# Models for Electromagnetic Metal Forming

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## Abstract

*This paper presents a comparison of different simulation options for electromagnetic metal forming in order to make preliminary investigations with adequate accuracy. Four simulation models are compared. The models mainly differ in their complexity, handling and necessary precondition program packages. The user has the choice to use a simple program with a defined program algorithm or to use a program with a higher programming complexity which accepts more information.*

## Keywords

Modelling, Computer, Simulation

## 1 Introduction

The lowering of costs and the reduction of the development times in view of ever larger competition is an essential objective for the producing business. Simulation tools especially for users in the range of Electromagnetic Forming (EMF) offer the opportunity to analyze the formation process and its effects already in the development stage. Compared to the expensive construction of prototypes, the variation of process parameters can be performed by simulations with significantly reduced costs.

## 2 Simulation Models

All presented models are suitable for the analysis of the electromagnetic field problems which results from a system configuration composed of an electromagnetic metal forming machine with installed energy storage, electromagnetic forming coil and electrically conductive tubular workpiece. The basic principle for creating the simulation models is illustrated in figure 1.

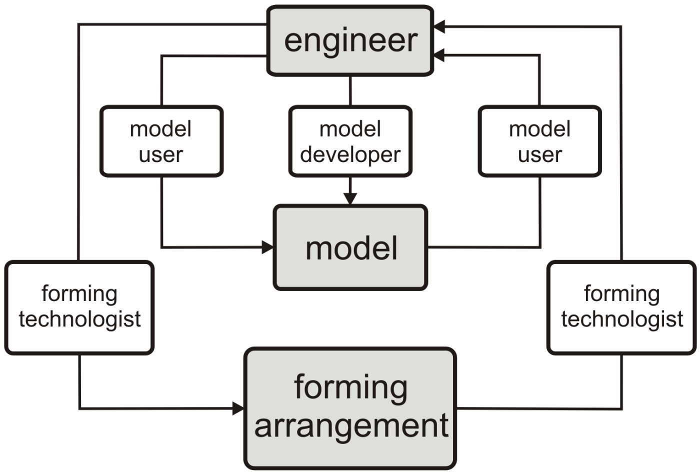


***Figure 1**: Scheme of model development*

At first, the engineer analyses the forming arrangement to get the necessary detailed insight. From the collected knowledge the engineer develops the model. In addition to the knowledge about the physical processes a great amount of training concerning the handling of model-formation software is essential for the development of computational models for electromagnetic metal forming. If the available model-formation software does not completely describe the required information in its full complexity, extensions will have to be carried out. Furthermore, knowledge of the inner function (interfaces) of commercial FEM calculation software and programming skills in higher programming languages are necessary to code and bind own routines. Such tasks were usually handled by developing groups. This leads to the creation of models which include all desired properties. The work with such model requires a certain amount of expert know-how. As a consequence, the maintenance and future extension depend on the availability of the software engineer. If the developers are not available, the further maintenance or extension won't be possible as a rule. The operation by somebody who was not involved in the development requires a great expenditure of documentation and operation introductions. For that reason the trend is to develop models which need no specific knowledge from the model user. Therefore the program has to be designed in the way that it could pass from the developer to the user. In most of the cases this requires the application of commercial model software. For simple models standard software is sufficient and does not require additional software. They can be provided to the user for training purposes and rough estimations of the expected parameters.

## 2.1 FEM Based Simulation Models

Complicated field problems are increasingly solved with the help of numeric computation methods in the range of electrical engineering. Instead of cost-intensive and time-consuming measurements, the modellings at the computer and a following numeric computation are being preferred today. Experimentally determined electromagnetic field values are necessary for verification of the simulation results. The FEM method transfers an electromagnetic boundary-value problem into a set of linear equations. The electromagnetic field problem must be computed in the time domain in the case of electromagnetic metal forming. The general form of the differential equation (1) is used for this purpose [1].

$$[L(\gamma)]\begin{bmatrix}\dfrac{\partial\vec{A}}{\partial t}\\ \varphi\end{bmatrix}+[K(\mu)]\begin{bmatrix}\vec{A}\\ 0\end{bmatrix}=\begin{bmatrix}\vec{J}\\ 0\end{bmatrix} \tag{1}$$

