TEST CASE DOCUMENTATION
AND TESTING RESULTS

TEST CASE ID EM-VAL-6.1

TEAM Workshop Problem 10

Tested with LS-DYNA® v980 Revision Beta

Thursday 16th August, 2012

Document Information	
Confidentiality	**external use**
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Contents

1 Introduction

1.1 Purpose of this Document

This document specifies the test case EM-VAL-6.1. It provides general test case information like name and ID as well as information to the confidentiality, status, and classification of the test case.

A detailed description of the test case is given, the purpose of the test case is defined, and the tested features are named. Results and observations are stated and discussed. Testing results are provided in section 4.1 for the therein mentioned LS-DYNA® version and platforms.

2 Test Case Information

Test Case Summary	
Confidentiality	external use
Test Case Name	TEAM Workshop Problem 10: Steel plates around a coil
Test Case ID	EM-VAL-6.1
Test Case Status	Under consideration
Test Case Classification	Validation
Metadata	TEAM problem

Table 1: Test Case Summary

3 Test Case Specification

3.1 Test Case Purpose

The purpose of this test case is to analyse the EM solver's capabilities at simulating non linear transient magnetic problems with Eddy currents.

3.2 Test Case Description

TEAM (Testing Electromagnetic Analysis Methods) represents an open international working group aiming to compare electromagnetic analysis computer codes. TEAM Workshops are meetings of this group. A series of TEAM Workshops was started in 1986 and has been organized in two-year rounds, each comprising a series of "Regional" workshops and a "Final" Workshop, as a satellite event of the COMPUMAG Conference. The TEAM problems consist in a list of test-problems, with precisely defined dimensions, constitutive laws of materials, excitations, etc., and each backed by a real laboratory device, on which measurements can be made.

The TEAM 10 problem defined in the TEAM workshop [2] is a nonlinear transient eddy current problem involving magnetization. An exciting coil is set between two steel channels, and a steel plate is inserted between the channels. The B-H curve of the steel is nonlinear and its values can be found in Table (2). The curve for high flux densities ($B \geq 1.8T$) is approximated by :

$$B = \begin{cases} \mu_0 H + (aH^2 + bH + c) & 1.8 \leq B \leq 2.22T \\ \mu_0 H + M_s & B \geq 2.22T \end{cases} \quad (1)$$

where μ_0 is the permeability of free space. The constants a, b and c are $-2.381e^{-10}$, $2.327e^{-5}$ and 1.590 respectively. M_s is the saturation magnetization of the steel ($2.16T$).

Figure (1) shows the geometry of the TEAM problem. Figure (2) shows the locations where the flux density will be measured and compared to experimental results given in [1].

B(T)	H(A/m)	B(T)	H(A/m)
0	0	0.8	289
0.0025	16	0.9	313
0.005	30	1.00	342
0.0125	54	1.10	377
0.025	93	1.20	433
0.05	143	1.30	509
0.1	191	1.40	648
0.2	210	1.50	933
0.3	222	1.55	1228
0.4	233	1.60	1934
0.5	247	1.65	2913
0.6	258	1.70	4993
0.7	272	1.75	7189
0.8	289	1.80	9423

