Loudspeaker design model: a toy problem for electromagnetic optimisation

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I. Problem Description

THE description of physical characteristics of the loudspeaker device (Figure 1) and its optimization are considered in this section. This model is inspired on the loudspeaker design example originally proposed by Infolytica Corporation [1]. The objective of this problem is the minimization of the total volume of material used, subject to the generation of a given magnetic flux density in the air gap defined by variable x_9. Mathematically, the problem is defined as:

$$\begin{aligned} &\min f(\mathbf{x}) = \text{Volume} \\ &\text{Subject to:} |\mathbf{B}| \geq B_{min} \end{aligned} \tag{1}$$

with $B_{min} = 1.9T$. Of course this problem can also be very easily turned into a multiobjective optimization example, by considering the minimization of volume and the maximization of the magnetic flux density.

Three different materials are considered in this model: **Air**, **Pure Iron** and **Magnet**. The characteristics for each of these materials is given in Table I.

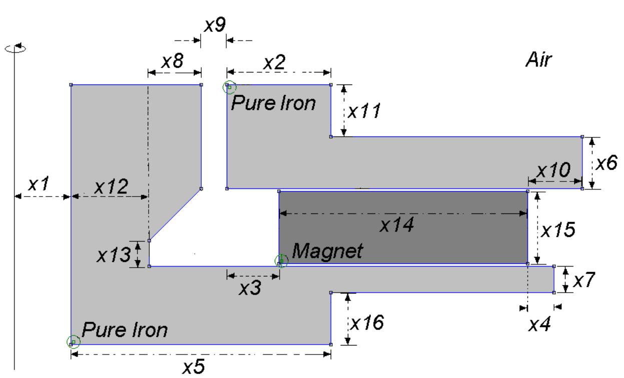

Fig. 1: Loudspeaker design model

TABLE I: Materials Used in the Loudspeaker Model

Material Label	Air	Pure Iron	Magnet
Specification	Air	Pure Iron	NdFeB 40 MGOe magnet
μ_r	1.0	*	1.049
H_c	0.0	0.0	979,000
σ	0.0	10.44	0.667

The nonlinear B-H characteristic for the **Pure Iron** is modeled by the quadratic interpolation of sample points, as shown in Figure 2. The data points used to model the nonlinear curve were obtained in the Materials Library of the *FEMM 4.2* finite element solver [2], and are given in Table II.

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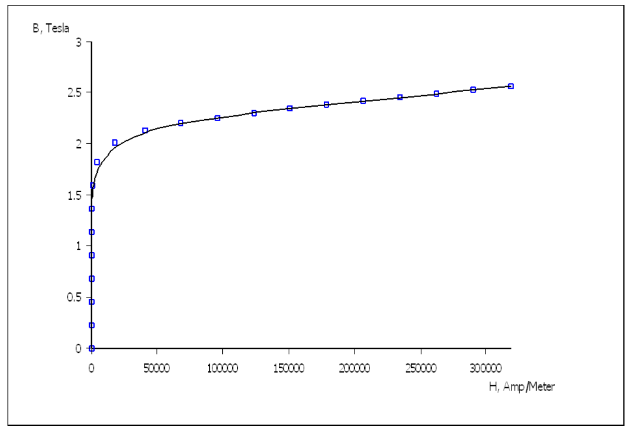

Fig. 2: B-H curve for the **Pure Iron**

TABLE II: Points used for modeling the B-H curve of the **Pure Iron**

H [A/m]	B [T]
0.0000	0.0000
13.8984	0.2271
27.7967	0.4541
42.3974	0.6812
61.4157	0.9083
82.3824	1.1353
144.6690	1.3624
897.7600	1.5894
4581.7400	1.8124
17736.2000	2.0100
41339.3000	2.1332
68321.8000	2.2000
95685.5000	2.2548
123355.0000	2.2999
151083.0000	2.3425
178954.0000	2.3788
206825.0000	2.4150
234696.0000	2.4513
262568.0000	2.4875
290439.0000	2.5238
318310.0000	2.5600

The recommended limits for each design variable are shown in Table III. This table also provides suggestions of fixed values, used in the case of lower-dimensional formulations of the problem.

