Model based design of a piezoelectric positioning system

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Abstract

Positioning systems are a fundamental part in many industrial systems and products ranging from measuring devices and manufacturing machines to braking or steering systems in the automotive industry. In each case, the different restrictions and use cases define specific requirements and design conditions, like availability of sensors, accuracy, or acceptable signal noise among others. These conditions impose technical requirements in the different components which must be defined and considered from the concept phase until the final validation. To make it possible, a clear design method is fundamental during the entire process. Besides, the use of models at component and system level merging the effects of the parts and domains (electrical, mechanical, software and so on) is fundamental to assuring the final result. In the present work the complete development process of a piezoelectric positioning system is described with a special focus on the developed mathematical models and their different complexity level depending on the design phase and objective. Therefore simplified representations will be used in the concept phase; they will be incrementally complicated as they are more and more accurate during the detail design of the different parts; and finally, a balanced complexity and accuracy compromise will be devised for the virtual system validation and the development of the model based control algorithm. In this case, the controllers are developed based on differential flatness and make use of the knowledge contained in the mathematical models for efficiently handling the nonlinearities and fulfilling the required dynamical conditions.

The platform is a 3 DoF positioning system for measuring systems and therefore tracking accuracy in both static and dynamic conditions is required. The actuators are APA-120 ML from Cedrat Group and the closed loop control uses the information from three embedded strain gauges or 6 capacitive sensors depending on the final application. The range of the platform is ±73µm in vertical movement, and ±0.8mrad in tip/tilt. The operation should assure a tracking error below 5% in a bandwidth of 25 Hz. Figure 1 shows the system and the design framework.

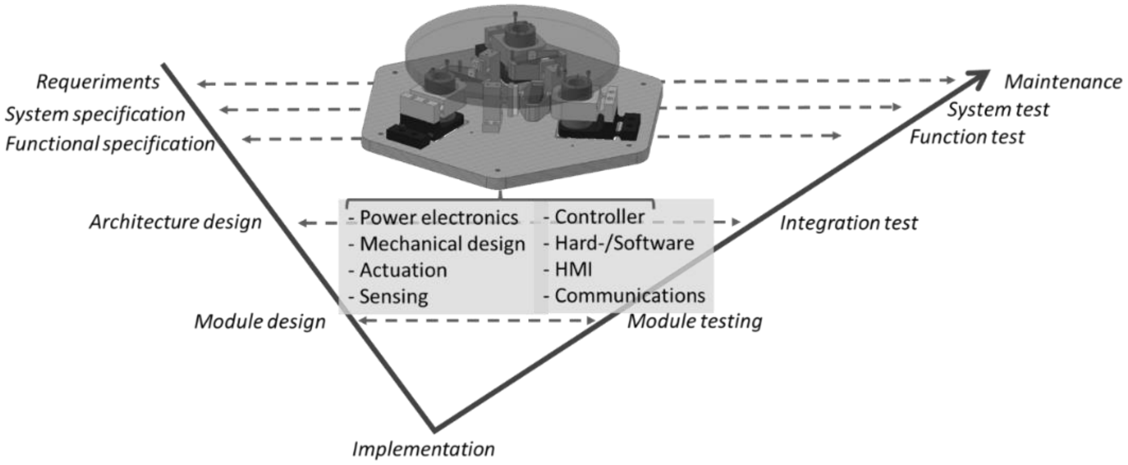

Figure 1: Piezolectric positioning system and design framework (V-diagram)

The design of the platform includes the mechanical elements, the actuators and sensors, the power electronics for actuation and signal conditioning, and the control architecture including software, communication interfaces and hardware. The mechanical design includes the kinematics of the system, the detailed design for assuring the required stiffness, the minimum crosstalk between degrees of freedom, and the absence of friction, which may cause hysteresis effects and low dynamic performance. The power electronics in combination with the proper selection of actuators and sensors deals with linearity, accuracy and resolution requirements, combined with EMC and low noise levels for avoiding noise leakage in the movement of the platform when powering the actuator or when using the sensor signal for the control feedback. Finally, the control algorithms have to be robust and stable, at the time the control architecture assures the proper real time restrictions, safety and operation.

Figure 2 shows the first example of models for the design of the actuation system. This detailed design corresponds with the component design phase in figure 1. In this case, the hysteresis phenomenon that appears in the piezoelectric actuator requires specific characterization tests. The figure shows the design process linked with the further module validation.

The same approach based on progressive complexity models is extended from the actuation line to the representation of the complete system. In this case, the previous models of the actuation line are embedded in the new description. The models can be seen in figure 3.

