

Electromagnetic hammer with impact

There are many technical systems that are based on the principles of construction of an Electromagnetic hammer with impact. The Figure shown 4.42 shows the sketch of such a system. The different classes of electromagnetic relays are described by these principles. The simulation of this system is supposed to show how one can build in Simulink de description of impact in connections with other systems.

Up until now in simulations simple values of parameters have been used. Matlab and Simulink allow a wide variety of variable so that these with their physical values can be set up. Nonlinear systems are much easier to understand and to command the construction of real systems if the values are set up from the ones that are in real use.

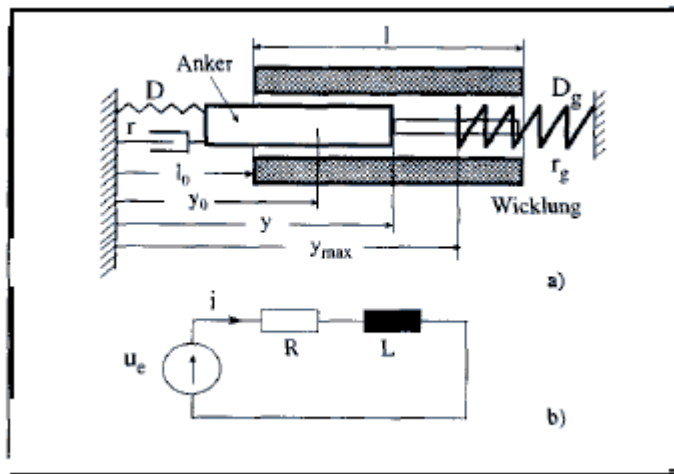


Fig. 4.42a) Electromagnetic hammer with impact b) Circuit for the connection of the coil
Bild 4.

The example of the electromechanical hammer will show how the mechanical process influence the size of the electrical part for the case where the dynamics of the system can not be analyzed by means of a separation of the mechanical and electrical subsystems. It will show also how the real parameters with their properties can be included in the simulation.

Starting from rest the following differential equation is deduced. The initial deflection is y_0 .

$$m\ddot{y} + r\dot{y} + D(y - y_0) = F_e \quad \text{für } y < y_{\max} \quad (4.89)$$

$$m\ddot{y} + r\dot{y} + D(y - y_0) = F_e - [r_g \dot{y} + D_g (y - y_{\max})] \quad (4.90)$$

für $y \geq y_{\max}$

Here Y , D etc r , R , D are the damping constant and the spring constant, which representation can be obvious from the sketch. The mass of the Armature is described by m and the impact happens

at y_{max} . A linear spring and a viscous damper approximately represent the impact without these being a restriction. Also other nonlinear models for the elasticity, damping and friction can be included in SIMULINK graphically. In order to calculate the electromagnetic force F , the induction in the Coil needs to be estimated. The law of continuous flux along flux lines which includes all the windings leads to:

$$H_{Anker} l_{Anker} + H_{Luft} (2l + l_0 - y) = Ni \quad (4.91)$$

For a core, which operates in the linear part of the magnetic diagram, is as follows;

$$\frac{B}{\mu_c} \left[\frac{l_{Anker}}{\mu_r} + (2l + l_0 - y) \right] \cong \frac{B}{\mu_0} (2l + l_0 - y) = Ni \quad (4.92)$$

$H_{Anker} + H_{Luft}$ will represent the intensity of the field in an iron armature in the air as U_r and U_0 describe the relative magnetic permeability of the armature and the permeability of the air. The Coil of the electromagnetic hammer has N windings, through which the current i circulates. The meaning of the distances l, l_0, y is to be appreciated from the sketch. From the last equations can one obtain the relationship for the induction in the coil of the magnet of the form

$$B = N \cdot i \cdot \mu_0 / (l_k - y), \quad (4.93)$$

where $l_k = 2l + l_0$. The magnetic flux will be, and for the inductivity gives the following dependency from the displacement of the armature.

$$L = N \cdot \phi / i = A \cdot \mu_0 \cdot N^2 / (l_k - y) = k_L / (l_k - y) \quad (4.94)$$

