ISSN: 1859-2171
e-ISSN: 2615-9562 TNU Journal of Science and Technology 203(10): 59 - 65

MODELING AND DYNAMIC SIMULATION OF ROBOT IRB 120 BASED ON SIMSCAPE MULTIBODY

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ABSTRACT

Commonly, the dynamic simulation of a robot manipulator is based on the identified mathematics model. It is difficult to add friction, actuator dynamics to this model so that these nonlinear dynamics usually are simplified or neglected. Therefore, the simulation result is idealized, and the reliability of the simulation seems to be in doubt. The paper presents the quasi-physical modeling of robot IRB 120 using MATLAB/Simscape Multibody for dynamic simulation. The bodies of the robot are assembled into a physical network with connections that represent physical domains. The fashions of the quasi-physical model are close to that of the actual robot. The effectiveness of the proposed modeling approach is demonstrated through some simulations.

Keywords: *Dynamic Model; Quasi-physical Modeling; Robot Manipulator; Simscape Multibody; Joint friction.*

Received: 28/10/2019; Revised: 24/11/2019; Approved: 30/11/2019

MÔ HÌNH HÓA VÀ MÔ PHỎNG ĐỘNG LỰC HỌC CHO ROBOT IRB 120 DỰA TRÊN SIMSCAPE MULTIBODY

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TÓM TẮT

Hiện nay việc mô phỏng động lực học cho tay máy robot thường dựa trên mô hình toán học đã được nhận dạng. Trong mô hình toán đó, các thành phần phi tuyến như ma sát và cơ chế chấp hành không hề dễ dàng khi muốn đưa vào để phản ánh đầy đủ bản chất vật lý của chúng. Do đó ảnh hưởng của các thành phần phi tuyến này thường được đơn giản hóa hoặc thậm chí bỏ qua khi xây dựng mô hình. Điều này đã làm lý tưởng hóa và giảm độ tin cậy của các kết quả mô phỏng. Bài báo này trình bày về xây dựng mô hình vật lý ảo và thực hiện mô phỏng kiểm chứng cho tay máy robot IRB 120 sử dụng MATLAB/Simscape Multibody. Các bộ phận cấu thành lên robot được lắp ráp và kết nối trong một môi trường mô phỏng vật lý ảo phản ánh bản chất vật lý tương tự trong thực tiễn. Vì thế, mô hình vật lý ảo của robot sẽ có các đặc tính và đáp ứng gần giống với robot thật. Các kết quả mô phỏng sẽ làm rõ sự hiệu quả của cách tiếp cận này trong việc mô hình hóa robot.

Từ khóa: *Dynamic Model; Quasi-physical Modeling; Robot Manipulator; Simscape Multibody; Joint friction.*

Ngày nhận bài: 28/10/2019; Ngày hoàn thiện: 24/11/2019; Ngày duyệt đăng: 30/11 /2019

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https://doi.org/10.34238/tnu-jst.2019.10.2263

1. Introduction

For robot simulation, many well-known techniques for establishing the mathematics model of dynamics of robot manipulators are published. It is difficult to add friction, dynamics of actuators, and other nonlinear dynamics to the mathematics model. These drawbacks can be overcome in the quasi-physical model built by Simscape Multibody. This is an effective approach for representing multibody systems because of the compliance with the real plant. The physical system modeling based on Simscape has been used successfully in many different fields: PV generators in microgrid scenario [1], graphene based nano-electronic systems [2], power PIN diodes [3], wind turbine gearboxes [4], three-wheeled electric vehicles [5], and so on. For robot manipulators, several applications using this approach are presented, e.g., Furuta pendulum [6], hexapod robots [7], 3-RPS parallel robotics [8], 2-DOF robots [9], 5-DOF robotic manipulators [10]. In this paper, the quasi-physical model of robot IRB 120 is constructed based on the CAD models including mass, inertias, joints, and constraints in 3-D geometry. Simscape Multibody can generate and simulate the model of robot IRB 120, which is conformable to the real performance instead of utilizing an actual plant or a prototype. The paper presents, firstly, the model of robot IRB 120 (section 2). Secondly, we build the quasi-physical model of the robot - from designing geometry bodies to completing the quasi-physical model (section 3). Thirdly, the comparison between the dynamic behaviors of mathematics model and quasi-physical model is given (section 4). Finally, some important conclusions are discussed in section 5.

