TEST CASE DOCUMENTATION
AND TESTING RESULTS

TEST CASE ID EM-VAL-3.1

TEAM Workshop Problem 12

Tested with LS-DYNA® v980 Revision Beta

Friday 23rd March, 2012

LSTC
Livermore Software
Technology Corp.

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1 Introduction

1.1 Purpose of this Document

This document specifies the test case EM-VAL-3.1. 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 12: Cantilevered beam in crossed field
Test Case ID	EM-VAL-3.1
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 analyze the EM solver's external time dependant magnetic field feature and to test its coupling with the structural solver.

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 12 problem is a coupled problem with moving conductor. A clamped beam is placed in a uniform magnetic field (see figure (1)). The magnetic field will have a first component exponentially decaying with time that will generate an induced current in the beam that will in turn, interact with the second constant component of the field and create a Lorentz force that will cause the beam's movement. The motion of the beam causes the current and deflection to be very different from what they would be if coupling were not present. The experimental results are based on a FELIX experiment [1].

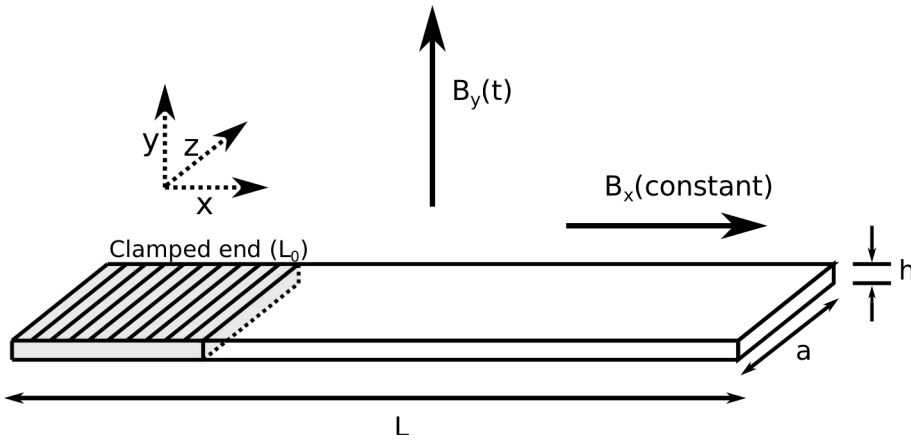

Figure 1: Schematic diagram for the cantilever beam

A preliminary set of testing will consist in only applying the orthogonal exponentially decaying component of the magnetic field ($B_y(t) = B_0 e^{-t/\tau}$). Thus, the Lorentz force will be parallel to the main direction of the beam and no movement will be generated. Several conductivities corresponding to different materials will be chosen. For each material, the

induced current will be compared to the experimental results [1].

The second set of testing will consist in adding the constant component of the magnetic field parallel to the main direction of the beam (B_x). Several values of B_x will be chosen and at each time the induced current as well as the beam's movement will be studied and compared to the experimental results.

3.3 Model Description

The geometrical parameters chosen for the beam described in Figure (1) are summed up in Table (2). Figure (2) and Table (3) offer a view and some information on the mesh used. Table (4) and Table (5) give some information on the parameters used for the preliminary and the complete set of testing. The material used for the analysis will be aluminum considered elastic.

Model Geometry	
L	487 (mm)
a	100 (mm)
h	3.175 (mm)
Clamped end (L_0)	76 (mm)