Table 2: B-H Steel plate curve

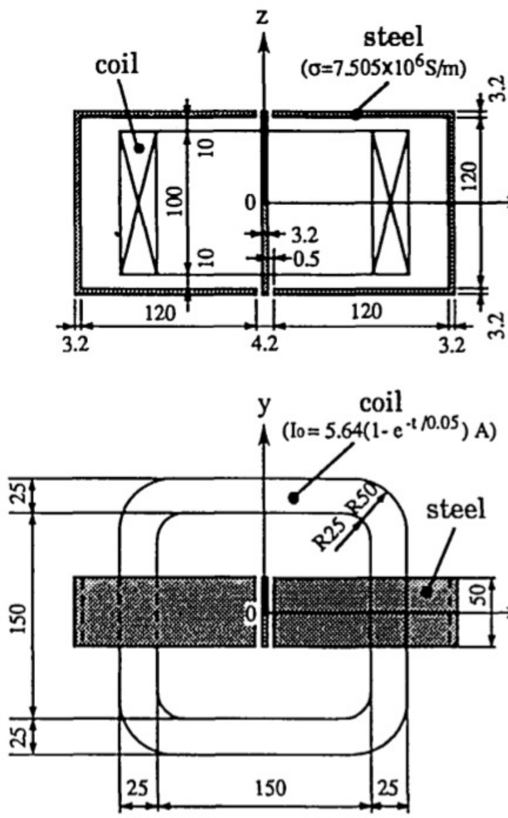

Figure 1: Test case sketch and dimensions

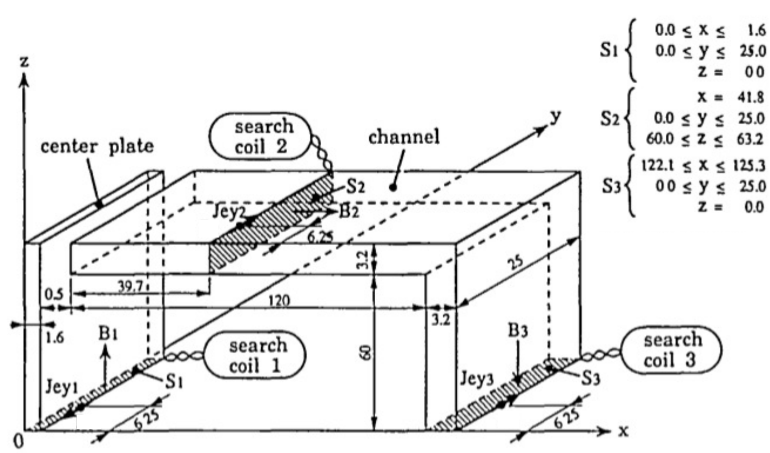

Figure 2: Flux Density Measurement Sections

3.3 Model Description

The conductivity of the steel plates is $7.505e^6 S.m^{-1}$. The number of turns of the coils is 162 and the current in the coil can be considered uniform. The exciting current I_0 varies with time as :

$$I_0 = I_m(1 - e^{-\frac{t}{\tau}}) \quad (2)$$

with $I_m = 5.64A$ and $\tau = 0.05s$.

The time constant has been chosen so that the Eddy current diffusion through the steel plate can not be neglected. Therefore, in order to make sure that the current density is correctly captured, several mesh densities in the thickness of the plate will be studied namely 2 elements, 4 elements and 8 elements through the thickness of the plates. Table (3) gives some information on the different meshes while Figure (3) offers a view of the mesh in the 4 elements case.

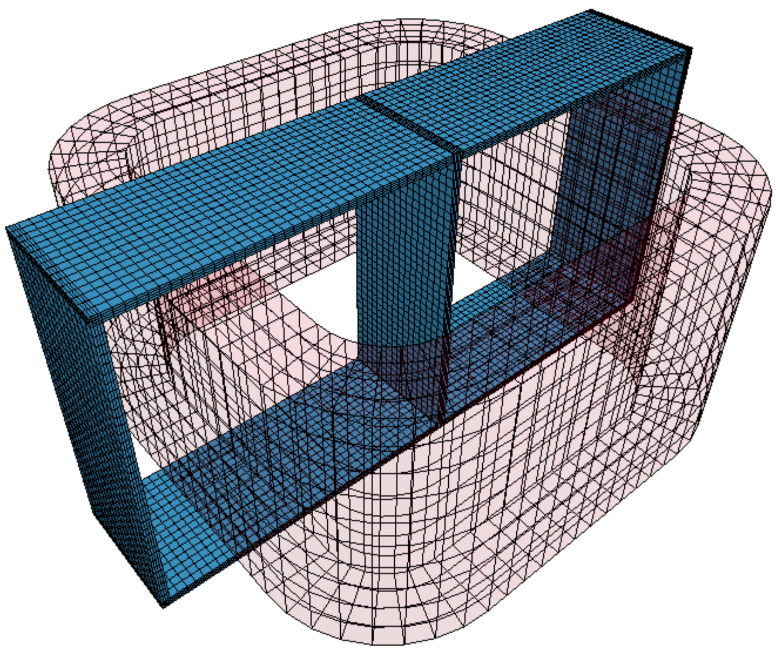

Figure 3: Test case Mesh

Model information	
Total number of Nodes (Coil and Plate) - 2 Ele. case	8921
Total number of Solid elements (Coil and Plate) - 2 Ele. case	5880
Total number of Nodes (Coil and Plate) - 4 Ele. case	28200
Total number of Solid elements (Coil and Plate) - 4 Ele. case	20928
Total number of Nodes (Coil and Plate) - 8 Ele. case	97076
Total number of Solid elements (Coil and Plate) - 8 Ele. case	80960

