

Trim Coils Final Design Review Supporting Stress Analysis

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Trim Coil Stress Analysis Overview

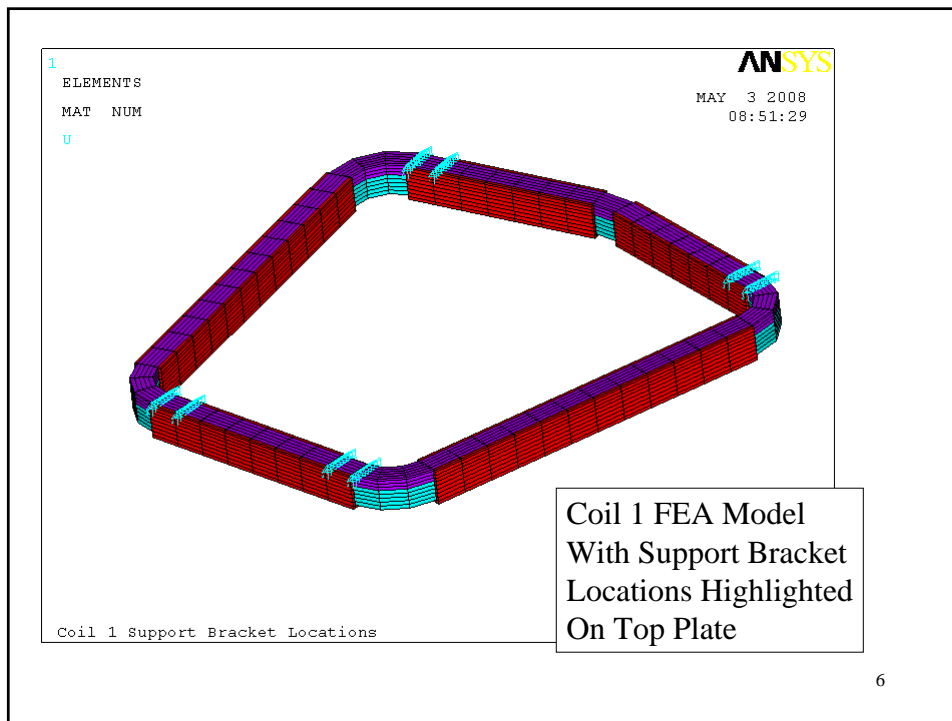
- ProE Geometry
- Finite Element Modeling Features
- Force Scan of Many Load Cases
 - Establish running load of 80#/in as worse case
- Local Model of Conductor Copper/Insulation to establish equivalent flexural properties and stress scale factors
- ANSYS Detailed Stress Plots
- Summary Stress Table

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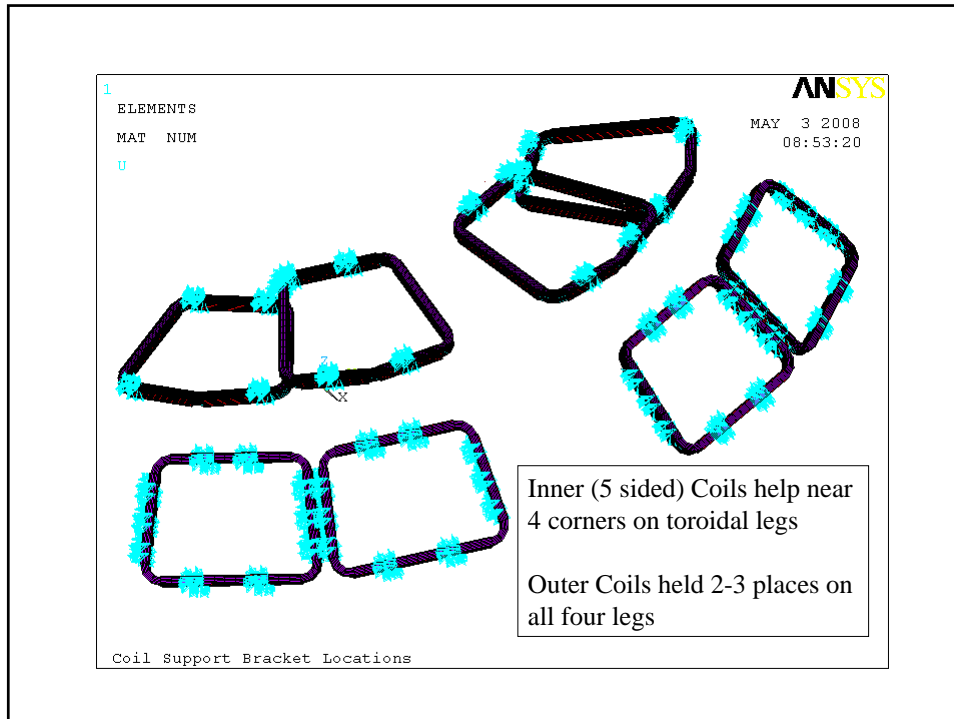
Finite Element Model Features

- Coil Modeled with Composite Properties for Copper and Insulation to minimize model size
 - Resultant plotted stress values must be scaled accordingly (~x2.2 for Cu, x0.25 for Insulation based on flexure)
- U Channels and Base (Top) Plate welded to form partial case
- Conductor free in corners
- Coil – Case contact assumes coefficient of friction of 0.3
- Supports model with simple fixed constraints at support locations
- Loading includes EM and Thermal Cool down
 - Since case is mounted to MCWF/TF/PF Structure, Only differential thermal contraction assumed

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Load Cases Investigated for EM Forces

- All GRD Load Cases at Multiple (5) time points
- Additional Flexibility Cases Identified by Physics
 - Iota Scan (2)
 - Shear Scan (2)
- **Max Running Loads Found**
 - 80 lb/in Inner Coils
 - 60 lb/in Outer Coils

- 2T High Beta
- 1.7T High beta
- 1.2T Long Pulse
- 1.7T Ohmic
- 320KA Ohmic
- 0.5 T TF
- Iota/Shear Scan
 - iota -0.10
 - **iota 0.19 (High TF Field)**
 - iota +0.20
 - iota 0.65

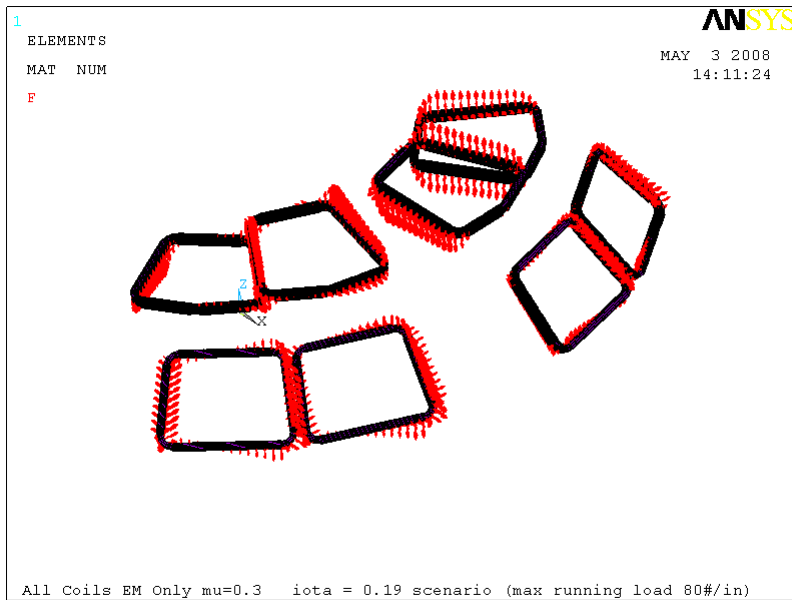
Running Load Comparison

Scenario	Time	Running Load	
		N/m	lb/in
1.2T_Long_Pulse	0	5783	33
	0.1	5783	33
	0.128	3869	22
	0.228	5467	31
	1.728	5464	31
1.7_Ohmic	0	8285	47
	0.1	8285	47
	0.14	4990	28
	0.24	4951	28
	0.44	4877	28
1.7T_High_beta	0	8283	47
	0.1	8283	47
	0.14	4893	28
	0.24	7531	43
	0.44	7531	43

Scenario	Time	Running Load	
		N/m	lb/in
2T_High_Beta	0	6595	38
	0.05	6595	38
	0.097	5783	33
	0.192	8773	50
	0.197	8773	50
320KA_Ohmic	0	5573	32
	0.1	5573	32
	0.206	6692	38
	0.306	6687	38
	0.506	6679	38
0.5T_TF		13944	80
iota/shear scan	-0.10	6882	39
	0.19	13752	80
	0.20	6178	35
	0.65	10040	57

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Iota = 0.19 Scenario Force Distribution



Force Scan Done with FORTRAN Code Benchmarked with ANSYS

Benchmark of Trim Coil Forces - Filament Model vs ANSYS Model Net Force On Trim Coils for Worse Case Scenario (2T HB t=0.197s)

		Coil 1	Coil 2	Coil 3	Coil 4	Coil 5	Coil 6	Coil 7	Coil 8
ANSYS	FX	-2096.4	-831.7	567.4	-422.2	-1155.9	2626.5	-1147.6	-322.6
	FY	-1817.0	993.9	4403.7	315.5	-3447.5	-3114.4	-268.2	-1124.0
	FZ	-3853.4	4882.3	2764.3	-1755.4	2100.1	1884.8	-2130.1	-1132.7
	Fnet	4748.1	5051.3	5230.3	1832.8	4199.0	4488.9	2434.4	1628.0
Forces5.f	FX	-2101.1	-837.3	554.6	-422.4	-1168.0	2602.4	-1171.4	-334.2
	FY	-1827.6	985.4	4410.9	300.2	-3440.6	-3112.0	-271.5	-1135.8
	FZ	-3853.1	4940.3	2777.2	-1762.7	2088.0	1861.9	-2160.0	-1163.7
	Fnet	4754.1	5106.7	5241.8	1837.3	4190.7	4463.6	2472.2	1660.1
Ratio	FX	1.00	0.99	1.02	1.00	0.99	1.01	0.98	0.97
	FY	0.99	1.01	1.00	1.05	1.00	1.00	0.99	0.99
	FZ	1.00	0.99	1.00	1.00	1.01	1.01	0.99	0.97
	Fnet	1.00	0.99	1.00	1.00	1.00	1.01	0.98	0.98

Forces in Newtons

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Material Properties taken from NCSX Online Materials Database

Trim Coils Material Properties

			Epoxy - CTD-101K		Copper		SS 304	
			RT	80K	RT	80K	RT	80K
Modulus	E	Gpa	12.9	16.7	125	137	200	
Poisson's Ratio	mu			0.27	0.34	0.34	0.29	
Thermal Coef of Expansion	alp	1e-6/K			16.70	8.30	16.60	
Average from RT		1e-6/K		10.00	16.7	14	16.6	12.3
Yield Strength		Mpa			240	270	240	485
					(10% Cold Work)			
Ultimate Strength	Ut	Mpa					620	1585
Compressive Strength	Uc	Mpa						
Shear Strength		MPa		108				
References			CTD Technology Development, Inc		NIST Monograph 177 Prop of Cu ... at Cryo Temps		Allegheny Ludlum Tech Data Blue Sheet	

Thermal Mismatch	
Cu_alp-SS_alp	2 1e-6/K
strain, e	0.00044
eE	60.3 Mpa
	8.7 Ksi

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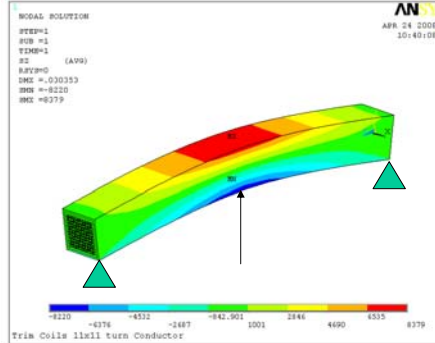
Conductor Modeled with Equivalent Properties calculated from Flexural Modulus Simulation

Equivalent Flexural Modulus and Stress Scaling for Trim Coils

	E, Mpsi	Sz, psi	E, Mpsi	Sz, psi	Sz/Sz	Sz/Sz_max
Cu Wire	17	18390	5.85	6620	2.78	2.19
Insulation	1.5	2111	5.85	8379	0.25	0.25

Composite
(Flex Model)