$\vec{A}$: Magnetic vector potential
$\vec{J}$: Current density
$[L]$: Conductivity matrix
$[K]$: Permeability matrix
$\varphi$: Electric scalar potential

The computation of the structure-mechanical transforming process can be accomplished in a subsequent simulation step. Thereby the result of the electromagnetic field simulation is the input of the structure-mechanical simulation. The fundamental motion equation (2) which must be solved reads:

$$[M]\{u''\}+[D]\{u'\}+[C]\{u\}=\{F(t)\} \tag{2}$$

$[M]$: Mass matrix
$[D]$: Damping matrix
$[C]$: Stiffness matrix
$\{u''\}$: Vector of the node acceleration
$\{u'\}$: Vector of the node velocity
$\{u\}$: Vector of the node displacement
$\{F(t)\}$: Load vector

### 2.1.1 Full-access-model for commercial program combined with required routine

EMF is a high-dynamic process with high transformation velocities. The deformation results from the electric currents in the forming coil and in the workpiece. The active force is the Lorentz force. Furthermore, the electromagnetic field and so the Lorentz force depends on the temporal current, on the distance between forming coil and workpiece and their geometries. Most of the simulation tools and models for EMF are limited to 2D axial symmetrical arrangements and to small deformations. 3D simulation models become ever more important for the exact process analysis and description of the process. This gap is filled by the model. The connection between electromagnetic field and temporal displacement of the workpiece is not negligible for example working a door handle recess out for the automobile industry. Therefore the interest in coupled electromagnetic-structure mechanical simulation models which can compute 3D arrangements and larger deformations increased in the last years. The requirements of a 3D simulation consist particularly in the increased number of nodes of the arrangement. The number of nodes drastically affects the simulation time and the necessary computer capacity. A purposeful choice of the discretisation density works against this fact [2].

The scheme of the full-access-model development for a commercial program combined with required routine is comparable with the scheme from Figure 1. This program algorithm is a very complex model for the simulation of the EMF process. The engineer is concerned with the forming arrangement and the forming process. He uses experimental results of the forming technologists. Due to analytic descriptions and such experimental results the model developer creates the model. After the model is generated, the engineer can carry out its investigations at the model. If he cannot use the model, he must contact the model developer, before conducting numerous investigations with the model. At some selected points of the arrangement the simulation results must be verified by experiments at the original forming arrangement. For the use of the model, a commercial available software package (ABAQUS/CAE) is necessary. It is to be demonstrated that the model user must have programming knowledge in handling the computation software ABAQUS/CAE based on the finite element method. Furthermore, the user must have experience in the range of the EMF. The required programming must knowledge cover the geometrical model production, the choice of a reasonable discretisation density, the definition of boundary conditions, the definition of material properties and the definition of initial conditions of the computation volume (pre-processing). Additional by the use of an embedded algorithm is required that was developed at the Chair of mechanics, University of Dortmund. This computation algorithm accomplishes the coupled electromagnetic-structure-mechanical field simulation. The representation of the computation results (post-processing) is realized in ABAQUS/CAE [3]. If the model user does not have development experiences especially of this program algorithm, the model will be unusable for the user.

### 2.1.2 Full-access-model for commercial program

A further possibility to simulate the EMF process offers the full-access-model for a commercial program. In this case, the commercial FEM program package (ANSYS) is necessary. It offers the possibility to analyze 2D axial symmetrical geometries or 3D geometries. The computations of 3D geometries have high requirements to the computer capacity. The typical temporal discharge current can be easily generated by an equivalent circuit that includes the machine parameters (capacity, inductance, ohmic resistance and charging voltage). Then the discharge current can be couple into the generated forming coil geometry. The coupling between the equivalent circuit and the FEM model is exemplary illustrated in Figure 2.

In the first computation step the electromagnetic field problem is calculated transiently and the magnetic body force density is determined or the magnetic pressure on the workpiece. In a next step a structure-dynamic simulation can follow to obtain the material deformation. The computations can be accomplished advantageously in the same software package. This facilitates the change between electromagnetic and structure-dynamic computation.

