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EXPERIMENTAL OBSERVATIONS OF THE COUPLING BETWEEN INDUCED CURRENTS AND
MECHANICAL MOTION IN TORSIONALLY SUPPORTED SQUARE LOOPS AND PLATES

PART 2: DATA INVENTORY

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ABSTRACT

A series of experiments was successfully conducted to investigate the coupling between induced currents and rigid body rotation in square loops and plates. The experiments were performed with the Fusion Electromagnetic Induction Experiment (FELIX) facility at the Argonne National Laboratory. The observed data exhibited the magnetic damping and magnetic stiffness effects which arise in coupled systems and agreed very well with previous analytic calculations.

The experimental arrangement consisted of a conducting test piece which was rigidly mounted in a nonconducting fixture. The fixture was centered on a nonconducting axial tube which was constrained for rotation by adjustable leaf springs. The four examined test pieces were a copper loop, a bronze loop, a copper plate, and a stainless steel plate.

Electric currents were induced in a test piece by pulsing a vertical magnetic field. A constant horizontal magnetic field was also imposed during an experimental shot. The interaction of the induced currents and the magnetic fields produced a net torque about the fixture axis. Measurements were made of the total current flowing around the test piece and the angular rotation versus time.

The analysis of the experimental results and some representative data can be found in Part 1. A complete inventory of the data from the test shots as well as the predicted responses can be found in Part 2.

I. INTRODUCTION

This two-part report describes a series of experiments which were conducted with the Fusion Electromagnetic Induction Experiment (FELIX) facility at Argonne National Laboratory to investigate the quantitative responses of magnetomechanically coupled square loops and plates. The first part¹ presented the details of the data analysis, some representative data, the overall results, and conclusions. This second part contains a complete inventory of all the test shots as well as the predicted responses.

A complete description of the experimental setup is given in Part 1, but a brief summary is also provided in the next section. This is followed by the three main test sections. Section III gives the mechanical tests. Section IV gives the dipole-field-only tests. Section V gives the combined field tests. A brief conclusion then follows.

II. EXPERIMENTAL SETUP

Four test pieces were investigated in this series of experiments. A copper loop, a bronze loop, a copper plate, and a stainless steel plate, designated by the prefixes of A, B, C, and D, respectively in this report. The test pieces were rigidly mounted in a nonconducting fixture suspended by a rotational spring system primarily characterized by a single fundamental mode of vibration.

Electrical currents were induced in the test pieces by a vertical magnetic field, referred to as the dipole field, decaying exponentially through a switchable resistance bank, referred to as the dipole resistor. Net torques were created by a constant horizontal field, referred to as the solenoid field. Measurements were made of the angle of rotation of the test piece versus time. Rogowski coil measurements of the total current flowing around the test piece were also taken as well as Rogowski coil measurements of the dipole bus current. Other measurements recorded during each shot included signals from a multiaxis Hall probe and shunts on the dipole power supply main bus, the dipole resistor, and the solenoid bus.

III. MECHANICAL DAMPING TESTS

Initial mechanical tests were made to determine the basic mechanical system parameters with no magnetic fields imposed. The mechanical damping tests were performed by rotating the test fixture with a test piece installed to an initial displacement for one of two spring settings, 2830 kN-m/rad or 8700 kN-m/rad, then suddenly releasing the fixture and allowing it to vibrate by itself. A set of data points was selected from the observed data and fitted to an ideal curve described in Part 1 to extract the natural frequency, damping ratio, and moment of inertia.

Table I lists the mechanical test files and gives the figure numbers which show the observed data and the fitted ideal decay curves. Table 2 lists the results of the tests. On Figs. A-M-1 to D-M-3, for each test, two plots are shown. The left plot shows the observed data as a solid line with asterisks indicating the points selected for fitting. The right plot shows

the same selected points as asterisks again but at an expanded scale. The solid line in the right plot indicates the fitted curve.

IV. DIPOLE-ONLY TESTS

A series of initial electrical tests with the dipole field only was used to determine the basic electrical system parameters. The applicable formulas and extracted values were presented in Part 1. Table 3 lists the test piece Rogowski coil measurement files and gives the figure numbers and parameters for the observed data. On Figs. A-D-1 to ABCD-D-1 the asterisks indicate the observed data and the solid line indicates the predicted curve.

Similarly, Table 4 lists the dipole resistor measurement files and dipole bus Rogowski coil measurement files and gives the figure numbers and parameters for the observed data. Figures RES-D-1 and RES-D-2 show the observed dipole resistor current as a solid line. Figures ROG-D-1 and ROG-D-2 show the observed dipole bus current as a solid line. Figures ROG-D-3 and ROG-D-4 show a selected portion of the observed data in ROG-D-1 and ROG-D-2 as asterisks and the predicted responses as solid lines.

