usage.

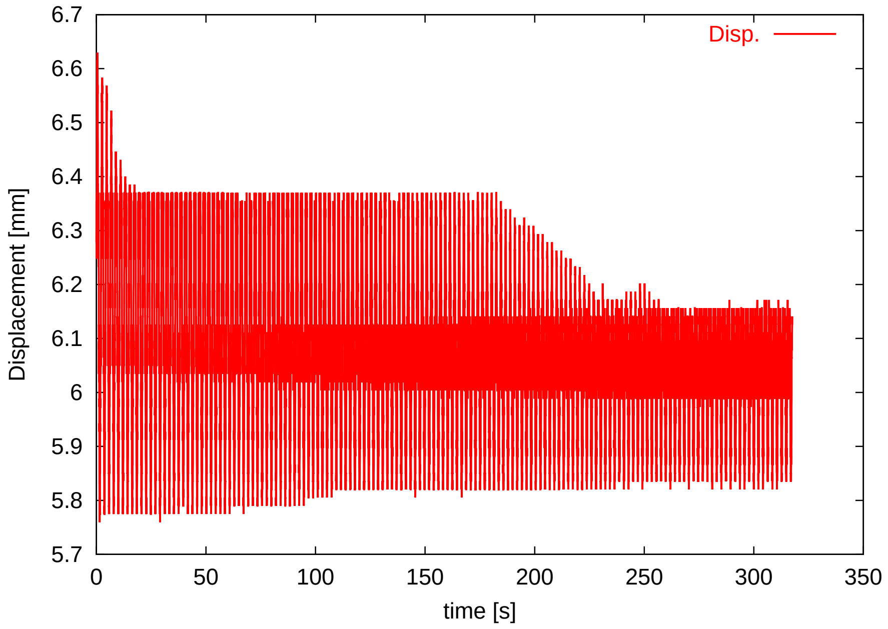

Figure 14. Displacement as a function of time.

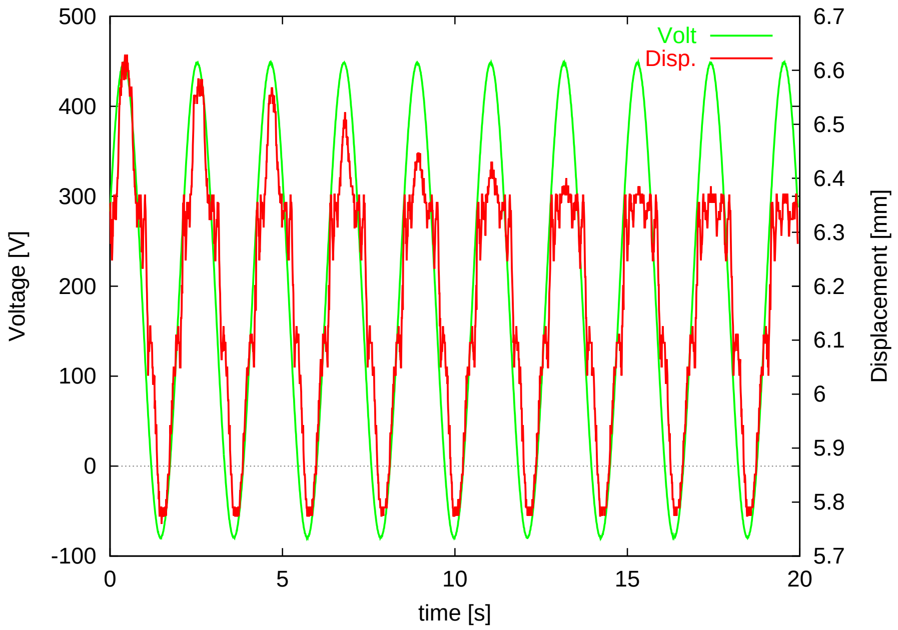

Figure 15. Displacement and voltage as a function of time in the period from 0 to 20 seconds.

