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Published in: Scientific Proceedings. EWEA Annual Conference and Exhibition 2015

Publication date: 2015

Document Version Publisher's PDF, also known as Version of record

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Testing of a new morphing trailing edge flap system on a novel outdoor rotating test rig

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Abstract

The morphing trailing edge system or flap system, CRTEF, has been developed and is being tested. After a promising wind tunnel test of the system in 2009 the INDUFALP project has been carried out from 2011-2014 to transfer the technology to full scale testing on an MW turbine.

To narrow the gap between wind tunnel testing and full scale prototype testing we developed the rotating test rig. The overall objectives with the testing rig are: 1) to test the flap system in a realistic environment with a realistic g-loading; 2) to measure the flap performance under real turbulent inflow and 3) to test the flap system in a realistic size and Reynolds number when compared with full scale applications.

The rotating test rig consists of a 2.2m blade section attached to a 10m boom and mounted on a 100kW turbine platform. It was installed in June 2014 and a short measurement campaign was conducted in the autumn 2014.

An important result of testing the flap system on the rotating test rig was operation of the flap system up to 30 rpm. which a g-loading of 9-10g comparable with the conditions on a 2-3MW turbine.

Another important result was the measured performance of the flap system. We found that about 5.0deg. flap angle gives the same load change as 1deg. pitch. This is somewhat lower than simulations have shown which are in the range of 2 to 3 deg. flap angle to 1deg. pitch angle for a 15% flap. The realistic, turbulent inflow is probably a major cause of this lower performance.

2. The developed flap technology – the CRTEF system

2.1 The flap actuation concept

The initial flap concept studies back in 2006 led to the design of the so-called Controllable Rubber Trailing Edge Flap (CRTEF) which comprises a morphing trailing edge manufactured in an elastic material with a number of voids inside. Their geometry are designed so that pressurizing some or all of the voids will create a deflection of the flap.

In an actual design shown in Figure 1 the CRTEF: Controlable Rubber Trailing Edge Flap Flap testing Morphing airfoil Rotating test rig Pressure measurements

1. Introduction

Considerable research on SMART blade technology has been conducted for more than 10 years and has shown big potentials for load reduction on MW turbines using distributed control for alleviation of the fluctuating loads along the blade span [1]. However, the requirements by the wind turbine industry of robust actuator solutions where the strongest specifications mean no metal and electrical parts in the blades have so far limited the use of the smart blade technology on wind turbines.

The development and testing of the morphing trailing edge flap system to be presented in the present paper, also called the Controllable Rubber Trailing Edge Flap (CRTEF), was initiated in 2006. The first prototype was tested in the laboratory in 2008 and in late 2009 wind tunnel measurements in the Velux wind tunnel in Denmark were conducted on a blade section of 1.9m span and 1m chord with a 15% trailing edge flap system [2]. From 2011 to 2014 the INDUFALP project, funded by the Danish national funding board EUDP, was conducted with the overall aim to transfer the technology from laboratory conditions to industrial manufacturing and application [3]. An important part of this work was the testing of the flap system on an outdoor rotating test rig in order to reduce the gap in test conditions between wind tunnel testing and full scale testing on a MW turbine.

In the present paper the developed flap technology will first be briefly described. Then the design and construction of the rotating test rig will be presented followed by a section with results from a few weeks test campaign in the autumn 2014.

2.2 Flap design and manufacturing

During the above mentioned INDUFALP project carried out by DTU Wind Energy in cooperation with the two industrial partners Hydratech and Rehau a flap design well suited for manufacturing by extrusion. Pressurizing the lower layer will give an upward deflection as shown in the upper part of Figure 1. Likewise, pressurizing the upper row of voids will give a downward deflection as shown in the lower part of Figure 1.

Figure 2 – The passive, load carrying part of the flap system.

