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Co-simulation analysis of the single stage screw feedback digital hydraulic cylinder

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Abstract. Taking the single-stage spiral feedback digital hydraulic cylinder as the research object, on the basis of analyzing its composition and mechanical feedback mechanism, we explored the idea of collaborative simulation based on AMESim and Simulink software, and finally realized the collaborative simulation of digital hydraulic cylinder. In this simulation, we use AMESim software to build the mechanical and hydraulic models, Simulink software to build the step-in motor model, and integrate the hydraulic model into the Simulink platform environment through the software interface. We can easily change the parameters to analyze its performance, and provide a convenient way for digital hydraulic cylinder performance optimization research.

1. Introduction

Because the connection of digital hydraulic components to the computer does not require a D/A converter, it eliminates the need for linear and continuity between various links for analog control, so the characteristic is that an output is proportional to a certain characteristic parameter of the input pulse sequence. Compared with the analog hydraulic components, we can find that the digital hydraulic components have the advantages of simple structure, good manufacturability, strong anti-pollution ability, and can work in harsh environments. At the same time, the output of the digital hydraulic components can be adjusted and controlled with high reliability by the pulse frequency or width, which has the characteristics of strong anti-interference ability and high control accuracy.

In recent years, the highly integrated electro-hydraulic digital hydraulic cylinder has become a research hotspot, and its applications have been continuously expanded. From the research perspective, simulation is a necessary auxiliary method. Most of the existing literatures use MATLAB, AMESim and other platform tools on the basis of mechanism modeling. Considering that the digital hydraulic cylinder is a multi-domain integrated system, if we want to comprehensively simulate it, each software platform needs to exert its own advantages. Through this method, we can easily build a simulation model and conclusion that is closer to the actual situation, and provide a more accurate model for the study of digital hydraulic cylinders. In this article, we will use AMESim and MATLAB/Simulink software interface, and combine the two software platforms. Through this method, we can give full play to the mechanical and hydraulic professional advantages of AMESim and the advantages of Simulink motor module [1]. Therefore, based on the above considerations, we have constructed a complete model of the digital hydraulic cylinder, and provided a convenient way to quickly realize the simulation of the digital hydraulic cylinder.



2. Structure and principle of single-stage spiral digital hydraulic cylinder

The structure of the single-stage spiral digital hydraulic cylinder is shown in Figure 1. And we can observe that it is mainly composed of stepper motor, slide valve, lead screw, feedback nut, piston rod and cylinder body, etc. The stepper motor is matched with one end of the slide valve core through a sliding key. The other end of the valve core is matched by an external thread and the internal thread of the coupling sleeve. The coupling sleeve and the screw are fixedly connected by a pin. The piston rod is a hollow structure, in which the screw is installed inside. The screw only rotates without moving left and right, and the feedback nut only moves left and right with the piston and does not rotate.

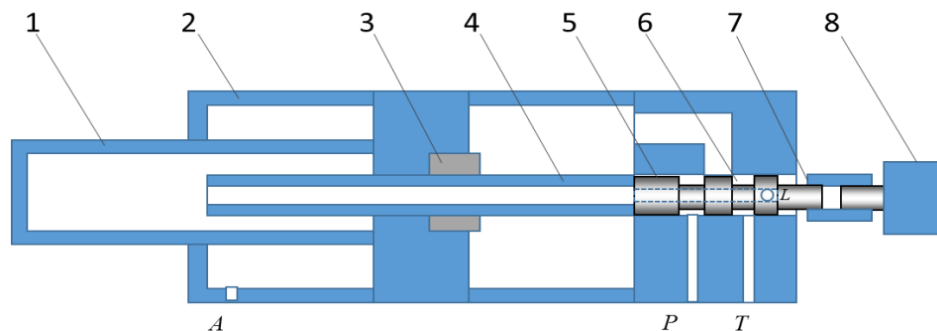


Figure 1. The schematic diagram of digital hydraulic cylinder.

