### **On The Simulation of Electromagnetic Forming Process of Tube Using Multiphysics Software**

**Presented by** 

Shyam Gawade M-Tech(CAD/CAM)

Dr. S.B. Sharma Production Engineering Dept. SGGS IE&T ,Vishnupuri, Nanded

### Dr. P. P. Date

Mechanical Engineering Dept. IIT Bombay

### **Outline of Paper**

- Aim of paper.
- High Velocity Forming(HVF).
- Electromagnetic forming(EMF).
- Simulation.
- Results and Conclusion.

### **Aim of Paper**

• Demonstrating that Electromagnetic process can be simulated with a relatively simple model that has good correspondence to experimental data.

 Also, the validated model should be able to predict deformation at energy levels that cannot be achieved within safe operating limits of the equipment used presently, but can serve as a guide for next generation equipment.

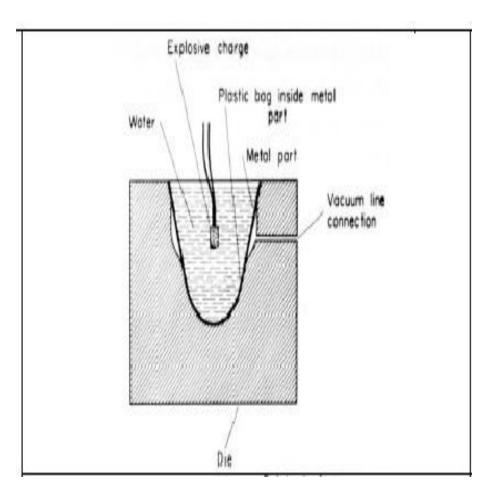
# What Is High Velocity Forming

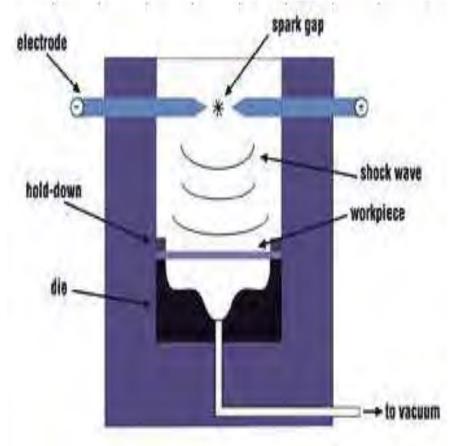
- High velocity forming (HVF) is the shaping of materials by rapidly conveying energy to them during short time durations.
- It is also known as a **HERF/HVF** process.
- The HVF forming velocity of workpiece reaches up to 100m/sec in less than 0.1 ms .
- The HERF processes are:

(i)Explosive, (ii)Electro-Hydraulic, and

(iii) Electromagnetic Forming.

EMF is the most widely used HERF process in industries

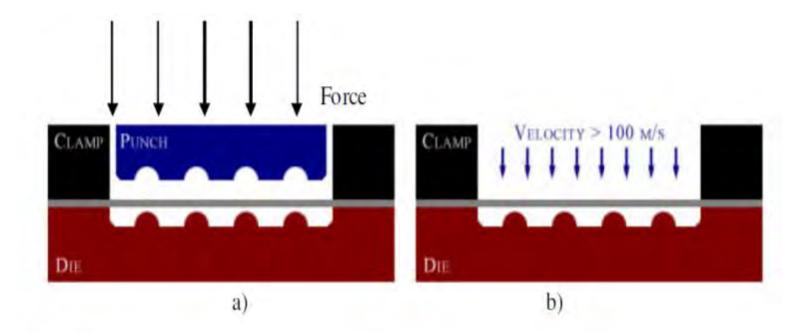




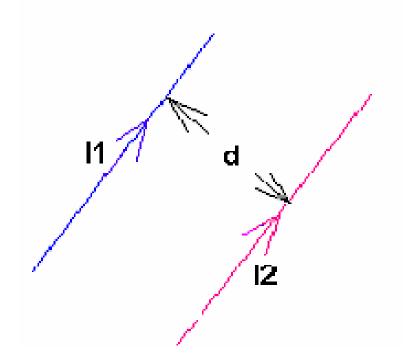
### Explosive[1]