Table 2: Test Case Geometry information

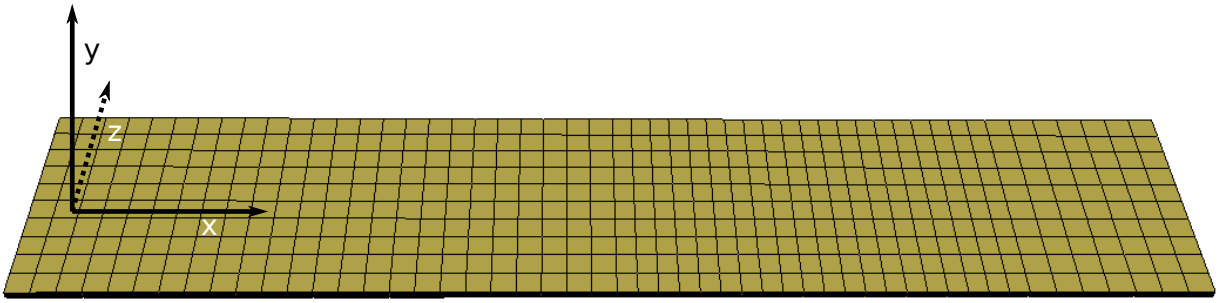

Figure 2: Test case Mesh

$$B_y(t) = B_0 e^{-t/\tau} \tag{1}$$

Mesh information	
Nodes	1632
Solid elements	1630
Number of through thickness elements	5

Table 3: Test Case Mesh information

Model physical parameters. Preliminary tests	
B_0	0.055 Tesla
τ	6.6 ms
Copper conductivity	58.1410^6 $\Omega^{-1}m^{-1}$
Aluminium conductivity	25.3210^6 $\Omega^{-1}m^{-1}$
Brass conductivity	16.3910^6 $\Omega^{-1}m^{-1}$

Table 4: Test Case Parameters. Prelimary tests.

Model physical parameters. Fully coupled tests	
B_0	0.055 Tesla
τ	6.6 ms
B_x	0.2, 0.5, 0.7, 0.9 Tesla
Aluminium conductivity	25.3210^6 $\Omega^{-1}m^{-1}$
Aluminium Density	2713 kg/m^3
Aluminium Young's Modulus	6.8910^{10} Pa

Table 5: Test Case Parameters. Fully coupled tests.

4 Test Case Results

4.1 Test Case observations

- **Preliminary tests** ($B_x = 0$, $B_y(t) = B_0 e^{-t/\tau}$ and $B_z = 0$) :

  Figure (3) shows the magnetic vectors at their peak all pointing in the direction orthogonal to the beam. The field is stronger in the center of the beam due to boundary effects. Figure (4) offers a view of the current density vectors. As expected, the induced current flows around in the beam in the orthogonal direction of the uniform imposed magnetic flow B_y. As can be seen on Figure (5), the numerical results capture very well the behavior of the induced current with only slight differences at the peak.