TABLE III: Limits of the search space

Parameter	min	max	fixed
x_1	3.0	12.0	5.0
x_2	1.0	4.0	3.0
x_3	1.0	4.0	1.0
x_4	-1.0	3.0	0.0
x_5	5.0	15.0	7.0
x_6	1.0	10.0	6.0
x_7	1.0	10.0	2.0
x_8	3.0	8.0	5.0
x_9	0.5	2.0	0.5
x_10	-1.0	3.0	0.0
x_11	1.0	7.0	1.0
x_12	0.05	2.0	0.5
x_13	0.5	2.0	1.0
x_14	5.0	12.0	7.0
x_15	1.0	5.0	4.0
x_16	1.0	10.0	1.0

II. FEMM MODEL

The loudspeaker model described above has been implemented using the LUA scripting language [3], for use with the Finite Element Method Magnetics (FEMM) v. 4.2 numerical solver [2]. The model implemented can handle batch evaluations, and will return an output file containing the values of magnetic flux density and the volume of the device. The FEMM solver can also very easily plot the magnetic field lines and flux density heatmaps. A short tutorial on the FEMM 4.2 solver is available online in [4].

III. HOW TO USE THE MODEL

1) Required Software:
   - Finite Element Method Magnetics v.4.2
   - Matlab (not *really* required, but some Matlab routines are provided)
2) Required files [5]:
   - loudspeaker.lua
   - CallFEMM_LS.m
   - LS_fun.m
3) Problem options:
   - Full model (16 variáveis)
   - Partial model (7 variables):
   $$[x_2,\ x_6,\ x_9,\ x_{10},\ x_{11},\ x_{14},\ x_{15}]$$
4) How to use:
   - Copy all files contained in [5] in a local folder (e.g., 'C:\loudspeaker\')
   - Enter the correct path in lines 33-35 of file *loudspeaker.lua*. Attention to the old-windows style of treating long names or names with spaces.
   - Enter the correct path in 5-8 of *CallFEMM_LS.m*. Attention to the old-windows style of treating long names or names with spaces.

A. Testing the model

You can verufy if the model is working by:

1) LUA script:
   - Open 4.2;
   - Select *File - Open LUA Script - loudspeaker.lua*
   - If *loudspeaker.lua* is correct, FEMM will execute a test simulation (defined by input file *loudspeaker.in* in [5]) and close automatically.
2) *CallFEMM_LS.m*:
   - Open Matlab and select the folder containing the loudspeaker files;
   - On the console, type:
     >> X = [5.0,3.0,1.0,0.0,7.0,6.0,2.0,5.0,0.5,...
     0.0,1.0,0.5,1.0,7.0,4.0,1.0]';
     >> Y = CallFEMM_LS(X)
   - If your path is correct, the FEMM 4.2 window should pop up in your screen, run the dummy simulation, and return the result:
     Y =
     0.5272
     0.0000
     0.0000
     The following call:
     >> F = LS_fun(X)
     should then yield the penalized objective function value:
     F =
     159.5294

Besides function *LS_fun.m*, the routines *LS_vol.m* and *LS_B.m* can be useful, since they return the volume and magnetic flux density values separately. The Matlab routines and the LUA script are all extensively commented, and can be easily adapted for a wide range of optimization routines.

IV. MAIORES INFORMAÇÕES

Questions, bug reports, comments and suggestions can be filed to [5], or sent directly to fcampelo@ufmg.br.

REFERENCES

[1] Infolytica Corporation, “Optimization - Minimizing Loudspeaker Mass”, *online*, available from: http://www.infolytica.com/en/applications/ex0086/
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[4] David Meeker, “Finite Element Method Magnetics v. 4.2 - Magnetics tutorial”, *online*, available from: http://www.femm.info/Archives/doc/tutorial-magnetic.pdf
[5] Felipe Campelo, “Loudspeaker design model”, *online*, available from: https://github.com/fcampelo/Loudspeaker-model