Figure 3 – The two actuation flap elements assembled with the load carrying part.
The manufacturing of the 2m long actuation parts was performed by Relau in a continuous thermoplastic extrusion process in form of a quasi endless 12 chamber hollow profile. For manufacturing the sealed ends of the hollow profiles, a special method of a contact welding process was developed.

2.3 Flap integration into the blade

The integration of the flap system into the blade should allow an easy mounting of the flap segments without any loss of strength. So flaps of e.g. 3m in length should be possible for two technicians climbing on the blade to dismantle a flap system and afterwards to re-mount the complete flap system. In addition, the design should allow for the use of variable chord length so they can be adapted to different flight conditions.

A big advantage of the constant chord flap is that it will reduce the requirements for blade trailing edge finishing a lot as the rest material from the blade can be used as a blade manufactured without the last about 10% of the trailing edge region along the span.

The blade section has the NACA0015 aerofoil shape and a constant chord length of 2.2 meter along the span. The aerofoil is covered with two shells of glass-epoxy composite material, Figure 7 and Figure 8. To fulfill the above requirements to the test rig design, the blade section is attached to the normal rotor. Figure 6. The blade section is used as a blade manufactured without the last about 10% of the trailing edge region along the span.

2.4 Mounting the 2m flap on a blade section

At an early stage of development of the flap system wind tunnel tests were carried out in the VELUX wind tunnel in Denmark. The unsteady aerodynamic response characteristics were derived showing a characteristic time constant of about 100ms. However, there is a big step from wind tunnel testing on a stationary blade section to full scale turbine application and therefore a so-called rotating test rig has been developed. A big advantage of the constant chord flap is that it will reduce the requirements for blade trailing edge finishing a lot as the rest material from the blade can be used as a blade manufactured without the last about 10% of the trailing edge region along the span.

The rotating test rig is /rotating tests] as shown in Figure 5. Pressure measurements were carried out on a blade section of 1.5m span and with a variable speed drive was installed so the rotational speed of the test section could be varied between 0 and 60 rpm.

The blade section is mounted on the shaft instead of a normal rotor. Figure 6. The blade section is used as a blade manufactured without the last about 10% of the trailing edge region along the span.
3.4 Pneumatic system for flap actuation

Pressurizing the voids can be done either by a hydraulic or a pneumatic system or by a combination of the two systems. The choice of system depends e.g. on the requirements for the actuation time constant and on how strong the restrictions are on having valves/wires in the blade.

In the present case a first option has been a pneumatic system developed and implemented by Hydratech Industries which were one of the industrial project partners in the INDUFLAP project. A compressor at the hub supplies pressurized air into 3 accumulators which are the black tubes mounted in the blade section shown in Figure 8. They have three different pressure levels: low, medium, and high. A series of 3 switches per flap side (‘positive’-upper, negative ‘lower’) control which of the three pressure levels is connected to the flap voids (on-off). A fourth switch per flap side controls the release of pressure. Controlling the switch valves allows for dynamic control of the pressure in the voids and therefore the flap deflection. The pressure at the flap inlets, the switches, the accumulators and the compressor are measured using pressure transducers.

3.5 Instrumentation

Besides the advantages by the rotating test rig mentioned above, one other major advantage by testing the flap system on a blade section is that it is possible to install a surface pressure measurement system which would be very complicated to implement on a full scale blade. By measuring the pressure distribution, the instantaneous aerodynamic loading can be derived and the performance of the flap system investigated.

The installed pressure system comprised 59 pressure holes distributed along the chord at the mid span position and additional 16 pressure taps at the 25% chordwise position to monitor the spanwise load distribution. The pressure taps were connected to two 64 channel Scanivalve pressure scanners mounted inside the blade section.
3.6 Calibration of the flap deflection correlated to actuation pressure

It was not possible to measure the flap deflection directly with a sensor (e.g. a strain gauge built into the flap) on the rotating test rig and therefore a calibration in the lab, correlating the flap deflection to the pressure in the voids has been used. The calibration set-up shown in Figure 15 was used. A laser sensor measured the flap deflection and the supply pressure in the two layers of voids was likewise measured. An example on how the flap deflection correlates with the pressure is shown in Figure 16. It is seen that there is a close correlation between pressure and deflection although there might be minor hysteresis effects.