V. COMBINED FIELD TESTS

Tables 5 and 6 list the files and figure numbers of the combined field tests using both the pulsed dipole field and the constant solenoid field. Tables 7 and 8 list the mechanical and electrical parameters which apply to the figure numbers.

Figures A-1 to A-18, B-1 to B-14, C-1 to C-18, and D-1 to D-6 show the observed data as asterisks, angle measurements on the left, test piece current on the right. The predicted responses calculated using the complete numerical solution including mechanical damping as described in Part 1 are indicated by dashed lines. The predicted responses calculated using the simplified analytic solution are indicated by solid lines.

Figure A-19 shows two shots taken with the same parameters to demonstrate the excellent repeatability of the tests. All shots were repeated at least once and this example was the worst disagreement found although the curves are essentially identical. No difference was observed in all but a handful of shots.

Figure C-19 shows two copper plate shots already presented, but this time with the uncoupled solutions shown as dashed lines. The solid lines indicate the simplified analytic solutions and the asterisks indicate the observed data as before.

The reader may note that all values of the parameter matrix were not used. The signals from the stainless steel plate and bronze loop became too small to measure at the longer time constants and the shots were omitted. A few shot files were lost due to computer disk errors although they were recorded on oscilloscope photographs. Examination of the photos showed similar responses to those already presented.

VI. CONCLUSION

A series of experiments was successfully conducted to investigate the quantitative responses of magnetomechanically coupled square loops and plates. The tests agreed very well with the predicted responses for both the loops and plates. In the combined field tests the expected effects due to magnetic stiffness and magnetic damping were both observed. The simplified solution obtained by using the small angle approximation proved to be very accurate over the parameter space of the experiments.

ACKNOWLEDGMENT

This work was supported by U.S. Department of Energy Contract Nos. DE-AC02-76-CHO-3073 and W-31-109-Eng-38.

REFERENCES

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TABLE 1. MECHANICAL TEST FILES

FIGURE	LABEL 1	LABEL 2	FILE 1	FILE 2
COPPER LOOP				
A-M-1	NF6D3KE	NF6IN004	2	3
A-M-2	NF6D3KE	NF6IN004	2a	--
A-M-3	NF2D3KA	NF3D3KC	199	200
A-M-4	NF6D3KD	---	193	--
BRONZE LOOP				
B-M-1	BNF3D3KA	BNF9KC	4	5
B-M-2	BNF3D3KA	BNF9KC	4a	--
B-M-3	BNF9KB	--	194	--
COPPER PLATE				
C-M-1	PNF3KA	PNF9KA	6	7
C-M-2	PNF3KA	PNF9KA	6a	--
C-M-3	PNF3KB	PNF9KB	195	196
STAINLESS STEEL PLATE				
D-M-1	SNF3KA	SNF9KA	8	9
D-M-2	SNF3KA	SNF9KA	8a	--
D-M-3	SNF3KB	SNF9KB	197	198

TABLE 2. MECHANICAL TEST RESULTS

FIGURE	3 kN (2830 N-m/rad)			9 kN (8700 N-m/rad)		
	ω_k	ζ	I	ω_k	ζ	I
COPPER LOOP						
A-M-1	41.2	0.010	1.67	70.7	0.015	1.74
A-M-2	(41.4)	(0.010)	(1.65)	(72.5)	(0.051)	(1.65)
A-M-3	41.4	0.011	1.65	--	--	--
A-M-3	41.3	0.011	1.66	--	--	--
A-M-4	41.5	0.010	1.64	--	--	--
BRONZE LOOP						
B-M-1	41.8	0.013	1.62	72.2	0.014	1.67
B-M-2	(42.1)	(0.016)	(1.60)	(73.8)	(0.041)	(1.60)
B-M-3	--	--	--	71.8	0.017	1.69
COPPER PLATE						
C-M-1	42.4	0.013	1.57	72.9	0.019	1.64
C-M-2	(42.6)	(0.019)	(1.56)	(79.0)	(0.069)	(1.39)
C-M-3	42.5	0.013	1.57	73.0	0.018	1.63
STAINLESS STEEL PLATE						
D-M-1	42.6	0.012	1.56	73.4	0.011	1.61
D-M-2	(43.0)	(0.016)	(1.53)	(73.9)	(0.020)	(1.59)
D-M-3	42.9	0.012	1.54	73.4	0.010	1.61

Numbers without parentheses indicate that the first 500 observed points were fitted to an ideal curve.

Numbers with parentheses indicate that the second 500 observed points were fitted to an ideal curve.

