System integration of an electromagnetic linear actuator.

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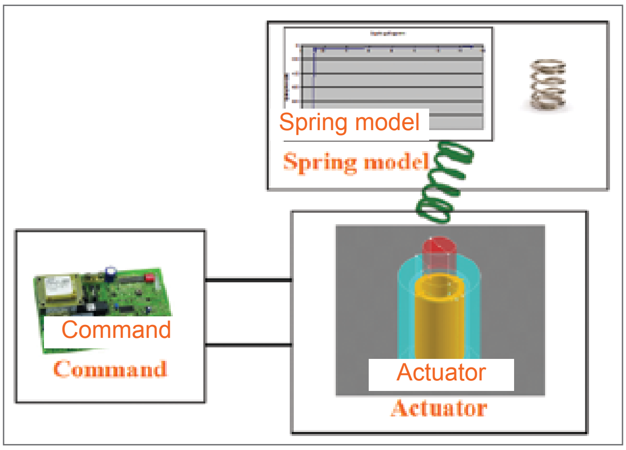
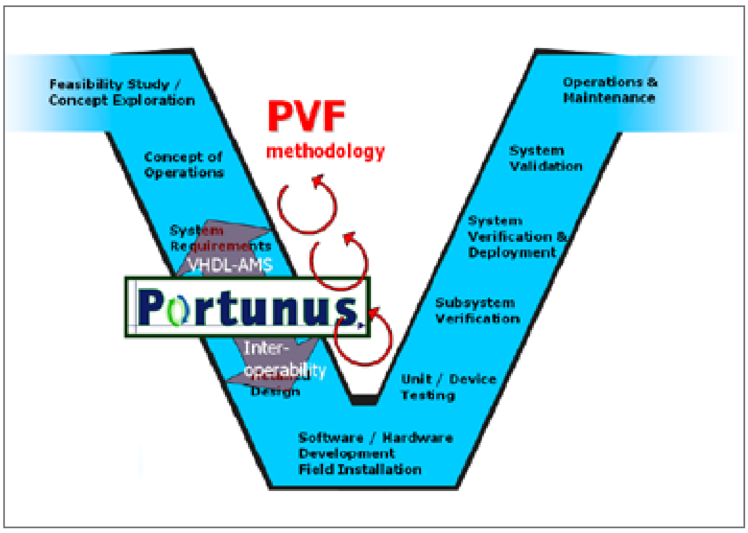
Linear actuators are electromagnetic systems that create motion in a straight line. They are used in machine tools and industrial machinery, in computer peripherals such as disk drives and printers, in valves and dampers, and in many other places where linear motion is required.
Today's challenge is to make an efficient design of an actuator which should meet several requirements: the influence of Eddy currents on the functioning of an actuator, optimizing the actuator, the best strategy command to manage energy consumption, etc. All those questions are crucial for designers.
The answer lies in simulation of the global system: model representation of the electromagnetic actuator is important, as is the working environment of the actuator. Generally, an actuator is surrounded by a command and a resistive force (spring, mass to move…).



Example of a contactor subdivided in 3 subsystems: the command, the electromagnetic actuator and the mechanical stress.



Scheme of the V-cycle methodology.

Multi-level representation

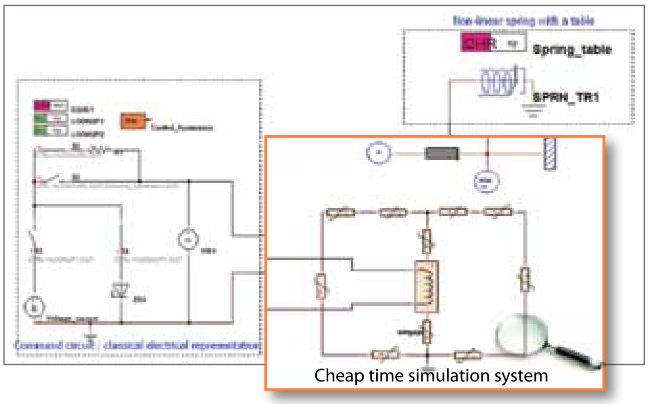
Each subsystem can be represented with different levels of modeling: every new level brings new information, enhancing subsystem accuracy. This is the "V" cycle design for mechatronic system. The V-model is a system development model designed to simplify understanding of complex systems. It allows us to go to a virtual prototype which could be undertested at each representation level.

With the Portunus system simulator, we focus on different model levels of electromagnetic actuator.
The software handles three levels of modeling that we propose to compare in this article:

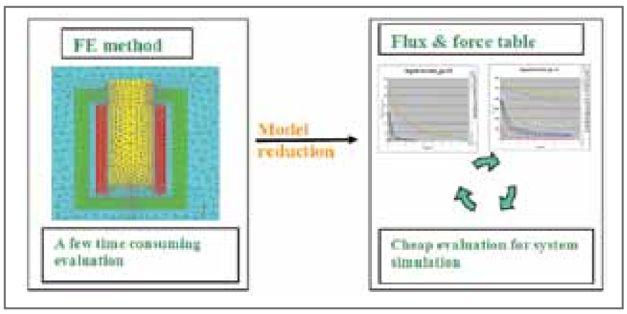
- **1. Analytical model with reluctance circuit**
- **2. Model with magneto-static tables from FE**
- **3. Full co-simulation with Flux FE software: transient study.**

1. Analytical method: reluctant model

This methodology uses a reluctance circuit network and is based on Kirchhoff's law. Portunus has a complete library dedicated to reluctance modeling.
The big advantage of this kind of model is cheap simulation time. However it can be difficult to get an accurate model, especially when iron is saturated.