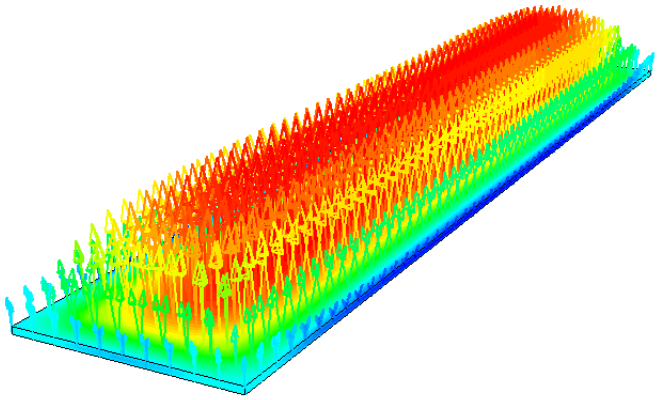

Figure 3: Test Case magnetic field vectors

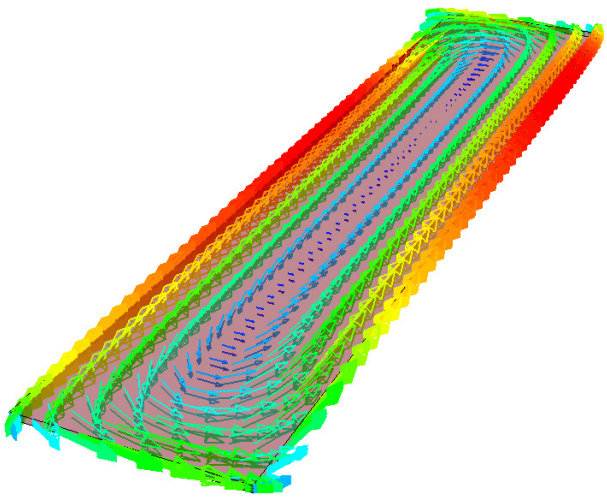

Figure 4: Test Case Current density vectors

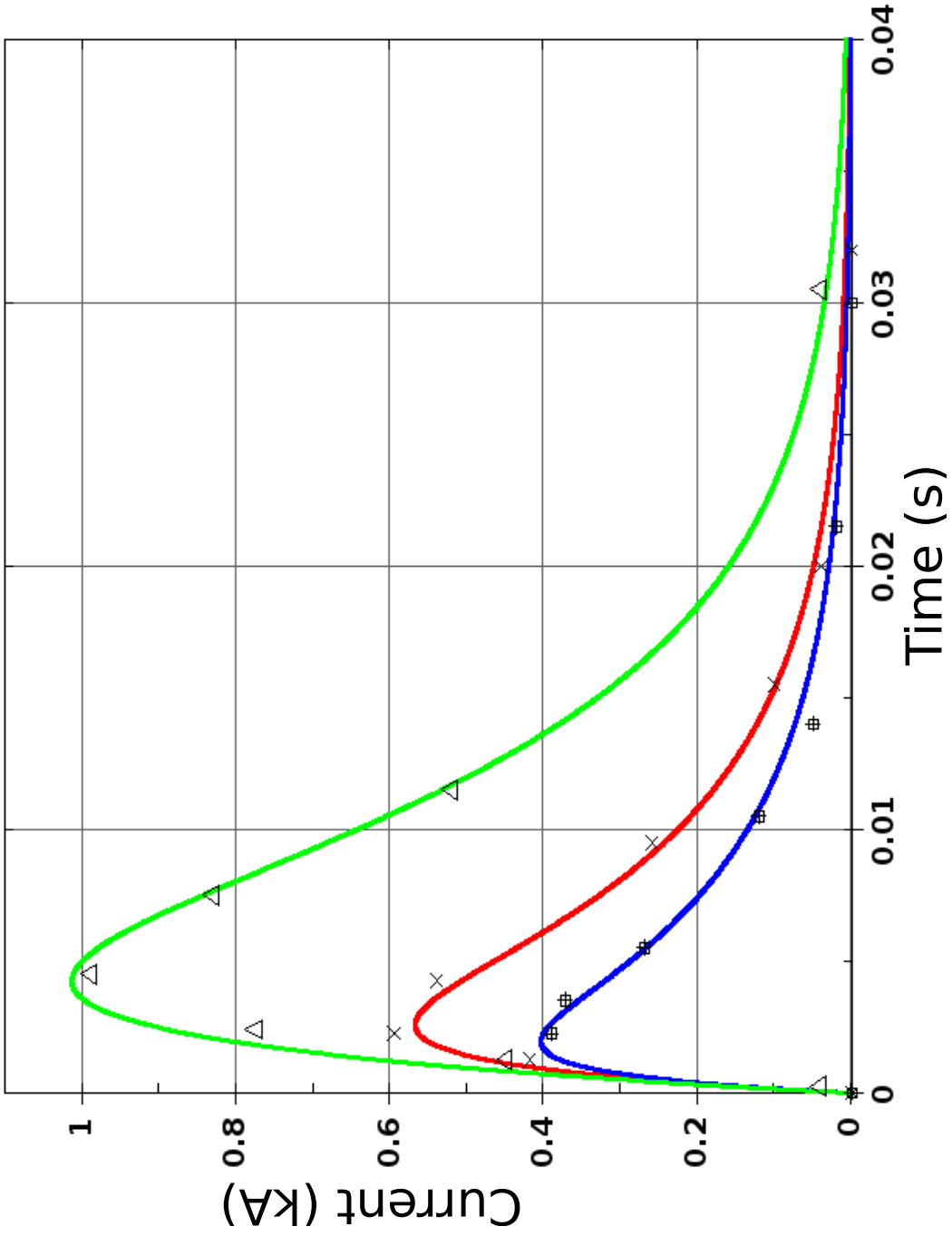

Figure 5: Preliminary comparison for the current induced on the cantilevered beams between numerical results (full line) and experimental points. From top to bottom : Copper (in green), Aluminum (in red), and Brass (in blue).