### Electro-Hydraulic[1]

# Traditional & Electromagnetic Forming[1]



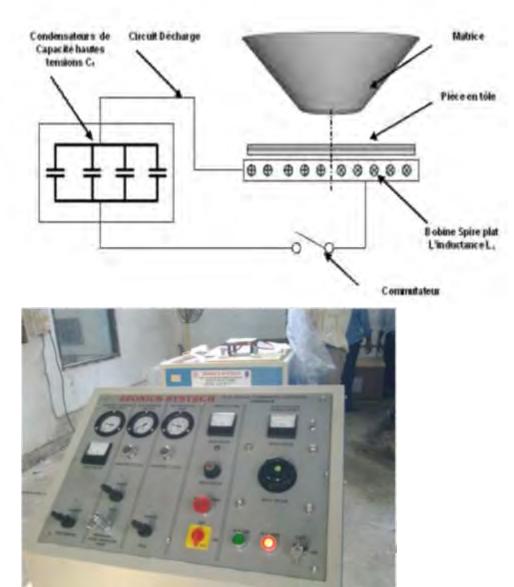
### **Principle of EM Forming**



$$\mathbf{F} = \frac{\mu_0}{2\pi d} \mathbf{I}_1 \mathbf{I}_2$$

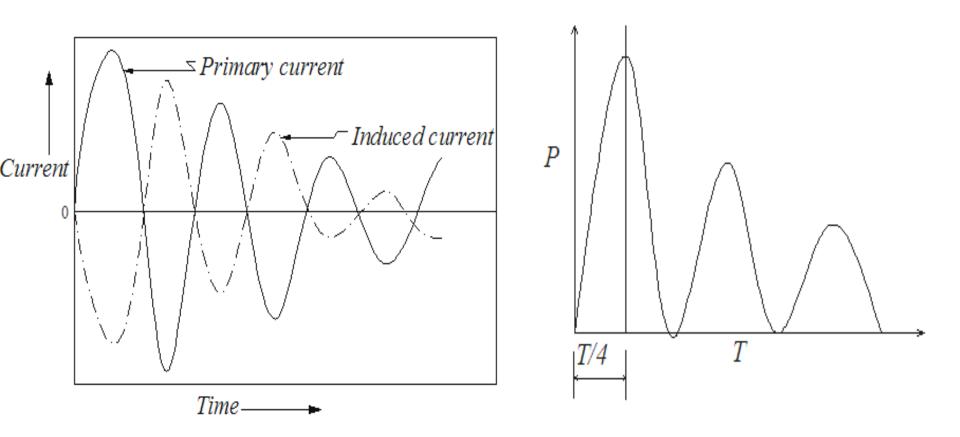
F = Force; N/m, I1, I2 = Current; A d = Spacing between conductors μ<sub>0</sub>=permeability of free space; H/m