2. Robot IRB 120

Robot IRB 120 which is one type of 6-DOF industrial robots produced by ABB corporation, has six revolute joints. The robot configuration with attached frames and the D-H parameters are described in **Fig. 1** and **Table. 1**.

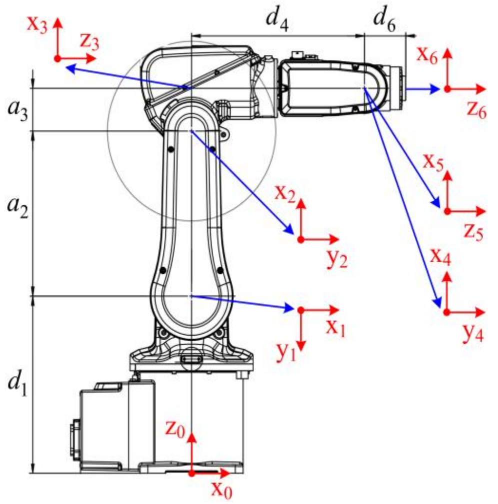


Fig. 1. *The attached frames of robot IRB 120*

Table 1. *D-H parameters of robot IRB 120*

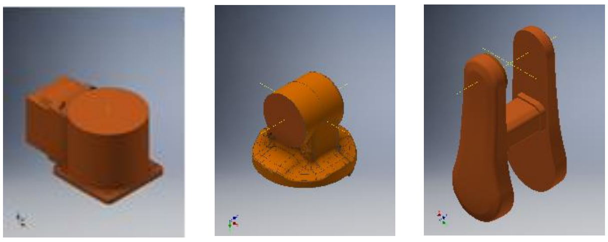
Joint i	θ_i [rad]	d_i [m]
1	q_1	$d_1 = 0.29$
2	$q_2-\frac{\pi}{2}$	$d_2 = 0$
3	q_3	$d_3 = 0$
4	q_4	$d_4 = 0.302$
5	q_5	$d_5 = 0$
6	q_6	$d_6 = 0.072$

Joint i	a_i [m]	α_i [rad]
1	$a_1 = 0$	$\alpha_1 = -\frac{\pi}{2}$
2	$a_2 = 0.27$	$\alpha_2 = 0$
3	$a_3 = 0.07$	$\alpha_3 = -\frac{\pi}{2}$
4	$a_4 = 0$	$\alpha_4 = \frac{\pi}{2}$
5	$a_5 = 0$	$\alpha_5 = -\frac{\pi}{2}$
6	$a_6 = 0$	$\alpha_6 = 0$

3. Quasi-physical modeling of robot IRB 120 using Simscape Multibody

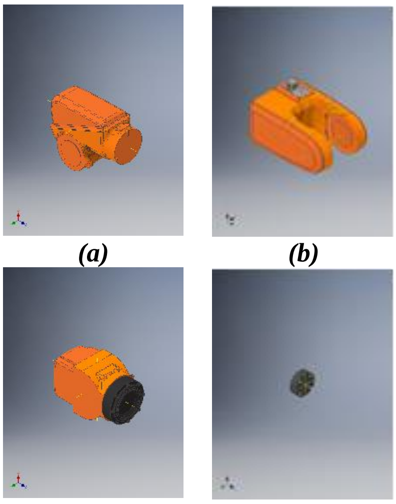
3.1 3D CAD models of links

For a real robot manipulator, it is too difficult to get the precise information about link centroids and inertia tensors of links. Hence, some powerful professional 3D mechanical design softwares such as Autodesk Inventor, SolidWork, or OnShape (here we use Autodesk Inventor) can be exploited to build the 3D models of robot IRB 120 links for exploring those parameters (**Fig. 2 - Fig. 3**).



(a) ***(b)*** ***(c)***

Fig. 2. *The base (a), link 1 (b), and link 2 (c) of robot IRB 120*



(a) ***(b)***

(c) ***(d)***

Fig. 3. *Link 3 (a), link 4 (b), link 5 (c), and link 6 (d) of robot IRB 120*

Based on the shape, structure, and material components of links of robot IRB 120; the approximated values of mass, link centroids, and inertia tensors can be achieved by performing the physics analysis method of Autodesk Inventor. The whole robot IRB 120 assembled from its parts is shown in **Fig. 4**.