TABLE 3. DIPOLE-FIELD-ONLY TEST FILES AND PARAMETERS

FIGURE	FILE	COMPONENT LABEL	COMPONENT FILE	DECAY TIME (ms)	DIPOLE FIELD (mT)
A-D-1	cl250	DP02001	44	11.7	33
		DP02003	45	21.6	33
		DP02005	46	39.0	33
		DP02007	47	106.3	33
A-D-2	cl500	DP05002	40	11.7	56
		DP05003	41	21.6	56
		DP05004	42	39.0	56
		DP05005	43	106.3	56
B-D-1	bl250	BDF9K108	52	11.7	33
		BDF9K106	51	21.6	33
		BDF9K122	176	39.0	33
B-D-2	bl500	BDF9K110	53	11.7	56
		BDF9K100	50	21.6	56
		BDF9K120	54	39.0	56
		BDF0K126	57	106.3	56
C-D-1	cp250	PDF9K001	18	11.7	33
		PDF9K007	21	21.6	33
		PDF9K009	20	39.0	33
		PDF9K016	22	106.3	33
C-D-2	cp500	PDF9K003	24	11.7	56
		PDF9K005	25	21.6	56
		PDF9K011	26	39.0	56
		PDF9K014	23	106.3	56
D-D-1	sp	SDF9K001	58	11.7	33
		SDF9K003	59	11.7	56
ABCD-D-1	sup	PDF9K001	18	11.7	33
		DP02001	44	11.7	33
		BDF9K108	52	11.7	33
		SDF9K001	58	11.7	33

TABLE 4. DIPOLE-FIELD-ONLY TEST FILES AND PARAMETERS

FIGURE	FILE	COMPONENT LABEL	COMPONENT FILE	DECAY TIME (ms)	DIPOLE FIELD (mT)
RES-D-1	res2	PDF9K001	18r	11.7	33
		PDF9K007	21r	21.6	33
		PDF9K009	20r	39.0	33
		PDF9K016	22r	106.3	33
RES-D-2	res5	PDF9K003	24r	11.7	56
		PDF9K005	25r	21.6	56
		PDF9K011	26r	39.0	56
		PDF9K014	23r	106.3	56
ROG-D-1	rog2	BDF9K114	137	11.7	33
		BDF9K104	135	21.6	33
		BDF9K116	136	39.0	33
		BDF9K130	150	106.3	33
ROG-D-2	rog5	BDF9K112	136	11.7	56
		BDF9K102	134	21.6	56
		BDF9K118	139	39.0	56
		BDF9K128	141	106.3	56
ROG-D-3	rog2g	BDF9K114	137	11.7	33
		BDF9K104	135	21.6	33
		BDF9K116	138	39.0	33
		BDF9K128	158	106.3	33
ROG-D-4	rog5g	BDF9K112	136	11.7	56
		BDF9K102	134	21.6	56
		BDF9K118	139	39.0	56
		BDF9K128	141	106.3	56

TABLE 5. COMBINED FIELD TEST FILES

FIGURE	LABEL 1	LABEL 2	FILE 1	FILE 2
COPPER LOOP				
A-1	DF3K114	DF3K111	17	16
A-2	DF3K104	DF3K109	39	15
A-3	DF3K105	DF3K107	38	37
A-4	DF9K031	DF9K003	36	11
A-5	DF9K033	DF9K005	35	13
A-6	DF9K035	DF9K007	34	14
A-7	DF3K115	DF3K121	79	75
A-8	DF3K117	DF3K123	68	189
A-9	DF3K120	DF3K125	190	73
A-10	DF9K037	DF9K013	71	76
A-11	DF9K039	DF9K011	70	77
A-12	DF9K041	DF9K009	98	67
A-13	DF3K127	DF3K133	132	153
A-14	DF3K129	DF3K135	133	154
A-15	DF3K131	DF3K137	152	155
A-16	DF9K029	DF9K019	131	126
A-17	DF9K027	DF9K021	130	127
A-18	DF9K025	DF9K023	129	128
A-19	DF9K007	DF9K008	14179	179
BRONZE LOOP				
B-1	BDF3K003	BDF3K009	84	96
B-2	BDF3K005	BDF3K011	82	88
B-3	BDF3K007	BDF3K013	80	85
B-4	BDF9K132	BDF9K138	94	90
B-5	BDF9K134	BDF9K140	93	191
B-6	BDF9K136	BDF9K142	92	87
B-7	BDF3K015	BDF3K021	106	109
B-8	BDF3K017	BDF3K023	107	110
B-9	BDF3K019	BDF3K025	108	111
B-10	BDF9K144	BDF9K145	101	100
B-11	BDF9K147	BDF9K149	105	104
B-12	BDF3K027	BDF3K033	156	160
B-13	BDF3K029	BDF3K035	157	161
B-14	BDF3K031	BDF3K037	159	162

