Induction Coil Gun Field-Circuit Analysis Based on Current Filament Method and Non-Overlapping Mortar Finite Element Method

Liu Shoubao, Ruan Jiangjun, Du Zhiye, Zhang Yujiao, Wang Dong, Huang Guodong
School of Electrical Engineering, Wuhan University
No.8, South Road of Eastern Lake, 430072, China
Liushoubao1983@126.com

Abstract — Inductive coil gun's performance analysis is very important for experimental research and electromagnetic optimization design. Circuit model is built based on current filament model (CFM), the government equations of CFM may boil down to initial value problem of non-linear variable coefficient ordinary differential equations, which can be solved by numerical method and is easy to program. Field model is built based on non-overlapping mortar finite element method (NO-MFEM). NO-MFEM which was used to build field model of coil gun is a new type of domain decomposition method, when dealing with moving eddy current problem, it decomposes the whole region into two sub-regions, one contains the moving part and the other contains the current source. The two sub-regions are meshed independently and the two sets of elements are non-conforming on the interface. In this paper field-circuit analysis of three stages coaxial inductive coil gun is carried out. By comparing the results of circuit model and field model, validity of the field-circuit method is proved.

I. INTRODUCTION

Coil launcher commonly constitutes by five parts: pulse power, high-speed switch, exciting coil, armature and projectile [1]. The pulse power loads electromagnetic energy on exciting coil after pulsed on. Transient magnetic field produced by the exciting coils induces circumferential eddy current in the armature. The circumferential eddy current interacts with radial component of the magnetic field which produces Lorentz force to drive the armature and projectile in the direction of muzzle. When armature arrives at an appropriate position, the next stage coil is fired, this process continues until the projectile is out of bore.

Coil gun's launching is a complex electromagnetic transient process; it is not easy to obtain main performance parameters. Compared with expensive prototype experiments, numerical simulation can save design cost and improve work efficiency greatly in the optimized design of coil gun. Numerical simulation model for coil gun can be divided into two types: circuit model and multi-physical field model [2]. The circuit model is simple and easy to program. According to the circuit model, dependence of result on variable parameters can be found easily. The multi-physical field model solves the problem from partial differential equation or integral equation, and can obtain various field quantities, such as magnetic flux density and eddy current density [3].

In the analysis of coil gun, if only circuit model is used, we can't get the field distribution, so precise analysis is impossible; if only field model is used, the simulation can't be carried out, since the current of exciting coils which is used as material property in field model doesn't know in advance. So it is absolutely essential to analyze coil gun based on field and circuit combined model.

II. BASIC PRINCIPLES OF CIRCUIT MODEL AND FIELD MODEL

A. Current Filament Model

CFM is explained in detail in [4]. CFM divides massive conductive parts of the armature into elementary volume elements, in which uniform distribution of current is assumed, a current filament is associated with every volume element, and its electrical parameters are calculated, the electrical and mechanical equations governing the behaviors of the system are formulated on the basis of the adopted equivalent network. Mutual inductance of current filament and exciting coil is calculated according to induction calculation manual, in order to reduce calculation errors caused by size difference of current filament and exciting coil, each exciting coil was divided into small sub-coils (schematic diagram of CFM is shown in Fig. 1.).

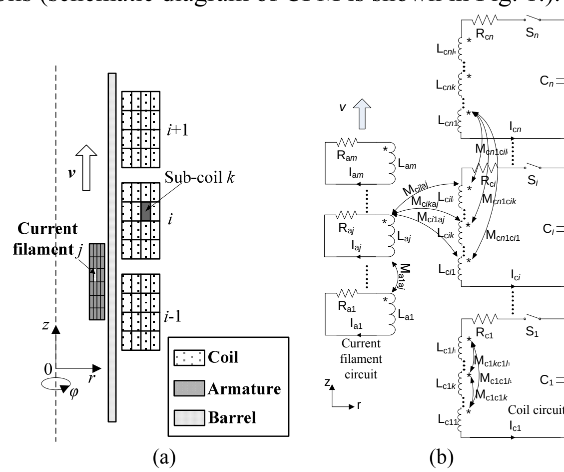
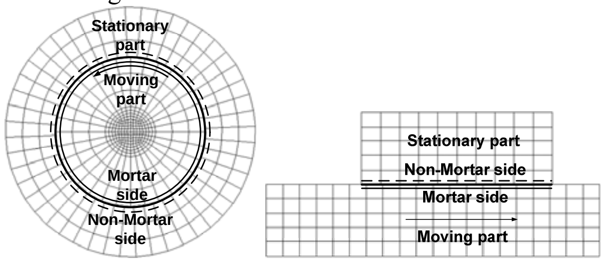


Fig. 1. Schematic diagram of CFM (a. CFM of coil gun; b. equivalent circuit)

B. Current Filament Model

Mortar element method (MEM) [5] is a new type of domain decomposition method; MEM introduces a discretized mortar space to approximate the original continuous function space. The continuity of DOFs across the non-conforming interface is ensured by the surface integration in a weak sense. When deals with moving conductor eddy current problem, NO-MFEM divides the whole region into two sub-regions, one contains the moving part and the other contains the source current. The two sub-regions were discretized independently with traditional finite elements and the two sets of elements are non-conforming on the interface. When the moving part changes location, it only needs to change the node coordinates in moving region. NO-MFEM can deal with two types of moving eddy current problem [6]-[7], as shown in Fig. 2.



