Best Paper Award... *The following is part 1 of a two-part article. This is the 2012 Wind Committee Best Paper Award Winner. Part II will be featured in the August issue of the* GGTN.

Performance Optimization of Wind Turbine Rotors with Active Flow Control (Part 1)

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Modern wind turbines have reached sizes and installed capacity levels previously unimaginable. Currently the largest rotors have diameters exceeding 150m and installed capacities of more than 6MW. The combination of large rotor dimensions, turbulent inflow field, terrestrial boundary layer profile and rotor yaw misalignment causes extremely high aeroelastic loads on wind turbine blades. In addition, the blades of modern wind turbines are extremely cost intensive components. Thus, a potential aerodynamic/aeroelastic load reduction could be very beneficial for the cost competitiveness of the entire wind turbine.

To reduce the loads and/or increase the performance of modern wind turbines, many passive and active flow control (AFC) solutions were investigated by the authors. After an extensive literature research on AFC solutions basic simulations were carried out to assess their potential for use on HAWT rotors. In a second phase the best performing AFC solutions were investigated in detail through experiments and numerical analyses (CFD) to characterize their performance. The experimental results of two solutions are presented in the following.

Flexible Trailing Edge Flap

The idea of the flexible flaps and the extension of that which is the morphing wing goes back to the beginning of aviation and is related to the investigation of the morphing behavior of the bird wings. From the aerodynamics point of view, the flexible flaps increase the camber of the airfoil thus modifying the Kutta condition for the flow and the circulation of the airfoil. The feasibility of the utilization of modern flexible flaps for AFC has been investigated extensively for use on helicopter rotors as well as on aircraft wings. The implementation of flexible flaps on wind turbines is a point currently under extensive investigation with several research projects focusing on various implementation strategies of the concept. Most of the research efforts focus on the implementation of flexible flaps for load alleviation during wind turbine operation rather than wind turbine power regulation which is the ultimate target of the current project.

The integration of flexible flap modules into the wind turbine blade structure is generally similar to the integration of plain rigid flaps. However, in the case of flexible flaps and due to the fact that there is no need for implementation of rotating shafts mounted at the sides of the flaps, it is possible to produce them in standalone modules. The current flexible flap (Figure 1) concept was tested on a DU96W180 airfoil which was measured in the wind tunnel. It was found that the flexible flap mechanism achieved very high control authority. Flap deflections towards the pressure side (lift increase) caused significant lift and drag increase. Additional wind tunnel measurements with vortex generators (VGs) at 60%c (suction side) revealed that despite the smooth flap curvature, the large flap deflection caused high pressure gradients, thus a large separation (i.e. high drag) on the suction side. When deflected towards the suction side (lift reduction), the flexible flap massively reduces the generated lift. At the angle of maximum Cl/Cd, where wind turbine airfoils usually operate, the negative flap deflection reduced the lift to zero. Such a large lift variation would allow significant wind turbine power regulation thus reducing the use of the traditional pitch system.

Fig. 1: Wind tunnel test blade with a pneumatically actuated high deflection flexible flap.

Active Gurney Flap / MicroFlap

The Gurney flap is a simple flat plate in the order of 1% of the chord length which is located perpendicular to the pressure side of the airfoil at the trailing edge. When properly sized, the Gurney flap will increase the total lift of the airfoil while reducing the drag. A lift increase in the order of 13% for a Gurney flap size of 0.5%c with minimal to no drag penalties for the low and moderate Cl values is usually expected. Serrated and slit Gurney flaps (i.e. micro tabs) have also been investigated in order to eliminate the 2D vortex shedding from the solid Gurney flaps which can cause vibration and noise. Micro flaps and active Gurney flaps are suitable for the task of load alleviation mostly due to their fast actuation capabilities. The actuating mechanism in the case of micro flaps requires low actuation forces due to the small size of the element. The integration of these elements in the blade structure is a relatively simple process since the elements and their actuators are very small and only minor changes need to be made in the blade structures.

To achieve a significant load reduction during the operation of the wind turbine a fast and reliable control and actuation system is needed. From the aerodynamic and mechanical point of view micro flaps are especially suitable for fast control and actuation. The active Gurney flap concept was tested in the wind tunnel by the authors under dynamic AoA variations to simulate unsteady inflow conditions. A high deflection micro flap was actuated by four digital electric servos with a maximum deflection rate of 360°/sec. A custom code was created to allow dynamic AoA variations of the test wing with simultaneous dynamic force measurements. In this way, the wind tunnel force balance delivered a lift measurement input signal. An additional high precision mechanical AoA sensor was attached to the wing assembly to extract accurate AoA measurements. This signal was used to feed an AoA variation pattern around a mean AoA position and through the force measurements of the balance to calculate the optimal Gurney flap deflection angle to stabilize the aerodynamic lift. Several actuation control strategies were tried during the tests in order to identify their performance differences. The AoA variation pattern during the dynamic tests with active Gurney flaps in the wind tunnel was initially set as an adaptable white noise profile but also as a pattern similar to the one extracted from aeroelastic wind turbine simulations.

In this way the performance of the active Gurney flap system could be more easily assessed for an actual wind turbine application. During the dynamic investigations various control strategies were tested, starting from standard PID controllers with semi-empirical parameter tuning models (Ziegler Nicholson method), to DIC (Direct Inverse Controllers) with neural network tuning strategies and pure self learning neural network controllers. The results of the closed loop measurements using the manually tuned PID-Controller showed a reduction potential for the dynamic lift loads in the range of 70% (Fig. 2) as well as a stable controller behavior. The DIC controller showed a load reduction of 36.8%, but also significant improvement potential with respect to its fine-tuning. ✻

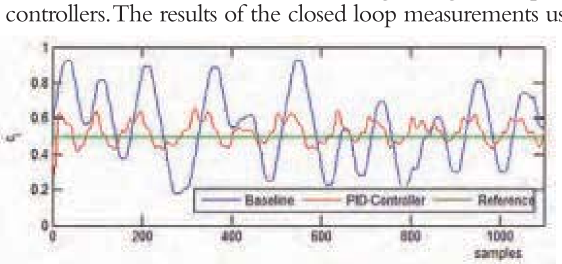

Fig. 2: Lift variation without (blue) and with (red) active Gurney flap element.