VHDL-AMS electromagnetic automatic modeling for system simulation and design

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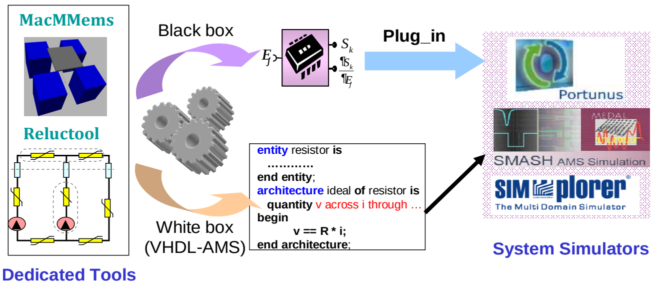
***Abstract*— With the increasingly high level of electromagnetical system integration, the modeling of both the system dynamic behavior and the detailed physics becomes necessary. VHDL-AMS, which is a powerful modeling language for hybrid DAE system, allows to describe a large range of multi-physical systems. It allows to use a single modeling approach and a single simulation tool to simulate the behavior of a complete system. The paper presents a methodology for a computer-aided generation of macro and micro electromagnetical devices for system simulation using VHDL-AMS.**

***Index Terms*— computer-aided modeling, electromagnetical devices, system level, VHDL-AMS.**

I. INTRODUCTION

For the design of dynamic electromagnetic systems, several tools are developed, characterized by different capabilities of modeling for different requirements. However, an important effort is needed by system designers to integrate a magnetic device into other systems or to reuse it. Therefore, it is important to improve the interoperability of magnetic simulation tools to make easier model exchange. A first approach, dedicated to component level simulation and using numerical PDE solvers, is based on the loose coupling of complex or binary models (i.e. black box) [1]. For the system level simulation, a preferred solution is to provide an explicit magnetic model (i.e. white box) which can be strongly coupled with other "white box" models (mechanical, thermal, economic…). The classical way to reach such a modeling is to make a regression model based on fine simulation results [2]. However, this approach does not suit for the system design since it matches only for few parameters and for a small range of variation.

The paper proposes an automatic "white box" modeling, using VHDL-AMS language [3], from dedicated macro and micro-magnetic tools developed in our laboratory: RelucTool [4] (reluctance networks models), and MacMMems [5] (Magnetic MEMS based on integral formulation).



```
entity resistor is
   …………
end entity;
architecture ideal of resistor is
   quantity v across i through …
begin
         v == R * i;
end architecture;
```

Fig.1. Process & Model interchange using VHDL-AMS

II. MODELING OF ELECTRO-MAGNETIC DEVICE

The reluctance network approach is based on the splitting up of a magnetic circuit into sub-elements (reluctances, sources...) [4]. The method, based on magnetic flux tubes, allows a simplified description of any magnetic device. So, the field distribution can be described by algebraic equations. The paper proposes some VHDL-AMS code generators from a dedicated tool (RelucTool) and applied on a dynamic E-shaped actuator (Fig.2), using different manners to compute magnetic forces.

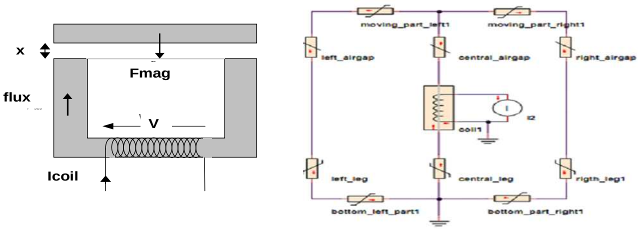


Fig.2. Dynamic E-shaped actuator and its reluctance network model

A. *VHDL-AMS structural reluctant models*

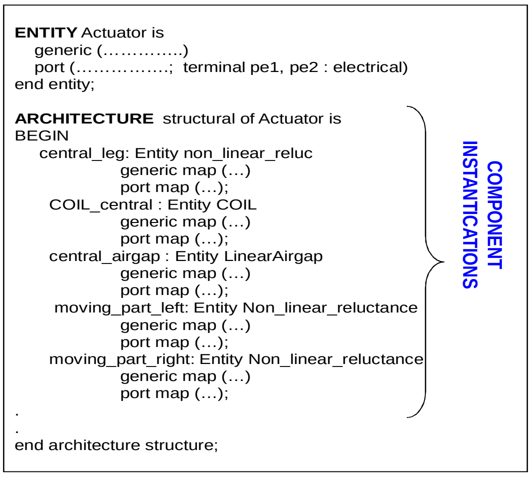
From a reluctance description of a magnetic circuit, RelucTool generates a dedicate application for simulation and pre-sizing. It allows to compute all the magnetic fluxes from the element characteristics (geometry, material, sources…).

We have proposed an extension of RelucTool to export the network model, including components and energetic connections, into VHDL-AMS.

For that, firstly a VHDL-AMS library of magnetic components such as linear reluctances, air-gap, magnetic coil, has been developed. Then, the reluctance description is translated into VHDL-AMS models. That means the structured network is translated, including all its components (reluctances, sources) as individual ENTITies with their own ARCHITECTURE, and defining the connections between them.

The automatic VHDL-AMS generator generates the corresponding topology in VHDL-AMS by analyzing reluctance description provided by the user on the RelucTool GUI. This topology consists of instances of components from VHDL-AMS magnetic library. This strategy is possible thanks to the ability to instantiate VHDL-AMS system components from generic one. This mechanism is applied to an E-shaped actuator (Fig.3).

