Design cycle of electromechanical actuator based on VHDL-AMS modeling

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***Abstract*— Electromagnetic Actuators are complex systems - belonging different physical domains, which should have a suitable representative model on each stage of the design cycle. The classical validation of such systems by separate simulation of each element does not offer the possibility to predict the behavior of the whole system. To overcome such limitations, we propose a unified architecture for the multi-level and multi-accuracy modeling of electromagnetic devices. In the paper, VHDL-AMS is used to support the dynamic behavioral and structural modeling of a multi-domain actuation system, and focuses on the multiple modeling of magnetic components for simulation and optimization studies and their integration into the V design cycle.**

***Index Terms*— electromechanical actuator, VHDL-AMS, V design cycle, multi-level modeling.**

I. INTRODUCTION

Dynamic system simulation requires simple and fast models to investigate the interactions between components in the hierarchical modeling of the design cycle. The basic approach in the design flow starts from the specifications to reach an overall design goal. Then the system is splitted up into subsystems and further refinements into components are built up. The design of any components is carried out before their integration into the global system. This design flow is a recursive process and is considered for every step of the design process (analysis, pre-sizing, and sizing). In the same way, several V-cycles are applied for component study in reference to the system (every component is assumed like a system).

The challenge while designing electromagnetic actuator is to deal with the diversity of subsystems containing complex systems and different physical domains (mechanical, magnetic and electrical). In this work, a top-down methodology for behavioral and structural modeling of multi-domain system is used as shown in Fig.1.

To deal with the numerous modeling approaches and data interactions between these different levels of the V cycles, several analysis tools have to be coupled. The use of system level modeling languages such VHDL- AMS [1] is suited to handle such requirements.

II. VIRTUAL PROTOTYPING USING VHDL-AMS

A. *Application: electromagnetic actuator*

Fig.2 shows a classical E-shaped actuator with a coil bounded to its central leg, which is controlled by an electrical current. The movable core is subject to damping sources due to springs. Upon power-up, the coil creates a flux which flows in the magnetic circuit and thus generates an electromagnetical force to move the core.

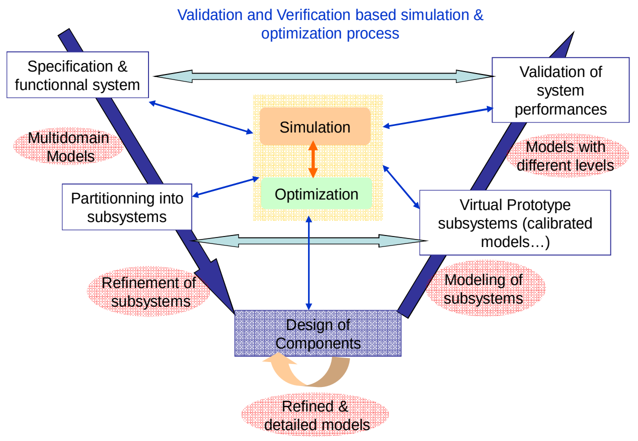

Fig.1. Reinforced design flow representation by simulation and optimization

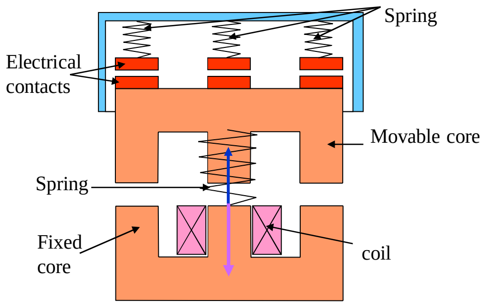

Fig.2. E-shaped actuator (Schneider Electric)

B. *Design levels of the electromagnetic actuator*

This section establishes different abstraction levels of modeling actuator in the design process, focusing on the modeling of magnetic components with multiple accuracies.

1) *Functional modeling*

The highest level of abstraction is the functional analysis of actuator system, in order to achieve customer requirements. It consists on translating its characteristics obtaining from the functional specifications into simulated functions. This analysis leads to formalized models through block diagrams and state machines. The functional model is developed using the approach proposed in [2].

2) *Structural modelling*

The structural model represents a coupling between the magnetic circuit, the electrical circuit feeding the coil and the mechanical system (the movement of plunger) (Fig.3). Here, only behavioral models are used.