Fig. 4. *Autodesk Inventor 3D model of robot IRB 120*

3.2 Quasi-physical modeling of robot IRB 120

The quasi-physical modeling of robot IRB 120 can be built by using MATLAB Simscape Multibody. For 3D mechanical systems, Simscape Multibody provides a multibody simulation environment which enables the bodies to be assembled into a physical network with connections that represent physical domains instead of using a signal-based approach. Simscape Multibody generates quasi-physical modeling of a complete multibody system then formulates and solves the equations of motion for the system. The quasi-physical model and visualization of robot IRB 120 using Simscape Multibody are depicted in **Fig. 5**.

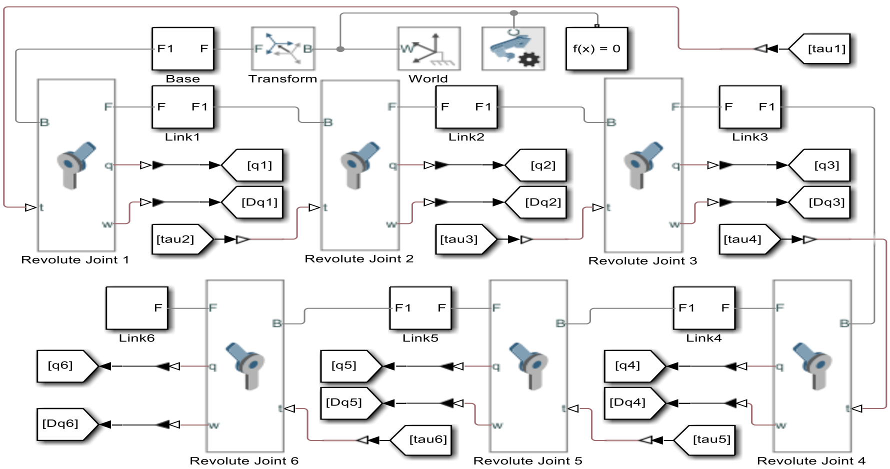


Fig. 5. *Quasi-physical model of robot IRB 120 constructed by Simscape Multibody*

4. Dynamic simulation

4.1. Dynamic simulation without joint friction

The effectiveness of the quasi-physical model can be illustrated through the comparison between the dynamic response of this model and that of the mathematics model for the same plant, i.e., robot IRB 120. The simulation schematic is shown in **Fig. 6** and the input torques are generated by the inverse dynamics as

$$\boldsymbol{\tau} = \mathbf{M}(\mathbf{q}_r)\ddot{\mathbf{q}}_r + \mathbf{C}(\mathbf{q}_r, \dot{\mathbf{q}}_r)\dot{\mathbf{q}}_r + \mathbf{g}(\mathbf{q}_r) \quad (1)$$

where $\mathbf{M}$ is the general inertia matrix, $\mathbf{C}$ is the Coriolis/centrifugal matrix, $\mathbf{g}$ is the gravity vector; $\mathbf{q}_r = [q_{1r}, \dots, q_{6r}]^T$ is the given trajectory of joints as follows [rad], which satisfies the initial condition: $\mathbf{q}_r(0) = \mathbf{q}(0)$ and $\dot{\mathbf{q}}_r(0) = \dot{\mathbf{q}}(0)$,

$$\begin{aligned} q_{1r} &= 1 - \cos(2\pi t) \\ q_{2r} &= 0.75(1 - \cos(2\pi t)) \\ q_{3r} &= 0.5(1 - \cos(2\pi t)) \\ q_{4r} &= 1.25(1 - \cos(2\pi t)) \\ q_{5r} &= 1 - \cos(2\pi t) \\ q_{6r} &= 1.5(1 - \cos(2\pi t)) \end{aligned} \quad (2)$$

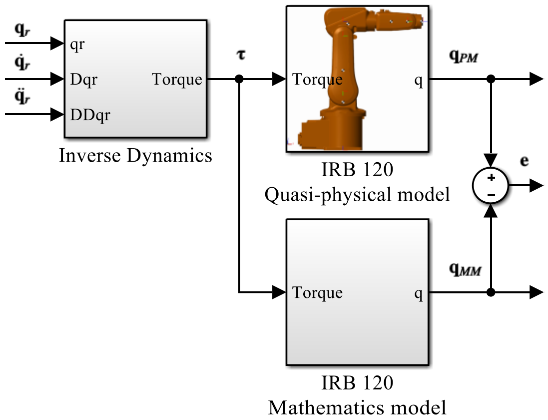


Fig. 6. *Dynamic simulation schematic for robot IRB 120*

The responses of two models and the output errors between two models are shown in **Fig. 8** and **Fig. 9**, respectively, under the act of same input torques described in **Fig. 7**.