5.85



Detailed Model of
121 Turns

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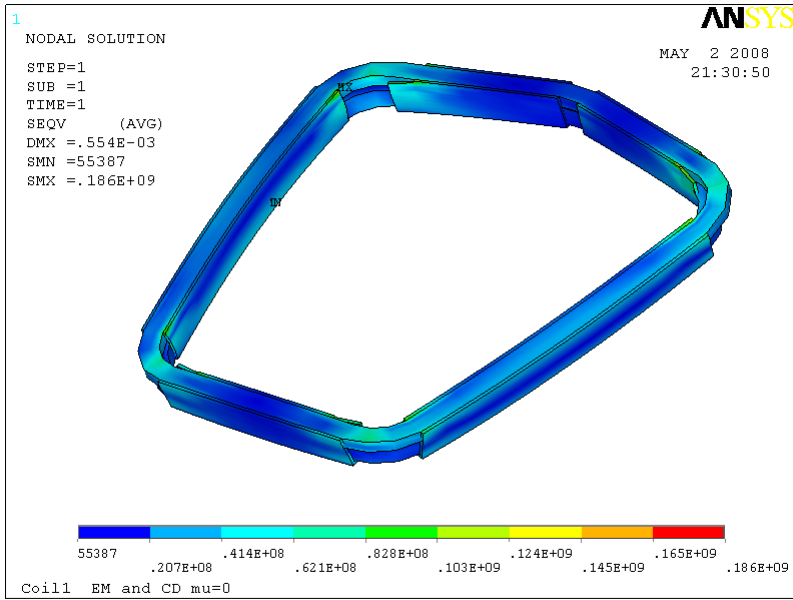
ANSYS Results Plots Worse Case Running Load of 80#/in

- Coil 1 EM + CD $\mu = 0$
- Coil 1 EM Only $\mu = 0$
- Coil 1 CD Only $\mu = 0$
- Coil 1 EM + CD $\mu = 0.3$
- Coil 1 EM Only $\mu = 0.3$
- Coil 1 CD Only $\mu = 0.3$
- All Coils EM + CD $\mu = 0.3$
- All Coils EM Only $\mu = 0.3$
- All Coils CD Only $\mu = 0.3$
- 4 Plots per Case Shown
 - All
 - Conductor Only
 - Top Plate Only
 - U Channels Only
 - + Other Details in some cases

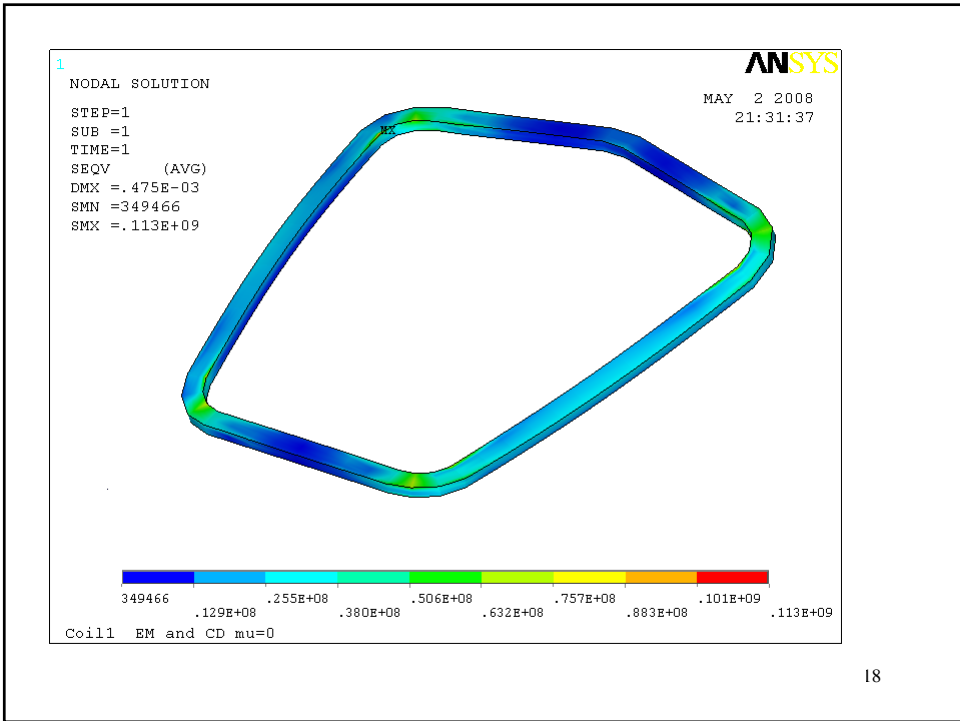
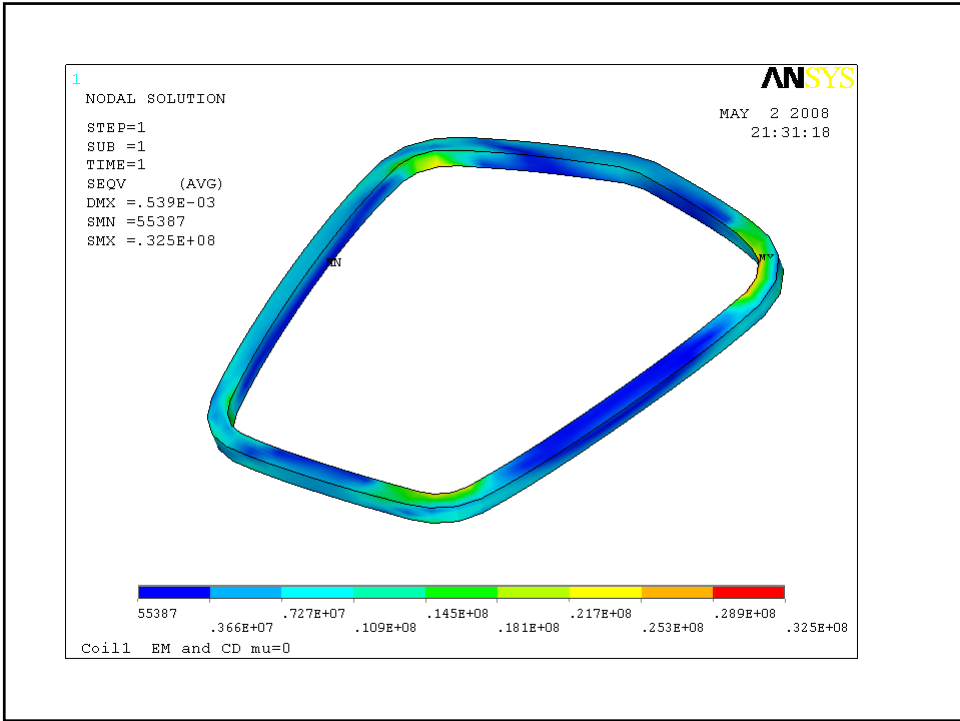
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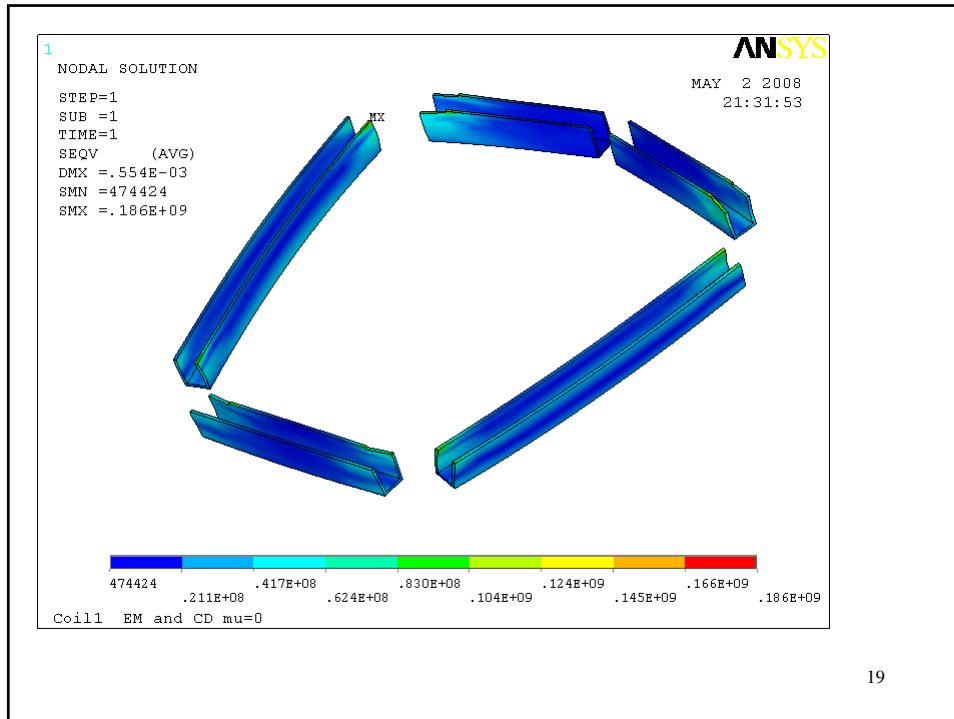
Coil 1 EM + CD $\mu = 0$

