Modelling and simulation of a hydraulic system used for wind turbines

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Abstract. For wind turbines, pitch control is essential. In some cases, especially in the case of large scale wind turbines, hydraulic control is used. In this paper a hydraulic system used in wind turbine pitch control is analysed. Modelling and simulation of hydraulic systems is necessary in order to acknowledge the drawbacks and advantages before starting the design of the system. By acknowledging, the differences between the model of a physical system and a system in a virtual environment, one can handle the improvement, in terms of price or time-consumption. Considering the proposed diagram of the pitch control hydraulic system, it is presented the block diagram created in MATLAB Simscape Fluids. Some results of the simulation are presented. There are included conclusions and plans for future work.

1. Introduction

The power extracted by the rotor of the wind turbine is essential determined by the blade pitch control [1]. Pitch control is also important in order to protect the turbine in the case of high values of the wind speed, reducing extreme loads to wind turbine rotor and structure.

In the past few years’ active pitch control, collective or individual, gains ground in wind turbine construction. Collective pitch control is the traditional method and most of the wind turbines are provided with. In this case, the commanded value for the pitch is sent simultaneous to all the blades. In this purpose hydraulic or electrical systems are used.

Researches presented in [2] demonstrate that a very significant reduction in operational loading can be achieved by means of individual pitch action. As it regards very large wind turbines with rating up to 15MW a research on this case [3] confirm individual pitch control as a future reliable solution.

2. Modelling for a hydraulic pitch control system

Modelling a hydraulic system is important in order to identify the parameters which influence the behaviour of the system in certain functioning conditions.

Pitch systems might be either electrical or fluid power systems, the distribution among the two types being equal. The rotation of the blade along their longitudinal axis is done by a double acting cylinder, controlled with a servo valve. Accumulator in pitch systems are equipped with pressure sensor on fluid side, which may be used as a feedback for controlling the accumulator fluid pressure. The amount of gas may be estimated by a combination of pressure signal and current volume of fluid contained in accumulator [4].
Figure 1 shows the diagram for the hydraulic pitch control system. In the case of three blades rotor, there are three similar circuits with common source. The common source is located in the nacelle of the wind turbine. Considering that the actuation cylinders are connected to the blades it is necessary to use flexible hoses. Proportional valve controls the position angle of the blade. Maintaining the blade in the position is important. It may be done either mechanically with a locking circuit or hydraulically using a pilot-operated check valve. Accumulator is the safety equipment and acts in the event of an important fault of the system. The system also assures protection of the rotor when the rods of the cylinders are fully extended and is realized stalling position which stops the rotation.

![Hydraulic diagram for the pitch control system](image)

The model for servo cylinder is well known, see e.g. [5] and [6]. Equations (1) - (5) describe the functioning of the system with the notations given in table 1:

\[
Q_1 = A \frac{dx}{dt} + V_1 \frac{dp_1}{dt} \quad (1)
\]

\[
-Q_2 = -\alpha A \frac{dx}{dt} + V_2 \frac{dp_2}{dt} \quad (2)
\]

\[
m \frac{d^2 x}{dt^2} + c \frac{dx}{dt} + kx + F = p_1 A - p_2 \alpha A \quad (3)
\]

\[
Q_1 = \mu A_1 \sqrt{\frac{2}{\rho} (p_0 - p_1)} \quad (4)
\]

\[
Q_2 = \mu A_2 \sqrt{\frac{2}{\rho} (p_2 - p_{\text{air}})} \quad (5)
\]

Laplace transforming and linearizing equations (1) - (5) results equations (6) - (10):

\[
Q_1 = AsX + \frac{V_1}{\beta_0} sP_1 \quad (6)
\]

\[
-Q_2 = -\alpha X + \frac{V_2}{\beta_0} sP_2 \quad (7)
\]
$$ms^2 \dot{X} + c \dot{X} + kX + F = P_1A - P_2\alpha A$$ \hfill (8)

$$Q_1 = K_1p_1$$ \hfill (9)

$$Q_2 = K_2p_2$$ \hfill (10)

| Table 1. Nomenclature. |
|------------------------|
| Notation | Meaning         |
| $V_1$     | Volume of forward chamber |
| $V_2$     | Volume of return chamber |
| $A$       | Area of the piston |
| $p_1$     | Pressure in forward chamber |
| $P_2$     | Pressure in return chamber |
| $m$       | Total mass |
| $k$       | Load spring gradient |
| $F$       | Load force at the blade |
| $x$       | Displacement of the piston |
| $\beta_o$ | Bulk modulus of the oil |
| $Q_1$     | Flow in forward chamber |
| $Q_2$     | Flow from return chamber |
| $\alpha$  | Rod influence on area |
| $\rho$    | Density of the oil |
| $c$       | Viscous damping coefficient |
| $A_{1,2}$ | Area of the orifice |
| $\mu$     | Flow coefficient |

3. Block diagram MATLAB Simscape Fluids

The simulation in Simscape Fluids supposes to configure the bloc diagram corresponding to hydraulic diagram [7]. In Figure 2 one can see the corresponding block diagram for the hydraulic diagram in Figure 1. In the diagram one may change rotation speed of the pump, pump displacement, pressure limited by the relief valve, piston area, volume of the accumulator, precharge pressure of the accumulator and the command low for the proportional valve.

In each case of simulation, it is possible to see the behaviour for the piston position, piston speed, flow in accumulator line, command for directional control valve, pump flow, flow to the cylinder, flow through pressure valve and pump discharge pressure.
Figure 2. Block diagram for the hydraulic pitch control system.

4. Simulation results
There are two sets of results presented in Figures 3 and 4. First is done for: piston area $A = 12 \cdot 10^{-3} \text{m}^2$, $\alpha \cdot A = 9 \cdot 10^{-3} \text{m}^2$, $V = 20 \cdot 10^{-6} \text{m}^3/\text{rad}$, $V_A = 2 \cdot 10^{-3} \text{m}^3$, $p_0 = 5 \cdot 10^6 \text{N/m}^2$, $p_{Sp} = 160 \cdot 10^5 \text{N/m}^2$. The second is done for: piston area $A = 12 \cdot 10^{-3} \text{m}^2$, $\alpha \cdot A = 9 \cdot 10^{-3} \text{m}^2$, $V = 20 \cdot 10^{-6} \text{m}^3/\text{rad}$, $V_A = 2 \cdot 10^{-3} \text{m}^3$, $p_0 = 3 \cdot 10^6 \text{N/m}^2$, $p_{Sp} = 160 \cdot 10^5 \text{N/m}^2$.

The command law for the proportional valve is presented in Figure 5.
Figure 3. Simulation results for first set of values.
5. Conclusions
For research of fluid power systems MATLAB Simscape Fluids is an efficient instrument and recent development makes this instrument even more useful.

For the general structure of a pitch control system it was configured the block diagram. It offers as result of simulation the piston position, piston speed, flow in accumulator line, command for directional control valve, pump flow, flow to the cylinder, flow through pressure valve and pump discharge pressure. Simulation was done in two cases study. Between these two the differences regarded the accumulator namely the volume and the precharge pressure. Results of simulation reveal the influence of parameters of the accumulator.

In the future work it will be considered pressure feedback and system regulator suitable in this case. It will be also considered and other parameters to be modified in the system in order to reveal their influence. It is also for interest if the hydraulic pitch control system is suited for medium and low power wind turbines for isolated consumers.

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