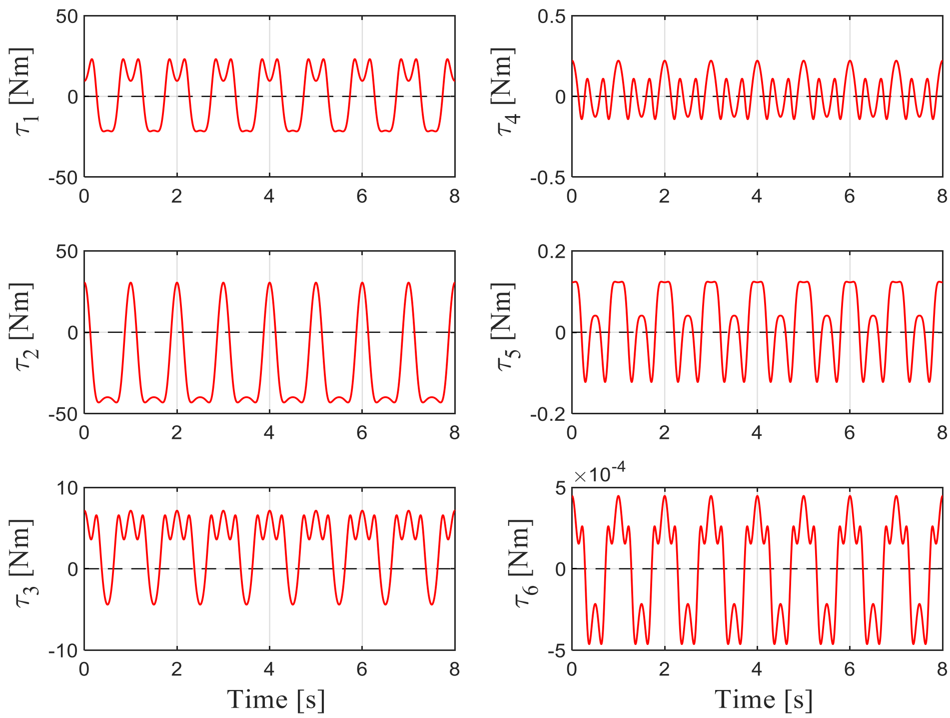


Fig. 7. *Input torques produced by Inverse Dynamics*

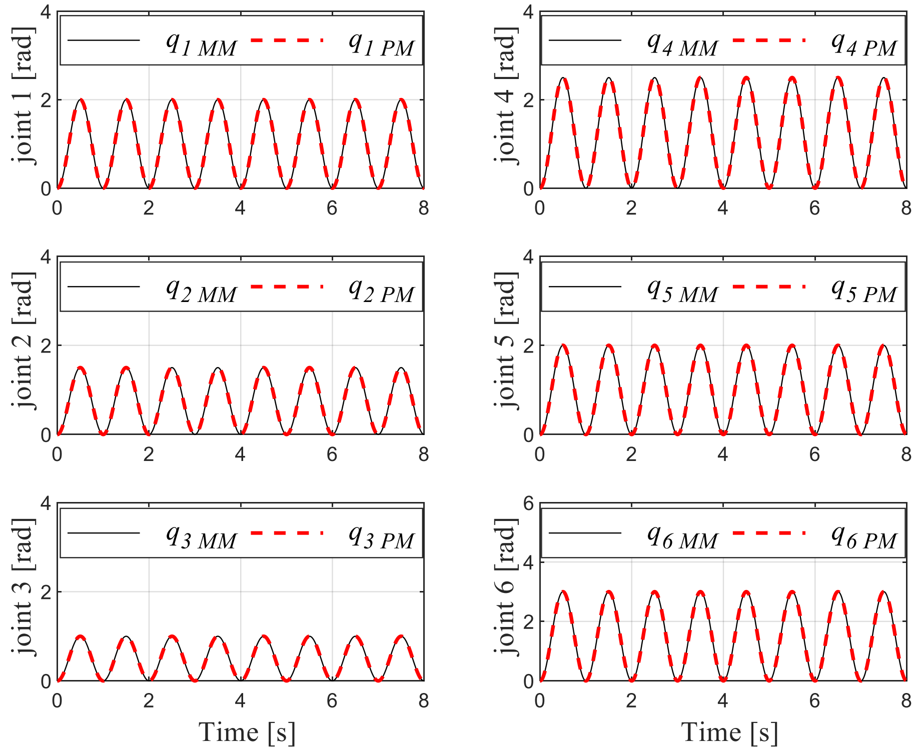


Fig. 8. *Responses of mathematics model (MM) and quasi-physical model (PM)*

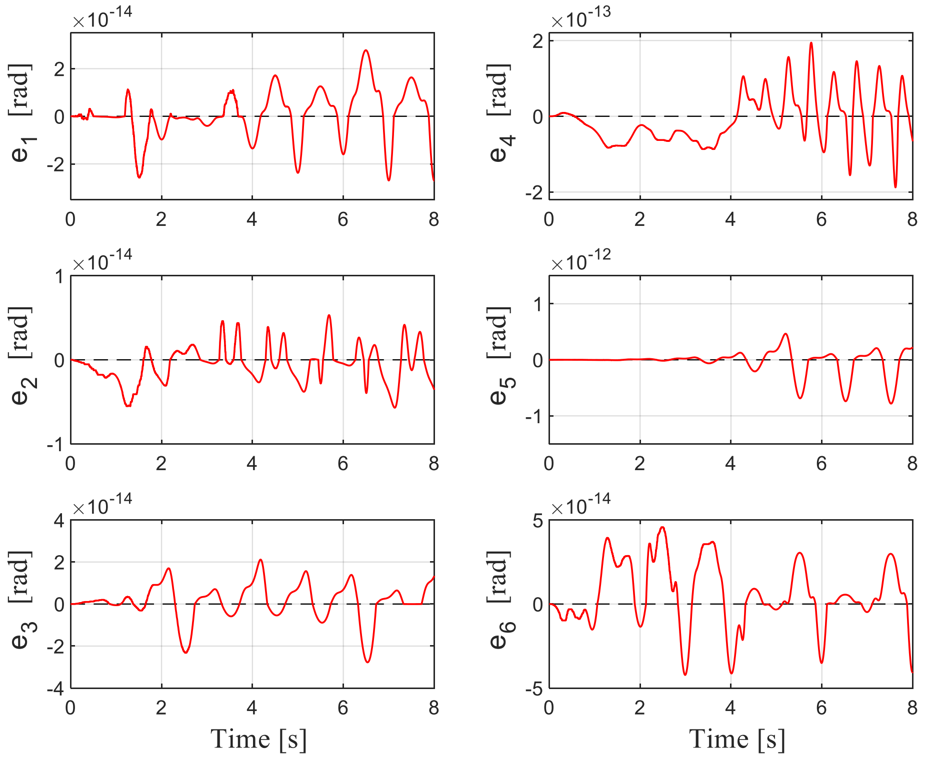


Fig. 9. *Output errors between two models*

Fig. 8 and **Fig. 9** show that the responses of two models are closely matched with slight tracking errors. Without considering friction, this result confirms that the quasi-physical model constructed by Simscape Multibody is equivalent to the mathematics model. Therefore, the quasi-physical model can be used instead of the mathematics model for robot simulation.