Example of reluctant circuit network for a plunger actuator.

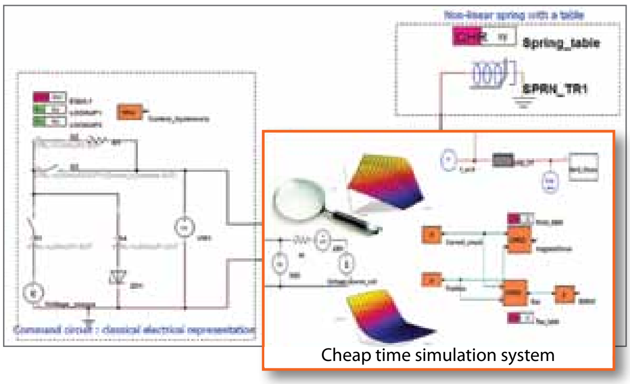


Reduction model of finite element methodology (2D/3D simulation with Flux => 1D simulation with Portunus).

(continued on page 13)

2. Model with magnetostatic tables

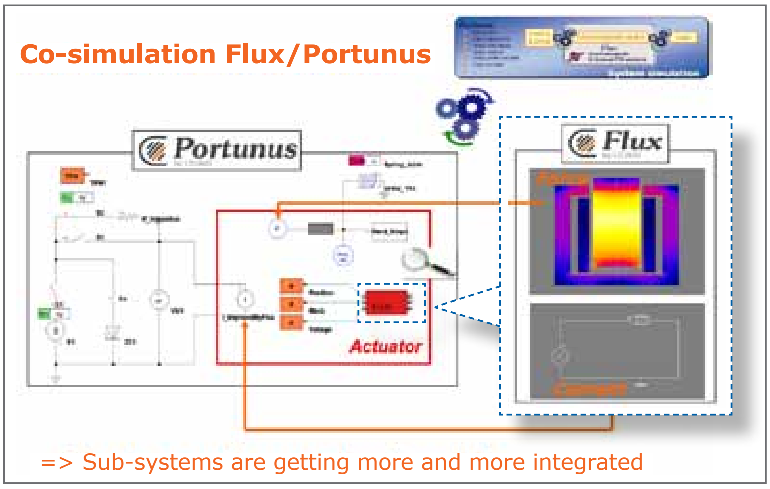
The aim of this method is to build a reduced accurate model of an actuator for a system simulation. Magneto-static table of force and flux is calculated with the finite element software Flux, according to position and current. So the accuracy of that model is contained in finite element methodology taking effective account of iron saturation. In addition to accuracy, one big benefit is that simulation time is short once the tables have been generated.
With the reluctant model, we can easily integrate response surface from FE model into Portunus:



Reduction model with finite element tables simulated under Portunus software.

3. Co-simulation model

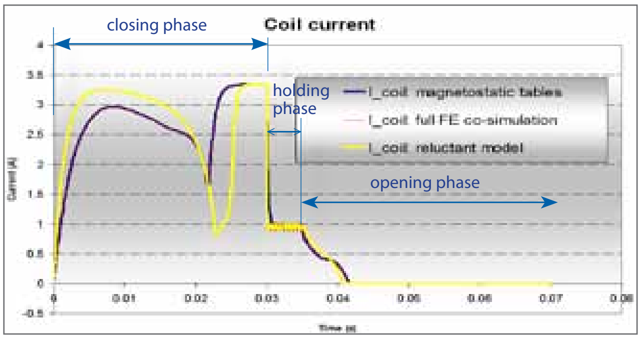
This method involves complete integration of the electromagnetic actuator. The magnetic model is represented by the FE software, Flux: a transient study incorporating Eddy currents (not possible with the two other methods). However, calculation time is longer than the two other models; this is why the method is adapted to perform a verification test when the virtual system is complete and optimized.



Finite element full co-simulation with Portunus and Flux software.

Comparison of the three models

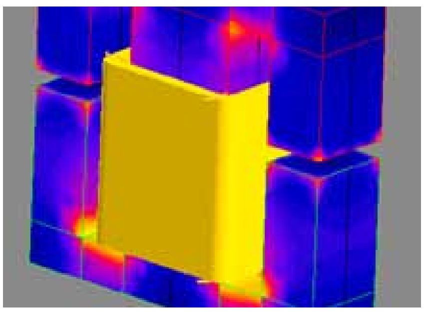
Below, we described the current curves of an electromagnetic actuator for each method presented previously:



This graph clearly shows that the magneto-static table method is as accurate as the full co-simulation using the finite element method without Eddy current: the two curves are superposed! Also, we see that the reluctant model is less accurate, even though the configuration produces a close approximation.

Conclusion

Reluctant models are powerful in fast pre-design of an electromagnetic actuator, making it an efficient way of roughly sizing a volume of iron in an initial approach.
Full co-simulation with the finite element method has a big drawback – long simulation time (due to finite element calculation) – although it does take other physics phenomena into account such as Eddy currents. This explains why it is an accurate method appropriate for final verification tests in order to see, for example, whether Eddy currents has a strong influence on a complex system.
Clearly compared to the last two methods, the magneto-static method with finite element response surface seems to be the best compromise between simulation time and accuracy for representing actuator behaviour in a mechatronic system.



	Analytic method	Finite Elements method			
	Model reluctant	Magnetostatic table		Co-simulation Flux/Portunus	
				Fast precision	High precision
Make the model (enter geometry, physic...)	–	++		+	+
Simulation time	+++	+++ Table already made	– Without production of tables	–	– –
Simulation time with Eddy Currents	No existing model			– –	– – –
Accuracy	– – –	++	++		+++