# **Electromagnetic Forming**





### Current and pressure in EMF Process

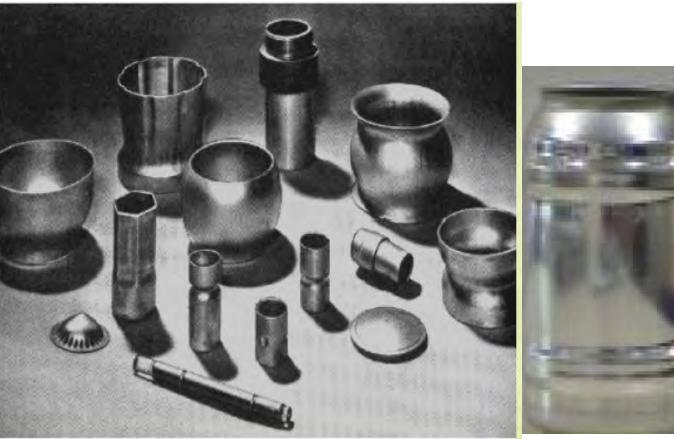


$$I(t) = \frac{V_0}{\omega L} e^{\frac{-R_s t}{2L}} \sin(\omega t)$$





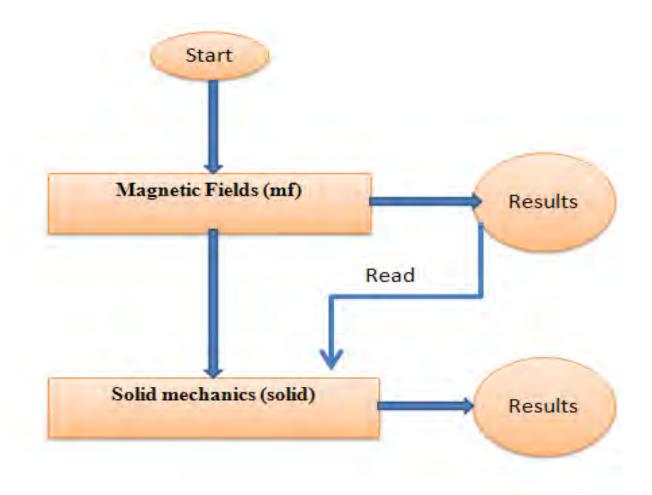
### Application



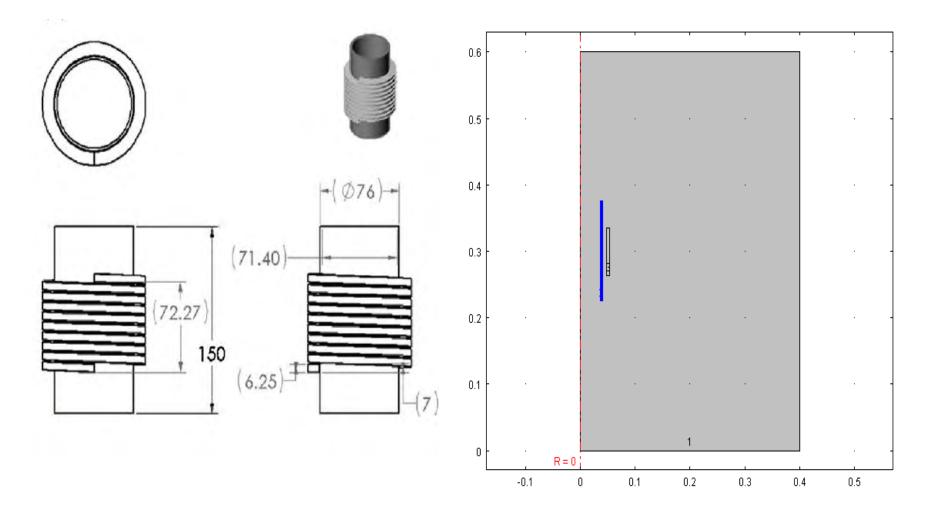
# Application



### **Simulation Flow Chart**



### **Modeling of EMF system**

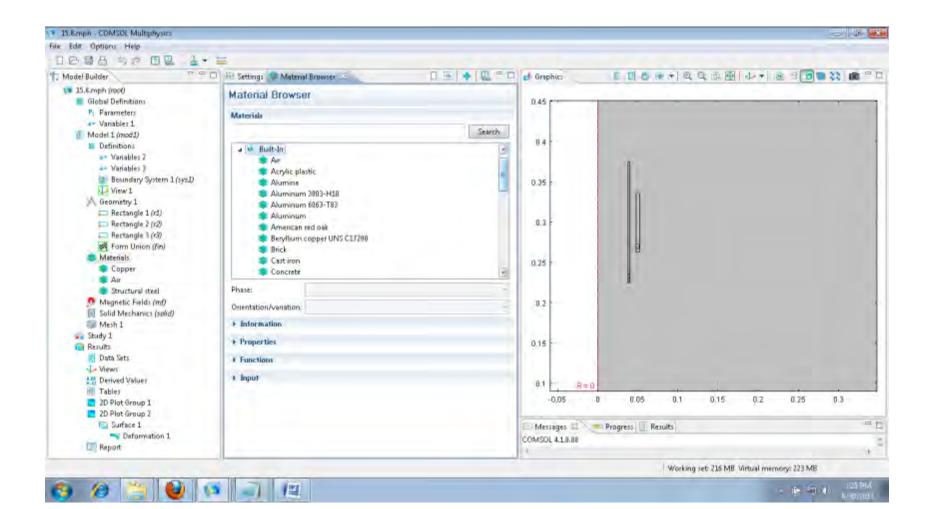


### **Global Parameters and Variables.**

$$I(t) = \frac{V_0}{\omega L} e^{\frac{-R_s t}{2L}} \sin(\omega t)$$

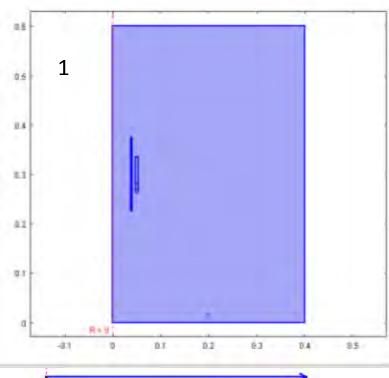
			👬 Settings	斗 Material Browser	
Settings	🏮 Material Browse	er)	a= Variat	oles	
Param	neters		👻 Variables	5	
			Name	Expression	Uni
Paramet	ers		I	(a/(d*b))*(e))*sin(d*t)	Α
Name	Expression	Value			
а	8612.68 [V]	8613 V			
Ь	100e-9[H]	1.0E-7 H			
с	10 [ohm]	10 Ω			
d	6677.79 [rad/s]	6678 rad/s			
q	.005 [m]	0.005 m		• 🕞 🗟	
9	.07227 [m]	0.07227 m	Name: I		
			Expression:	:	
				(exp((-c*t)/(2*b)))*sin(d*t)	

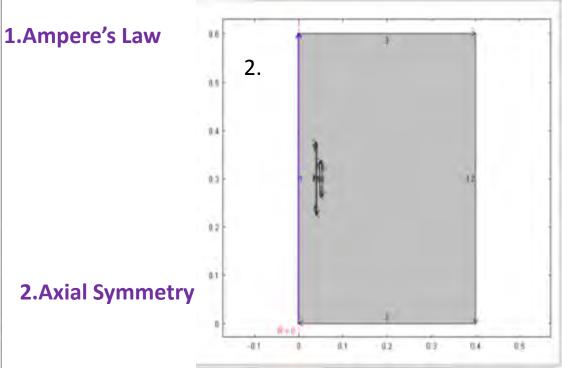