Here is the constant K a proportionality factor in [H/m]. For the electromagnetic force F as derivative from the magnetic energy $Li/2$ over the variable y can one obtain finally the following equation.

$$F_e = (i^2 / 2) \frac{dL}{dy} = (i^2 / 2) \cdot k_L / (l_k - y)^2 \quad (4.95)$$

The current of the coil in the electric circuit from Fig 4.42b is given by the differential equation:

$$u_e = R \cdot i + \frac{d}{dt} (L \cdot i) = R \cdot i + L \frac{di}{dt} + i \frac{dL}{dy} \frac{dy}{dt} \quad (4.96)$$

The second term of the above equation includes the dependency of the path of the inductivity in the calculation of the induced voltage. For the construction of the Simulink model, it is assumed that the time derivative of the current from the above equation is known.

$$\frac{di}{dt} = \frac{1}{L} \left[u_e - R \cdot i + \frac{k_L}{(l_k - y)^2} \frac{dy}{dt} i \right] = \quad (4.97)$$

$$\frac{(l_k - y)}{k_L} (u_e - R \cdot i) + \frac{1}{(l_k - y)} \dot{y} \cdot i$$

By means of an integration block, the current will be determined. After that the terms of the right side can be built and from that obtain the above indicated time derivative of the current.

The impact of the armature (striker) will be simulated with the model of fig 4.42 (stoss1.m;stoss1.mdl), which is shown here in a testing environment. It does not contain yet the spring and damping of the limit, which simulate the impact, but only the necessary parameters for the construction of this force, are available. With the dead zone block one acquires the path $(y-y_{max})$, which is deemed to be the deformation of the replacement spring of the limit (the spring that simulated the element after the impact). When the limit y_{max} is reached, the velocity, which is necessary for the calculation of the damping force, must be available. This must be reached with the help of the Switch block. Both turn on the velocity only if the limit is over crossed. In order to test this part of the model we produce the Test generator for the velocity with a sinusoidal signal. The generator for the displacement of the striker produces saw form signal. The function is in this way easy to test. Fig 4.4

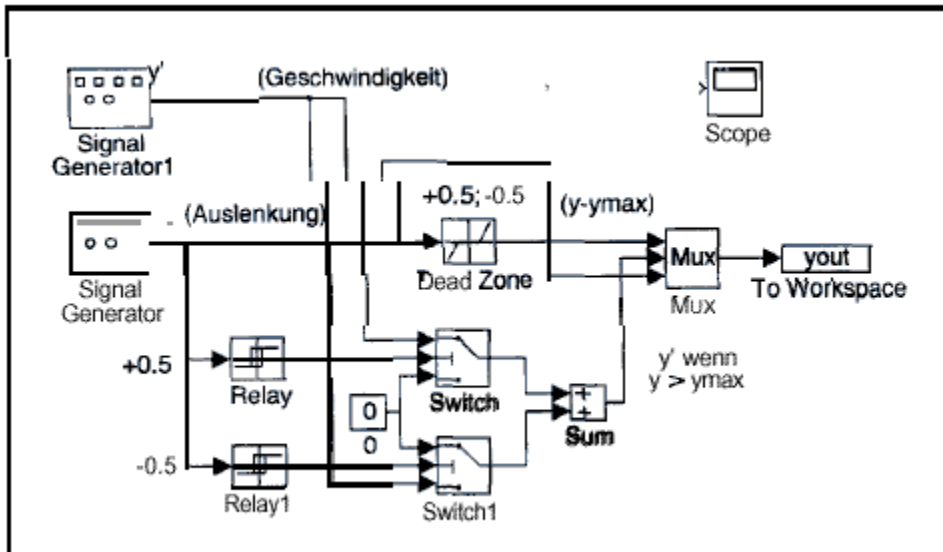


Bild 4.43 SIMULINK-Model for the simulation of the impact, here embedded in a test environment. (s-stoss1.m; s-stoss1.mdl).

The model is laid out for impact on both sides of the electromechanical hammer although here it experiences an impact by means of switching on of the current. In the model of the system we chose the dead zone and switch wave of the second relay sufficiently small (in amount big), so that a limitation ($y > y_{max}$) takes place.