The scheme of the full-access-model for a commercial program is illustrated in Figure 1. There is a direct connection between model operator and model developer. The

Model developer must understand the physical background of the EMF process or cooperate with a transforming technologist. The model is noted in a typical software language. Therefore the model user must understand this language and the physical background of the process. If the model user has programming knowledge and the understanding about the forming arrangement, the direct access is not limited for this simulation model.

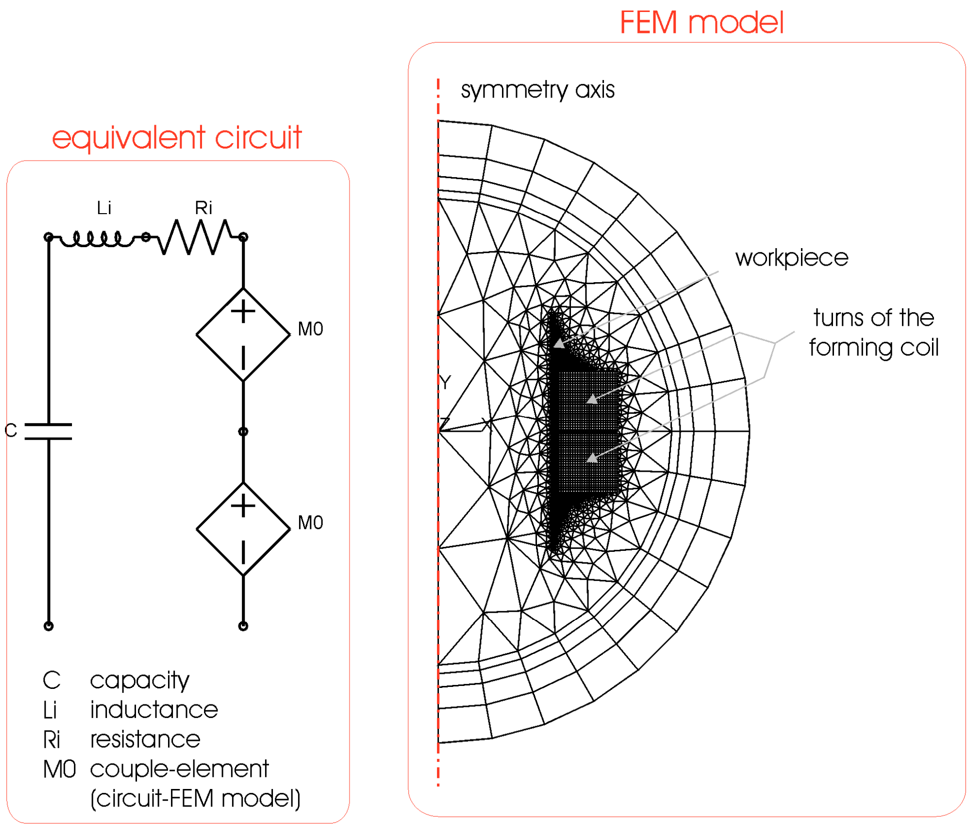


***Figure 2**: Coupling between equivalent circuit and FEM model*

### 2.1.3 Limited-access-model for commercial program

If there's the need for a simply operating simulation model, a model can be generated, which can used without programming knowledge and without knowledge about the forming arrangement. For this example the commercial software package (ANSYS) is needed. In this case the user operation is limited to the fact that a preassigned source code is loaded into ANSYS. The source code is programmed in such a way that a set of parameters can be entered by the model user. Thus, the model can be used for similar tasks of computation.

Figure 3 shows in contrast to the previously presented models the possibility of the model transfer from the model developer to the model user. There is no more direct connection between the model-development side and the model-user side. The possible field of application of the model is limited by the defined range of the parameters. An adjustment of the model to other computation arrangements requires a re-programming by the model developer.