### **Define Material**



# Magnetic Field Boundary Condition

Magnetic field physics is applied to all domain





3

#### **3.**Magnetic Insulation

on 4

#### **4.Initial value**



#### Magnetic vector potential:

	£	1	
А	£	pho	Wt/m
	E.	I	

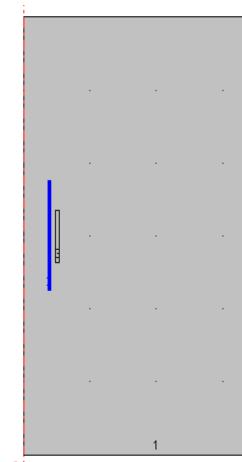
1(atm)	Pa
Coordinate System Selection	
Coordinate system:	
Global coordinate system	•
<ul> <li>Multi-Turn Coll Domain</li> </ul>	
Coil name:	
1	
Relative permeability:	
Pr From material	
Relative permittivity:	
Fr From material	
Coil conductivity:	
acout 6e7[S/m]	Sim
Number of turns:	
N 9	
Coil wire cross-section area:	
Acost .007*.00625	m <sup>2</sup>
Coil excitation:	
Current	
Coll current	
Icent 1/(.007*.00725)	A

	·	
ł		

#### **5.Multi-Turn Coil Domain**

# Solid Mechanics Boundary Condition

### Solid Mechanics is applied to domain 2



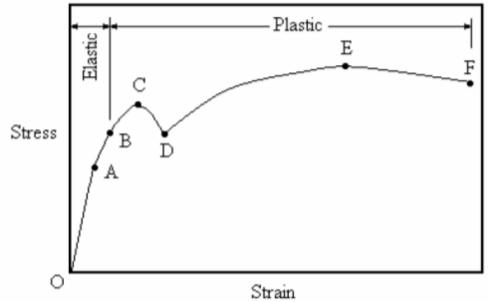


#### **1.Initial Values**

$$\sigma_{\text{hard}} = \sigma_{y} \left[ 1 + \left(\frac{\dot{\varepsilon}}{P}\right)^{m} \right] - \sigma_{yield}$$