1-Piston 2-Hydraulic cylinder 3-Feedback nut 4-Screw 5-Control spool 6-Valve port 7-Coupling sleeve 8-Stepper motor

Assuming that the piston of the oil cylinder starts to be in a balanced state, the controller sends a pulse signal to the stepper motor. When the stepper motor receives the pulse signal, it will output a certain angular velocity or angular displacement according to the corresponding rule. This movement is transmitted to the valve core through the sliding key. Under the action of the thread, between the valve core and the coupling sleeve, the valve core rotates and produces an axial displacement. If the valve core moves to the left, the high-pressure oil path is connected to the rodless cavity, and the return path is connected to the rod cavity. Then the rodless cavity pressure increases, the piston and the feedback nut move to the right together. At the same time drive the screw turn begin to rotate proportionally, and the direction of rotation is opposite to the running direction of the stepper motor. Under this circumstance, the screw will drive the coupling sleeve to rotate, so that the valve core moves to right; the valve port is closed; the piston is in a balanced state, and a stepping process ends. Similarly, if the input pulse signal is reversed, the stepper motor reverses, and the piston retracts in reverse. In this way, through the ingenious structure of the valve core, the lead screw and the feedback nut, the negative position feedback of the mechanical mode is realized, and a closed-loop is formed in the inner part, which shows the corresponding relationship between the pulse number and the piston displacement.

The digital hydraulic cylinder is a closed loop servo hydraulic actuator, which uses the position of the screw on the piston to achieve the precise mechanical feedback. Looking from the outside, as long as the stepper motor frequency and running time (that is, the number of pulses) are input, the piston rod will do the corresponding motion. It can be seen that this control method is very simple. But in its internal, movement relationship is very complicated, which mainly reflects on the valve core. When the motor drives the valve core movement, the feedback nut transmits displacement of the piston rod through the screw to the valve core is a feedback exercise. Therefore, the valve core is jointly controlled by stepper motor and screw feedback. Under the control of the valve core opening size determines the movement speed and displacement of the piston rod; in addition, its motion force is the most complicated, including the axial driving force of the motor, the axial driving force of the spiral feedback, the steady and transient fluid force and the friction force.

3. Based on AMESim and Simulink co-simulation ideas and modeling

3.1. Co-simulation ideas

Based on the above analysis, we can conclude that the calculation of the whole model is a modeling problem in multi-disciplinary fields, which includes the calculation of mechanical, the hydraulic and the electronic control. And the method of co-simulation is integrating software from different disciplines, that can exert the advantages of them. Hence, it can be regarded as an effective method to analyze the complex systems in multi-disciplinary fields. Based on AMESim, mechanical and hydraulic coupling modeling can be achieved, but the detailed model of the stepper motor has not been provided in AMESim, and the stepper motor model can be easily established in Simulink library. Through the combination of the two software, we can build the complete model of digital hydraulic cylinder easily, the idea is as shown in the Figure 2.

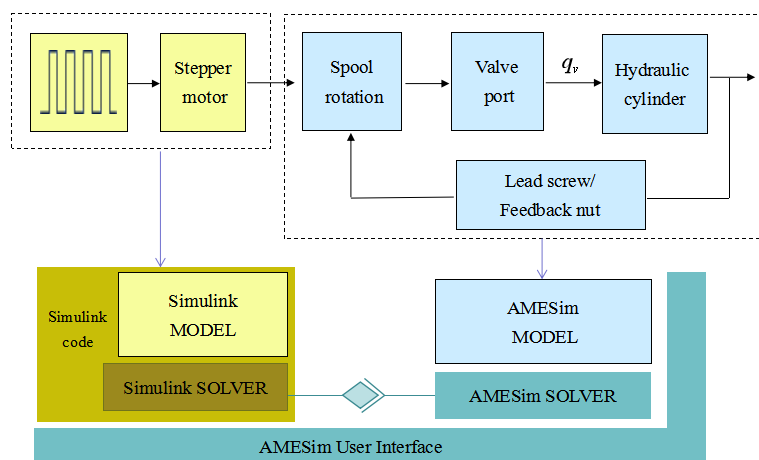


Figure 2. The block diagram of digital hydraulic cylinder system modeling and simulation.