Table 3: Test Case Mesh information

4 Test Case Results

4.1 Test Case observations

Figure (4) shows the magnetic flux density vectors ($\vec{B}$ field) following the direction of the plaques at a very early time during the simulation. The symmetry of the problem can be clearly identified. Figure (5) shows the current density vectors across the central steel plaque section at a very early time in the simulation. As can be observed, with only two elements in the thickness, no gradient can be captured. With four elements, the current diffusion through the plaque can already be captured while the eight element case further refines the gradient. This explains the behavior of the results for the average flux density measurements through the three sections in Figure (6), (7) and (8). In the two elements case, the magnetic field rises and reaches saturation far too quickly when compared to the experiment. It is interesting to note however that the final saturation fields are not too far away from the experimental results. For the four element case, the results are globally in good agreement and the final saturation fields are close to those of the experiment with a slightly bigger discrepancy in the B_2 case. With eight elements in the thickness, the results are in very good agreement with the experiments.

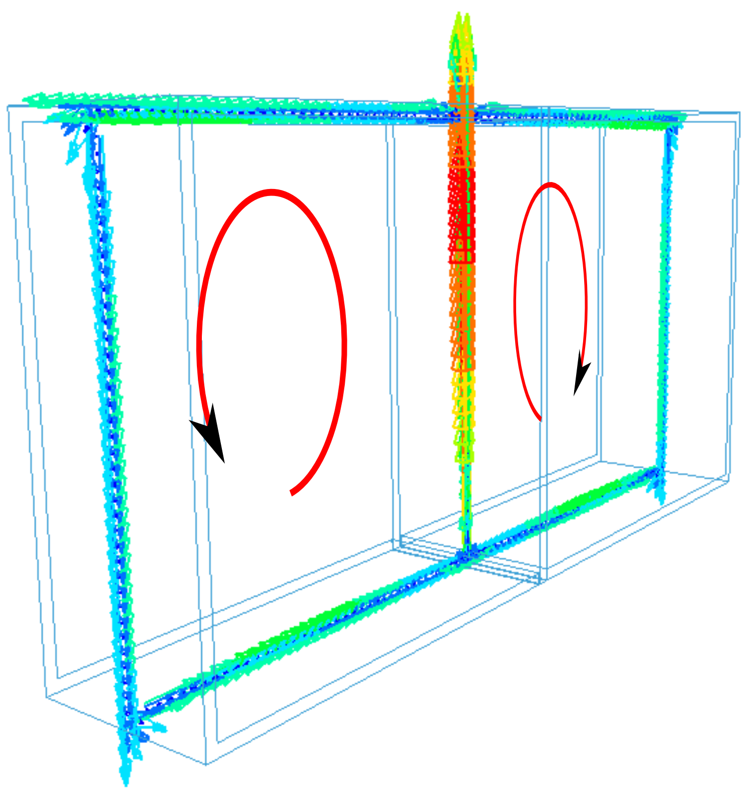

Figure 4: Magnetic flux density vectors in the plaques for t=0.5 ms.