4.4 500 to 900 V at 0.45, 1 and 5 Hz

In this section the actuator is tested in an upper voltage range from 500 to 900 volt. In Figure 19 the displacement is shown as function of the input voltage for 0.45, 1 and 5 Hz. The level of displacement and the amplitude is within an acceptable range of error. The reason for the smoother curve at 5 Hz is that all the curves were done for the same sample frequency.

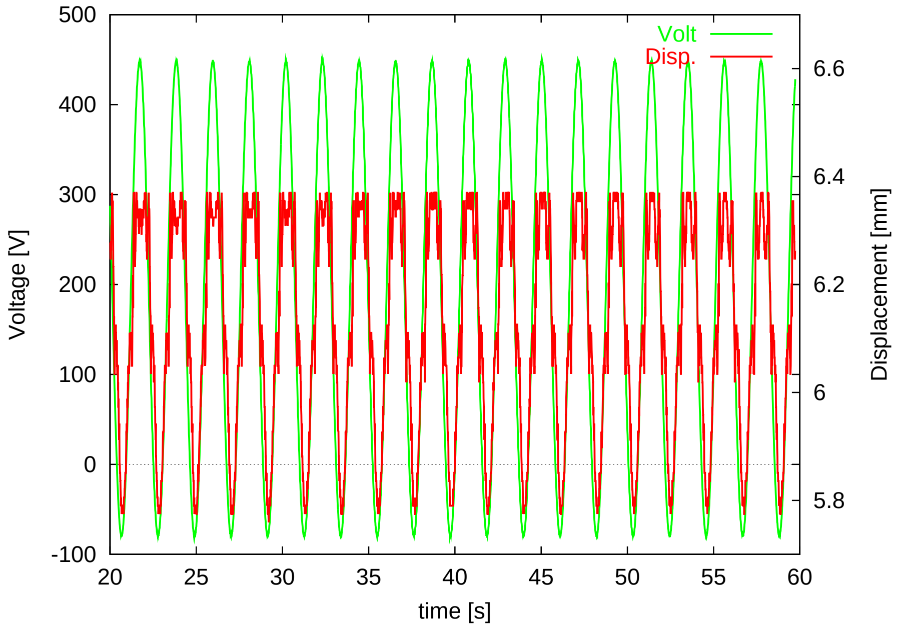

Figure 16. Displacement and voltage as a function of time in the time period from 20 to 60 seconds.

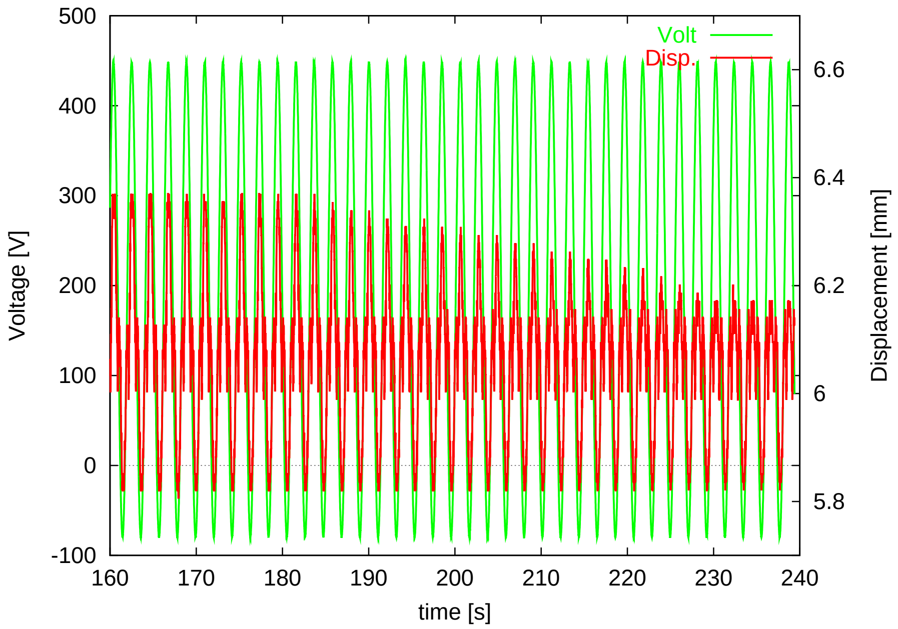

Figure 17. Displacement and voltage as a function of time in the period from 160 the 240 seconds.