TABLE 6. COMBINED FIELD TEST FILES

FIGURE	LABEL 1	LABEL 2	FILE 1	FILE 2
COPPER PLATE				
C-1	PDF3K001	PDF3K008	83	28
C-2	PDF3K003	PDF3K010	81	29
C-3	PDF3K012	--	30	--
C-4	PDF9K018	PDF9K024	97	31
C-5	PDF9K020	PDF9K027	86	32
C-6	PDF9K022	PDF9K029	192	33
C-7	PDF3K014	PDF3K020	118	121
C-8	PDF3K016	PDF3K022	119	122
C-9	PDF3K018	PDF3K024	120	123
C-10	PDF9K031	PDF9K037	112	115
C-11	PDF9K033	PDF9K039	113	116
C-12	PDF9K035	PDF9K041	114	117
C-13	PDF3K026	PDF3K032	169	172
C-14	PDF3K028	PDF3K034	170	173
C-15	PDF3K030	PDF3K036	171	174
C-16	PDF9K043	PDF9K049	163	166
C-17	PDF9K045	PDF9K051	164	167
C-18	PDF9K047	PDF9K053	165	168
C-19	PDF3K008	PDF3K012	2830	30
STAINLESS STEEL PLATE				
D-1	SDF9K018	SDF9K024	146	149
D-2	SDF9K020	SDF9K026	147	150
D-3	SDF9K022	SDF9K028	148	151
D-4	SDF9K030	SDF9K031	142	143
D-5	SDF9K033	SDF9K035	188	144
D-6	SDF9K037	SDF9K038	145	124

TABLE 7. COMBINED FIELD TEST PARAMETERS

FIGURE	SPRING CONSTANT (kN)	DECAY TIME (ms)	DIPOLE FIELD(S) (mT)	SOLENOID FIELD(S) (mT)
COPPER LOOP				
A-1	2.83	11.7	56	53 (105)
A-2	2.83	11.7	33 (56)	210
A-3	2.83	11.7	33	420 (840)
A-4	8.70	11.7	33 (56)	210
A-5	8.70	11.7	33 (56)	420
A-6	8.70	11.7	33 (56)	840
A-7	2.83	39.0	33 (56)	210
A-8	2.83	39.0	33 (56)	420
A-9	2.83	39.0	33 (56)	840
A-10	8.70	39.0	33 (56)	210
A-11	8.70	39.0	33 (56)	420
A-12	8.70	39.0	33 (56)	840
A-13	2.83	106.3	33 (56)	210
A-14	2.83	106.3	33 (56)	420
A-15	2.83	106.3	33 (56)	840
A-16	8.70	106.3	33 (56)	210
A-17	8.70	106.3	33 (56)	420
A-18	8.70	106.3	33 (56)	840
A-19	8.70	11.7	56	840
BRONZE LOOP				
B-1	2.83	11.7	33 (56)	210
B-2	2.83	11.7	33 (56)	420
B-3	2.83	11.7	33 (56)	840
B-4	8.70	11.7	33 (56)	210
B-5	8.70	11.7	33 (56)	420
B-6	8.70	11.7	33 (56)	840
B-7	2.83	39.0	33 (56)	210
B-8	2.83	39.0	33 (56)	420
B-9	2.83	39.0	33 (56)	840
B-10	8.70	39.0	33 (56)	210
B-11	8.70	39.0	56	420 (840)
B-12	2.83	106.3	33 (56)	210
B-13	2.83	106.3	33 (56)	420
B-14	2.83	106.3	33 (56)	840

TABLE 8. COMBINED FIELD TEST PARAMETERS

FIGURE	SPRING CONSTANT (kN)	DECAY TIME (ms)	DIPOLE FIELD(S) (mT)	SOLENOID FIELD(S) (mT)
COPPER PLATE				
C-1	2.83	11.7	33 (56)	210
C-2	2.83	11.7	33 (56)	420
C-3	2.83	11.7	56	840
C-4	8.70	11.7	33 (56)	210
C-5	8.70	11.7	33 (56)	420
C-6	8.70	11.7	33 (56)	840
C-7	2.83	39.0	33 (56)	210
C-8	2.83	39.0	33 (56)	420
C-9	2.83	39.0	33 (56)	840
C-10	8.70	39.0	33 (56)	210
C-11	8.70	39.0	33 (56)	420
C-12	8.70	39.0	33 (56)	840
C-13	2.83	106.3	33 (56)	210
C-14	2.83	106.3	33 (56)	420
C-15	2.83	106.3	33 (56)	840
C-16	8.70	106.3	33 (56)	210
C-17	8.70	106.3	33 (56)	420
C-18	8.70	106.3	33 (56)	840
C-19	2.83	11.7	56	210 (840)
STAINLESS STEEL PLATE				
D-1	8.70	11.7	33 (56)	210
D-2	8.70	11.7	33 (56)	420
D-3	8.70	11.7	33 (56)	840
D-4	8.70	39.0	33 (56)	210
D-5	8.70	39.0	56	420 (840)
D-6	8.70	106.3	56	210 (420)