The magnetic force equation can be described using virtual works. However, VHDL-AMS supports only time differentiation. A first solution can be found for specific actuators using predefined energy derivation on air gap elements but it is not generic. For that, users have to add by themselves the equations of forces into their VHDL-AMS models. A second solution, discussed in the next section, is to generate the global analytical model of the network, associated with an automated symbolic derivation which offers the computation of energy of the whole system and magnetic forces.



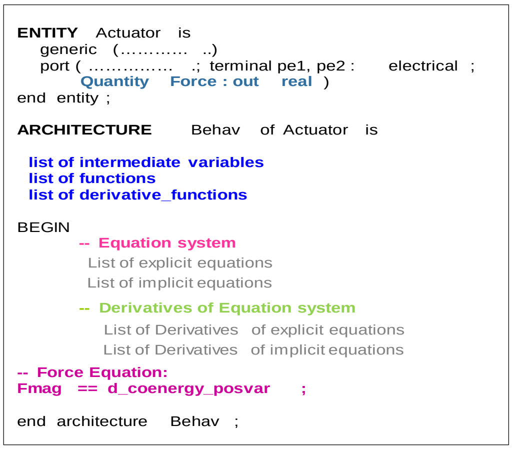
```
ENTITY Actuator is
   generic (…………..)
   port (…………….;  terminal pe1, pe2 : electrical)
end entity;

ARCHITECTURE  structural of Actuator is
BEGIN
    central_leg: Entity non_linear_reluc
                 generic map (…)
                 port map (…);
      COIL_central : Entity COIL
                 generic map (…)
                 port map (…);
      central_airgap : Entity LinearAirgap
                 generic map (…)
                 port map (…);
       moving_part_left: Entity Non_linear_reluctance
                 generic map (…)
                 port map (…);
      moving_part_right: Entity Non_linear_reluctance
                 generic map (…)
                 port map (…);
.
.
end architecture structure;
```

Fig 3: VHDL-AMS code of the structural model of E-shape actuator

B. *VHDL-AMS global behavioral models*

RelucTool is able to generate the analytical model with forces computation. From the designer GUI description of the reluctance network, Reluctool converts its elements into explicit equations and analyses the circuit topology to establish an implicit equations system. Then, all the symbolic derivatives of fluxes are made to complete the model with forces.

So, we have proposed a new extension of RelucTool by introducing a VHDL-AMS generator based on exporting the global analytical model. Fig. 4 presents the generated VHDL-AMS model, for a global behavioral model with a computation of forces, applied to an E-shaped actuator.



```
ENTITY   Actuator   is
    generic   (…………  ..)
    port ( ……………   .;  terminal pe1, pe2 :      electrical   ;
           Quantity    Force : out     real  )
end  entity ;

ARCHITECTURE       Behav    of  Actuator    is

  list of intermediate  variables
  list of functions
  list of derivative_functions

BEGIN
           -- Equation system
             List of explicit equations
             List of implicit equations

           -- Derivatives of Equation system
                List of Derivatives    of explicit equations
                List of Derivatives    of implicit equations
-- Force Equation:
Fmag    == d_coenergy_posvar      ;

end  architecture    Behav   ;
```

Fig 4: VHDL-AMS code of the behavioral model of E-shape actuator

III. MODELING OF ELECTROMAGNETIC MEMS

The interaction between elementary models in the micro domain differs from the macro world due to the lack of ferromagnetic materials conductors of the field. The functional gathering of Magnetic MEMS requires integral computations (Biot-Savart law, Colombian equivalent approach, magnetic-moment method) to obtain fields and forces. It also requires complex interactions between elements (target/sources; space positions and orientation of elements). This kind of interaction is not easy to be handled using the composition of VHDL-AMS components. So, we propose to use MacMMems [5], which is a dedicated tool for such system modelling. It uses elementary models (magnets and conductors) and generates parameterized semi-analytical models.

The paper proposes an extension of the tool to generate VHDL-AMS models. Integrals formulations, which are not supported by the language, have to be used [5]. The full paper will detail the method and its application to a diamagnetic levitation system (fig. 5).

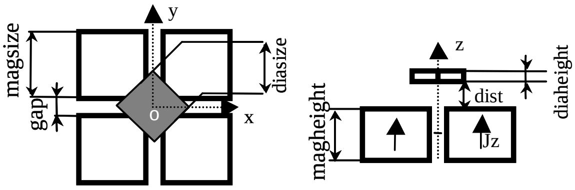


Fig.5. Geometrical parameters of magnets and diamagnetic ball.

IV. CONCLUSIONS

The paper proposes an automatic model generation methodology to create VHDL-AMS models from two dedicated tools for magnetic systems: RelucTool (reluctance networks) and MacMMems (magnetic MEMS). In this work, different solutions to export models to VHDL-AMS are presented. An automatic generator from RelucTool have been developed and applied to a dynamic E-shaped actuator. A methodology of exporting behavioural of magnetic MEMS from MacMMems is described and presented on a diamagnetic levitation. The whole methodology, based on MDA (Model Driven Architecture), will be presented in the full paper.

In future work, those automatic generators should be performed and extended to deal with more complex modelling systems.

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