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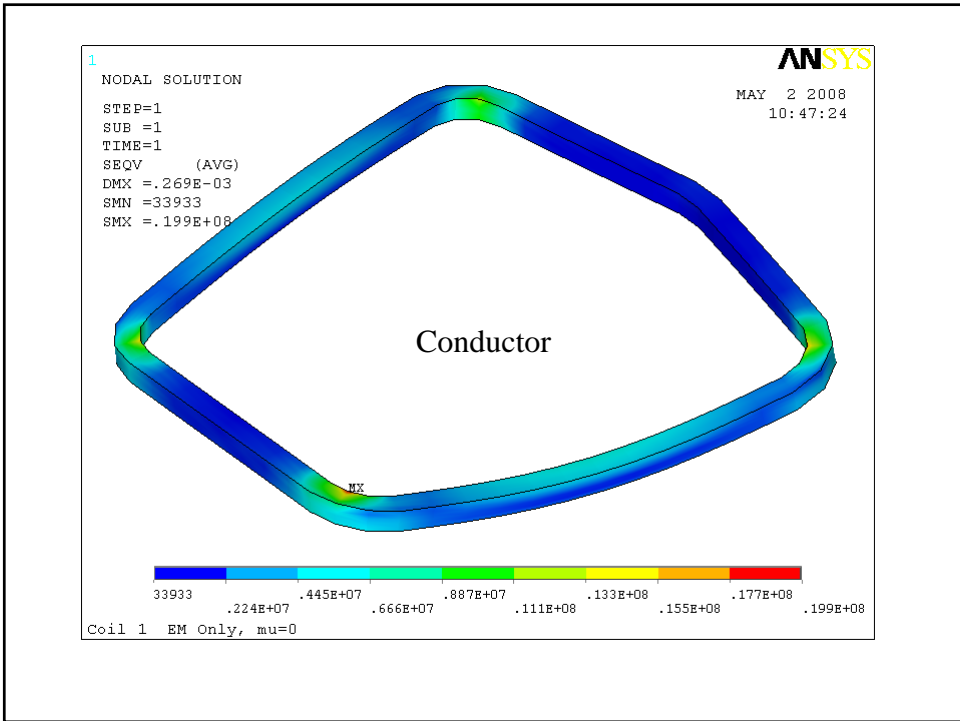
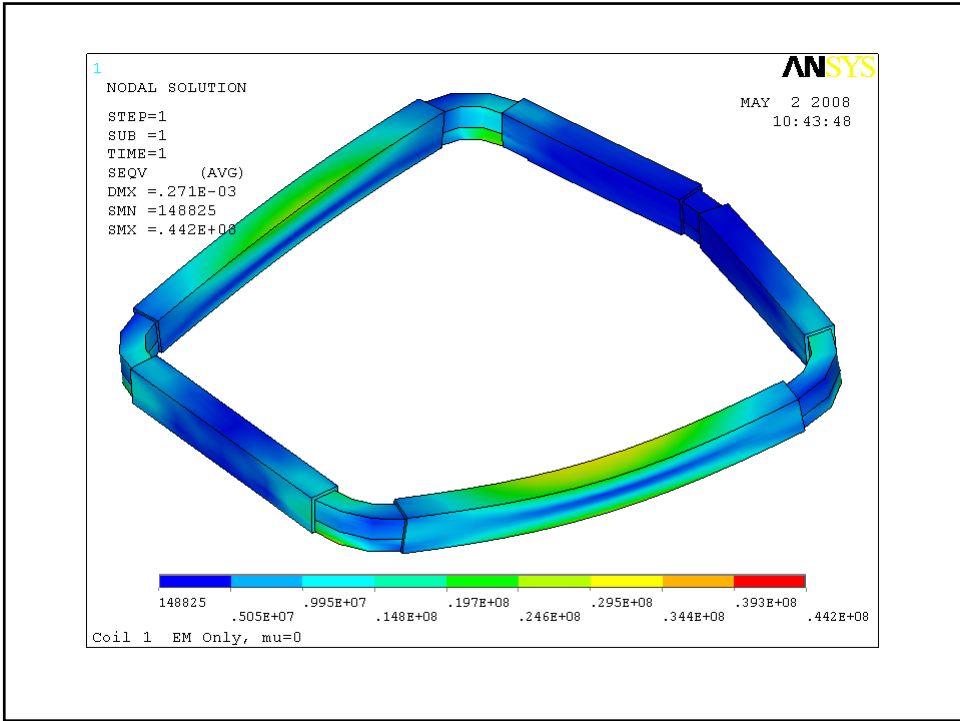
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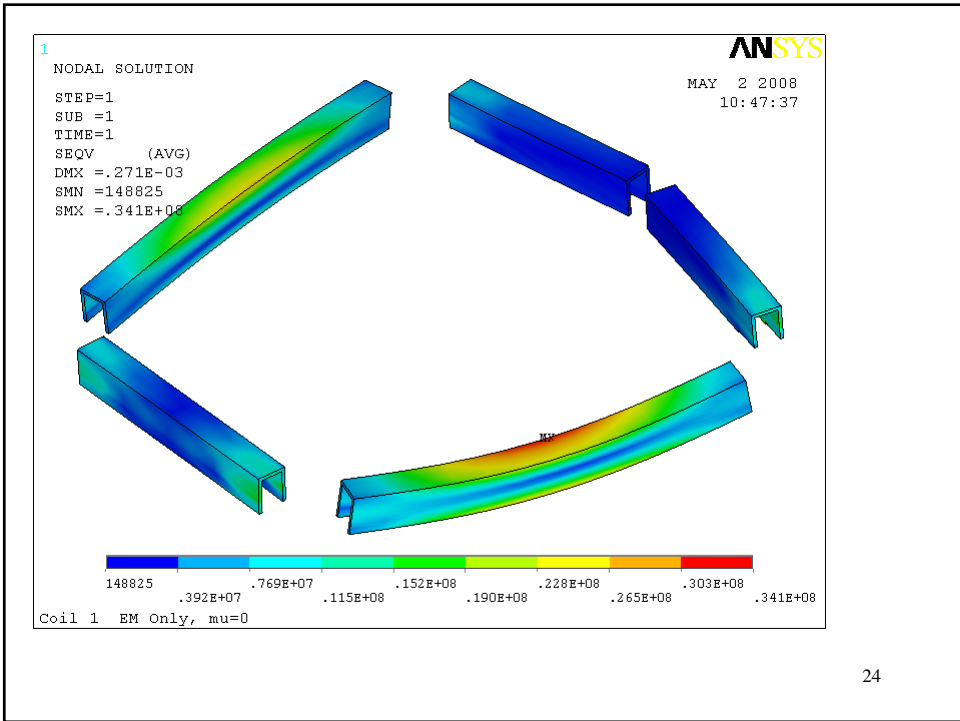
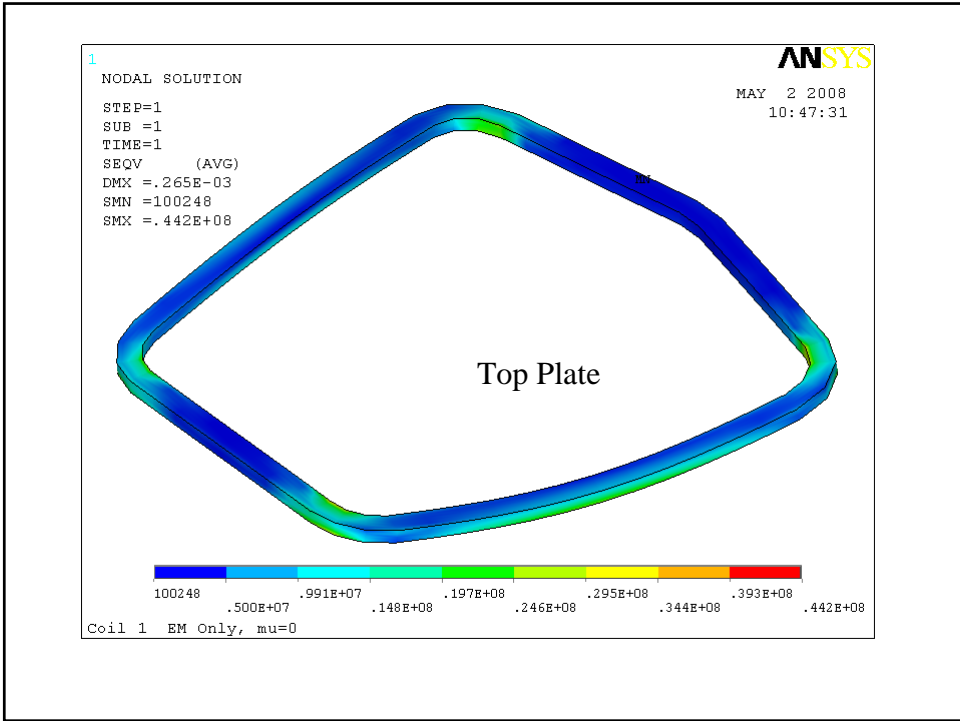




Coil 1 EM Only $\mu = 0$

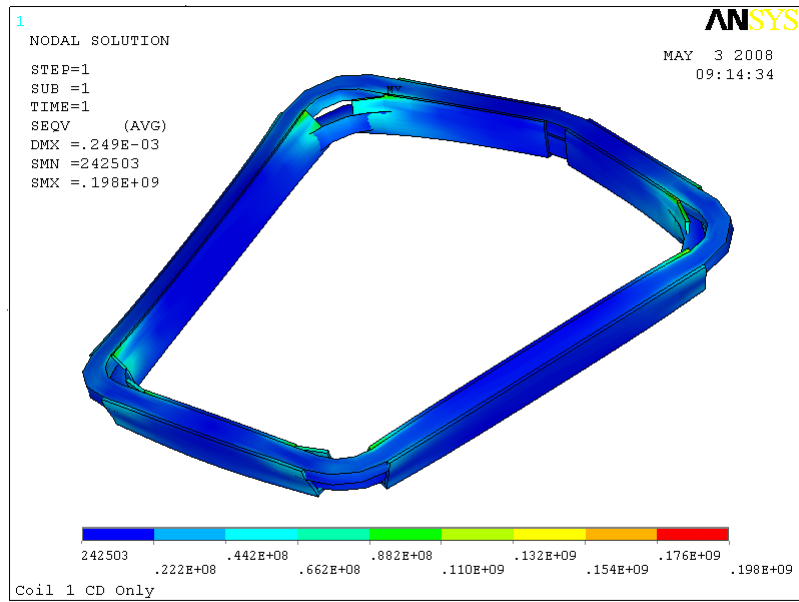
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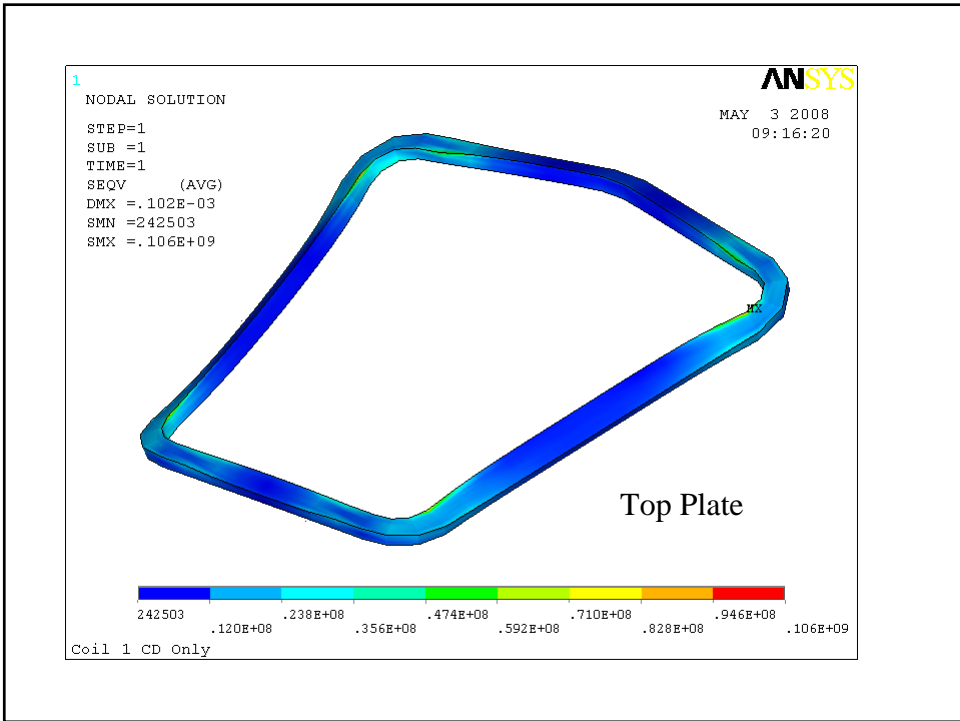
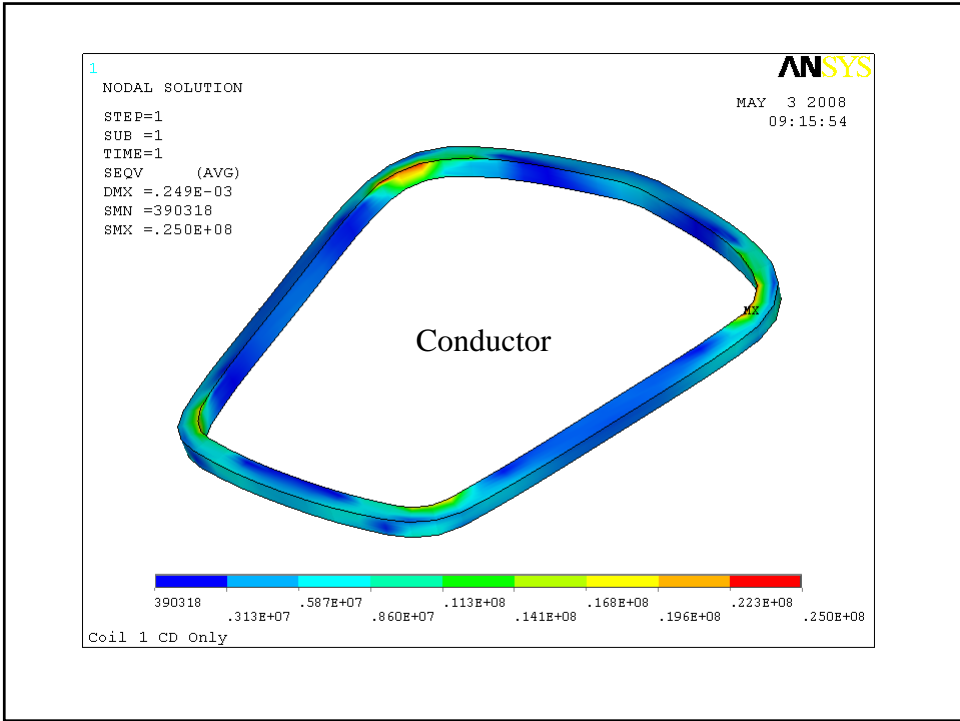