The nonlinear differential equations can be built without difficulty in SIMULINK. The complete model however is harder to make it run correctly. Divisions in subsystems with simplified assumptions simplify settings of the parameters and help us understand which connections or relations definitely are responsible for the stability and convergence or the solution.

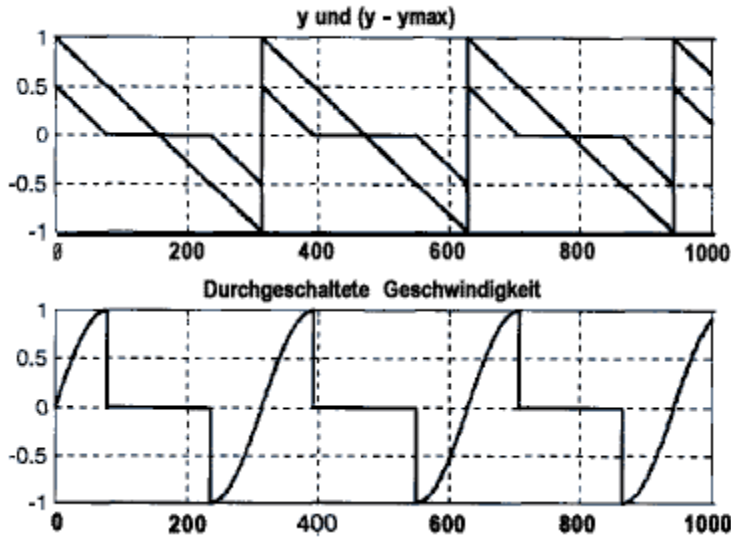


Bild 4.44 Run of the signals in SIMULINK model, which are produced by the parameter for the building of the spring and damper, which simulate the impact.

As first system it was investigated the case where the current is assumed constant by means of a relative huge resistance, which suppresses the nonlinear inductivity. We investigated then only the influence of the displacement on the drive force. This influence builds in the model a coupling and in a linear observation one obtains a control system for a second order system represented through the mechanical part. In principle it is an unconditionally stable system. The SIMULINK model for this case can be managed without problems.

In the initial highly nonlinear system it is added the dynamics of first order of the current loop and the nonlinear inductivity produces additional coupling. Now, one cannot ascertain whether in a linearized observation the parameters of a third order system with coupling lead to instabilities or whether the integration procedures do not converge. As a way out the diffusion of the non-linearities was investigated. For the path dependency of the inductivity of the electromagnetic hammer the following simplifications are accepted.

$$L(y) = L = \frac{k_L}{(l_k - y)} \cong L_0 + k_y (y - y_0) \quad (4.98)$$

Wobei

$$L_0 = k_L / (l_k - y_0) \quad (4.99)$$

und

$$k_y = \left. \frac{dL}{dy} \right|_{y=y_0} = \frac{k_L}{(l_k - y_0)^2} \quad (4.100)$$

From this it follows a linear relationship for the Driving force in relation to y and a nonlinear dependency from i :

$$F_c = \frac{\partial}{\partial y} \left(L(y) \frac{i^2}{2} \right) \cong \frac{i^2}{2} k_y y = \frac{i^2}{2} k_y (y - y_0) + \frac{i^2}{2} k_y y_0 \quad (4.101)$$

For the electrical circuit it is deduced a nonlinear differential equation of the form:

$$u_e = i.R + \frac{d}{dt} (L(y).i) = i.R + i.k_y.\dot{y} + (L_0 + k_y(y - y_0)) \frac{di}{dt}, \quad (4.102)$$

Which by means of reformatting as follows can be written as:

$$\frac{di}{dt} = (u_e - i.R - i.k_y.\dot{y}) \frac{1}{(L_0 + k_y(y - y_0))} \quad (4.103)$$

For the new nonlinear differential equations results itself a SIMULINK model (s-stoss2 .m; s-stoss2 .mdl), which is shown in Fig 4.45. Above can one recognize the under system which delivers the parameter for the simulation of the impact. After follows the model of the mechanical part, which is moved by the electrical force, which is built in the lower part. The dynamics of the electrical circuit up until the output current contain the simulation of the nonlinear inductively over the coupling with the hammer displacement and the corresponding velocity. After that, the nonlinear electrical driving force is built from the current and the coupling with the hammer displacement.

