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Hydraulic pitch control system for wind turbines: Advanced modeling and verification of an hydraulic accumulator

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ABSTRACT

Hydraulic pitch systems provide robust and reliable control of power and speed of modern wind turbines. During emergency stops, where the pitch of the blades has to be taken to a full stop position to avoid over speed situations, hydraulic accumulators play a crucial role. Their efficiency and capability of providing enough energy to rotate the blades is affected by thermal processes due to the compression and decompression of the gas chamber.

This paper presents an in depth study of the thermodynamical processes involved in an hydraulic accumulator during operation, and how they affect the energy efficiency of the component.

An initial evaluation of the popular thermal time constant model is made and compared with experimental results for a 6 L accumulator, showing that the current estimation techniques for the thermal time constant are not suited for the application studied, predicting higher heat losses in the gas and resulting in lower pressure buildup. Furthermore, it is shown that the assumption of a constant value for the thermal time constant can provide extremely accurate results, provided that the compression ratios of the process are known in advance. For varying compression ratios, dynamical effects play an important role and the accuracy of the model decreases.

To study the thermal processes, a simplified axisymmetric CFD model of the accumulator is developed. The results show that the main heat transfer losses are associated with heat diffusion in the solid parts of the accumulator, making up to 20% of the total heat losses. It is also shown that the heat transfer processes and the thermal time constant are tightly connected to variations in gas mass, in rate of change of volume and compression ratios. Comparison with experimental results validate the CFD model accurately, showing high level of agreement and repeatability between the predicted pressures and temperatures and the experimental measurements.

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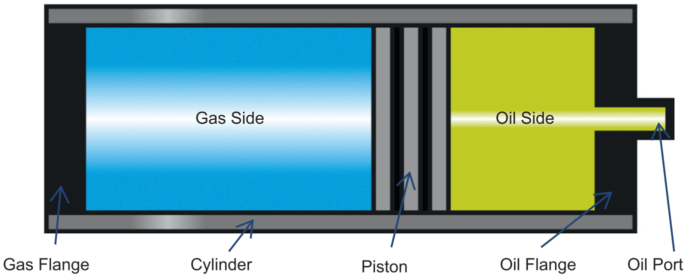

Fig. 1. Basic layout of a piston type hydraulic accumulator.

1. Introduction

In modern pitch controlled wind turbines, hydraulic systems play an important role regulating their power production, e.g. by controlling the pitch angle of the blades [1]. In general, these systems consist of a hydraulic pump that supplies the oil flow, which is then routed by a set of control valves to a linear actuator attached to the blade (in one or two anchor points on the blade root) and its linear displacement is converted to an angular rotation of the blade. The purpose of the hydraulic control system is to ensure an efficient power production and to protect the turbine from dangerous situations like over-speeding or blade failures. When these emergency situations arise, the hydraulic system has to be able to pitch the blades up to a position where the turbine stops, meaning turning the blades to 90 degrees compared to the wind direction, as fast and reliable as possible. Hydraulic pitch systems include accumulators that store energy during normal operation, in terms of compressed gas (Fig. 1), and when the system performs an emergency stop, the accumulators provide high pressure flow to the actuators so the blade can be turned to the desired stop position.

In an ideal situation, all the energy stored in the accumulator can be utilized and delivered to the hydraulic system without thermal losses at the gas side during compression and expansion, but in reality, the process is not adiabatic. The gas experiences pressure and temperature variations with changes in volume, thus heat is transferred to the solid parts of the accumulator, and consequently to the environment, either through convection, conduction or radiation.

The complexity of these phenomena has been studied and modeled with empirical correlations that provide fairly accurate results for very specific situations [2–5]. Little is reported about what is truly happening in the gas side of the accumulator. A thermal model for accumulators based on heat conduction i.e. an over-all equivalent conduction to all convection contributions were presented in [6] while [7] presented experiments that supports that the heat transfer cannot be described by the average Reynolds number of a cyclic process alone. Further insight into the problem has been reported by [8] who presents numerical studies of a gas spring and the heat transfer during cyclic compression and expansion. Correlations for such cyclic behavior was also the scope of [9] where correlations based on experiments for characterization of the heat transfer in a reciprocating compression-expansion cycle were presented. More recently and in association of the accumulators used for hydraulic systems [10] presented a dynamic model where heat transfer coefficients for the gas-wall interface are table values. The stratified temperature in the gas is not considered, however these effects may increase the local heat transport significantly. A similar type of model were presented in [11] where the heat conduction and convection is modeled similarly but wall temperatures are computed by use of a finite difference model along the outer shell.

For accumulators used in hydraulic systems that posses a non-cyclic behavior there is a need to improve the fidelity of the models of the thermo fluid dynamics behavior i.e. natural convection phenomena, that occurs in the interior of the gas volume. A better understanding of this can help improve current linear models, ultimately leading to optimization on the pitch control systems of the wind turbines, for example by reducing the size or the number of accumulators used per blade.

This paper describes the thermodynamical processes involved in an accumulator in operational conditions in detail and how these are affected by different factors, such as initial pressure and temperatures and compression speeds, in order to setup a simple lumped model for the accumulator. The overall goal is to discuss the accuracy and precision of the actual modeling techniques and how they can be improved. By gaining insight through CFD much more accurate time-constants can be obtained and consequences of e.g. accumulator positioning and direction can be taken into account.

The paper is organized as follows. In Section 2 a brief description of the problem of heat losses in hydraulic accumulators is introduced. Section 3 follows with a deeper explanation and description of the thermal time constant model, a description of the experimental setup used for validation of the models and finishing with an optimization study of the proper time constant to use in the case studied. Section 4 describes the whole CFD modeling and setup. Section 5 presents the validation of the CFD model while Section 6 demonstrates the obtained results, explanations and comparisons with the experimental data. Finally, Section 7 finalizes the work with conclusions on the results and recommendations for future investigations.