The result of the calibration was 1.85 deg.bar to the one side and 1.48 deg.bar to the other side.

4. Experimental results

An important result of testing the flap system on the rotating test rig was operation of the flap system up to 30 rpm, which is the same as the system will be exposed to on a 2-3 MW turbine. It was not possible to measure the flap deflection directly with a sensor (e.g. a strain gauge built into the flap) on the rotating test rig in the autumn 2014 the focus was on characterization of the flap performance using prescribed flap variations. An example is showed in Figure 17 where the flap angle was changed with 10 deg. each 10 sec.

Figure 18 – A square pattern change of flap angle with a period of 10s.

10s. The aerodynamic normal force integrated from the measured pressure distribution is seen to change with the flap angle. The unsteadiness in the inflow due to the turbulence and tower shadow is also clearly seen in the aerodynamic loading.

One way of characterizing the flap performance was carried out in the following way. A few 10min. time series were measured at a constant rotational speed of 20 rpm, with a square change pattern of the flap angle with a period of 10s. as shown in Figure 18. The flap angle variation was not completely symmetrical around 0deg. but the mean total amplitude was around 15deg when using the time sequences marked with red and blue, respectively, in Figure 18. To achieve a wide range of inflow angles the pitch setting was changed from one 10min. time series to the next.

The normal force loading was derived from the pressure data and then binned on the measured inflow angle derived from the five hole pitot tube measurements, Figure 19.

From that figure we can now derive that the average change in normal force due to a degree change in flap angle is about 32% of the average change in normal force due to a degree change in inflow angle.

The result of the calibration was 1.85 deg.bar to the one side and 1.48 deg.bar to the other side.

5. Conclusion

The morphing trailing edge system or flap system, ORTEF, has been developed over the last 10 years at DTU Wind Energy. After a promising wind tunnel test of the system in 2009 the INDUFALP project has been carried out from 2011-2014 to transfer the
technology from laboratory to industrial applications. During that work a flap design was developed where the manufacturing is done in an extrusion process using the santrophene material for one of the components.

To narrow the gap between wind tunnel testing and full scale prototype testing we developed the rotating test rig. The overall objectives with the rotating test rig are: 1) to test the flap system in a realistic rotating environment with a realistic g-loading; 2) to measure the flap performance in real turbulent inflow and 3) to test the flap system in a realistic size and realistic Reynolds number.

The rotating test rig consists of a 2.2m blade section attached to a 10m boom and mounted on a 100kW turbine platform. It was installed in June 2014 and a short measurement campaign was conducted in the autumn 2014. Instantaneous aerodynamic loading in a cross section of the blade was derived from pressure measurements providing detailed insight into the unsteady flap response.

An important result of testing the flap system on the rotating test rig was operation of the flap system up to a 30 rpm, which combined with a 10m radius gives a g-loading of 9-10g which is comparable to the conditions on a 2-3MW turbine.

Another important result was the measured performance of the flap system. As the blade section has a low aspect ratio we have chosen to compare the flap load response with the pitch load response as the pitch is the normal control system. We found that about 5 deg. flap angle gives the same load change as 1 deg. pitch. This is somewhat less than simulations have shown in the past which are in the range of 2 to 3 deg. flap angle to 1 deg. pitch angle for a 15% flap. The realistic, turbulent, inflow is probably a major cause of this lower performance.

Acknowledgements

The presented research and development work was partly carried out within the project “Industrial adaptation of a prototype flap system for wind turbines” which was been funded by the Danish development and demonstration programme EUDP under contract J.nr. 64010-0458.

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