DEPARTMENT OF ENERGY TECHNOLOGY
AALBORG UNIVERSITY

PhD Public Defence

Title:	Design and Optimization of Fast Switching Valves for Large Scale Digital Hydraulic Motors
Location:	Pontoppidanstræde 101, Room 23
Time:	Friday 14 November 2014 at 13.00
PhD defendant:	Daniel Beck Rømer
Supervisor:	Associate Professor Henrik Clemmensen Pedersen
Moderator:	Associate Professor Michael Møller Bech
Opponents:	Associate Professor Søren Juhl Andreasen, Dept. of Energy Technology, Aalborg University (Chairman) Prof. dr. E. A. (Elena) Lomonova, Eindhoven University of Technology (TU/e), The Netherlands Prof. Dipl.Ing. Dr. Rudolf Scheidl, Johannes Kepler University Linz, Austria

All are welcome. The defence will be in English.

After the public defence there will be an informal reception in Pontoppidanstræde 101 room 25/27.

DEPARTMENT OF ENERGY TECHNOLOGY
AALBORG UNIVERSITY

Abstract:

The present thesis is on the design, analysis and optimization of fast switching valves for digital hydraulic motors with high power ratings. The need for such high power motors origins in the potential use of hydrostatic transmissions in wind turbine drive trains, as digital hydraulic machines have been shown to improve the overall efficiency and efficient operation range compared to traditional hydraulic machines.

Digital hydraulic motors uses electronically controlled independent seat valves connected to the pressure chambers, which must be fast acting and exhibit low pressure losses to enable efficient operation. These valves are complex components to design, as multiple design aspects are present in these integrated valve units, with conflicting objectives and interdependencies.

A preliminary study on a small scale single-cylinder digital hydraulic pump has initially been conducted. Here, experimental measurements were compared to a corresponding pump model, which included a number of dynamic effects concerning the low pressure seat valve movement and its electro-magnetic actuator. The pump model was found to predict the digital pump response with reasonable accuracy, but this preliminary model included some soft parameters that were not based on known physical quantities.

Having experimental confidence in a small scale unit, attention has been turned towards the design of seat valves for large scale motors. A method for generally setting the valve requirements to obtain high efficiency was developed, where the efficiency was characterized in terms of valve switching time and flow coefficient. A suitable valve topology for large power motors was determined, resulting in annular valve geometry with a moving coil linear actuator. Transient electro-magnetic Finite Element Analysis (FEA) predicted the moving coil actuator to have superior performance compared to state of the art actuator solutions in the field.

Detailed analysis on a pressure chamber in a motor was conducted using transient 3D Computational Fluid Dynamics (CFD) simulation, including dynamic fluid domain boundaries to account for piston and valve movements. This CFD model was found to be able to simulate the chamber response, but suffers from being computationally expensive to run. A simplified lumped parameter model, based on steady CFD results, was developed and shown to compare reasonably well with the more detailed results from the transient CFD model.

An optimization method for seat valves suitable for digital hydraulic motors is presented, based on subsequent optimization and analysis of subdomains of the valve. This method includes; an optimization of the plunger and seat geometry based on a structural FEA with contact elements, a flow geometry optimization utilizing steady CFD analysis, valve stiction effects analysis, virtual mass and damping effects modeling based on transient CFD, heat dissipation analysis and an optimization of the actuator based on transient electro-magnetic FEA. The optimization method is shown applied to the selected valve topology, resulting in a well performing seat valve suitable for large scale hydraulic motors based on model predictions.

The valve designed using the above method was manufactured in order to validate the model predictions experimentally, and the transient actuator force response was found experimentally to correspond well with the model predictions. Further experiments are needed, however, to validate all aspects of the valve design.

The research documented in this dissertation has contributed with dimensioning guidelines and topology analysis of seat valves suitable for large scale digital hydraulic motors and detailed analysis methods for the pressure chambers of such machines. In addition, modeling methods of seat valves within this field have been developed, and a design method utilizing these models including optimization of subdomains has been developed and applied.