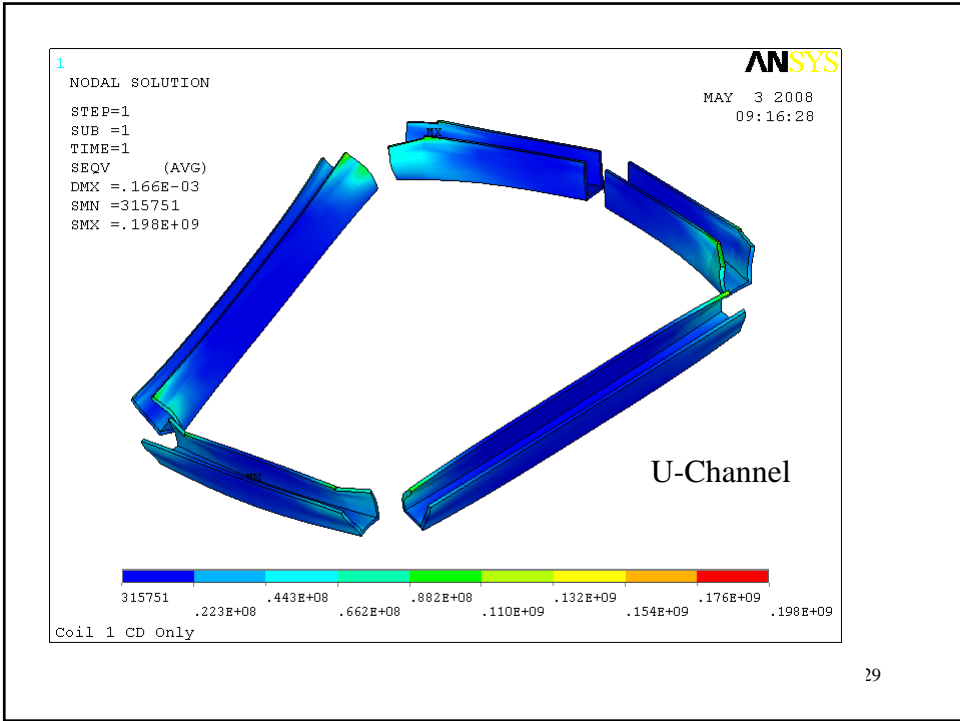


Coil 1 CD Only $\mu = 0$

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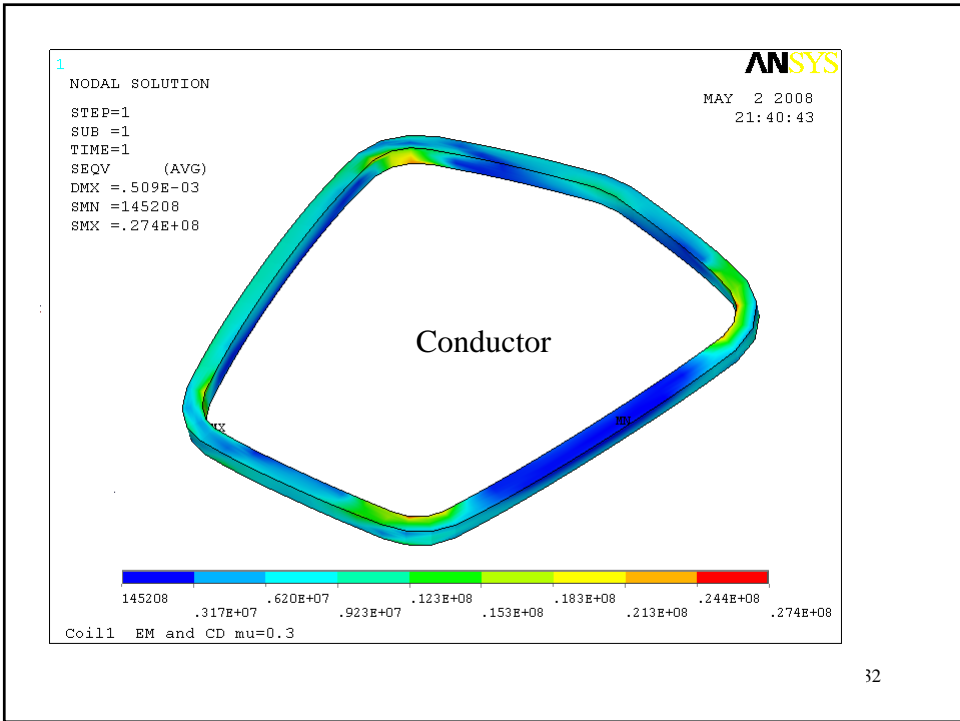
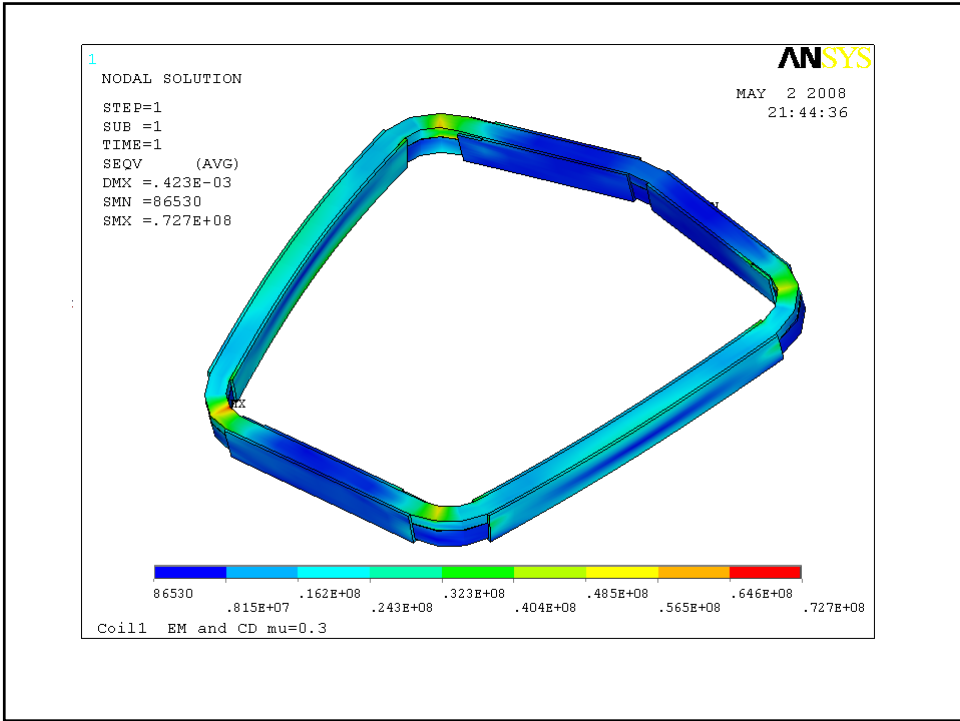


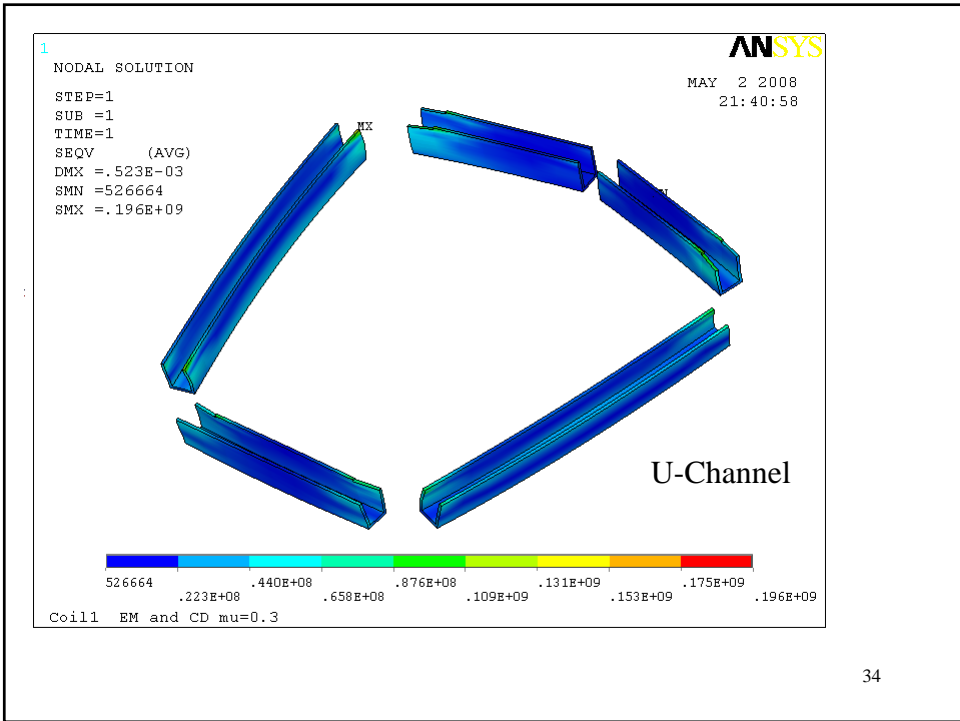
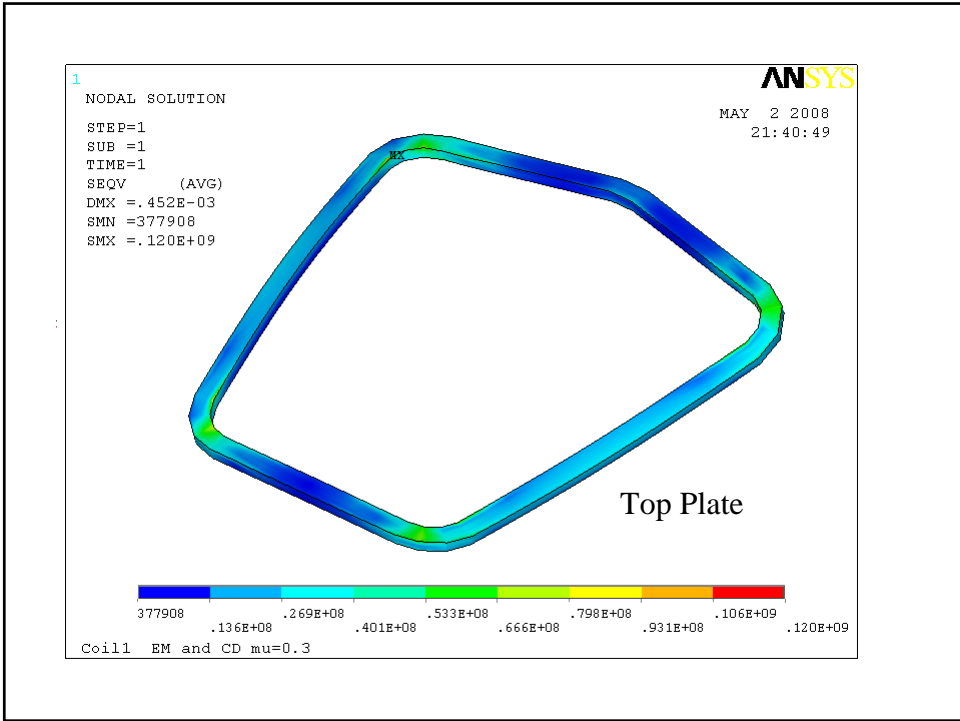