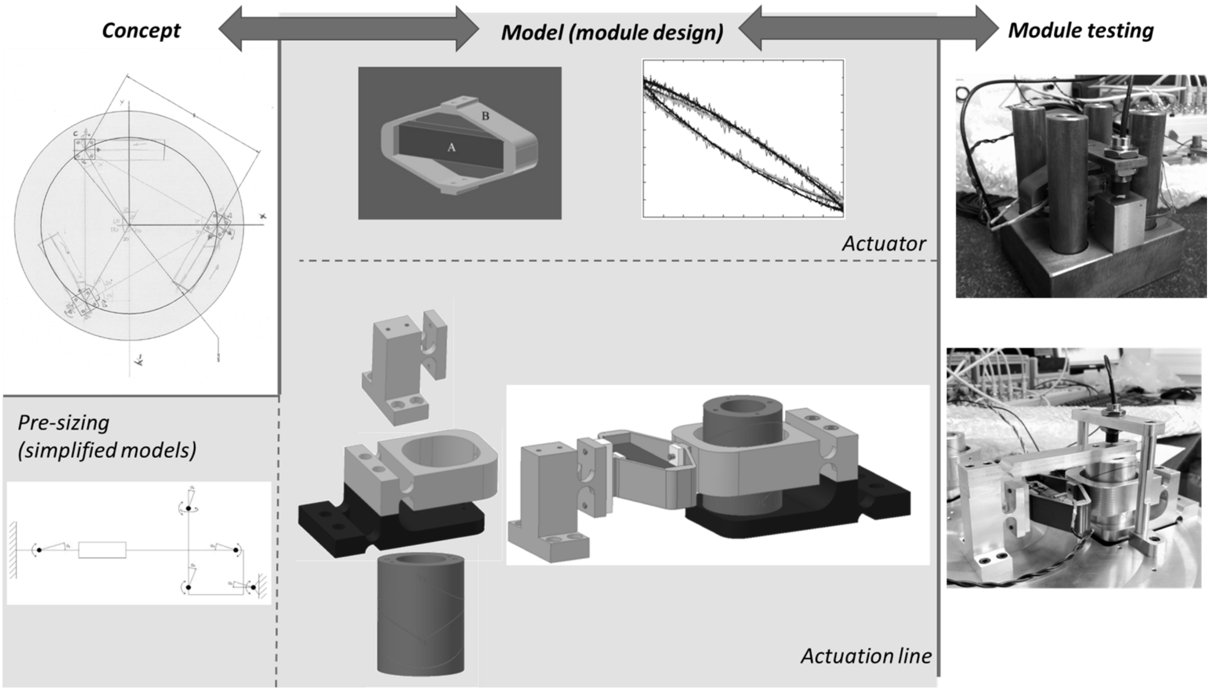

Figure 2: Actuation line design models and experimental validation

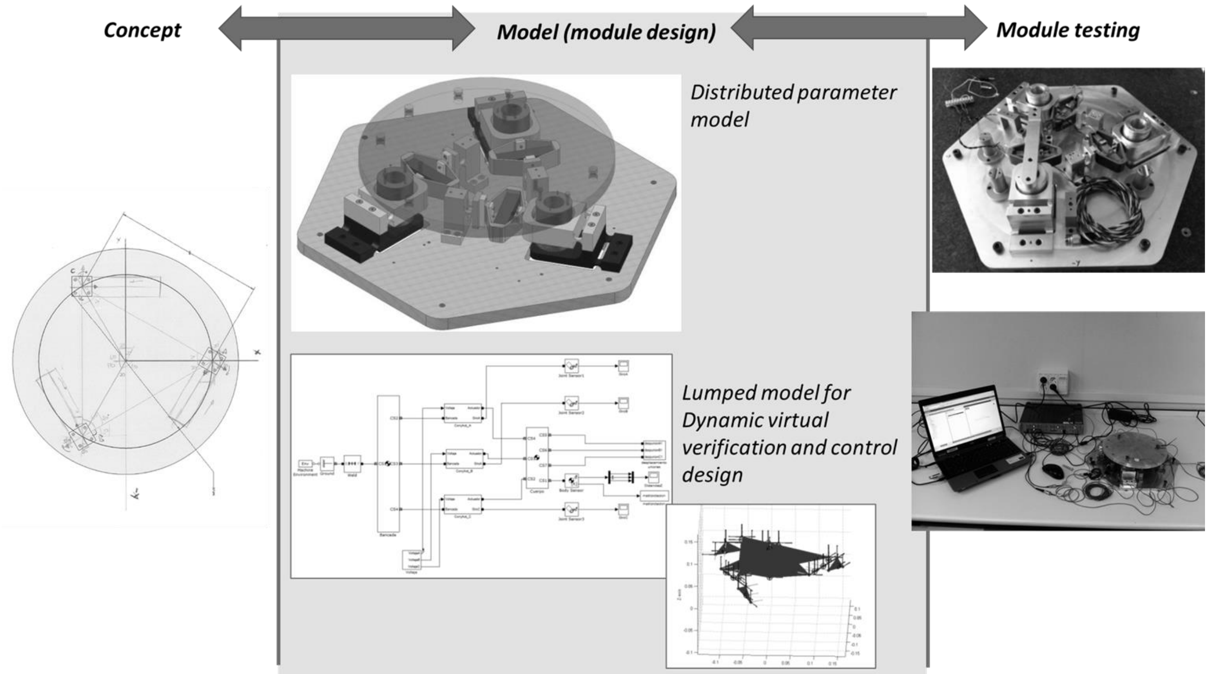

Figure 3: Platform design models and experimental validation

The simplified models developed in the previous phases are embedded in the controller. The algorithm is based on differential flatness and it successfully handles the nonlinearities of the system, which allows a fast tracking of a reference trajectory thanks to the coupling between the command and the trajectory. The same basic property can be used both for