- **Fully coupled tests** ($B_x \neq 0$, $B_y(t) = B_0 e^{-t/\tau}$ and $B_z = 0$) :

  Figure (6) shows the acceleration vectors that are in this case directly proportional to the Lorentz force (Now $F_y^{Lorentz} = j_z \wedge B_x \neq 0$). Four mode of vibration can be identified. Figure (7) shows the deflection of the beam for various B_x values. It can be observed that for $B_x = 0.2$, the beam oscillates at its natural vibration frequency, the current decays quite smoothly with only small perturbation due to deflection. For $B_x = 0.5$, the damping becomes obvious as the displacement peak is significantly less marked then the first one. For higher values of B_x, after a first swing, the beam slowly returns to rest at the equilibrium position. Figure (8) and (9) shows the good agreement between these observations and the experimental results [1].

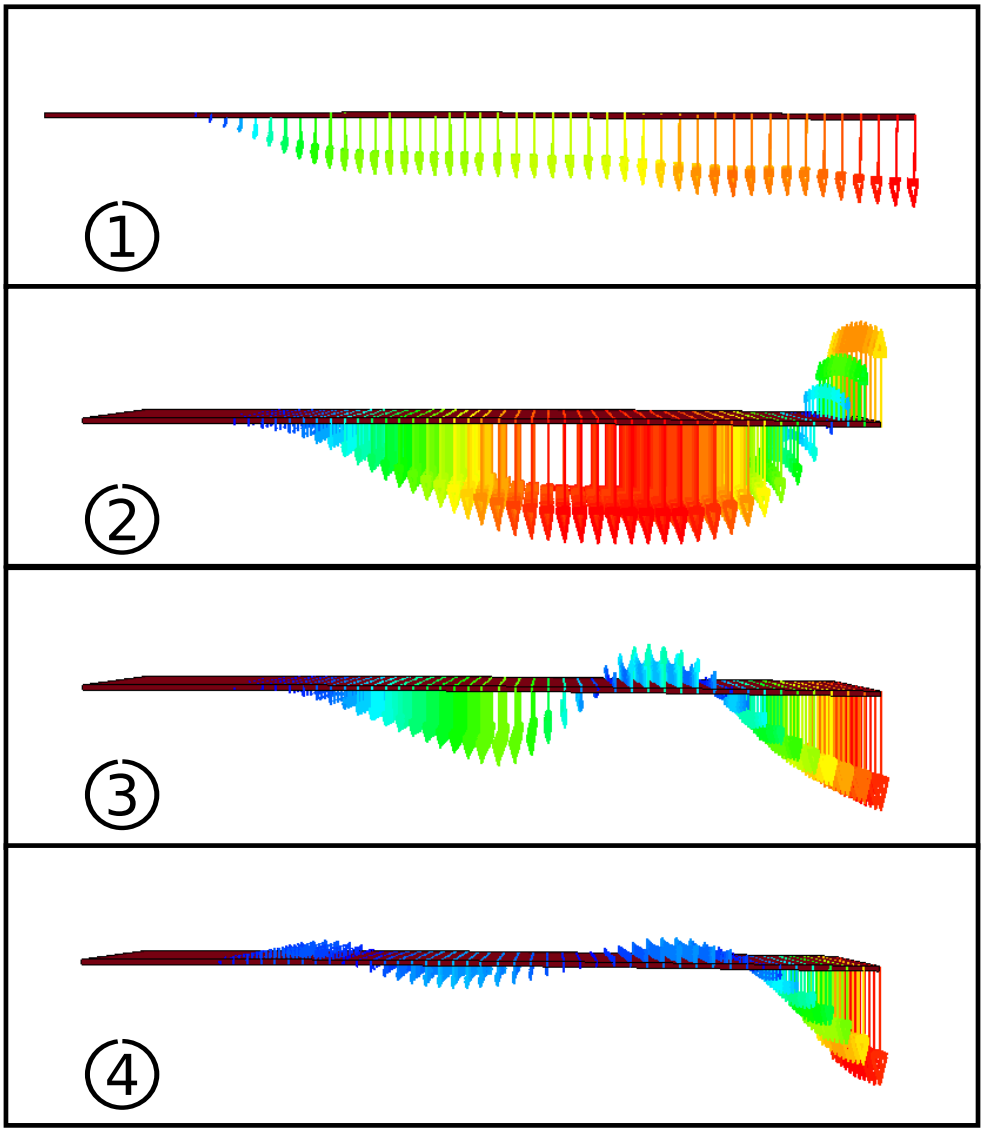

Figure 6: Characteristic Modes of vibration. Acceleration vectors

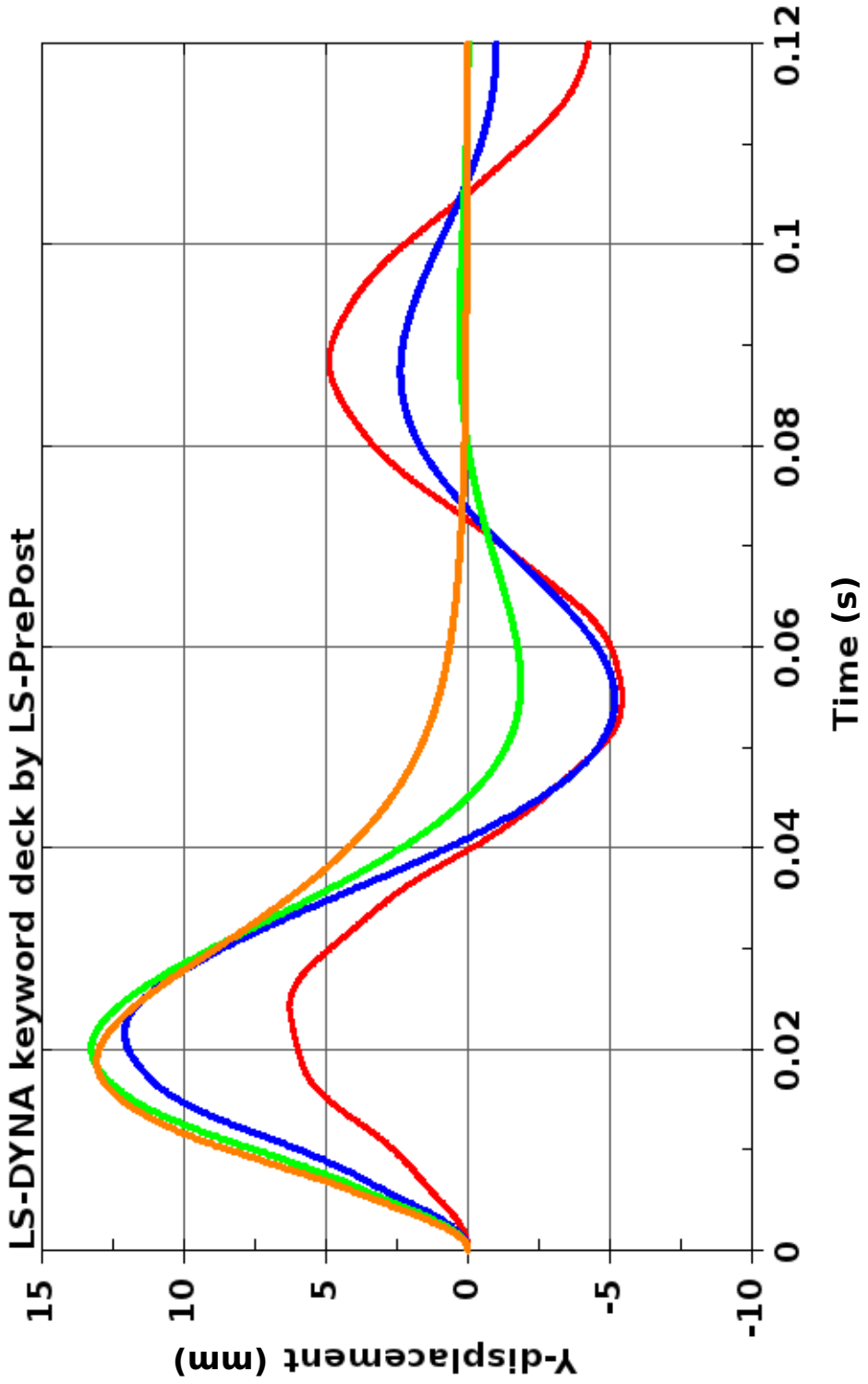

Figure 7: Deflection at the free end for $B_x = 0.2$T (in red), $B_x = 0.5$T (in blue), $B_x = 0.7$T (in green) and $B_x = 0.9$T (in orange)