4.2. Dynamic simulation with joint friction

Both joint friction and actuator dynamics can be added to the robot IRB 120 Simscape-based model, which makes the virtual robot manner conforming to the reality. Here we just add the rotational friction (3) described in **Fig. 10** and **Fig. 11** represented by to every revolute joint of the quasi-physical model, which makes the virtual robot closer to the real robot. Friction torque τ_{Fi} which is a function of joint velocity ω_i is approximated in the following equation as the sum of Stribeck τ_{Si}, Coulomb τ_{Ci}, and viscous friction τ_{Vi} [11]:

$$\tau_{Fi} = \sqrt{2e}(\tau_{brki} - \tau_{Ci})\exp\left(-\left(\frac{\omega_i}{\omega_{Si}}\right)^2\right)\frac{\omega_i}{\omega_{Si}} + \tau_{Ci}\tanh\left(\frac{\omega_i}{\omega_{CLi}}\right) + \tau_{Vi} \qquad (3)$$

where $\tau_{brki} = \tau_{Si(0)} + \tau_{Ci}$ is the breakaway friction torque, $\tau_{Si(0)}$ is the Stribeck friction torque at the vicinity of zero velocity, $\tau_{Vi} = k_{vi}\omega_i$, k_{vi} is the viscous friction coefficient, ω_{Si} and ω_{CLi} are the Stribeck and Coulomb velocity thresholds.

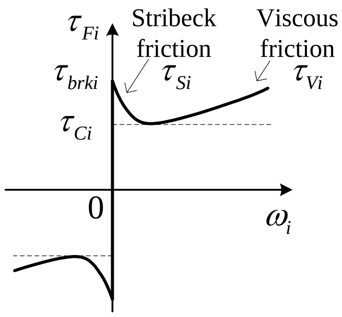


Fig. 10. *Rotational friction torque*

The dynamic responses under the torques generated by the inverse dynamics (1) are shown in **Fig. 12**. Under friction effects, the joints cannot track the references after a few cycles. The simulation shows the advantage of using Simscape-based quasi-physical model in the presence of friction.

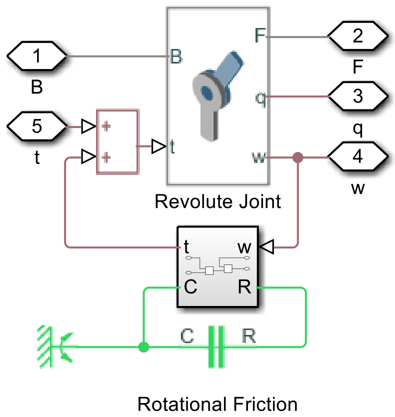


Fig. 11. *Revolute joint including friction*

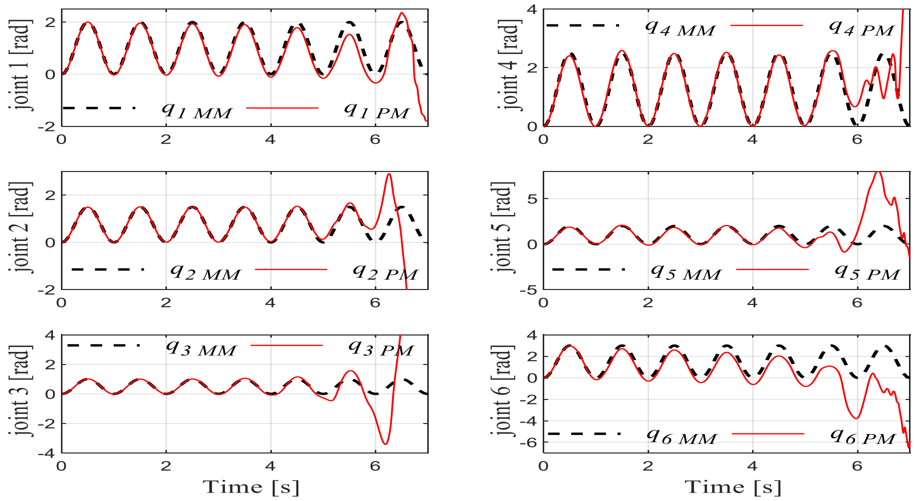


Fig. 12. *Responses of mathematics model (MM) and quasi-physical model including joint friction (PM) under torques provided by inverse dynamics*

5. Conclusions

The analyses of dynamic simulations in this paper show the effectiveness of the Simscape-based quasi-physical modeling for robot manipulators. The robot simulation is conventionally executed with the identified mathematics model which is not convenient to add complicated terms such as friction, actuator dynamics. By using quasi-physical models, the reliability of the simulation is improved, and we can test the system for possible failures early in the design process. Moreover, the fidelity of the identified model can be regulated and/or verified by comparing the dynamic response between this model and the quasi-physical model. From design work to reality, this kind of approach in simulation can considerably reduce both time and cost of research and development.

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