### 2.Elastoplastic

Material



E	rom material		2
Paisso	on's ratio;		
L Fr	rom material	-	
Density	<i>r.</i>		
ρ Fra	om material	-	
+ Plasti	city Model		
Yield fu	anction F:		
van Mi	ises stress	+	
$F = \sigma_t$	$m_{\text{resc}} - \sigma_{\text{ys}},  Q = F$		
Yield st	tress level:		
$\sigma_{\rm YsD}$	User defined	•	
	400e6	Pa	
Harden	ning model:		
hotrop	anc.	•	
Isotrop	ic hardening:		
Use ha	rdening function data	*	-
$\sigma_{ys} = 0$	$\sigma_{ys0} + \sigma_h(\epsilon_{psc})$		
Harden	ing function:		
$\sigma_h(\epsilon_{pe}$	) sigma	Pa	
- Geon	netric Nonlinearity		
Inclu	ude geometric nonlinearity		-

B	lody Load	
Dom	ains	
Sele	ction: Manual	•
2		ñ <mark>*</mark>
+ Eq	pation	
+ Co	oordinate System Selection	
Coo	ordinate system:	
Glo	bal coordinate system	•
+ Fo	rce	
Loa	d type:	
Lo	ad defined as force per unit volume	
Los	d:	
$\mathbf{F}_V$	User defined	
	mista	1
	0	z N/m

**3.Coupling Body Load** 

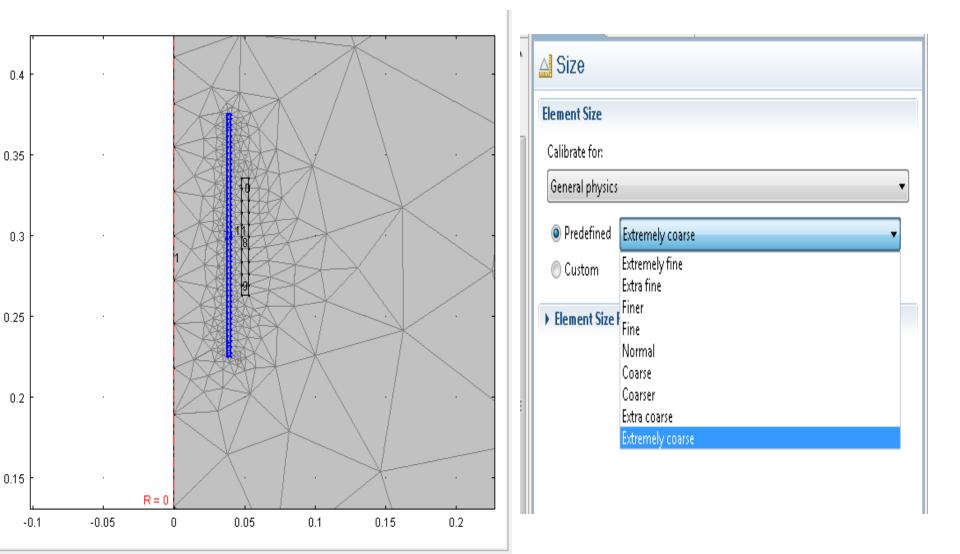
#### 4.Prescribed Displacement

Boundaries	6	
Selection:	All boundaries	
1 (not ap) 2 (not ap) 3 (not ap) 4 5 6 7 8 (not ap)	olicable)	
+ Equation	1	
• Coordin	ate System Selection	
Coordinat	e system)	
Global co	ordinate system	•
+ Prescrib	ed Displacement	
Ø Standa	d natation	
Prescrit	and in R direction	
14. 14		
Prescrit	ped in Z direction	
W <sub>0</sub>		111