Based on the Smulink, we build the component motor simulation model, the pulse signal is inputted to the stepper motor ant turn out angle signal; based on AMESim, we can structure hydraulic cylinder, control spool and spiral coupling mechanism feedback model to achieve control spool receives angular displacement signal, to piston output displacement signal; through AMESim and Simulink direct interface to achieve data transfer, we chose the pattern based on Amesim and Co-simulation.

3.2. The stepper motor model based on Simulink [2]

As shown in the Figure 3. is the Simulink simulation model of the stepper motor. We transmit the pulse generated by the pulse generator to the step motor driver to drive the stepper motor to rotate. And it mainly needs three subsystem modules, namely Measurement Signal module, Original Signal module and Signal Converter module. The parameters of the stepper motor and pulse signal are shown in the Figure 4 and Figure 5.

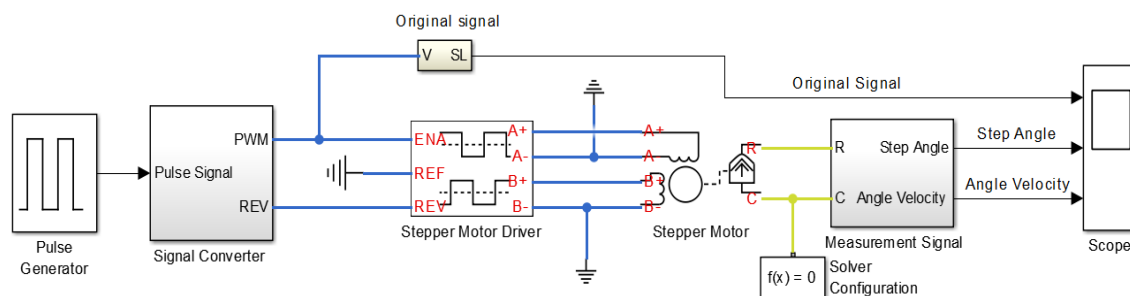


Figure 3. The Simulink simulation model of the stepper motor.

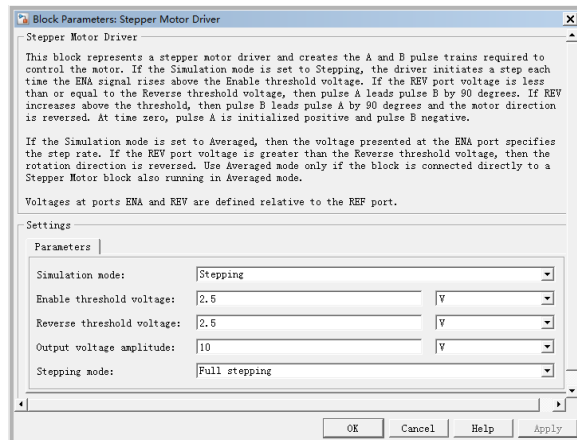


Figure 4. The parameters of the stepper motor.

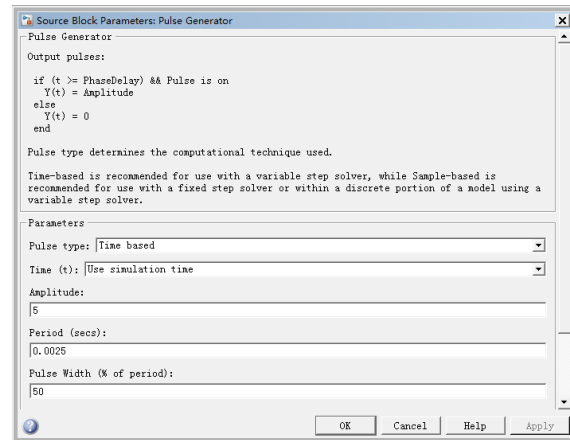


Figure 5. The parameters of the pulse signal.