Coil 1 EM + CD $\mu = 0.3$

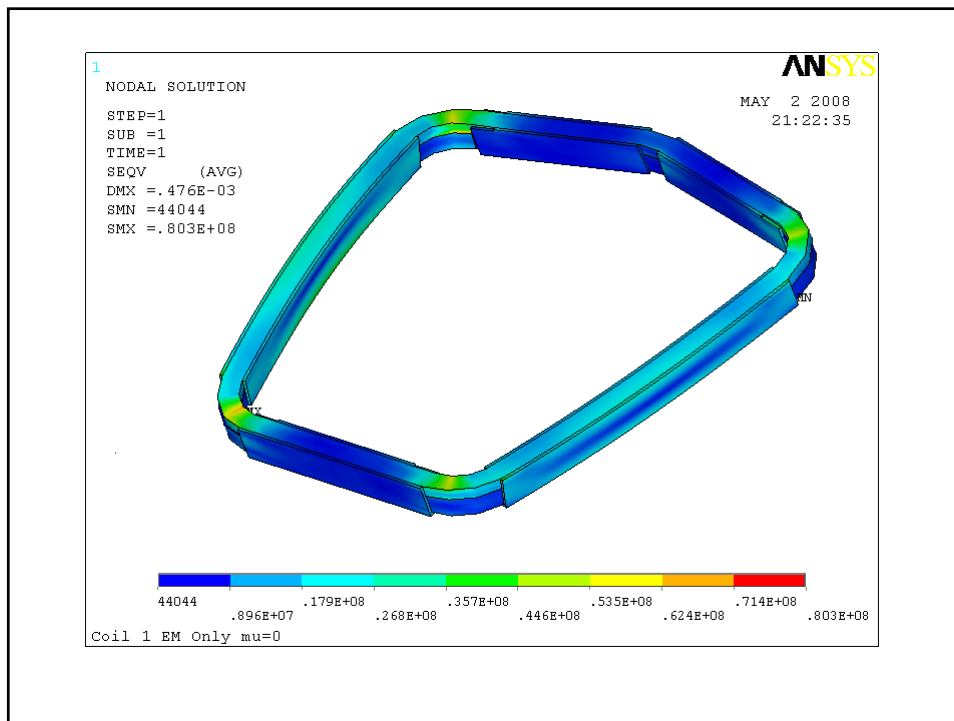
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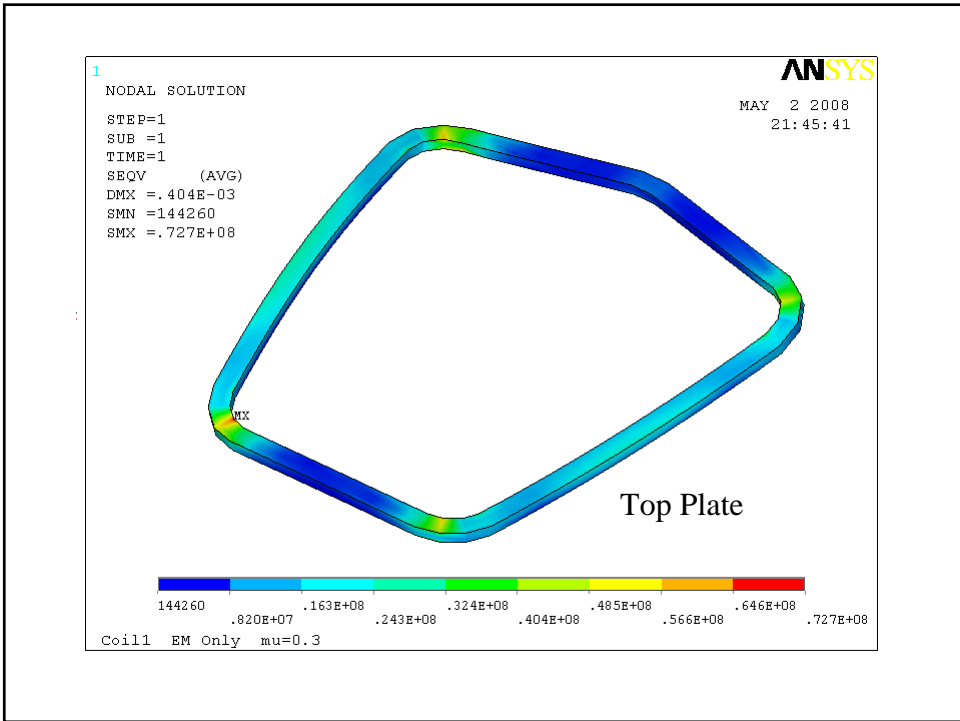
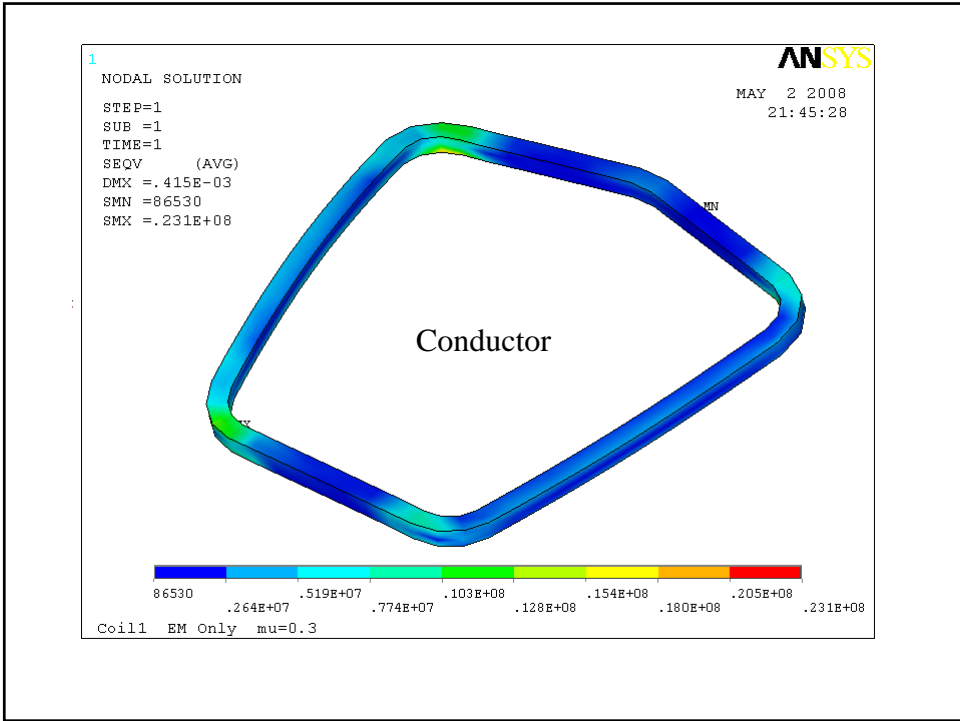


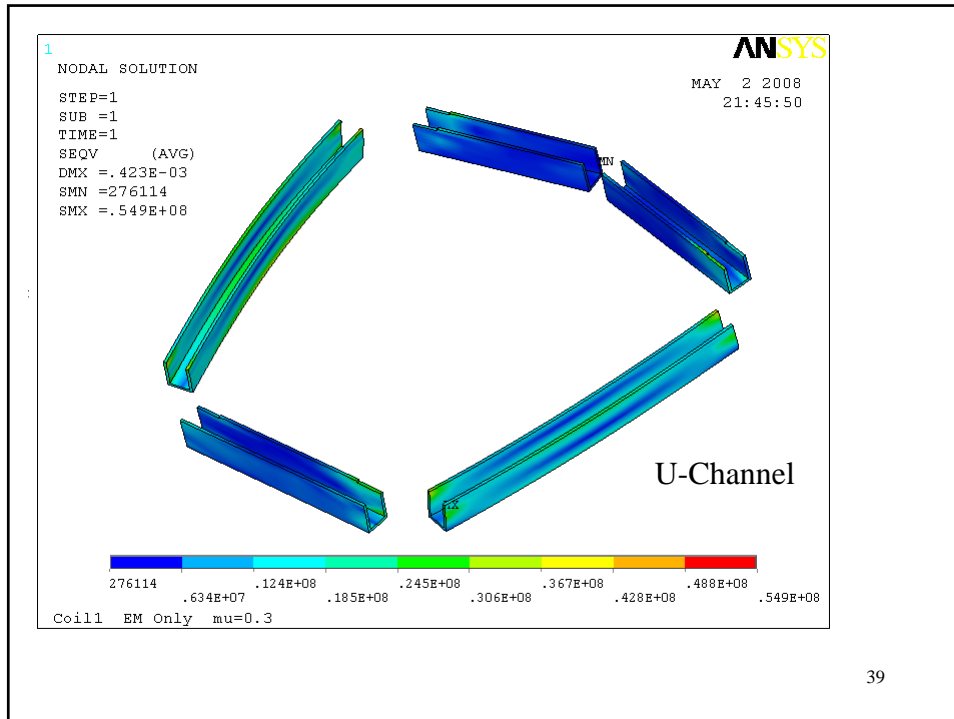


Coil 1 EM Only $\mu = 0.3$

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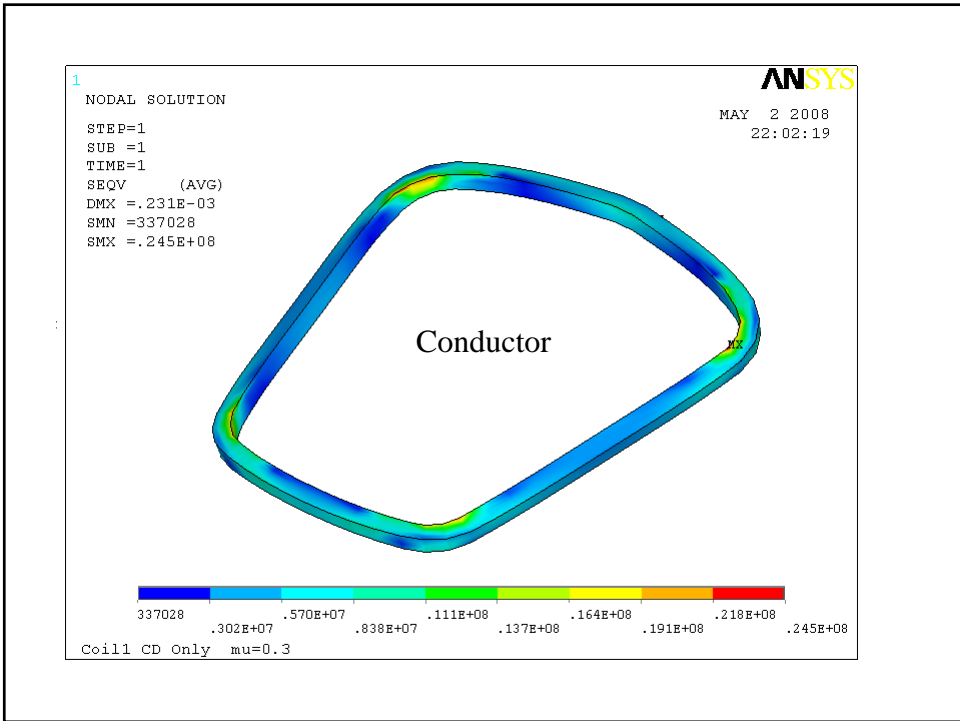
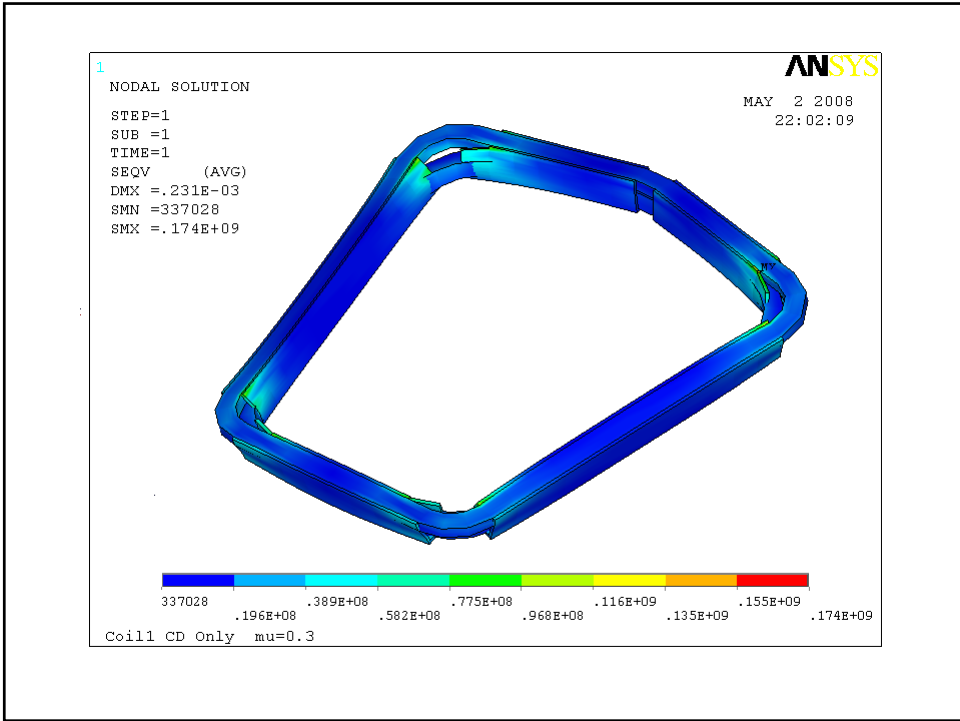


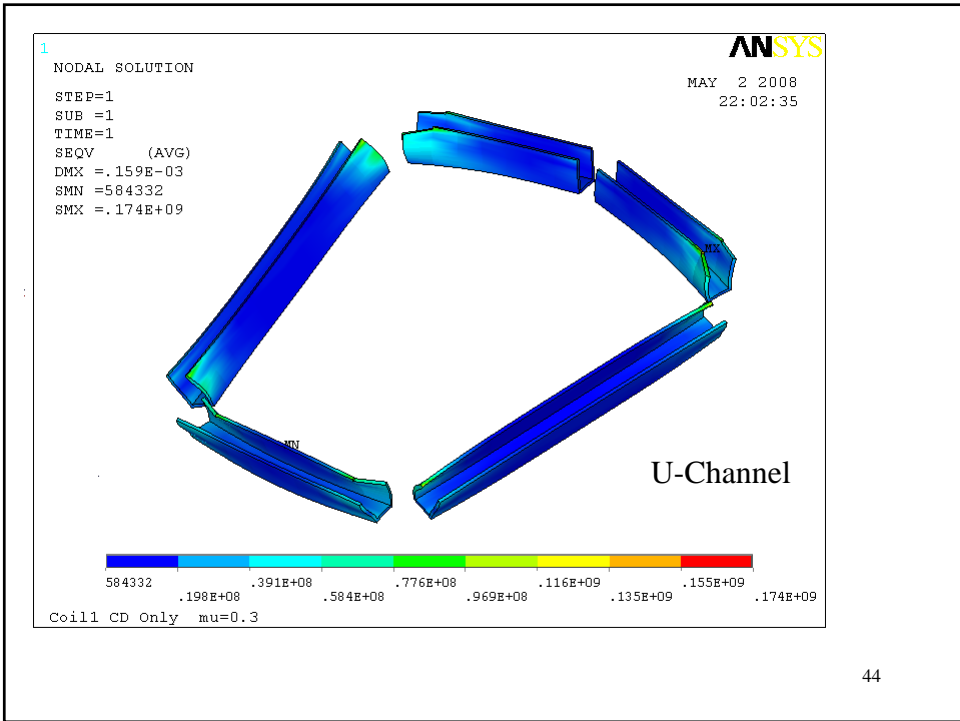
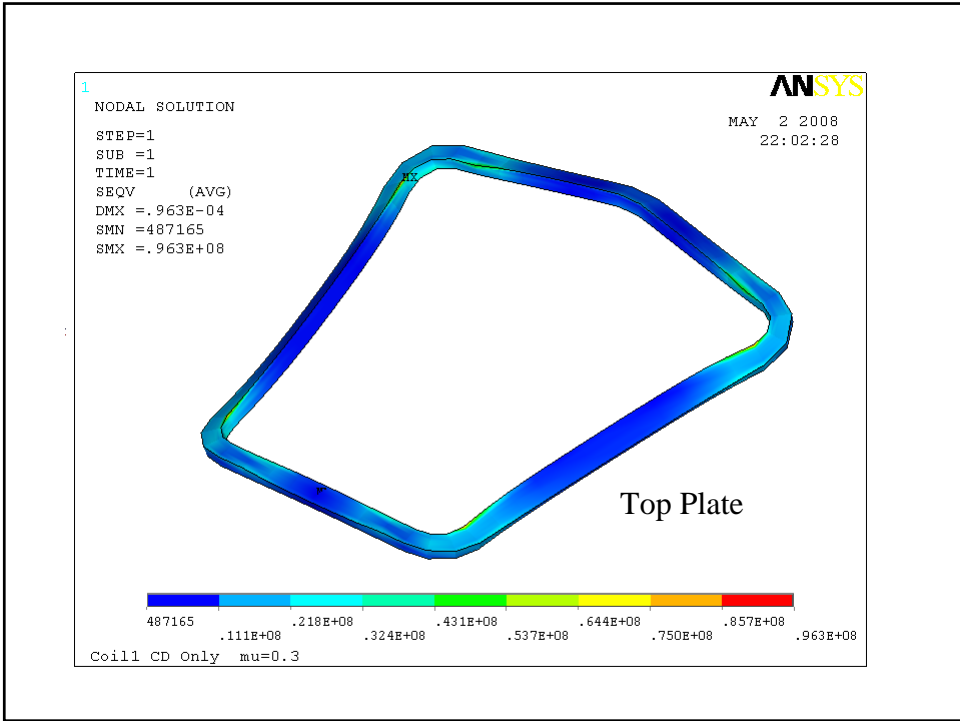