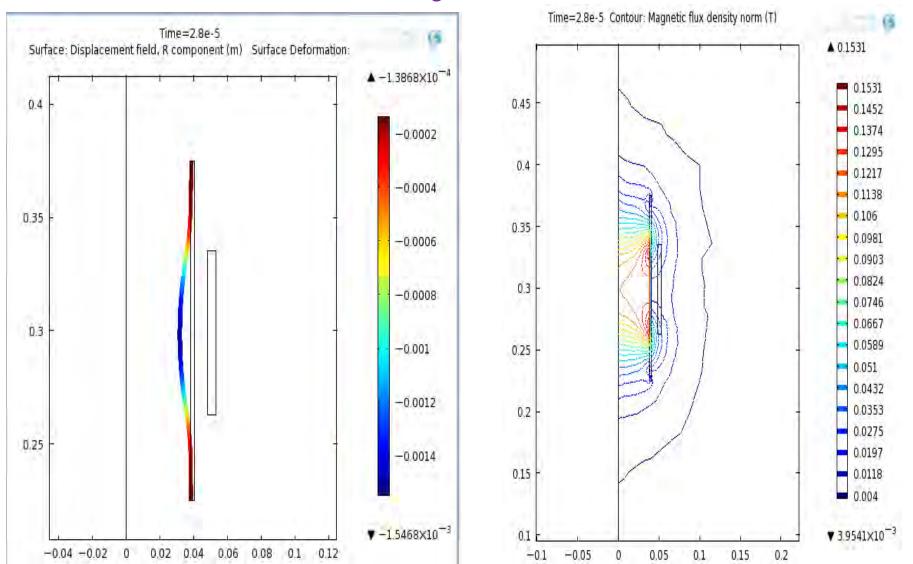
💁 Time Deper	ndent
Times:	range(0,2e-7,28e-6) s
Relative tolerance:	0.01
▶ Results While So	lving
▼ Mesh Selection	
Geometries:	
Geometry 1	