Figure A-M-1

Mechanical Damping Tests: Copper Loop

Nominal Spring Constants Indicated in Parentheses

Asterisks = selected observation points
 Solid line (left) = observed data
 Solid line (right) = fitted curve

Figure A-M-2

Mechanical Damping Tests: Copper Loop

Nominal Spring Constants Indicated in Parentheses

Asterisks = selected observation points
 Solid line (left) = observed data
 Solid line (right) = fitted curve

Figure A-M-3

Mechanical Damping Tests: Copper Loop

Nominal Spring Constants Indicated in Parentheses

Asterisks = selected observation points
 Solid line (left) = observed data
 Solid line (right) = fitted curve

Figure A-M-4

Mechanical Damping Test : Copper Loop

Nominal Spring Constants Indicated in Parentheses

Asterisks = selected observation points
 Solid line (left) = observed data
 Solid line (right) = fitted curve

Figure B-M-1

Mechanical Damping Tests: Bronze Loop

Nominal Spring Constants Indicated in Parentheses

Asterisks = selected observation points
 Solid line (left) = observed data
 Solid line (right) = fitted curve

Figure B-M-2

Mechanical Damping Tests: Bronze Loop

Nominal Spring Constants Indicated in Parentheses

Asterisks = selected observation points
 Solid line (left) = observed data
 Solid line (right) = fitted curve

Figure B-M-3

Mechanical Damping Test : Bronze Loop

Nominal Spring Constants Indicated in Parentheses

Asterisks = selected observation points
 Solid line (left) = observed data
 Solid line (right) = fitted curve

Figure C-M-1

Mechanical Damping Tests: Copper Plate

Nominal Spring Constants Indicated in Parentheses

Asterisks = selected observation points
 Solid line (left) = observed data
 Solid line (right) = fitted curve

Figure C-M-2

Mechanical Damping Tests: Copper Plate

Nominal Spring Constants Indicated in Parentheses

Asterisks = selected observation points
 Solid line (left) = observed data
 Solid line (right) = fitted curve

Figure C-M-3

Mechanical Damping Tests: Copper Plate

Nominal Spring Constants Indicated in Parentheses

Asterisks = selected observation points
 Solid line (left) = observed data
 Solid line (right) = fitted curve

Figure D-M-1

Mechanical Damping Tests: Stainless Steel Plate

Nominal Spring Constants Indicated in Parentheses

Asterisks = selected observation points

Solid line (left) = observed data

Solid line (right) = fitted curve

Figure D-M-2

Mechanical Damping Tests: Stainless Steel Plate

Nominal Spring Constants Indicated in Parentheses

Asterisks = selected observation points
 Solid line (left) = observed data
 Solid line (right) = fitted curve

Figure D-M-3

Mechanical Damping Tests: Stainless Steel Plate

Nominal Spring Constants Indicated in Parentheses

Asterisks = selected observation points
 Solid line (left) = observed data
 Solid line (right) = fitted curve

Figure A-D-1

33 mT (nominal 25 mT) Dipole-Field-Only Tests: Copper Loop

Test piece Rogowski measurements and predicted curves
 Nominal decay times indicated in parentheses

Asterisks = observed data
 Solid line = predicted curve

Figure A-D-2

56 mT (nominal 50 mT) Dipole-Field-Only Tests: Copper Loop

Test piece Rogowski measurements and predicted curves
 Nominal decay times indicated in parentheses

Asterisks = observed data
 Solid line = predicted curve

Figure B-D-1

33 mT (nominal 25 mT) Dipole-Field-Only Tests: Bronze Loop

Test piece Rogowski measurements and predicted curves
 Nominal decay times indicated in parentheses

Asterisks = observed data
 Solid line = predicted curve

Figure B-D-2

56 mT (nominal 50 mT) Dipole-Field-Only Tests: Bronze Loop

Test piece Rogowski measurements and predicted curves
Nominal decay times indicated in parentheses

Asterisks = observed data
Solid line = predicted curve

Figure C-D-1

33 mT (nominal 25 mT) Dipole-Field-Only Tests: Copper Plate

Test piece Rogowski measurements and predicted curves
 Nominal decay times indicated in parentheses

