論 文 の 内 容 の 要 旨

論文題目　A Study on Effective Control Mechanisms for Dynamic Flowfields around a Pitching Airfoil Using a DBD Plasma Actuator
(ピッチング翼周り動的流れ場の
DBDプラズマアクチュエータによる
効果的な制御メカニズムに関する研究)

氏　　名　　福本　浩章

Many kinds of fluid machinery are often operated in the environment where velocities and directions of flow around them have frequency fluctuation, resulting in deterioration in aerodynamic performances due to flow separation and stall. The stall phenomenon in a dynamic flowfield is called as “dynamic stall” and is distinguished from the stall phenomenon in a stationary flowfield. Details of dynamic stall around airfoils have been extensively investigated in the past several decades. It has been revealed that dynamic stall process is characterized by formation of a laminar separation bubble near the leading edge, its breakdown, formation of a dynamic stall vortex, and full stall after the convection of dynamic stall vortex into the wake. The dynamic stall results in increase in structural fatigue loading and deterioration of efficiency of fluid machinery, even if the operational conditions are under the rated condition. Dynamic stall can be observed around various flowfields; the examples of the flowfields severely suffered from dynamic stall are the flowfields around rotating blades of wind turbines and helicopters. Or the flowfield even around non-rotating blades, dynamic stall can occur in case of severe wing-gust encounters and it can lead aviation accidents. Therefore, mitigating or preventing dynamic stall has large beneficial effects on efficiency of fluid machinery.

In the past several decades, a lot of control technologies for separated or dynamically stalled flow have been studied in order to improve efficiency of fluid machinery. Recently, a dielectric barrier discharge (DBD) plasma actuator is proposed as a prospective alternative device to current complex mechanical or pneumatic systems. A typical plasma actuator consists of two thin electrodes and a dielectric. Because of its simple structure and high responsivity, it have been received a lot of attention as the perspective control device, and many researches have proved the applicability of the DBD plasma actuator for controlling separated flows around fluid machinery. Since stationary flowfields are main target of separation control in most of the previous studies, knowledge of effective control mechanisms of the DBD plasma actuator on dynamic flowfields is limited.

The objective of this thesis is to find the guidelines of the DBD plasma actuators to effectively enhance aerodynamic performances of wind turbine. In order to address this goal, the focus is put on clarifying the control effects of the DBD plasma actuator on dynamic flow fields, their control mechanisms, and the corresponding effective DBD plasma actuator parameter for each control effect. In this thesis, high-fidelity flow computation using large eddy simulations are conducted so as to investigate the details of the unsteady flowfield controlled by the DBD plasma actuator. The flowfield is modeled from that around a whole wind turbine to that around a pitching airfoil in the current research so as to evaluate as many cases as possible in details. The target flowfields are set to the flowfields around a pitching NACA0012 airfoil and a NACA63_3-618 airfoil at Reynolds number of 2.56×10^5. These airfoils dynamically pitch around their quarter-chord location from the leading edge with the reduced frequency of 0.02π. Under these flow conditions, the flowfields undergo the deep dynamic stall.

This thesis comprises seven chapters. Chapter 1 introduces backgrounds and previous studies. Chapter 2 describes problem settings. Chapter 3 then describes governing equations, numerical methods, and numerical modeling of a DBD plasma actuator.

In Chapter 4, validation and verification results are described. The validation and verification studies show the significance of the spanwise length of the computational domain on dynamic flowfields. Through the validation and verification study, the sufficient spanwise length to resolve the flowfield through the entire pitching cycle is clarified.

In Chapter 5, the control effects of the DBD plasma actuator on the dynamic flowfield around a pitching NACA0012 airfoil are investigated and then the control effects, these mechanisms, and the corresponding effective DBD plasma actuator parameters are arranged. Investigation on the flowfield with DBD plasma actuator control revealed that the control effects can be arranged as three major ones; delaying dynamic stall onset, enhancing aerodynamic forces during full-stall, and promoting reattachment. The detailed investigations clarified the control mechanisms of each control effect and revealed the effective DBD plasma actuator parameters for each control effect. In delaying dynamic stall onset, the actuation frequency that can effectively stimulate the instability of the leading edge shear layer is effective. In enhancing aerodynamic forces during full-stall and promoting reattachment, the effective actuation frequency depends on the frequency of the vortex shedding from the leading edge shear layer and the frequency based on the characteristic length and velocity of the large vortex which emanates from the leading edge. The findings in this chapter are summarized into two; the first is the related understandings of the control effects, mechanisms and the corresponding effective

DBD plasma actuator and the second is that the dynamic stall process and the control effects can be divided into some discrete stages/effects and discussions on the control effects and thus on the effective DBD plasma actuator parameters can be conducted isolated to each other control effect.

In Chapter 6, the conclusions in Chapter 5 are utilized to the dynamic flowfield around a pitching NACA63_3-618 airfoil in order to support the conclusions and to discuss the effective control mechanisms and effective DBD plasma actuator parameters for controlling the dynamic flowfield around a pitching laminar airfoil. The flowfield around a NACA63_3-618 airfoil has a different stall type from that around a NACA0012 airfoil. The result is that, however, the flow control attempts based on the findings from NACA0012 airfoil show good enhancements in the aerodynamic performances. The result that the case with adaptive switching of the actuation frequency show great enhancements in the aerodynamic performances supports the validity of the procedure for determining the parameters; the DBD plasma actuator parameters are determined by the investigation only on the flowfield in the corresponding stage of dynamic stall process. The control results and additional considerations on the applicability of the findings suggest that the findings in this thesis are applicable to dynamic flowfields around various airfoils at various Reynolds number regime as long as the dynamic stall is characterized by LSB, and with various reduced frequencies.

Chapter 7 concludes this thesis. The goal of this thesis is attained by successfully revealing the control effects, mechanisms and the corresponding DBD plasma actuator parameters, not only for a simple airfoil but also for a practical airfoil.