3.3. Modeling of digital hydraulic cylinder mechanical hydraulic mechanism based on AMESim

Using the modular modeling method based on hydraulic component geometry in the HCD library of AMESim software, we will establish the detailed component model considering the dynamic performance of moving body, fluid compressibility, friction, leakage, hydrodynamics and other factors, and it can simulate almost all the hydraulic components. The established mechanical hydraulic component models are shown in the Figure 6. As for the digital hydraulic cylinder, we use the screw feedback mechanism. In this way, we can use the screw nut pairs provided in the mechanical library to establish the connection with the hydraulic cylinder and the control valve [3].

The control valve is the core of digital hydraulic cylinder. According to the actual structures, its simulation model can be composed of BA0012, BA0011 modules in HCD library and a mass block in a mechanical library. From the Figure 6, the mass block on the right represents the valve core, and the mass block can be set with forming limits at both ends to control the maximum displacement of the spool. According to the actual situation, the valve core adopts cylindrical section, and in the BA0012 and BA0011 modules, the piston diameter and rod diameter can be modified according to the actual three-way valve.

In the hydraulic cylinder model, the two modules, BAP12 and BAP11, represent a rod cavity and a rodless cavity, and by default the acting area of the two cavities is the same. If the two chambers need different areas of action, we can set to different piston rod diameters to achieve [4].

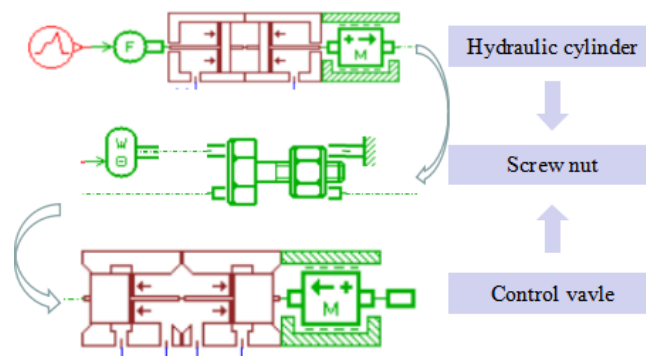


Figure 6. Model of main mechanical hydraulic components.

4. Co-simulation implementation based on AMESim and Simulink

A digital hydraulic cylinder mechanical simulation model is created in AMESim sketch mode. And the interface is used to construct an icon for the Simulink model. We can set the number of input and

output ports, define the icon name and select the joint simulation interface for the interface type. After that we will connect the model to the corresponding part of the interface icon. In the ‘Submodel Mode’, we select the appropriate sub-model for each module of the system, as shown in the Figure 7. Then we select the appropriate submodel for each module of the system in the ‘Parameter Mode’. When entering “run mode”, the process of converting AMESim model to S-function that can be called in Simulink is complete.

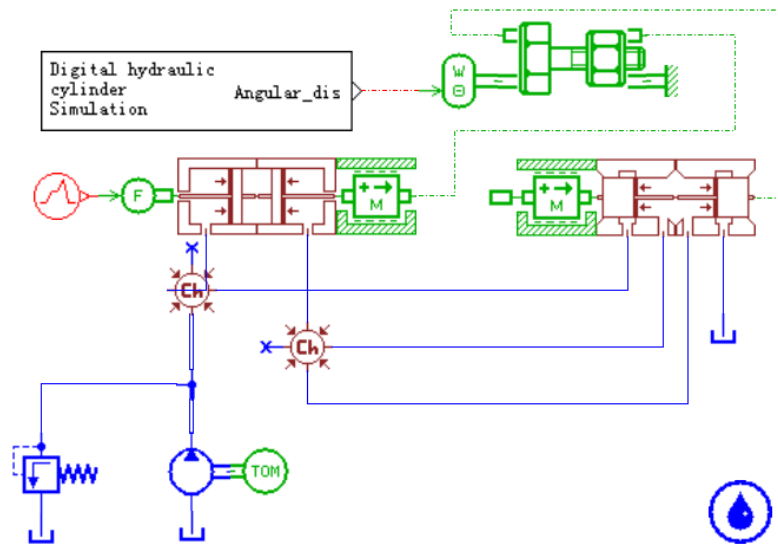


Figure 7. AMESim co-simulation model.