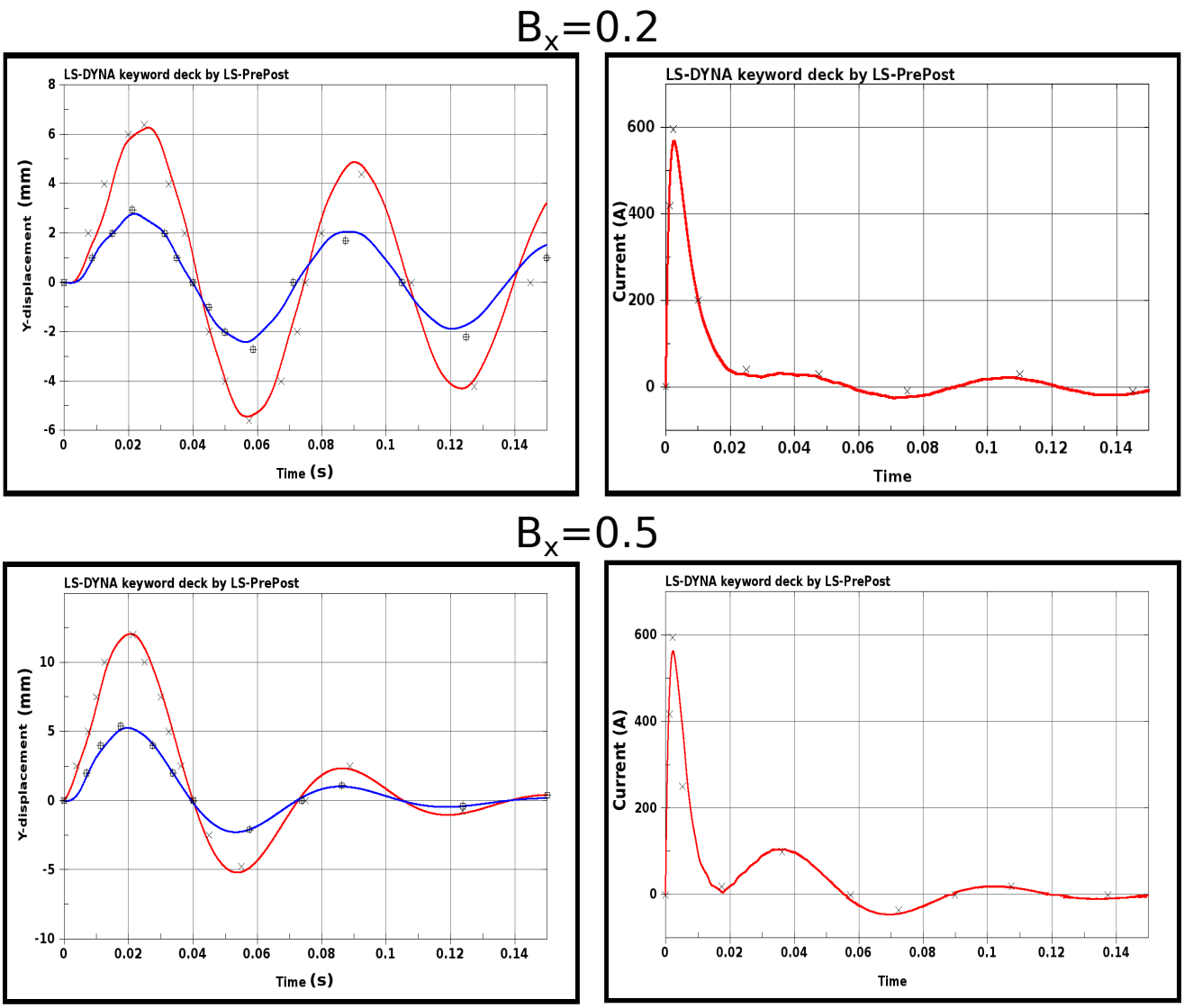

Figure 8: Current and deflection at the free end (in red) and 167 mm from the free end (in blue). Comparison between numerical results (full line) and experimental results (points). $B_x = 0.2$T and $B_x = 0.5$T