tracking and active vibration control. Figure 4 shows the former approach. In both cases, the dynamic performance is improved using hysteresis compensators that embed the hysteresis models obtained during the identification of the actuator behaviour.

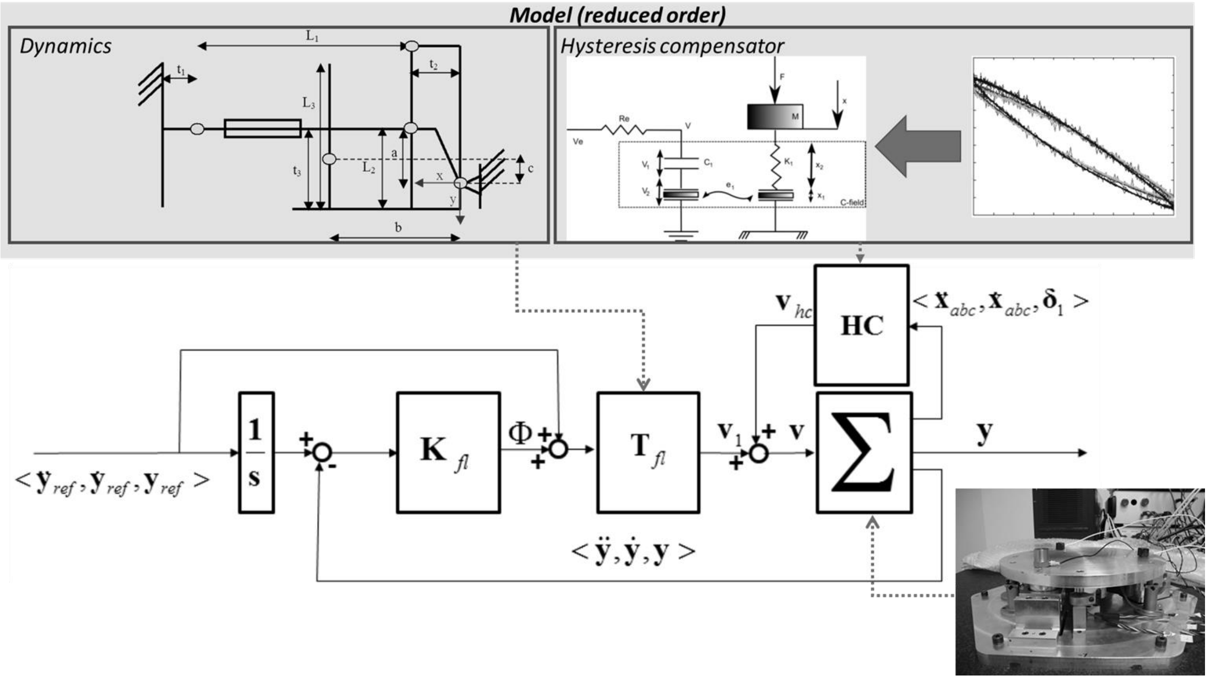

Figure 4: Models used in the controller based on differential flatness

This work shows the importance of a rational development of models in the development process in order to assure the fulfilment of the system requirements and to support the design of the different components.