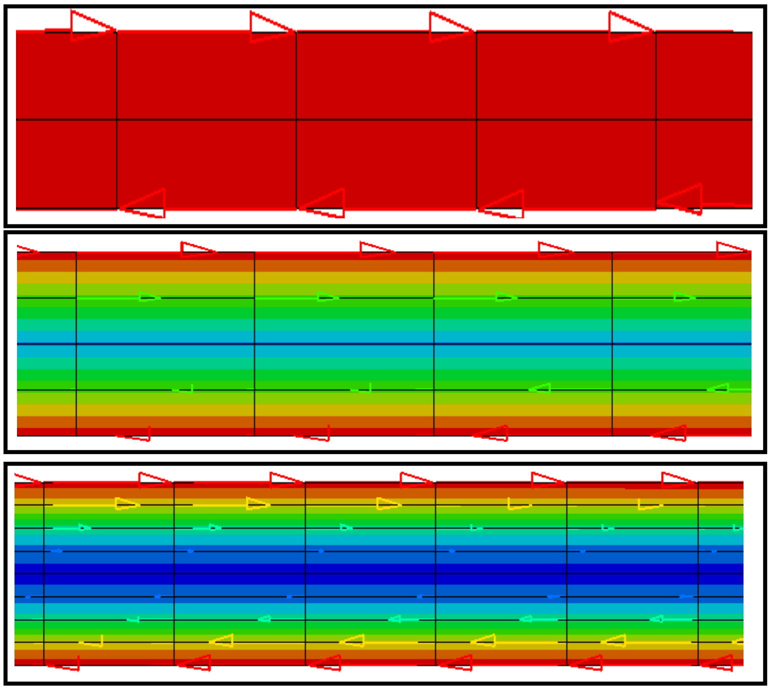

Figure 5: Central Cross Section current density vectors at t=0.5 ms

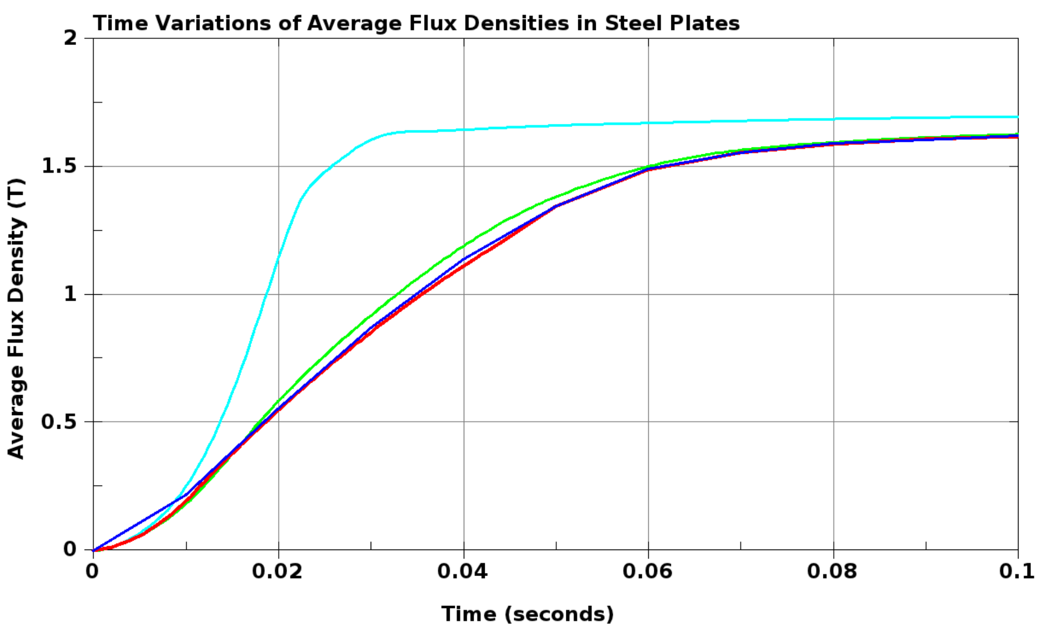

Figure 6: Average flux density through Section B_1. Comparison between the experimental results (in Dark Blue) [1], the 2 Ele. case (in Cyan), the 4 Ele. case (in Green) and the 8 Ele. case (in Red).