(a) (b)

Fig. 2. Movement pattern suitable for NO-MFEM(a. rotation model; b. linear slide model)

III. CIRCUIT-FIELD ANALYSIS OF INDUCTION COIL GUN

A three-stage coaxial inductive coil gun is adopted and its field-circuit analysis is carried out. First, circuit model of the coil gun is built; its structure diagram is shown in Fig. 3. Current waveform of exciting coils and current filaments obtained from circuit simulation are shown in Fig. 4.

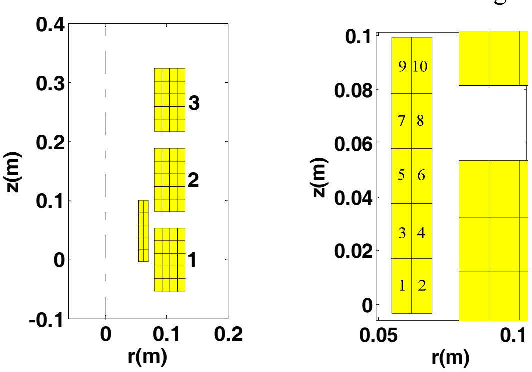
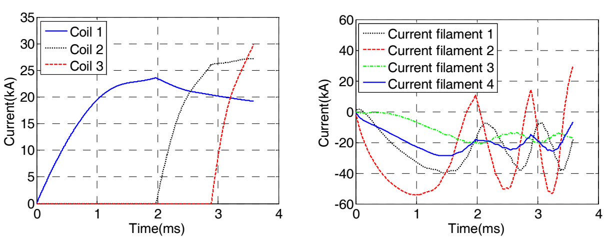


Fig. 3. Structure diagram and division of armature and coils



(a) (b)

Fig. 4. Current waveform of circuit model (a. current of exciting coil; b. current of the first four current filaments)

The coil gun's field model is built based on NO-MFEM, as shown in Fig. 5. The coil currents obtained from circuit model are used as material properties of exciting coils in field model. In every time step, when the armature moves, it is only need to change nodes coordinate in Ω_1. Field quantities such as eddy current density, magnetic flux density are displayed in Fig. 6. Results of the two models are compared (as shown in Fig. 7.) and the validity of field-circuit is proved.

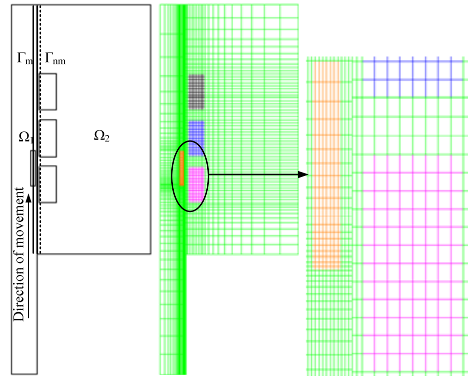
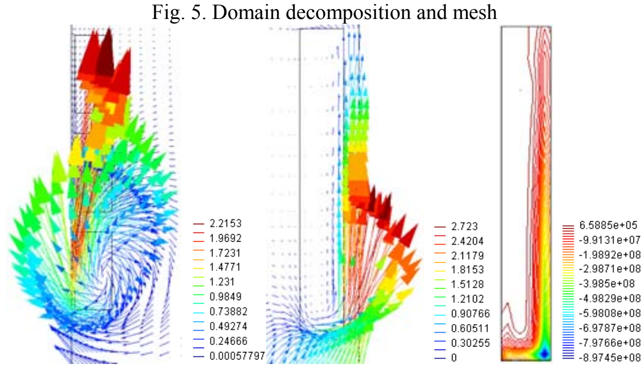
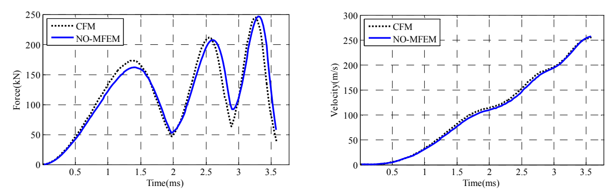


Fig. 5. Domain decomposition and mesh



(a) (b) (c)

Fig. 6. Field distribution at 0.1ms (a. flux density vector of exciting coil; b. flux density vector of armature; c. contour of eddy current in armature)



(a) (b)

Fig. 7. Results comparison of CFM and NO-MFEM (a. force; b. velocity)

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