COUPLED MULTIBODY SYSTEM DYNAMICS AND ITS APPLICATION ON SELF-PROPELLED ARTILLERY SYSTEM

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Summary In many industrial applications, complex mechanical systems can be modelled as multibody systems (MBS) that interact with electrical, flowing, elastic structures and other subsystems. We have to face the following problems when study coupled system dynamics if using the ordinary dynamic methods: 1) It is necessary to develop the global dynamic equations of the system, and the order of system matrices involved in the global dynamic equations is rather high for complex mechanical systems. 2) As the subsystems may exhibit different time scales, the step size of standard integration methods, which are usually limited by the time scales of active components, will cause the computational cost to increase. 3) The solution behaviour of each subsystem in most coupled systems is completely different. The choice of proper integration methods for the whole system is difficult. Therefore efficient dynamic analysis for such coupled mechanical systems has become a research focus in the field of MBS dynamics. In this paper, the discrete time transfer matrix method of MBS (MS-DT-TMM) and multirate time integration algorithm are combined to study the dynamics and co-simulation of coupled mechanical systems. The dynamic simulation of a coupled SPAS is given to validate the method. This method doesn't need the global dynamic equations and has a low-order system matrix, and therefore exhibits high computational efficiency. Besides, in the proposed method, each subsystem can be handled by different solvers and each solver can be tailored to the corresponding subsystem, which provides a convenient choice for numerical simulation of complex mechanical systems. The proposed method has advantages for dynamic design of coupled mechanical systems, and can be extended to other coupled systems in a straightforward manner.

DYNAMICS MODEL OF A COUPLED SELF-PROPELLED ARTILLERY SYSTEM

A SPAS is a typical coupled system due to some interactions between projectile and gun tube during launch. This coupling causes the SPAS launch dynamics to be complicated and highly nonlinear. As shown in Fig. 1, a SPAS can be divided into a MBS subsystem-I and a projectile subsystem-II. The MBS subsystem-I can be divided into various elements according to its structure. The elements (1-12, 25-36, 38 and 40) are regarded as elastic hinges. The element (42) is regarded as translational hinge. The wheels (13-24) are regarded as lumped masses. The undercarriage, traversing mechanism, elevating mechanism, gun breech, and muzzle brake (37, 39, 41, 43 and 47) are regarded as rigid bodies. The gun tube (45) is regarded as a flexible body connected by corresponding fixed hinges (44, 46). In the following section, the two subsystems of the SPAS will be modelled separately.

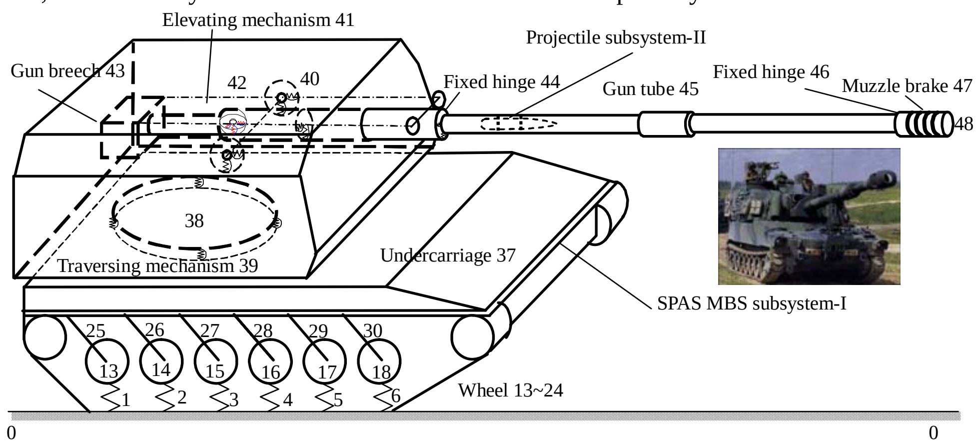

Fig 1 Dynamic model of coupled self-propelled artillery system

DYNAMIC MODELING FOR TWO SUBSYSTEMS OF THE SPAS

Launch dynamic equation of projectile subsystem

When the projectile moves along the gun tube during launch, some contact and impact will occur between them. Gravity, the contact force between the rotating band and the gun tube, air pressure of the powder gas, the contact force between the front band and the gun bore and the corresponding moment would act on the projectile. Considering these forces and moments, according to Newton's law of motion and the absolute angular momentum theorem, the dynamic equations of a non-symmetrical projectile in a gain-twist rifled gun tube can be obtained in the following form [1].

$$\ddot{\xi}_{\mathrm{II}}(t) = \mathbf{F}(\xi_{\mathrm{II}}, \dot{\xi}_{\mathrm{II}}, \xi_{\mathrm{I}}, \dot{\xi}_{\mathrm{I}}, t) \quad (1)$$

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where ξ_{II}, and $\mathbf{F}$ are the generalized coordinates and the generalized force on the projectile, respectively, ξ_{I} is the coupling motion parameters of MBS subsystem-I. $\dot{\xi}$ and $\ddot{\xi}$ represent the first and second order derivatives of ξ with respect to time.