5.Study-Time Dependant

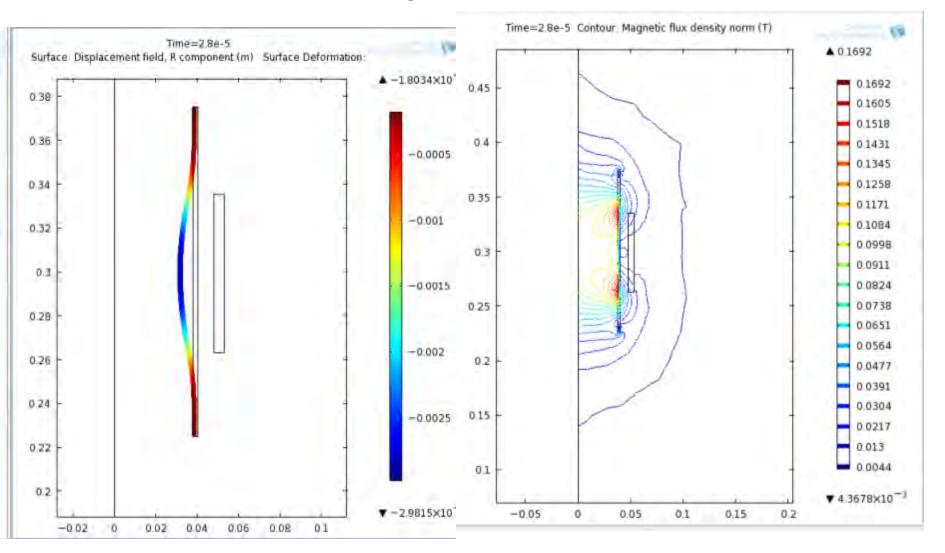
### Meshing



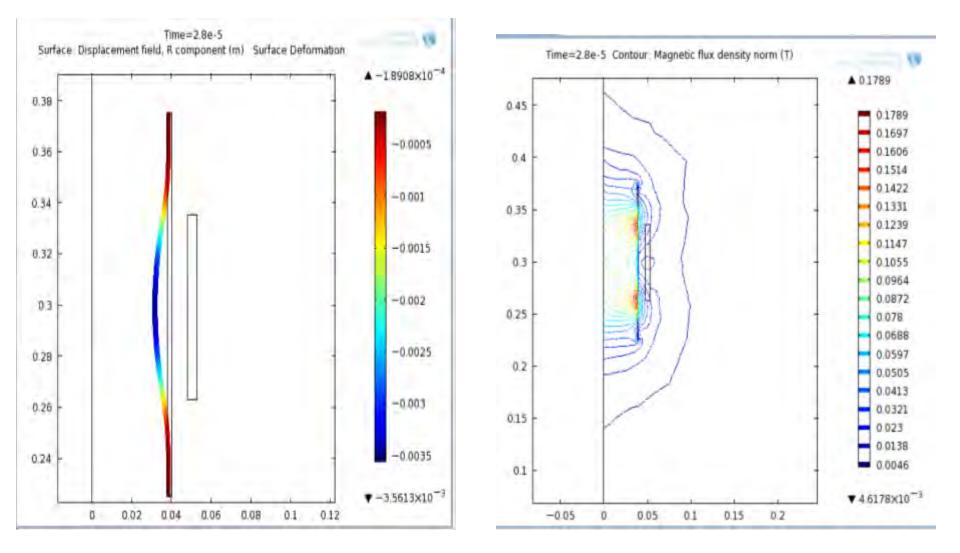
### Displacement and Magnetic Flux Density for 8kJ



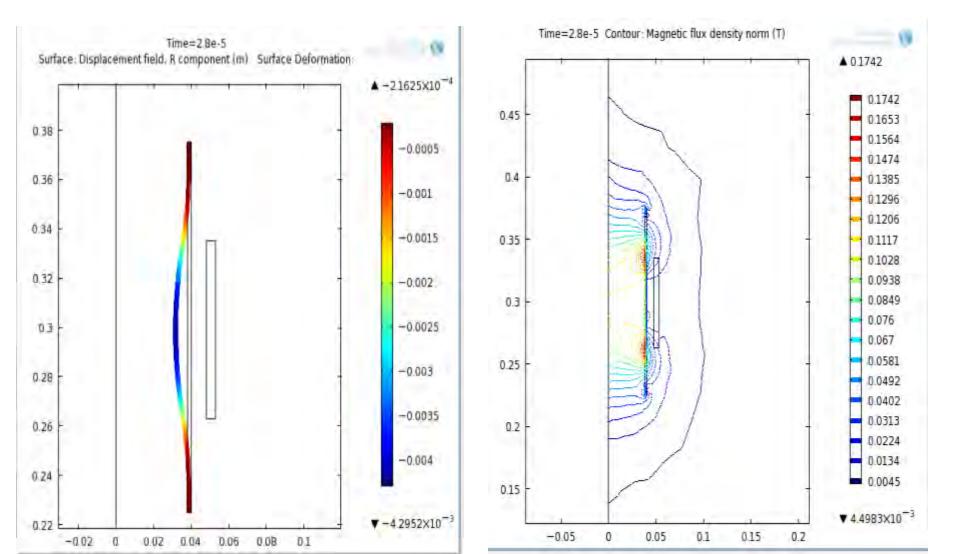
## **Displacement and Magnetic Flux Density for 15.8 kJ**



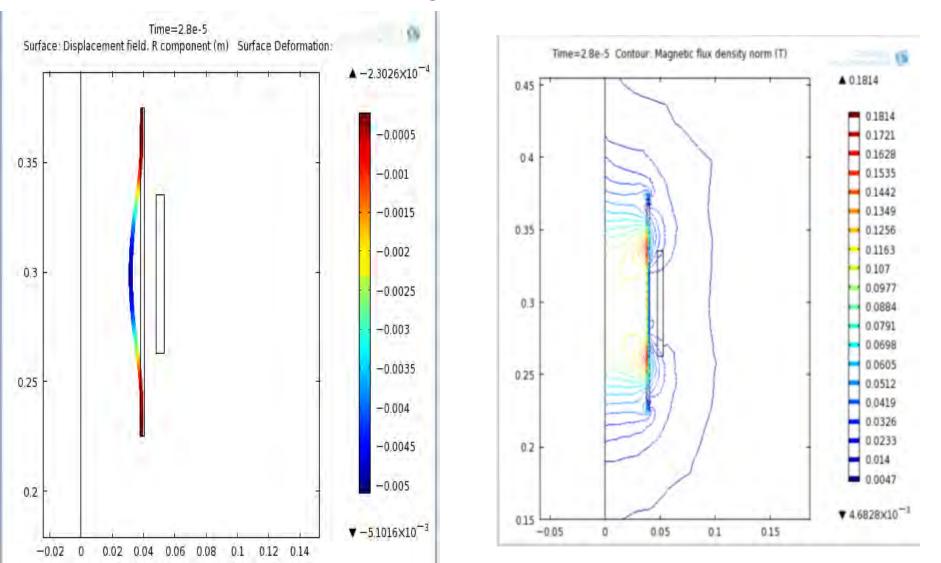
# Displacement and Magnetic Flux Density for 18 kJ