Coil 1 CD Only mu = 0.3

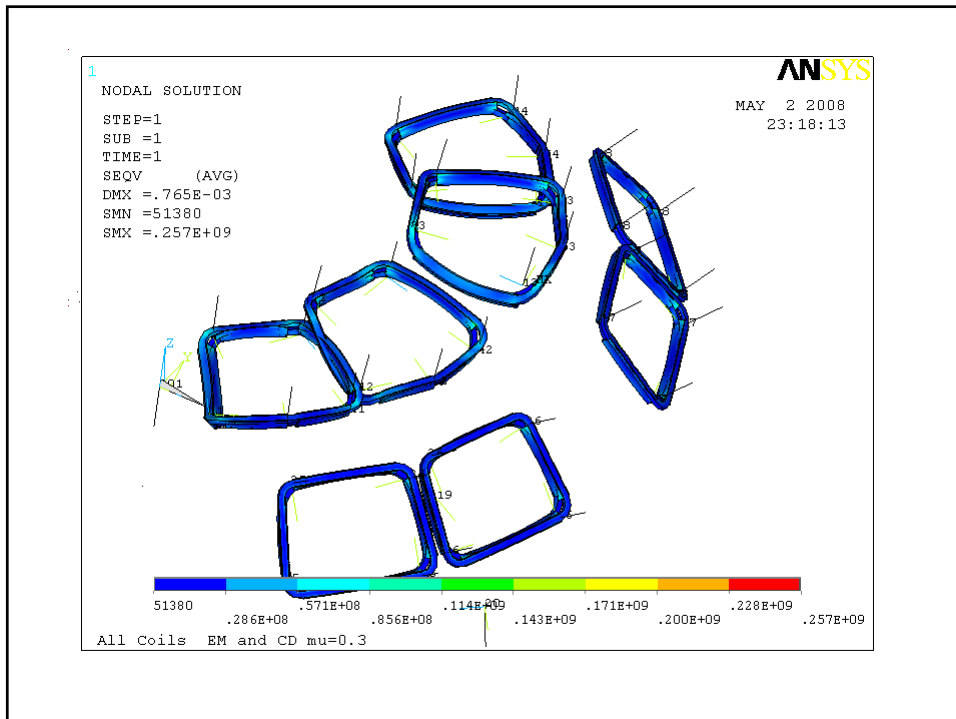
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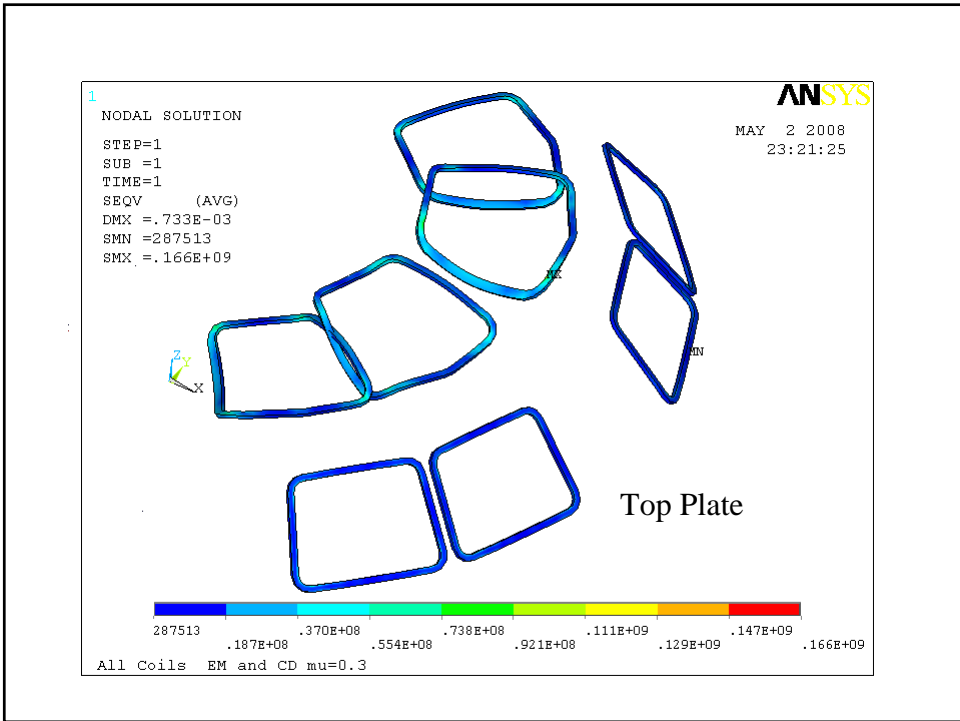
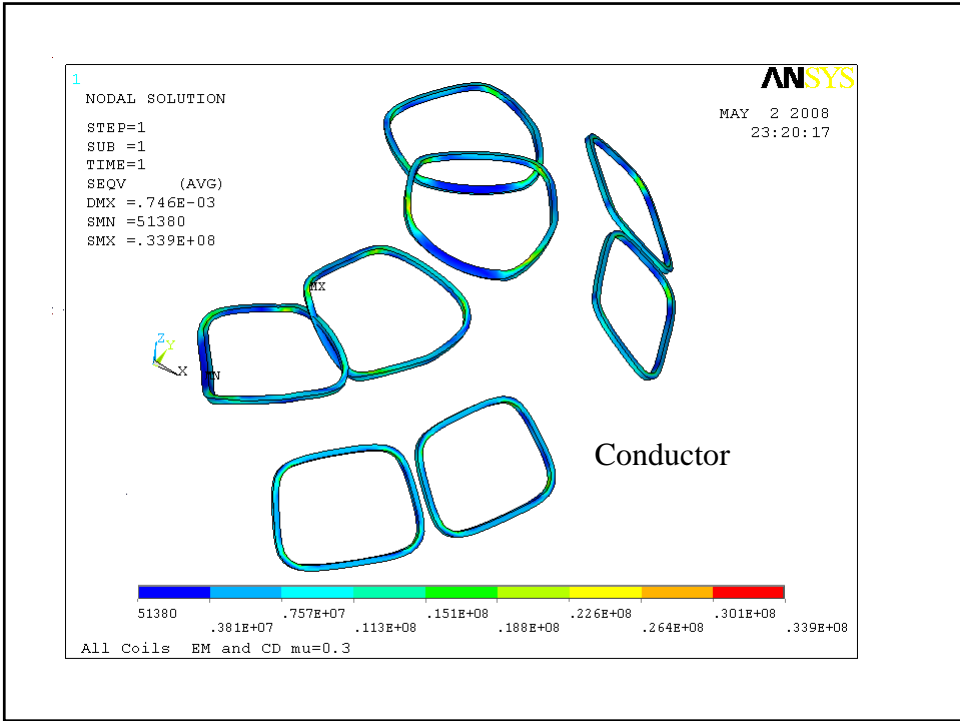


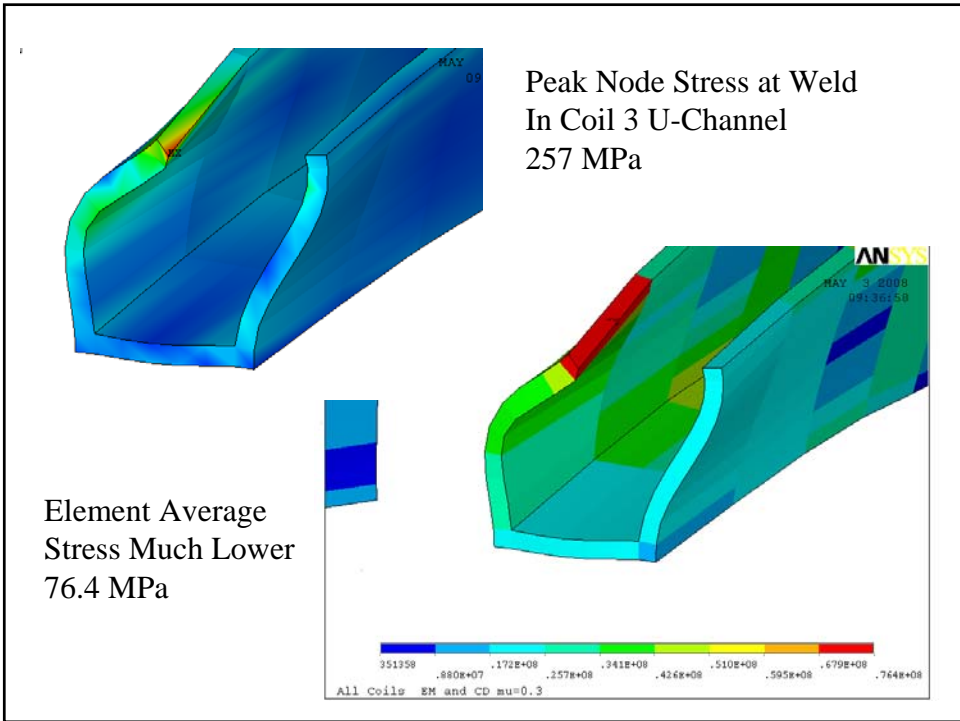
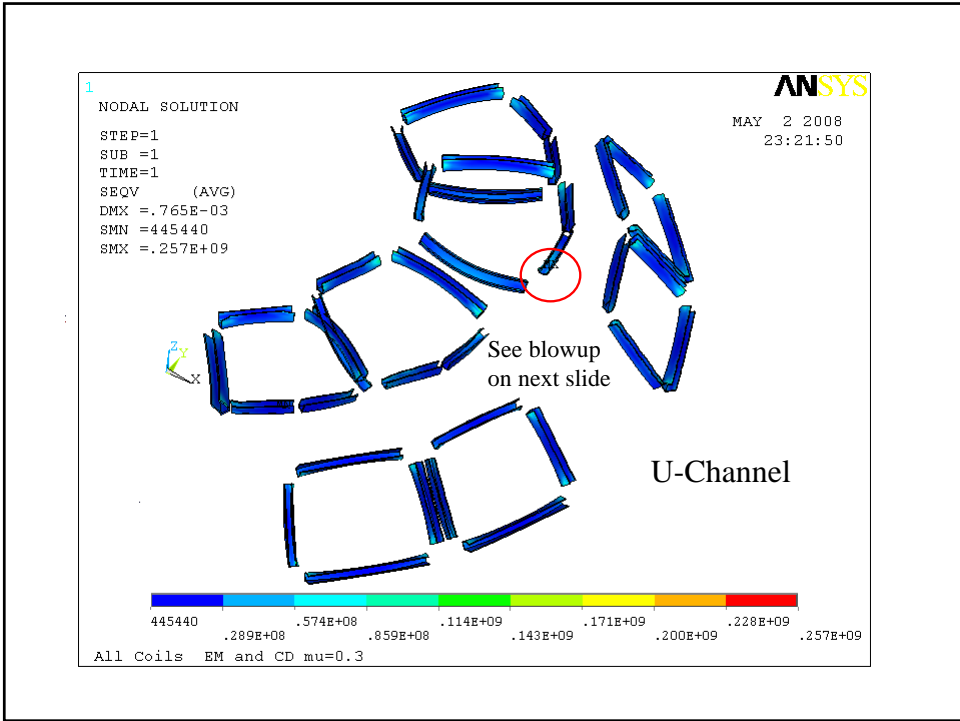