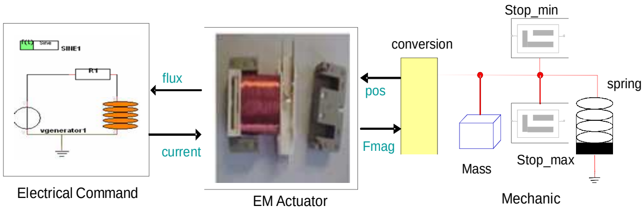

Fig.3. Structure modeling of E-shaped actuator

The models used in our application for the electrical and mechanical subsystems are simple. To design the magnetic device, physical aspects are carried out by using computation tools with either fine modeling or behavioral modeling. We focus on it in next section.

C. Modeling levels of the magnetic components

To improve the accuracy and to refine the global model, various methods may be used to carry out of magnetic device model. In this way, different accuracies of the magnetic models are developed for different analysis (Fig.4).

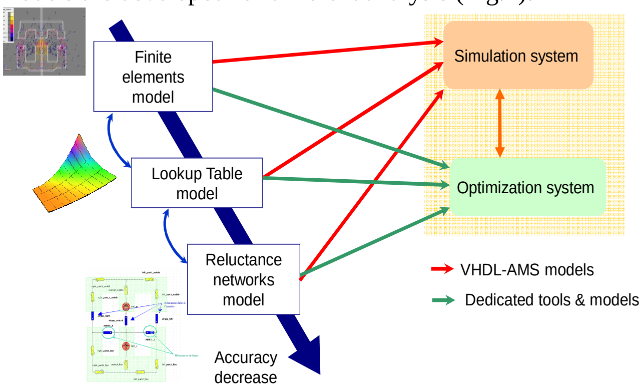

Fig.4. Design cycle of an E-shaped actuator : multi- accuracy models and simulation & optimization process

- *Fine modeling using FEM*

A finite element method (FEM) is chosen for static or dynamic analysis, in order to take into account non-linearities of the device such as fringing effects. A coupling strategy between FEM tool (FLUX2D™) and system simulators (as SMASH™ or PORTUNUS™) is developed based on VHDL-AMS interoperability function [3]

- *Lookup table*

The approach based on parametric sweeps includes the geometry and excitation of the model. This method is used in FEM tools to create a lookup table model from which the exact behavior may be caught. This model has two inputs: the coil current and the core position, and two outputs: the magnetic force and the flux on coil. The paper proposes a generic standardized lookup table model that can read data and use interpolation functions has been developed in VHDL-AMS.

- *Reluctance networks*

Reluctance networks are an efficient approximation for system simulation and suited very well to optimization [4]. A library of magnetic components such as linear and non-linear reluctances, air-gap, magnet and coil, has been developed on VHDL-AMS. Allowing global force computation from component composition is a difficult task and will be discussed in the full paper.

III. Results and Discussions

Simulations of the actuator have been performed using several VHDL-AMS models, from the simulation of the specifications to detailed simulations. The following results are obtained from the system simulation using (for the magnetic part) a lookup table provided by the Flux2d FEM software.

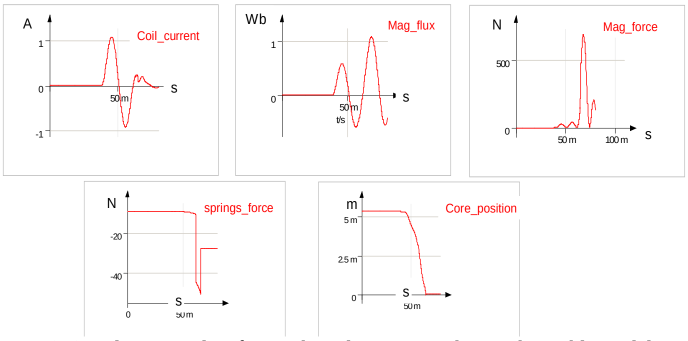

Fig.3. Simulation results of an E-shaped actuator with a Lookup table model

This multi-level system simulation, based on a single environment using VHDL-AMS generic language, allows designer to iterate between functional modeling levels, structural levels and fine component simulations. For example it allows to simulate the magnetic component using FEM software with its environments (control and load).

IV. Conclusions

VHDL-AMS, as a unified modeling language, has to support all the necessary modeling concepts to support multi-domain aspects of systems. The paper demonstrates the use of this functionality in order to do multi-method modeling in order to perform multi-physical and multi-level simulations. The development of a design hierarchy for appropriate subsystems allows the designer to mix multiple levels of abstraction to observe and evaluate interactions between interdependent subsystems.

An E-shaped actuator system involving electrical, mechanical, and magnetic domains was developed and used in a V-shaped cycle. Several approaches for detailed modeling of the used magnetic device will be outlined and provided to be used for different objectives in the full paper.

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