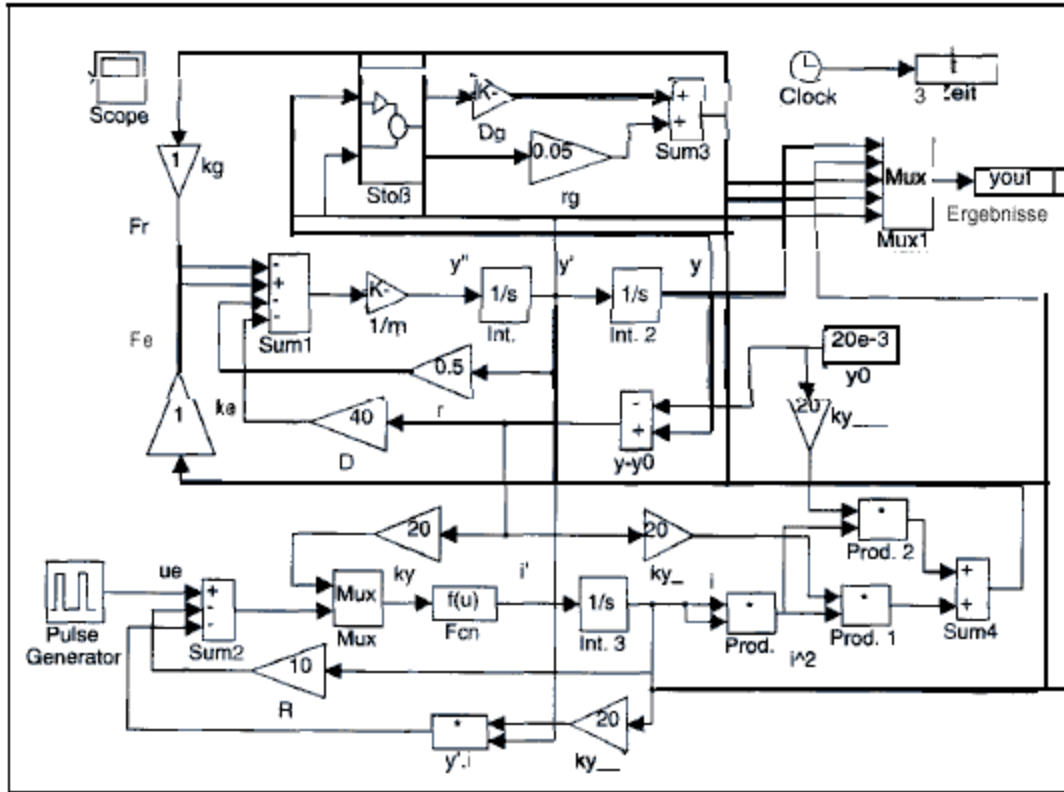
Those parameters of the model were deduced from a reel electromagnetic hammer. So, the initial position 20mm and the strike 40 mm were chosen. The other parameters were chosen as:

$$L_0 = 0,5[\text{H}]; k_y = 20 [\text{H/m}]; R = 10 [\Omega]; \quad u_e = 12 [\text{V}] \text{ Impulse};$$

$$m = 0,1 [\text{kg}]; D = 40 [\text{N/m}]; r = 0,5[\text{N.s/m}]; D_s = 1000 [\text{N/m}];$$

$$r_x = 0,05[\text{N.s/m}];$$

A simple Matlab program (d-s toss2 . m) can produce the results of the simulation. Fig 4.45 a shows the hammer displacement and the velocity of the armature of the electromagnetic hammer. One can recognize the impact at 40mm and the free vibration of the spring-mass system at the switch off of the input voltage and short circuit the input $U_e=0$. The higher vibration frequencies which are better observed in the velocity diagram, appear at the impact against the higher spring constant D_g of the spring which simulates the impact limit. The current becomes high at when it is turned on; it is influenced by the movement and does not show anymore the typical non-oscillating curve as in the case of a constant inductively (Fig 4.46b).



