ABAQUS implementation guidelines for "Experiments and numerical implementation of a boundary value problem involving a magnetorheological elastomer layer subjected to a non-uniform magnetic field"

Charles Dorn[a], Laurence Bodelot[b], Kostas Danas[b*]

[a] *Graduate Aerospace Laboratories, California Institute of Technology, Pasadena, California 91125, USA*
[b] *Solid Mechanics Laboratory (LMS), Ecole Polytechnique, Palaiseau 91128, France*
[*] *Corresponding author: konstantinos.danas@polytechnique.edu*

This document explains the ABAQUS input file used to model the boundary value problem (BVP) presented in:

Dorn, C., Bodelot, L., and Danas, K., "Experiments and numerical implementation of a boundary value problem involving a magnetorheological elastomer layer subjected to a non-uniform magnetic field" *Journal of Applied Mechanics*, 2021.

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1. Contents

For the two BVP configurations considered in the paper, "coil plus core" and "core-only", the following files are included:

1. BVP_input.inp: ABAQUS input file
2. FB_HEX8.f: user defined element
3. mesh.inp: defines mesh geometry
4. mesh_dummy.inp: defines dummy mesh

2. Unit system

The following unit system is used in the code:

- Energy density: MPa
- Mesh coordinates and displacements: mm
- Current applied to coil: kA
- B-field: T

3. Parameter definitions

The first section of the input file defines the parameters of the BVP, which are described as follows. All values listed in the input file are consistent with the above unit system.

Coil parameters: `Rin`, `Rout`, and `Hcoil` are the inner radius, outer radius, and height of the coil in mm. The number of turns of wire in the coil is `cTurns`. In the mesh, the central axis of the coil is parallel to the z-axis, passing through `x0, y0`.

Permeability of air: `mu0`

MRE properties: Referring to Table 1 in the paper, G_m and G'_m for the MRE are defined as `Gm` and `Gmp` in the input file. Similarly, $\mu_0\chi_p$ and m_p^s are defined as `xmup`, and is `xmsp`. The volume fraction of particles is `c`. The parameter `cflag` includes a coupling term in the energy density when set to 1, and neglects coupling when set to 0. The parameter `nsrimre` is set to 1 to perform reduced integration. Setting `imatmre`=1 ensures the user element uses the correct energy density for the MRE.

Air properties: Referring to Table 1 in the paper, G_m and G'_m for the air are defined as `Ga` and `Gpa`. The parameter `nsria` is set to 0, so reduced integration is not performed. Setting `imata`=3 ensures the user element uses the correct energy density for the air. Magnetic parameters for the air are irrelevant and set to zero.

Coil properties: Referring to Table 1 in the paper, G_m and G'_m for the coil are defined as `Gc` and `Gpc`. To indicate the presence of a current density in the coil, `cjc` is set to 1. All other materials should have `cj` set to zero. The parameter `nsric` is set to 0, so reduced integration is not performed. Setting `imatc`=3 ensures the user element uses the correct energy density for the coil. Magnetic parameters for the coil are irrelevant and set to zero.

Iron properties: Referring to Table 1 in the paper, G_m and G'_m for the coil are defined as `GI` and `GpI`. Similarly, m_s and χ are defined as `msI`, and is `chiI`. The parameter `nsriI` is set to 0, so reduced integration is not performed. Setting `imatI`=2 ensures the user element uses the correct energy density for iron. The parameter `C6I` is a flag for the magnetic part of the iron energy in `imat`=2 and is set to 1.

Penalty: The Coulomb gauge penalty parameter ξ is defined by `ksi` in the input file.

Loading parameters The acceleration g due to gravity is denoted `Gmag`. The prescribed displacement to clamp the MRE is denoted `Uclamp`. The current applied to the wires of the coil is `Imag`.

4. Notes

- The input file is structured to include three load steps. First, `Step-g` applies gravity. Second, `Step-0` applies clamping boundary conditions to the MRE. Finally, `Step-1` applies current to the coil.
- The current implementation has additional dummy parameters (`dummy1`, `dummy2`, etc.) that are not used in the present modelling. They are kept to allow for easy addition of more modelling variables as required by the user.
- The code takes on the order of 20 hours to run on 12 cpus.
- To run the code in ABAQUS/Standard, type in the terminal:
  `abaqus job=<jobname> input=BVP_input.inp user=FB_HEX8.f cpus=<no_cpus> interactive`