Asterisks = observed data
 Solid line = predicted curve

Figure C-D-2

56 mT (nominal 50 mT) Dipole-Field-Only Tests: Copper Plate

Test piece Rogowski measurements and predicted curves
 Nominal decay times indicated in parentheses

Asterisks = observed data
 Solid line = predicted curve

Figure D-D-1

33 mT and 56 mT (nominal 25 mT and 50 mT) Dipole-Field-Only Tests:
Stainless Steel Plate

Test piece Rogowski measurements and predicted curves
11.7 ms (nominal 10 ms) decay time

Asterisks = observed data
Solid line = predicted curve

Figure ABCD-D-1

33 mT (nominal 25 mT) Dipole-Field-Only Tests and Predicted Curves
11.7 ms (nominal 10 ms) decay time

Asterisks = observed data
Solid line = predicted curve

Figure RES-D-1

33 mT (nominal 25 mT) Dipole-Field-Only Tests:
 Dipole resistor shunt measurements
 Nominal decay times indicated in parentheses

Figure RES-D-2

56 mT (nominal 50 mT) Dipole-Field-Only Tests:
 Dipole resistor shunt measurements
 Nominal decay times indicated in parentheses

Figure ROG-D-1

33 mT (Nominal 25 mT) Dipole-Field-Only Tests:
 Dipole bus Rogowski measurements
 Nominal decay times indicated in parentheses

Figure R06-D-2

56 mT (Nominal 50 mT) Dipole-Field-Only Tests:
 Dipole bus Rogowski measurements
 Nominal decay times indicated in parentheses

Figure ROG-D-3

33 mT (Nominal 25 mT) Dipole-Field-Only Tests:
Dipole bus Rogowski measurements and predicted curves
Nominal decay times indicated in parentheses

Asterisks = observed data
Solid line = predicted curve

Figure ROG-D-4

56 mT (Nominal 50 mT) Dipole-Field-Only Tests:
 Dipole bus Rogowski measurements and predicted curves
 Nominal decay times indicated in parentheses

Asterisks = observed data
 Solid line = predicted curve

Figure A-1

Combined Field Tests: Copper Loop

Asterisks = Observed Data
 Dashed Line = Complete Numerical Solution
 Including Mechanical Damping
 Solid Line = Simplified Analytic Solution

Figure A-2

Combined Field Tests: Copper Loop

Asterisks = Observed Data
 Dashed Line = Complete Numerical Solution
 Including Mechanical Damping
 Solid Line = Simplified Analytic Solution

Figure A-3

Combined Field Tests: Copper Loop

Asterisks = Observed Data
 Dashed Line = Complete Numerical Solution
 Including Mechanical Damping
 Solid Line = Simplified Analytic Solution

Figure A-4

Combined Field Tests: Copper Loop

Asterisks = Observed Data
 Dashed Line = Complete Numerical Solution
 Including Mechanical Damping
 Solid Line = Simplified Analytic Solution

Figure A-5

Combined Field Tests: Copper Loop

Asterisks = Observed Data
Dashed Line = Complete Numerical Solution
Including Mechanical Damping
Solid Line = Simplified Analytic Solution

Figure A-6

Combined Field Tests: Copper Loop

Asterisks = Observed Data
 Dashed Line = Complete Numerical Solution
 Including Mechanical Damping
 Solid Line = Simplified Analytic Solution

Figure A-7

Combined Field Tests: Copper Loop

Asterisks = Observed Data
Dashed Line = Complete Numerical Solution
Including Mechanical Damping
Solid Line = Simplified Analytic Solution

Figure A-8

Combined Field Tests: Copper Loop

Asterisks = Observed Data
 Dashed Line = Complete Numerical Solution
 Including Mechanical Damping
 Solid Line = Simplified Analytic Solution

Figure A-9

Combined Field Tests: Copper Loop

Asterisks = Observed Data
 Dashed Line = Complete Numerical Solution
 Including Mechanical Damping
 Solid Line = Simplified Analytic Solution

Figure A-10

Combined Field Tests: Copper Loop

Asterisks = Observed Data
 Dashed Line = Complete Numerical Solution
 Including Mechanical Damping
 Solid Line = Simplified Analytic Solution

Figure A-12

Combined Field Tests: Copper Loop

Asterisks = Observed Data
 Dashed Line = Complete Numerical Solution
 Including Mechanical Damping
 Solid Line = Simplified Analytic Solution

Figure A-13

Combined Field Tests: Copper Loop

Asterisks = Observed Data
 Dashed Line = Complete Numerical Solution
 Including Mechanical Damping
 Solid Line = Simplified Analytic Solution

Figure A-14

Combined Field Tests: Copper Loop

Asterisks = Observed Data
 Dashed Line = Complete Numerical Solution
 Including Mechanical Damping
 Solid Line = Simplified Analytic Solution