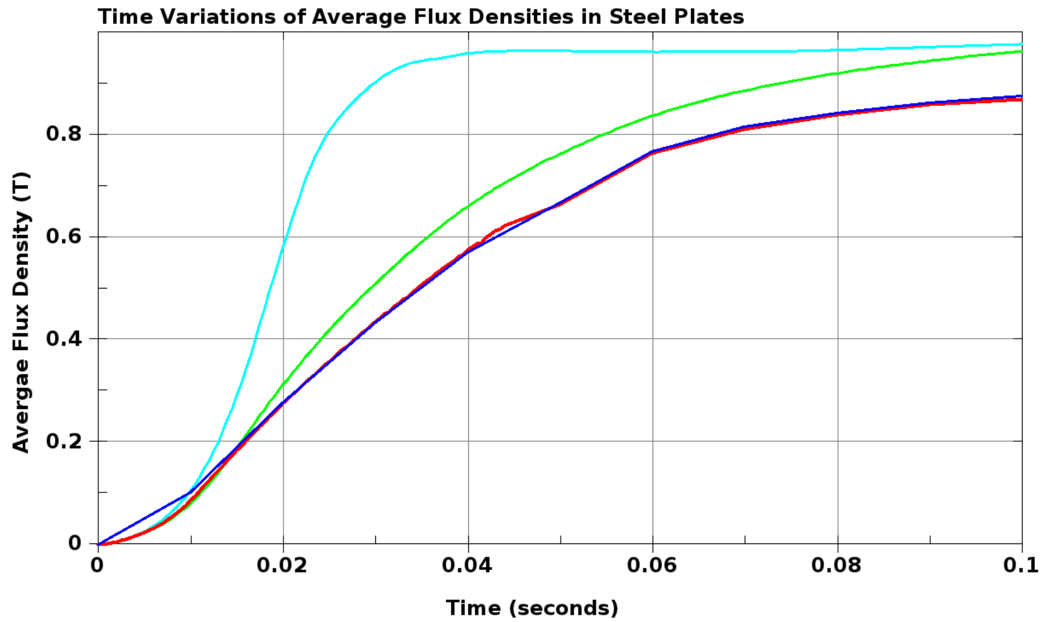

Figure 7: Average flux density through Section B_2. Comparison between the experimental results (in Dark Blue) [1], the 2 Ele. case (in Cyan), the 4 Ele. case (in Green) and the 8 Ele. case (in Red).

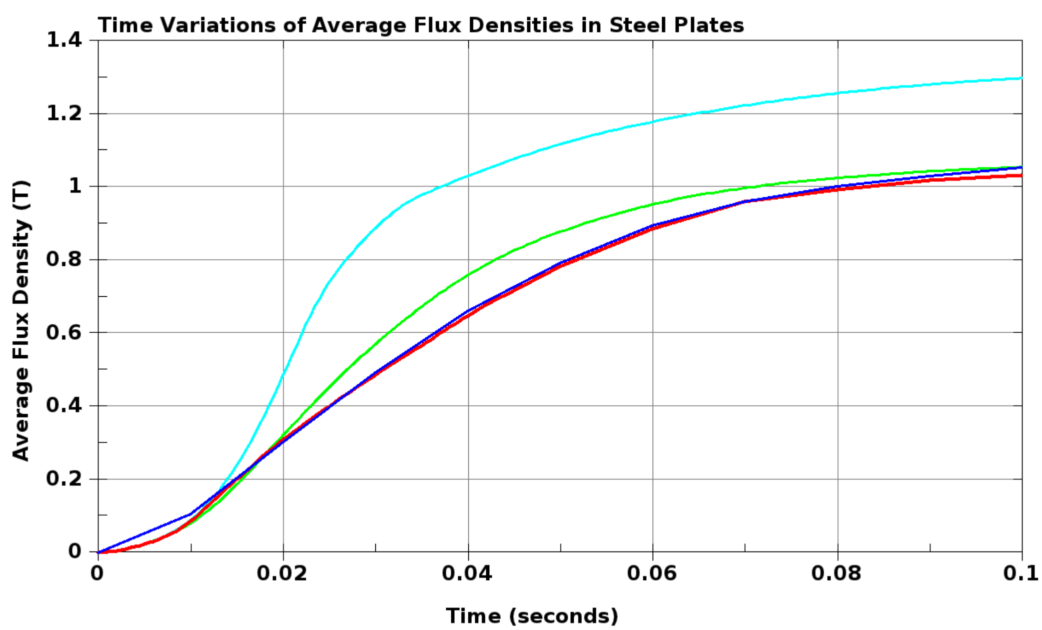

Figure 8: Average flux density through Section B_3. Comparison between the experimental results (in Dark Blue) [1], the 2 Ele. case (in Cyan), the 4 Ele. case (in Green) and the 8 Ele. case (in Red).

References

[1] T. NAKATA, N. TAKAHASHI, AND K. FUJIWARA, *Summary of results for benchmark problem 10 (steel plates around a coil)*, COMPEL-The International Journal for Computation and Mathematics in Electrical and Electronic Engineering, 14 (1995), pp. 103–112.

[2] L. TURNER, ed., *TEAM Workshops, Test Problems*, Fusion Power Program, Argonne National Lab., USA, 1988.