# Displacement and Magnetic Flux Density for 21 kJ



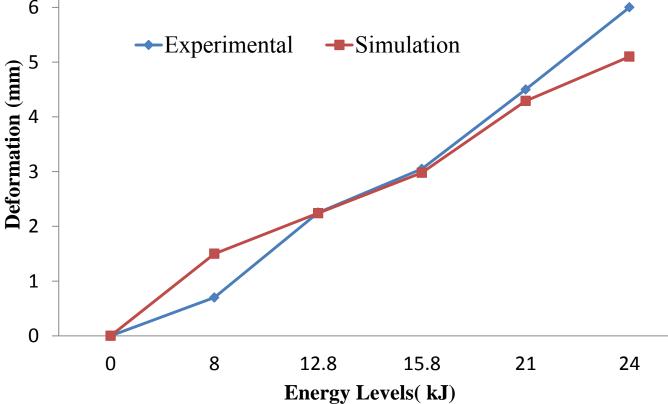
## **Displacement and Magnetic Flux Density for 24 kJ**



### Results

Energy	Rise time	Final	Final	%	Predicted
(KJ)	(µS)	deformation	deformation	reduction	%
		Expt.(mm)	simulation		reduction
			(mm)		
8	28	0.7	1.5	1.8	3.4
12.8	28	2.25	2.24	5.9	5.87
15.8	28	3.05	2.98	8.0	7.9
18	28	3.15	3.5	8.1	9.1
21	28	4.5	4.29	11.8	11.25
24	28	6	5.1	15.9	13.4

# Graph of Deformation (mm) against Energy Levels (kJ)



### **Conclusion.**

- Simulations were carried out on the electromagnetic compression of high strength (440MPatensile strength) 76.2mmdiameter, 2.3mm wall thickness tubes.
- Significant final deformations over a length of about 75mm were obtained with a fixed 9-turn helical compression coil.
- About 8% and 15% reductions in diameter were developed with 16 kJ and 24 kJ discharges from separate commercial capacitor banks.
- Comparisons between simulations and experimental data from litrature gave confidence that a simple numerical model can reliably predict system performance.
- COMSOL Multiphysics is very user friendly software, easy to operate and gives good simulation results.



- Kristin E. Banik, Factors Effecting Electromagnetic Flat Sheet Forming Using the Uniform Pressure Coil, MS thesis, Graduate School of the Ohio State University.
- A. Vivek, K.-H. Kim, G.S. Daehn, Simulation and instrumentation of electromagnetic compression of steel tubes, Journal of Materials Processing Technology 211 (2011) 840– 850
- S d kore, p.p. date, s.v. kulkari, Electromagnetic Welding of Flat Sheets, PhD thesis, IIT Bombay,2007
- Moon FC. Magneto Solid Mechanics. John Willey & Sons Inc; 1984.
- Moon FC. Magneto Solid Mechanics. John Willey & Sons Inc; 1984.
- S.S. Prakash Alapati, S.V. Kulkarni, Coupled Magnetic-Structural Finite Element Analysis, Excerpt from the Proceedings of the COMSOL Conference 2009 Bangalore

### Acknowledgement

- Production Engineering Department, SGGS IE&T, Nanded.
- Dr. P. P. Date, Mechanical Engineering Department, IIT Bombay.
- Dr. S. V. Kulkarni, Electrical Engineering Department, IIT Bombay.
- COMSOL Support Group