Figure A-15

Combined Field Tests: Copper Loop

Asterisks = Observed Data
 Dashed Line = Complete Numerical Solution
 Including Mechanical Damping
 Solid Line = Simplified Analytic Solution

Figure A-16

Combined Field Tests: Copper Loop

Asterisks = Observed Data
 Dashed Line = Complete Numerical Solution
 Including Mechanical Damping
 Solid Line = Simplified Analytic Solution

Figure A-17

Combined Field Tests: Copper Loop

Asterisks = Observed Data
Dashed Line = Complete Numerical Solution
Including Mechanical Damping
Solid Line = Simplified Analytic Solution

Figure A-18

Combined Field Tests: Copper Loop

Asterisks = Observed Data
 Dashed Line = Complete Numerical Solution
 Including Mechanical Damping
 Solid Line = Simplified Analytic Solution

Figure A-19
Combined Field Tests: Copper Loop
Observed Data
Repeatability Illustration

Figure B-1

Combined Field Tests: Bronze Loop

Asterisks = Observed Data
 Dashed Line = Complete Numerical Solution
 Including Mechanical Damping
 Solid Line = Simplified Analytic Solution

Figure B-2

Combined Field Tests: Bronze Loop

Asterisks = Observed Data
 Dashed Line = Complete Numerical Solution
 Including Mechanical Damping
 Solid Line = Simplified Analytic Solution

Figure B-3

Combined Field Tests: Bronze Loop

Asterisks = Observed Data
 Dashed Line = Complete Numerical Solution
 Including Mechanical Damping
 Solid Line = Simplified Analytic Solution

Figure B-4

Combined Field Tests: Bronze Loop

Asterisks = Observed Data
 Dashed Line = Complete Numerical Solution
 Including Mechanical Damping
 Solid Line = Simplified Analytic Solution

Figure B-5

Combined Field Tests: Bronze Loop

Asterisks = Observed Data
 Dashed Line = Complete Numerical Solution
 Including Mechanical Damping
 Solid Line = Simplified Analytic Solution

Figure B-6

Combined Field Tests: Bronze Loop

Asterisks = Observed Data
 Dashed Line = Complete Numerical Solution
 Including Mechanical Damping
 Solid Line = Simplified Analytic Solution

Figure B-7

Combined Field Tests: Bronze Loop

Asterisks = Observed Data
 Dashed Line = Complete Numerical Solution
 Including Mechanical Damping
 Solid Line = Simplified Analytic Solution

Figure B-8

Combined Field Tests: Bronze Loop

Asterisks = Observed Data
 Dashed Line = Complete Numerical Solution
 Including Mechanical Damping
 Solid Line = Simplified Analytic Solution

Figure B-9

Combined Field Tests: Bronze Loop

Asterisks = Observed Data
 Dashed Line = Complete Numerical Solution
 Including Mechanical Damping
 Solid Line = Simplified Analytic Solution

Figure B-10

Combined Field Tests: Bronze Loop

Asterisks = Observed Data
 Dashed Line = Complete Numerical Solution
 Including Mechanical Damping
 Solid Line = Simplified Analytic Solution

OBSERVED PULSE FROM 2200 Mc CYCLOTRON

ADJUSTED TIME (SECONDS)

0.2252
1.8506
2.0250
1.21e-08
1.05e-01
0.2109
-0.0530
1.96e-01
1.8710
0.6266
0.0135

Observed Points From 990 To 1289. [M = 300]

Observed Points From 990 To 1289. [M = 300]

Observed Points From 991 To 1290. [M = 300]

Observed Points From 991 To 1290. [M = 300]

Figure B-13

Combined Field Tests: Bronze Loop

Asterisks = Observed Data
 Dashed Line = Complete Numerical Solution
 Including Mechanical Coupling
 Solid Line = Simplified Analytic Solution

Figure B-14

Combined Field Tests: Bronze Loop

Asterisks = Observed Data
 Dashed Line = Complete Numerical Solution
 Including Mechanical Damping
 Solid Line = Simplified Analytic Solution

Observed Points From 990 To 1289. [M = 300]

Observed Points From 990 To 1289. [M = 300]

Observed Points From 990 To 1289. [M = 300]

Observed Points From 990 To 1289. [M = 300]

Figure C-1

Combined Field Tests: Copper Plate

Asterisks = Observed Data
 Dashed Line = Complete Numerical Solution
 Including Mechanical Damping
 Solid Line = Simplified Analytic Solution

Figure C-2

Combined Field Tests: Copper Plate

Asterisks = Observed Data
Dashed Line = Complete Numerical Solution
Including Mechanical Damping
Solid Line = Simplified Analytic Solution