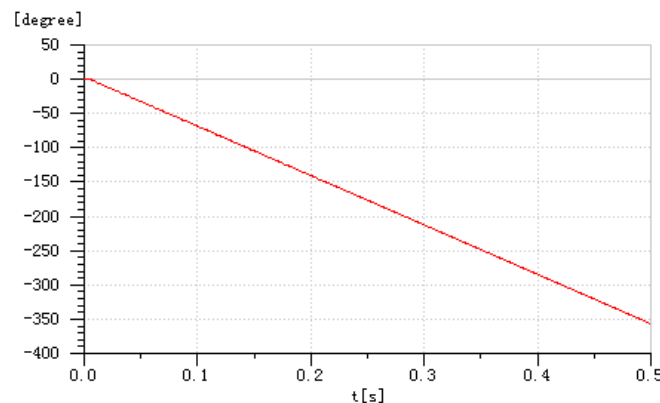


Figure 8. The input angle signal curve.

The parameterization and extension of Simulink need to use S-function, and the call syntax of S-function can interact with the solver in AMESim. Hence, we can add S-function to the model of Simulink through S-function module, and then connect the control algorithm model in Simulink to the controller in AMESim, so that we can combine AMESim and Simulink.

Set up the stepper motor model in Simulink of Matlab, and set the S-function name to the file name plus ‘_’ in the “S-Function” module parameter setting dialog box, and the parameter setting to “1 0.01”. The first parameter indicates whether to generate the AMESim result file, 1 indicates to generate, and 0 indicates not to generate; the second parameter indicates the time interval for outputting the result file. Set the simulation parameters to start the joint simulation.

The input angle signal of the screw nut is shown in the Figure 8. Run the simulation for 0.5s and check the simulation results [5]. And part of the simulation curves is shown as the Figure 9 and Figure 10. From these figures, we can find out that they basically reflect the working condition of the digital

hydraulic cylinder. By using this Co-simulation model, we will conveniently analyze and optimize the performance of digital hydraulic cylinder by changing the parameters of pulse signal frequency, driving load, oil pressure, valve port coverage, screw diameter and lead length conveniently.

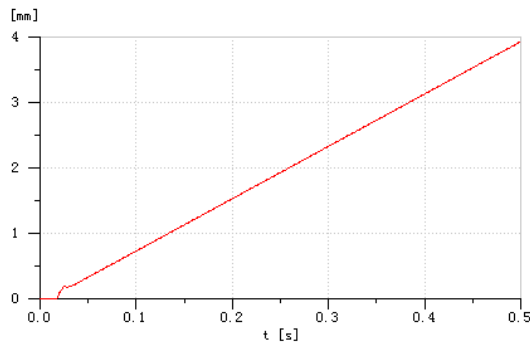


Figure 9. The piston displacement response curve.

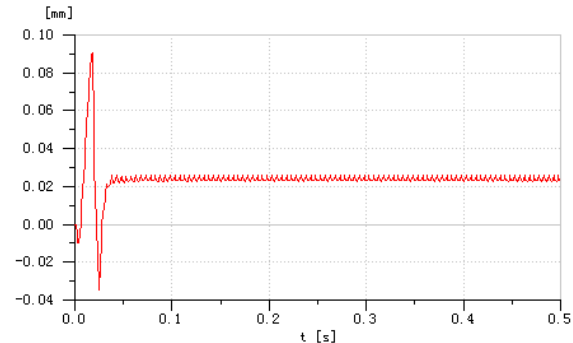


Figure 10. The spool displacement response curve.

5. Conclusions

Digital hydraulic cylinder is an integration of electromechanical hydraulic system. The simulation software of this system is involved in the modeling and simulation analysis of the system. In this article we make use of the advantages of two software fields, exploring the idea of Co-simulation based AMESim and Simulink. By using AMESim software, we establish the mechanical and hydraulic coupling model easily, and the stepper motor model is established by using Simulink software. Then we integrate and simulate the mechanical hydraulic model by software interface, and built the digital hydraulic cylinder simulation model of electromechanical fluid integration. Finally, based on this model, we can easily change the parameters to optimize the performance of the digital hydraulic cylinder.

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