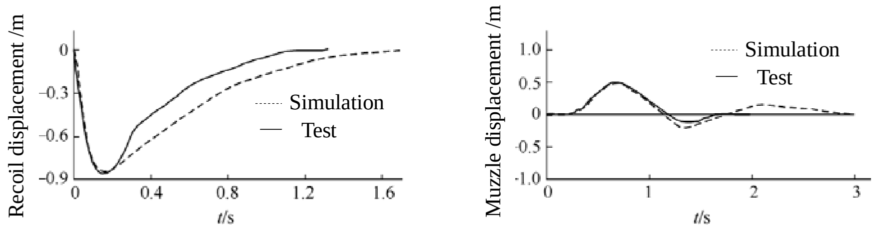
Dynamic modeling for MBS subsystem by using MS-DT-TMM

In our study, MS-DT-TMM [2, 3] is used for dynamic modeling of the MBS subsystem of the SPAS. Linearizing the dynamic equations of each element of the MBS subsystem, the transfer equations and transfer matrices of these bodies and hinges can be developed individually. By assembling the transfer equations of the elements, the overall transfer equation and overall transfer matrix of a MBS subsystem can be obtained easily. Assembling the transfer equations of the elements, the overall transfer equation and transfer matrix of any complex MBS can be obtained. Applying the boundary conditions of the MBS subsystem of the SPAS, one can obtain algebra equations about the unknown state variables of the boundary state vectors as

$$\overline{\mathbf{U}}_{\mathrm{all}}(\xi_{\mathrm{II}}(t_i),\dot{\xi}_{\mathrm{II}}(t_i),t_i)\overline{\mathbf{z}}_{\mathrm{all}}(t_i)=\mathbf{X}_{42\times1}(\xi_{\mathrm{II}}(t_i),\dot{\xi}_{\mathrm{II}}(t_i),t_i) \tag{2}$$

CO-SIMULATION OF THE COUPLED SPAS

The time integration of a coupled system by standard methods becomes inefficient since the time stepsize for the overall system is restricted by the time scale of the fastest subsystem. Multirate methods [4, 5] that allow using different time stepsizes in different subsystems offer a large potential for saving computing time. In this study, the multirate integration is introduced for coupled system dynamics. The latent subsystem is integrated using a larger step size while the active subsystem is updated using a smaller step size. The dynamics of the SPAS and the projectile can be obtained by the proposed co-simulation algorithm, and the computational results are compared with results obtained by launch experiment. The time history of recoil displacement and muzzle displacement are given in Figs.2. It can be seen clearly from Fig. 2 that the results of the recoil displacement and the muzzle displacement obtained by the proposed method are in good agreement with test data, which also validates the dynamic model, the proposed method, and its numerical stability.



(a) Recoil displacement (b) Muzzle displacement

Fig 2 Time history of recoil displacement and muzzle displacement

CONCLUSIONS

In this paper, taking a coupled SPAS as an example, the MS-DT-TMM and multirate time integration algorithm are used to study the dynamics and co-simulation of coupled mechanical systems. The dynamic simulation of the SPAS is compared with test to validate the method. Compared with ordinary methods, this method has the following advantages for the dynamics of coupled mechanical systems: (1) The MS-DT-TMM is introduced for dynamic modelling of MBS subsystems and the global dynamic equations of MBS subsystems are not needed, which simplifies the dynamic modelling and the solution procedure of coupled mechanical systems. (2) Irrespective of the size of a system, the matrices involved in this method are always small, which greatly reduces the computational time and memory storage requirement. (3) In such a co-simulation approach, the subsystems can be handled by different solvers and each solver can be tailored to the corresponding subsystem, which provides a convenient choice for numerical simulation of complex mechanical systems. (4) From the numerical viewpoint, this co-simulation approach provides a possibility for parallel computation. It has advantages for dynamic design of complex coupled systems.

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