Figure C-3

Combined Field Test : Copper Plate

Asterisks = Observed Data
 Dashed Line = Complete Numerical Solution
 Including Mechanical Damping
 Solid Line = Simplified Analytic Solution

Figure C-4

Combined Field Tests: Copper Plate

Asterisks = Observed Data
 Dashed Line = Complete Numerical Solution
 Including Mechanical Damping
 Solid Line = Simplified Analytic Solution

Figure C-5

Combined Field Tests: Copper Plate

Asterisks = Observed Data
 Dashed Line = Complete Numerical Solution
 Including Mechanical Damping
 Solid Line = Simplified Analytic Solution

Figure C-6

Combined Field Tests: Copper Plate

Asterisks = Observed Data
 Dashed Line = Complete Numerical Solution
 Including Mechanical Damping
 Solid Line = Simplified Analytic Solution

Figure C-7

Combined Field Tests: Copper Plate

Asterisks = Observed Data
 Dashed Line = Complete Numerical Solution
 Including Mechanical Damping
 Solid Line = Simplified Analytic Solution

Figure C-8

Combined Field Tests: Copper Plate

Asterisks = Observed Data
 Dashed Line = Complete Numerical Solution
 Including Mechanical Damping
 Solid Line = Simplified Analytic Solution

Figure C-9

Combined Field Tests: Copper Plate

Asterisks = Observed Data
 Dashed Line = Complete Numerical Solution
 Including Mechanical Damping
 Solid Line = Simplified Analytic Solution

Figure C-10

Combined Field Tests: Copper Plate

Asterisks = Observed Data
 Dashed Line = Complete Numerical Solution
 Including Mechanical Damping
 Solid Line = Simplified Analytic Solution

Figure C-11

Combined Field Tests: Copper Plate

Asterisks = Observed Data
 Dashed Line = Complete Numerical Solution
 Including Mechanical Damping
 Solid Line = Simplified Analytic Solution

Figure C-12

Combined Field Tests: Copper Plate

Asterisks = Observed Data
 Dashed Line = Complete Numerical Solution
 Including Mechanical Damping
 Solid Line = Simplified Analytic Solution

Figure C-13

Combined Field Tests: Copper Plate

Asterisks = Observed Data
 Dashed Line = Complete Numerical Solution
 Including Mechanical Damping
 Solid Line = Simplified Analytic Solution

Figure C-15

Combined Field Tests: Copper Plate

Asterisks = Observed Data
 Dashed Line = Complete Numerical Solution
 Including Mechanical Damping
 Solid Line = Simplified Analytic Solution

Figure C-16

Combined Field Tests: Copper Plate

Asterisks = Observed Data
 Dashed Line = Complete Numerical Solution
 Including Mechanical Damping
 Solid Line = Simplified Analytic Solution

Figure C-17

Combined Field Tests: Copper Plate

Asterisks = Observed Data
 Dashed Line = Complete Numerical Solution
 Including Mechanical Damping
 Solid Line = Simplified Analytic Solution

Figure C-18

Combined Field Tests: Copper Plate

Asterisks = Observed Data
 Dashed Line = Complete Numerical Solution
 Including Mechanical Damping
 Solid Line = Simplified Analytic Solution

Figure C-19

Combined Field Tests: Copper Plate

Asterisks = observed data
Dashed line = uncoupled numerical solution
 including mechanical damping
Solid line = simplified analytic solution

Figure D-1

Combined Field Tests: Stainless Steel Plate

Asterisks = Observed Data
 Dashed Line = Complete Numerical Solution
 Including Mechanical Damping
 Solid Line = Simplified Analytic Solution

Figure D-2

Combined Field Tests: Stainless Steel Plate

Asterisks = Observed Data
 Dashed Line = Complete Numerical Solution
 Including Mechanical Damping
 Solid Line = Simplified Analytic Solution

Figure D-3

Combined Field Tests: Stainless Steel Plate

Asterisks = Observed Data
 Dashed Line = Complete Numerical Solution
 Including Mechanical Damping
 Solid Line = Simplified Analytic Solution

Figure D-4

Combined Field Tests: Stainless Steel Plate

Asterisks = Observed Data
 Dashed Line = Complete Numerical Solution
 Including Mechanical Damping
 Solid Line = Simplified Analytic Solution

Figure D-5

Combined Field Tests: Stainless Steel Plate

- Asterisks = Observed Data
- Dashed Line = Complete Numerical Solution
Including Mechanical Damping
- Solid Line = Simplified Analytic Solution

Figure D-6

Combined Field Tests: Stainless Steel Plate

Asterisks = Observed Data
 Dashed Line = Complete Numerical Solution
 Including Mechanical Damping
 Solid Line = Simplified Analytic Solution

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