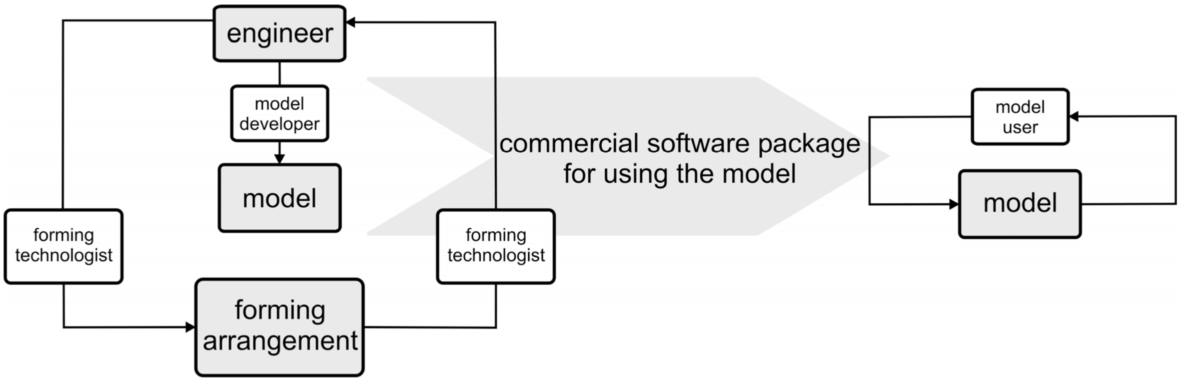


***Figure 3**: Scheme of limited-access-model development for commercial program*

## 2.2 Engineering Standard Software

The engineering standard software is an interactive model for the computation of the magnetic pressure at the workpiece. The magnetic pressure at the surface of the workpiece represents the fundamental value for the evaluation of the effect during the magnetic forming process. As an example a program was created at the University of Magdeburg for the determination of the magnetic pressure at the surface of the workpiece. The program runs on Windows computers and requires only small computer capacity. The computation is based on the solution of coupled differential equations. These are a result of the electrical circuit diagram, consisting of forming arrangement, forming coil and workpiece. Substantial model parameters like the internal inductance, the internal resistance and the couple factor between the forming coil and the workpiece were determined by a preceding FEM simulation. Then the differential equation problem can be numerically solved for this arrangement.

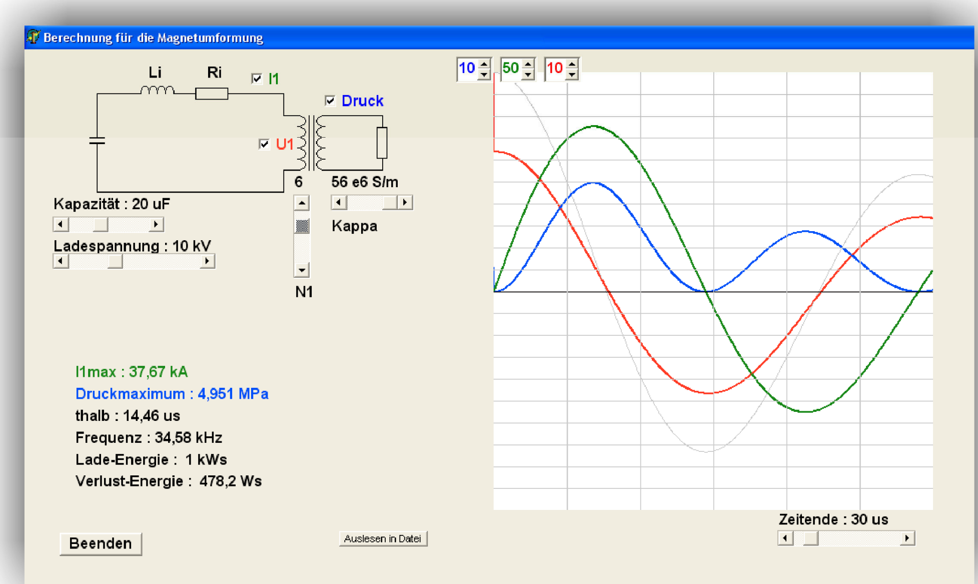


***Figure 4**: Operator interface for engineering standard software*

The development of the engineering standard software is comparable in principle with scheme from Figure 3. The model user does not require the knowledge of the model developer and the physical knowledge of the forming technologist. Furthermore, no commercial software package is necessary. The model must be generated by the model developer and by the forming technologist.

