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# Sequential coupling simulation for electromagnetic–mechanical tube compression by finite element analysis

*Y.U. Haiping**, *L.I. Chunfeng*, *D.E.N.G. Jianghua*

*School of Materials Science and Engineering, Harbin Institute of Technology, Harbin 150001, PR China*

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ABSTRACT

A sequential coupled field analysis of electromagnetic tube compression process has been performed by using the finite element method (FEM). A 2D axisymmetric electromagnetic model based on the magnetic vector potential is proposed for the calculation of magnetic field and magnetic forces; and Newmark integration method is used to calculate the dynamic plastic deformation of tube in the mechanical model. In each time step during the simulation, the transient magnetic forces acting on the tube are obtained from the electromagnetic model, which are then used as input load to the mechanical model. According to the tube deformation calculated, the geometry of the electromagnetic model is updated. Therefore, the sequential coupling simulation is realized between the electromagnetic model and the mechanical model, whose results are more accurate than the loosing coupling simulation method. The radial deformation along the outer generatrix of deformed tube wall is presented as a function of time and the plastic strain energy of electromagnetic tube compression is analyzed.



## 1. Introduction

High-velocity electromagnetic forming (EMF) can be a flexible and cost-effective alternative to the conventional metal stamping and forming processes. As shown in Fig. 1, EMF is accomplished by connecting an actuator (typically a solenoid coil consisting of copper windings) in series with a high-energy capacitor bank and high-voltage switch. Upon discharging the capacitor bank *C*, a large current *I* runs through the actuator and induces currents in the metallic workpiece. The presence of these induced currents inside the magnetic field of the actuator results in Lorentz forces in the workpiece that can be made to cause plastic deformation (Jablonski and Winkler, 1978; William, 1989). EMF process is very complex that consists of varying system parameters, dynamic constitutive equations, dynamic deformation and impact contact between the workpiece and forming die.

The coupling of electromagnetic field and mechanical field is one of the main problems in the theoretical study of EMF. Some attempts have been made to solve Maxwell's equations in electromagnetic tube expansion, in which the deformation velocity of tube is included (Bendjima et al., 1997). However, they have given neither formal nor complete statement of the initial boundary value problem. Rather, the effects of velocity are treated by a special technique that consists in creating a geometric band subdivided into sub-regions designating the tube as a part of air, to which appropriate physical properties are assigned at each displacement step. A macro-element of time-dependent width has been used to model the expanding gap between the coil and tube (Mohellebi et al., 1998; Azzouz et

* *Corresponding author.*
E-mail address: haipingy@hit.edu.cn (Y.U. Haiping).
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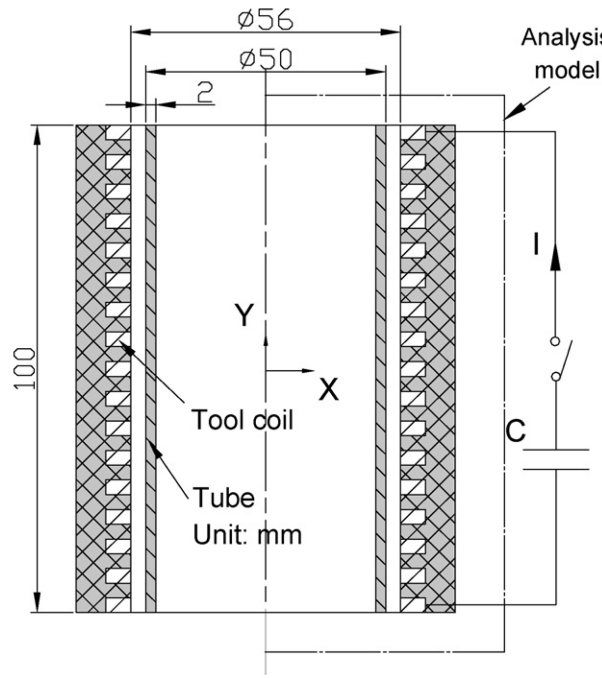


**Fig. 1 – System model for electromagnetic tube compression.**

al., 1999). The simulation of deforming process is obtained by the modification of the macro-element size through the modification of its matrix while retaining the same mesh topology. These methods mentioned above can only be used to solve the tube expansion problem. Meriched et al. (2000) has described a numerical method to solve the problem of electromagnetic forming of clamped thin circular metal sheets by using a flat spiral coil, which includes circuit analysis, electromagnetic field calculation and dynamic plastic deformation of the sheet. Whereas, the total investigations mentioned above are corresponding to the expansion deformation of plate or tube, and there are few reports on the coupled field analysis of the electromagnetic tube compression.

A link between the electromagnetic field analysis software and the mechanical field code has been developed, by which some finite element modeling of electromagnetic tube compression have been performed (Hainsworth et al., 1996; Imbert et al., 2005; Oliveria et al., 2005). During the solution, a first analysis solves for the electromagnetic loading on conductors using electromagnetic field software. Then, a second analysis uses the mechanical code to solve the dynamic response of tube using the results from the first analysis as forcing functions. However, the deformation of the tube has not been taken into account at all in pursuing the coupling between the electromagnetic and mechanical solvers.

Therefore, in this work, a sequential coupling numerical simulation for the electromagnetic tube compression is performed by means of Multi-physics software ANSYS. The effects of tube deformation are taken into account in pursuing the coupling between the electromagnetic and the mechanical solvers in this simulation. The changes of radial displacement along the outer generatrix of tube with time are presented with 3D diagram. The plastic strain energy of electromagnetic tube compression and its ratio to the discharge energy are analyzed. The tube profile simulated is qualitatively good mirrored by that of experiment.

## 2. Experiment of electromagnetic tube compression

An experimental setup is shown in Fig. 2, where the machine is EMF-30 with the total capacitance 702 μF and the discharge voltage up to 10 kV. The coil is coaxial and concentric with tube and the efficient zone of coil is indicated. Geometry of finite element models in the following analysis and all parameters of discharge current are gotten from the setup. The experimental value of tube compression is used to validate the corresponding value from the simulation.

## 3. Sequential simulation by FEM

The schematic flowchart of the implemented algorithm is illustrated in Fig. 3. An electromagnetic model and a mechanical model are established, respectively. In each time step during the simulation, firstly, the transient magnetic forces acting on tube, including radial and axial components, are calculated from the electromagnetic model, which are then used as input load to simulate high-velocity deformation of tube from the mechanical model. Whereafter, the tube geometry is updated according to the deformation results. Then, the transient magnetic forces are calculated again based on the updated tube geometry in next time step. Therefore, the sequential coupling simulation is established between the electromagnetic and mechanical models. A period of total simulation time is 200 μs and one time step is 5 μs.

The main properties of all contributing materials are given in Table 1. The dimensions of two models are shown in Fig. 1.

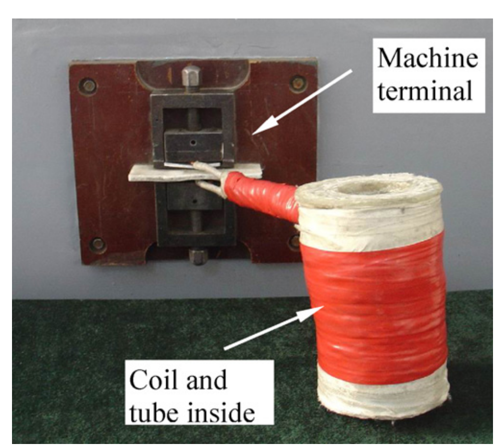


**Fig. 2 – Experimental setup for electromagnetic tube compression.**