4.45 SIMULINK-Model1 of the electromagnetic hammer with impact (s-stoss2.m; s-stoss2.mdl)

A confirmation of the simplified model can occur only by means of a physical experiment. At the university of Applied Sciences Karlsruhe the original nonlinear differential equations were solved with an appropriate integration algorithm and the results were confirmed experimentally. For small displacements of the striker as is the case in many technical applications brought the simplification of the differential equations brought the same result.

Displacement and Velocity

Current of the electromagnetic hammer and back emf at impact

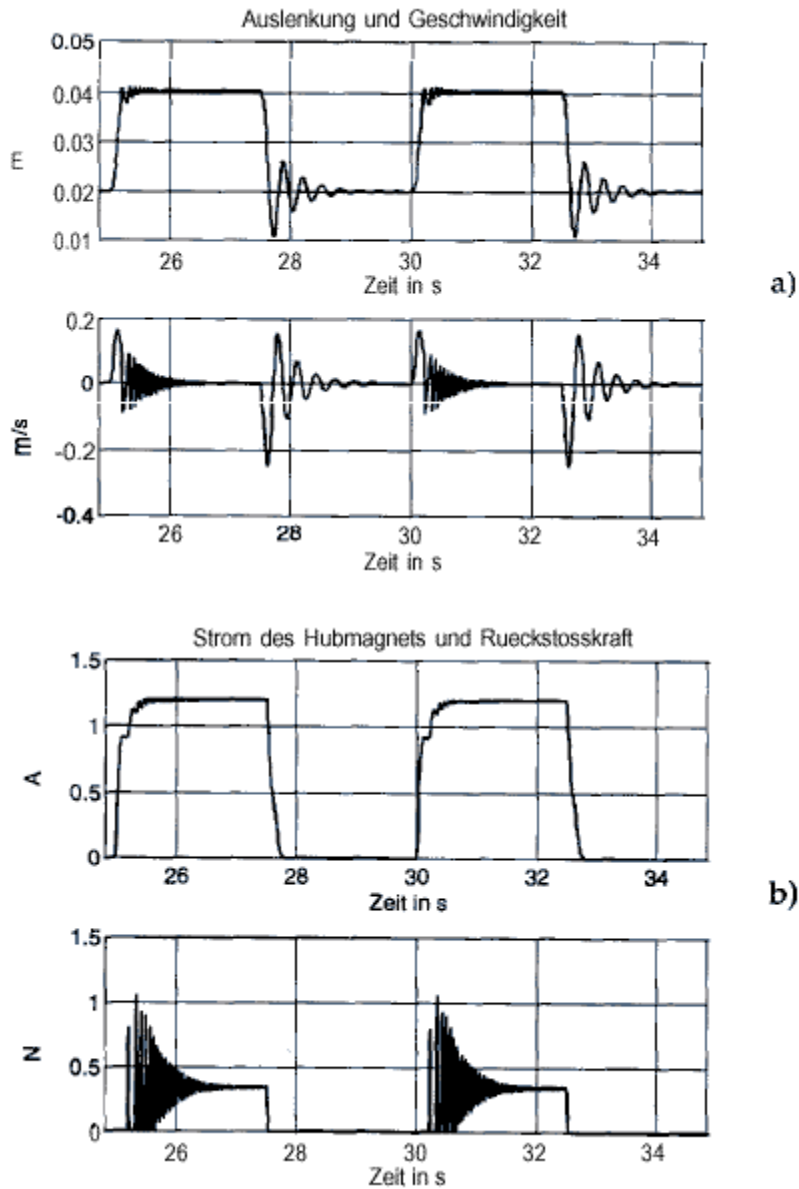


Fig 4.46 a) Displacement and velocity of the armature
 b) Current and back emf at impact (s-sfoss2.m;s-sfoss2.mdl; d-sfoss2.m)