In Figure 4 the operator interface of the engineering standard software is represented. The geometry, the parameters of the forming arrangement and the material properties have influence on the magnetic pressure. The user can specify important parameters like the capacity, the charging voltage, the number of turns of the forming coil and the electrical conductivity of the workpiece within a certain range over scroll bars. A change of these parameters leads to immediate changes of the graphs, as for the charging voltage, the electrical current, the voltage of the coil and the magnetic pressure. Important maximum values are read out in a text output. Due to the fact that the geometry cannot be changed by the model operator, the applicability of the model is limited to a defined transforming arrangement.

## 3 Conclusions

The aim of this paper is to present different possibilities of simulation models for the EMF process. The models especially differ in the required software and in the knowledge of the model user.

| **model** | **software** | **programming knowledge** |
|---|---|---|
| full-access-model for commercial program combined with required routine | commercial software package + routine | knowledge in the programming language (ABAQUS)+ knowledge of the routine |
| full- access -model for commercial program | commercial software package | knowledge in the programming language (ANSYS) |
| limited-access-model for commercial program | commercial software package | none |
| engineering standard software | standard software | none |

***Table 1***: *Characteristics of the simulation models*

In table 1 the four simulation models are compared. The customer has the possibility to decide for a suitable model in view of the operator benefit, the software requirement and the programming complexity. The model operator must simultaneously be the model developer, to use the full-access-model for a commercial program combined with required routine or the full-access-model for a commercial program. Both models can be adapted to the respective EMF process as far as possible (geometry, material and machine parameter). In these cases a commercial software package is needed. In the sense of a simple calculation of the magnetic pressure for a defined forming arrangement, the computation can be preferably accomplished with the limited-access-model with a commercial program. However, the use of a commercial software package is needed. The engineering standard software offers a simpler operator benefit without a commercial software package.

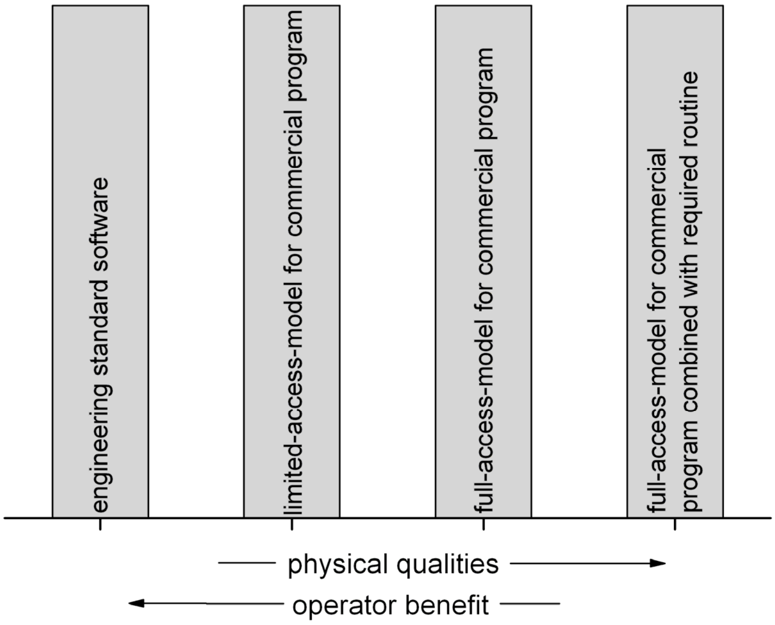


***Figure 5**: Connection between operator benefit and physical qualities*

As shown in Figure 5, a contradistinction exists between the physical quality and operator benefit with the presented simulation models. Therefore, the operator benefit decreases with rising physical quality.

### Appendix

In the presentation several models are shown and demonstrated. The advantages and limitations of the respective models will be explained and evaluated.

## References

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