All Coils EM + CD $\mu = 0.3$

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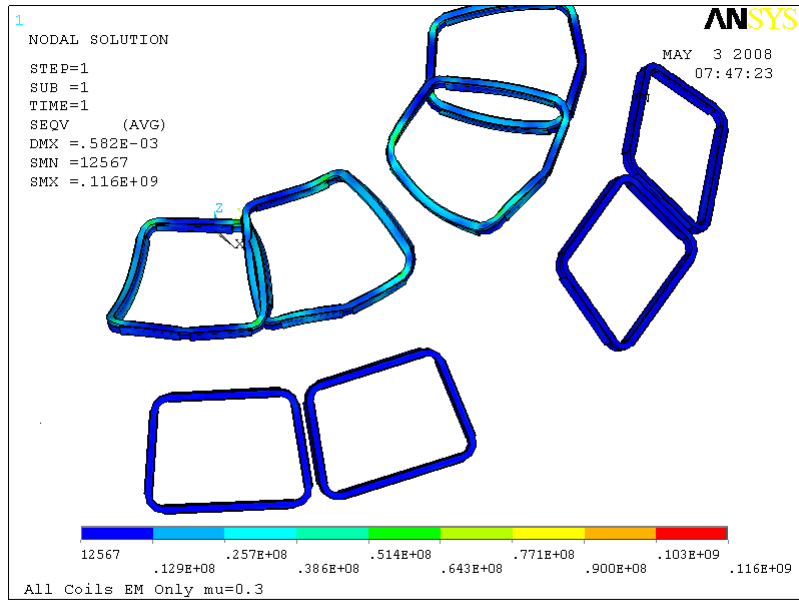




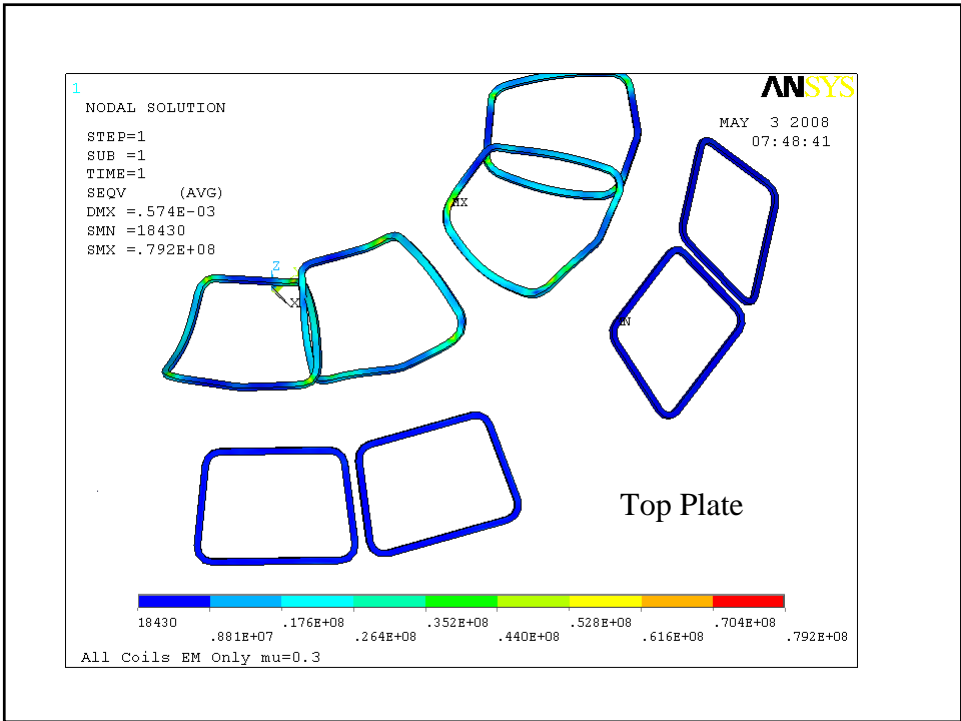
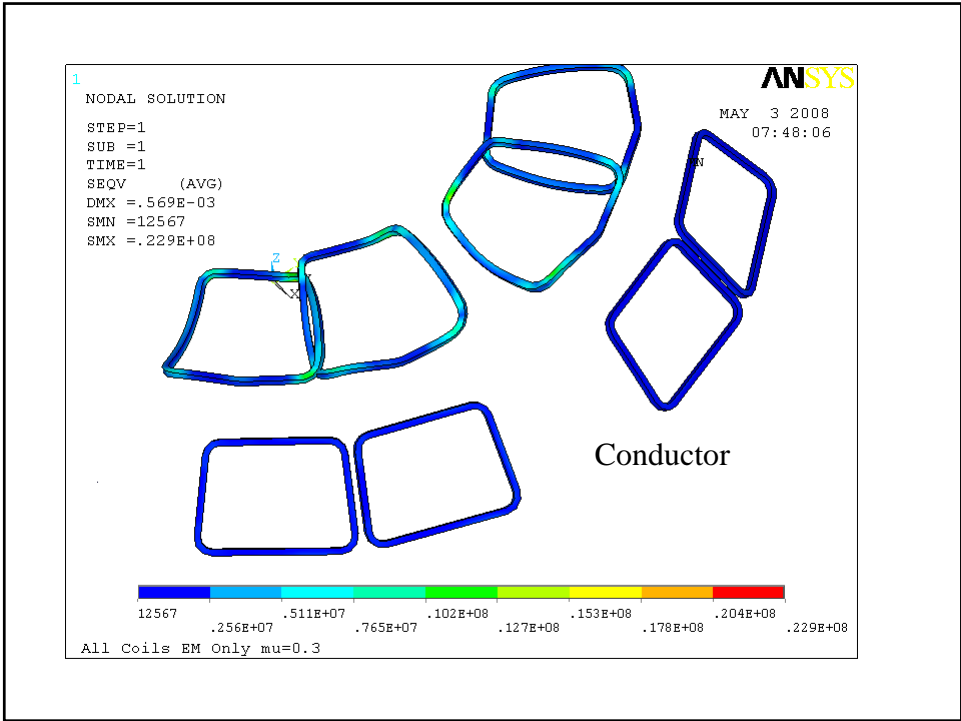


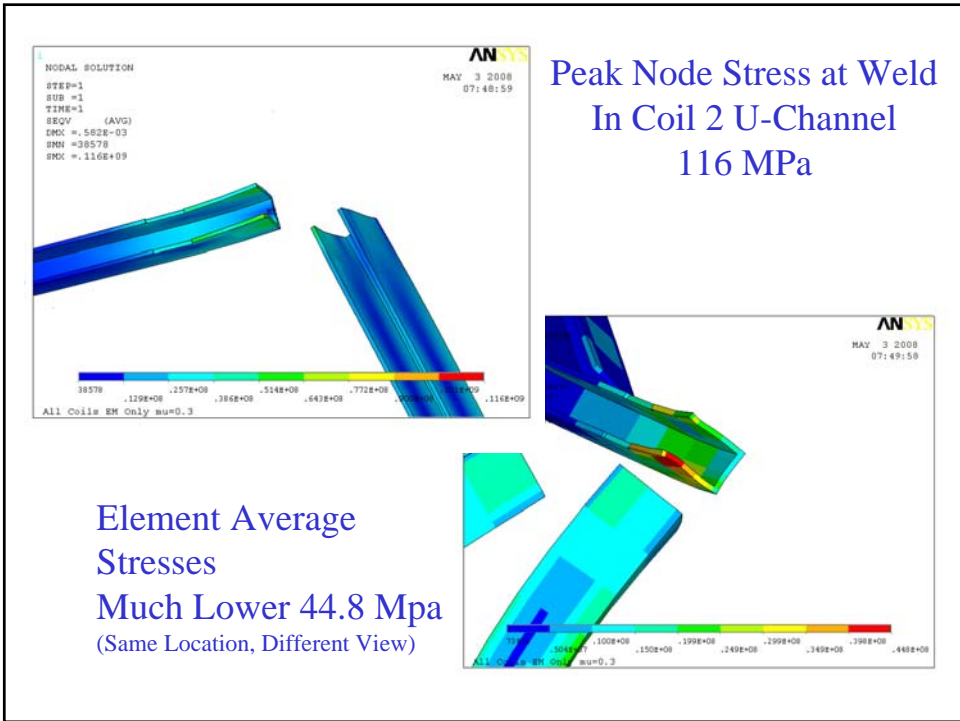
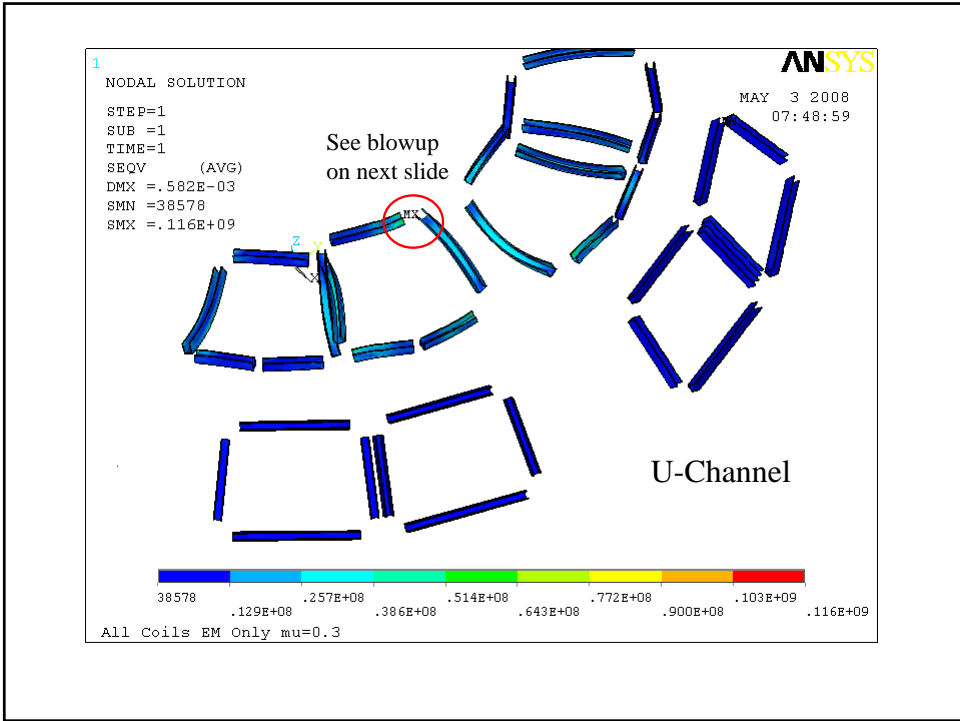
All Coils EM Only $\mu = 0.3$

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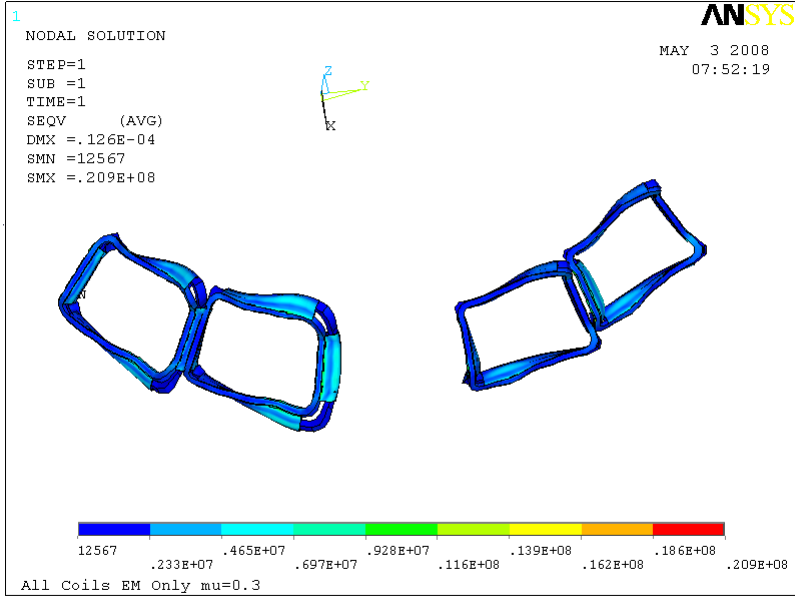