4.5 Different intervals at 0.45 Hz

In this section the following intervals are tested; -450 to -50V, -200 to 200V, 200 to 600V and 500 to 900V. The resulting responses can be seen in Figure 20. As just discussed the actuator response for the ranges where there are negative voltages are unpredictable. The high voltage range series are as expected. The hysteresis loops are small for the highest ranges while the response for the series 200 to 600V has more hysteresis. These results are as expected from the peak-to-peak results.

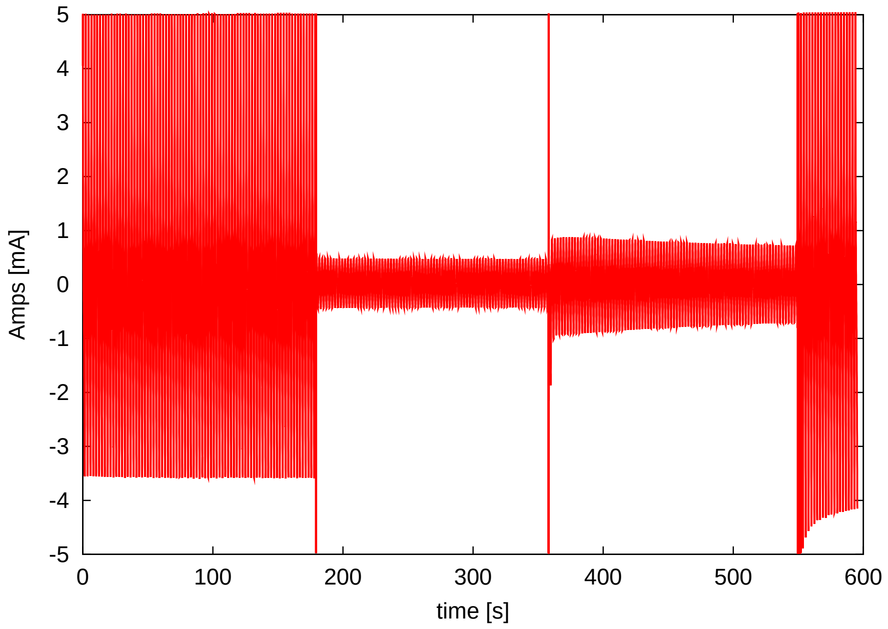

Figure 18. Amps as a function of time.

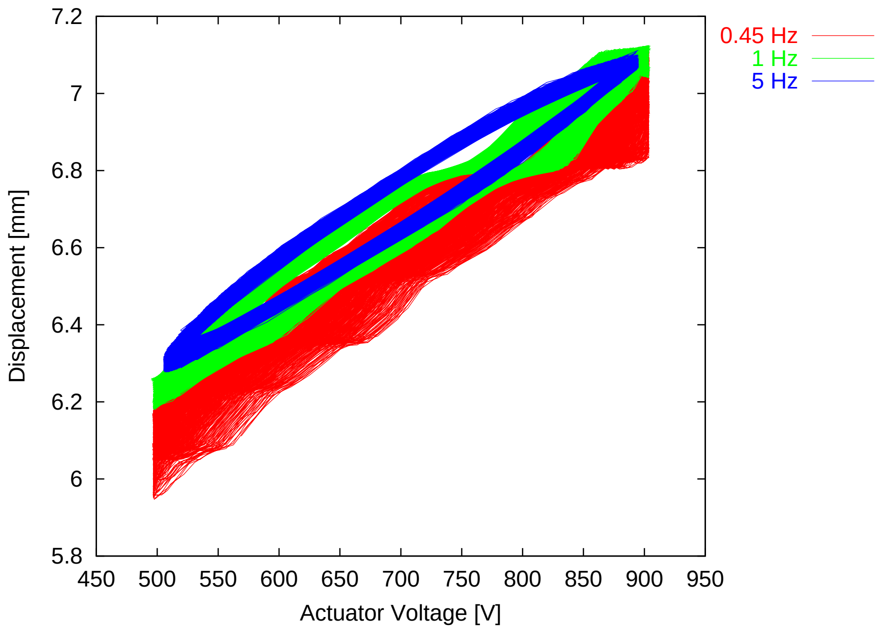

Figure 19. Displacement as a function of actuator input voltage for different input frequencies.