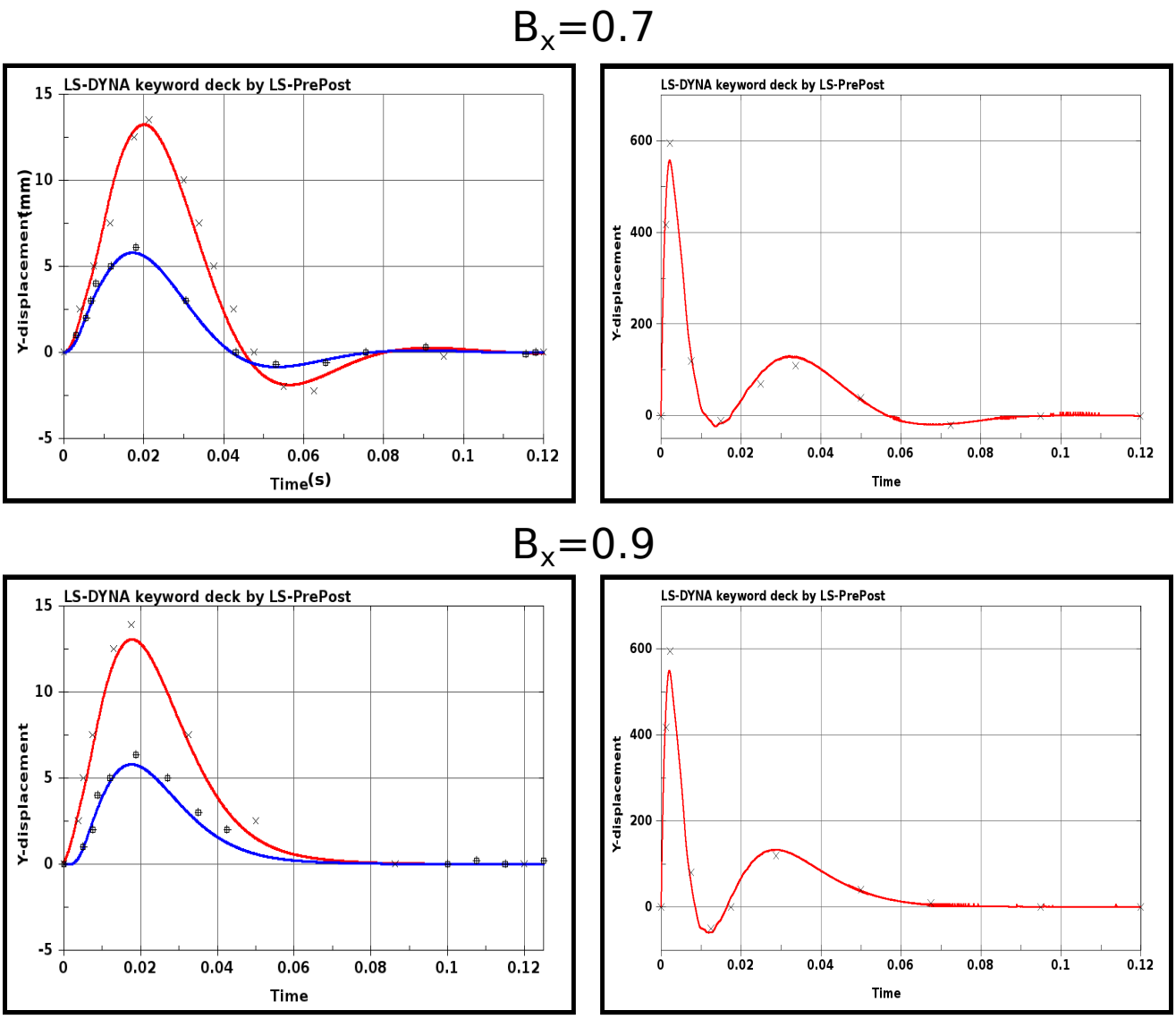

Figure 9: Current and deflection at the free end (in red) and 167 mm from the free end (in blue). Comparison between numerical results (full line) and experimental results (points). $B_x = 0.7$T and $B_x = 0.9$T

References

[1] T. Q. H. L-R. Turner and S. Y. Lee, *Analysis of the felix experiments with cantilevered beams and hollow cylinders*, Fourth Eddy Current Seminar Rutherford Appleton Laboratory, (1986).