4.6 Actuator comparison

The wind tunnel test section is a nearly 2 meter section and the actuators are about 52 mm wide, hence, a number of (about 40) actuators must be fitted to the profile section and they must work together giving the same response. In this section to different actuators (of the same kind) are tested.

In Figure 22 a comparison of the voltage-displacement response is shown for the two actuators. The green curve is actuator 2 and it can be seen that the

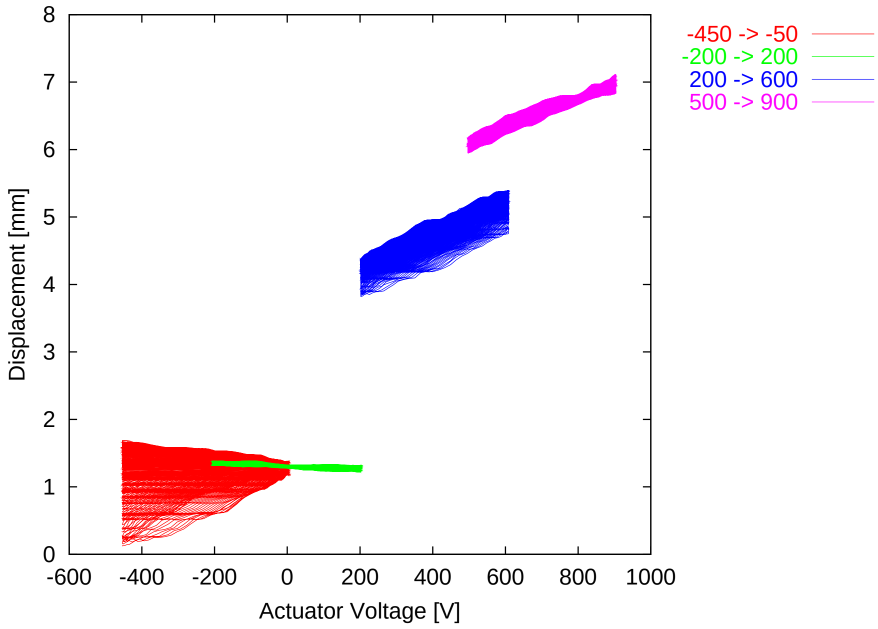

Figure 20. Displacement as a function of actuator input voltage.

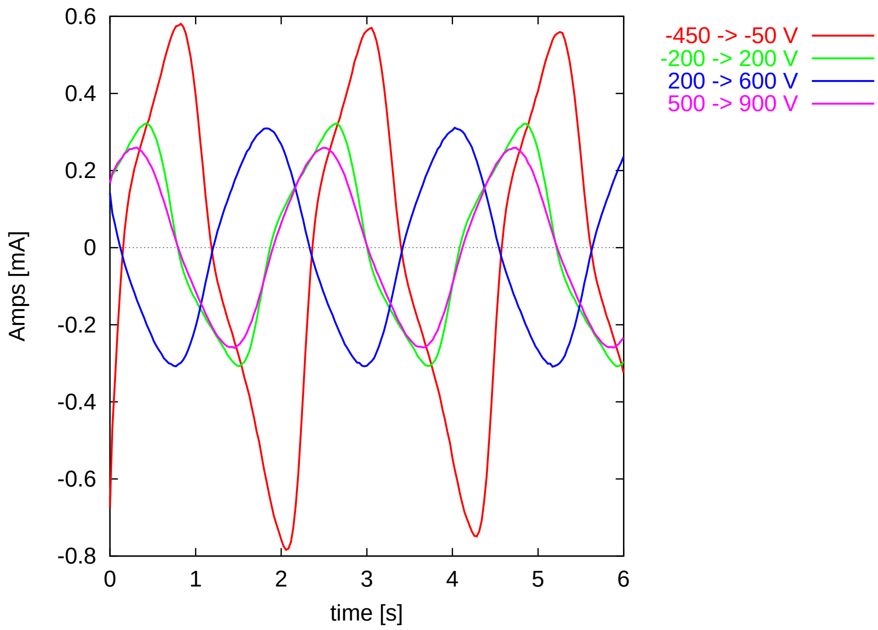

Figure 21. Amps as a function of time.

amplitude of actuator 2 is about 0.6 mm larger than that of actuator 1. The hysteresis opening is also larger for actuator 2.

From this it can be concluded that it is necessary for the wind tunnel test to insure that all 40 actuators are giving the same response. This will be forced be attaching a metal guidance rod that will overlap all actuators.

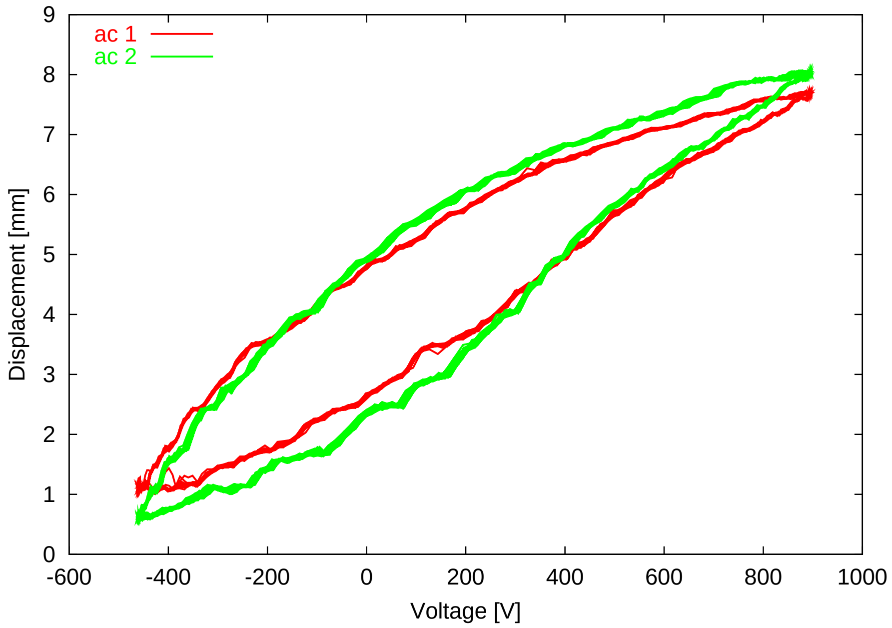

Figure 22. Displacement as a function of actuator input voltage.

5 Conclusions

In this report a measurement study of the TH-6R actuator from Face International Co. The actuator will be used as a Adaptive Trailing Edge Geometry (ATEG) in a wind tunnel test to illustrate and verify the potential of using an ATEG to alleviate fluctuating loads on a wind turbine.

The results showed that using the actuator in the negative voltage range can result in unpredictable output response. Hence it should be avoided in the wind tunnel test. Using the negative range should only be when using the actuator in peak-to-peak situations (from -450 to +900V).

Furthermore, it was seen that the reproducibility of the output response from two different actuators of the same kind is marginal. There was an error of about 0.6 mm from two different actuators. It is therefore imperative that the actuators will be forced to give the same response in the wind tunnel test.

References

[1] www.faceco.com.

[2] Buhl, T., Gaunaa, M., and Bak, C., "Potential Load Reduction Using Airfoils with Variable Trailing Edge Geometry," *Journal of Solar Energy Engineering*, Vol. 127, 2005, pp. 503–516.

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