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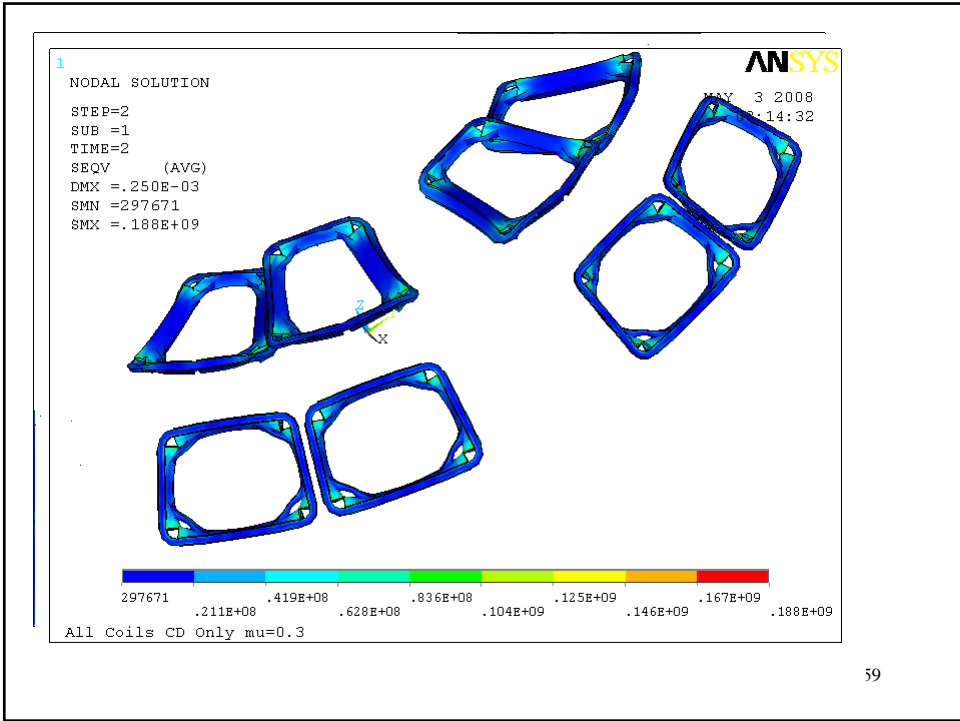




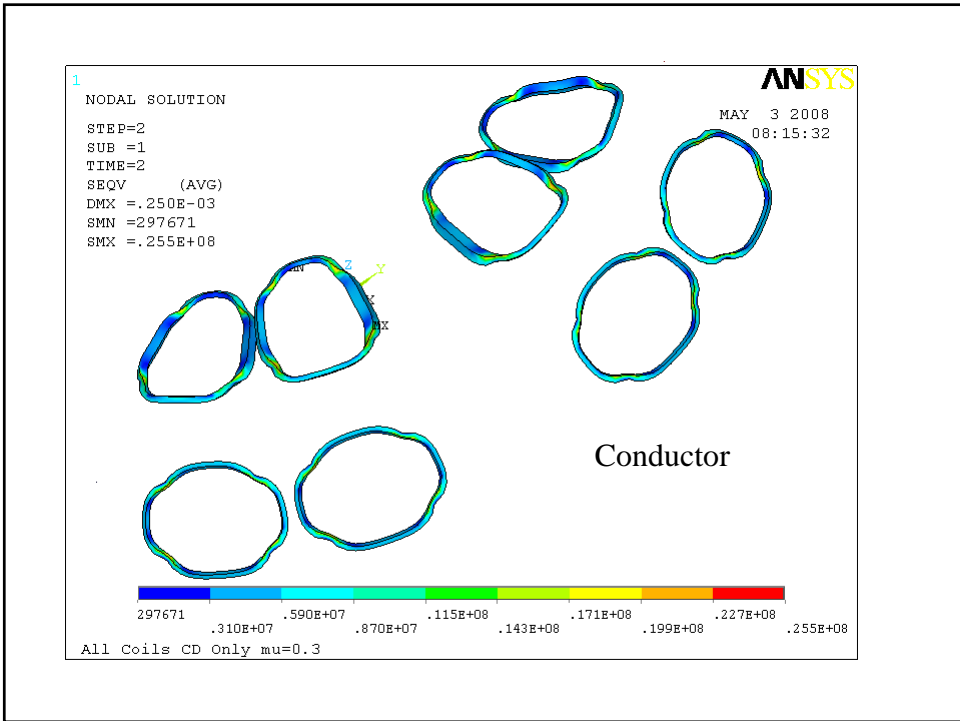
Outboard Coils EM Stresses Much Lower

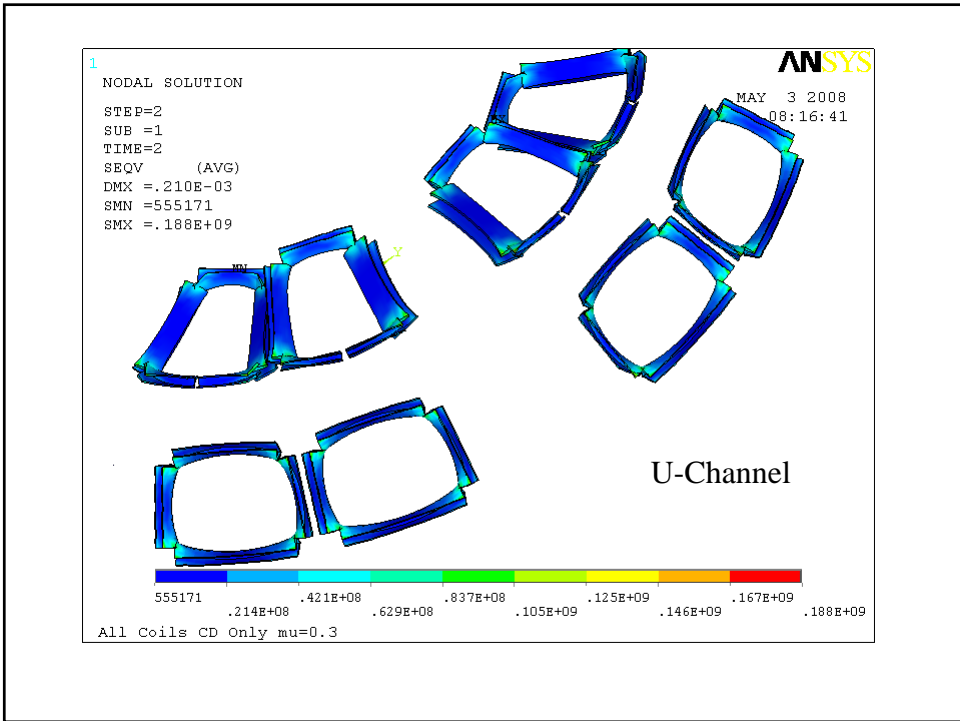
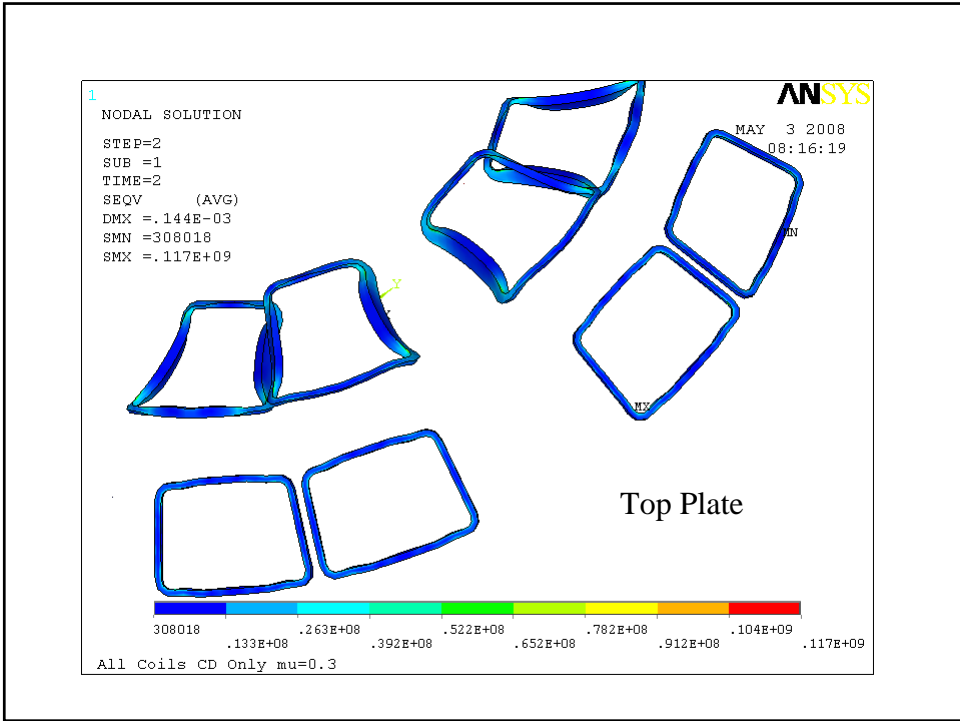


All Coils CD Only $\mu = 0.3$



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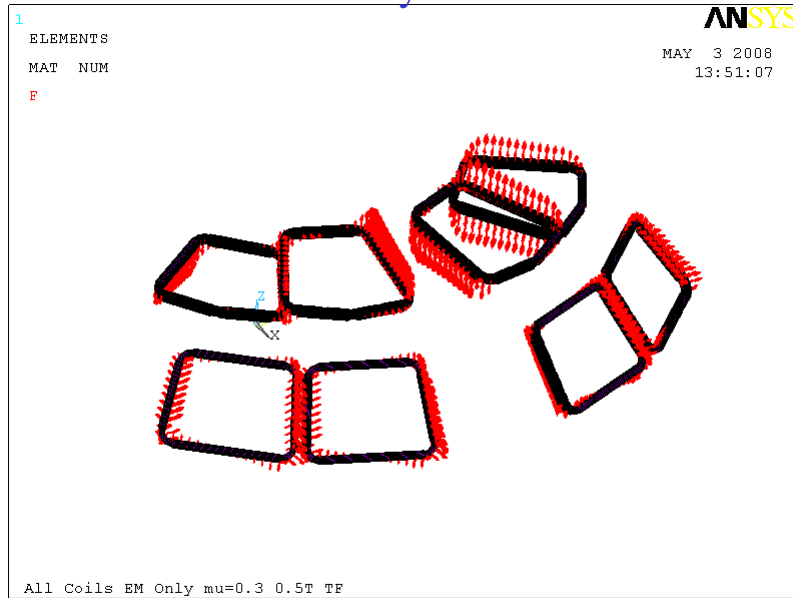


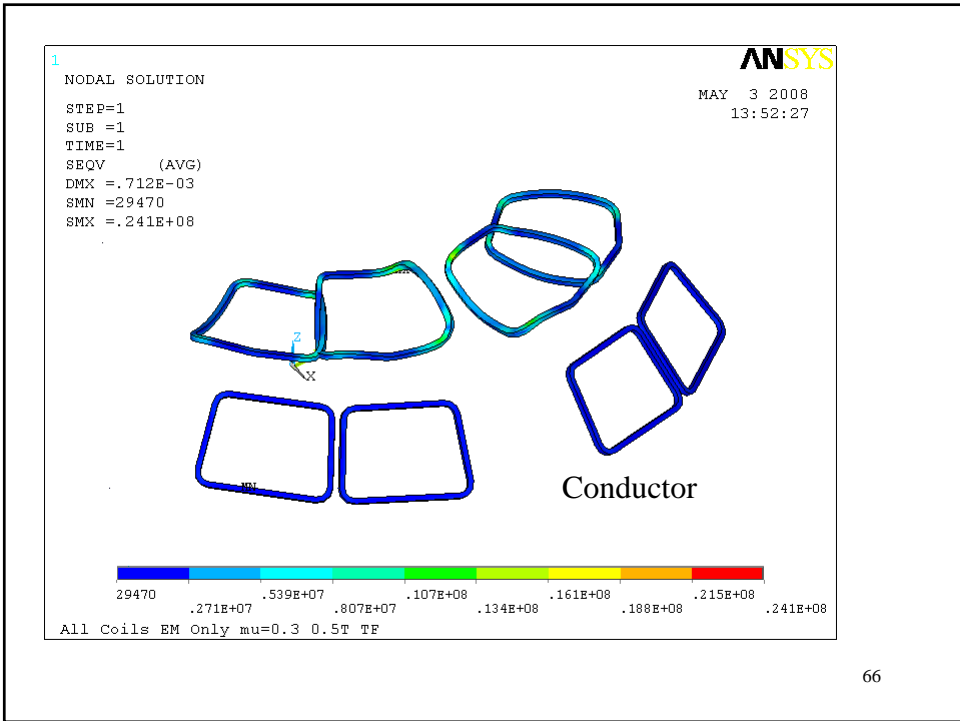
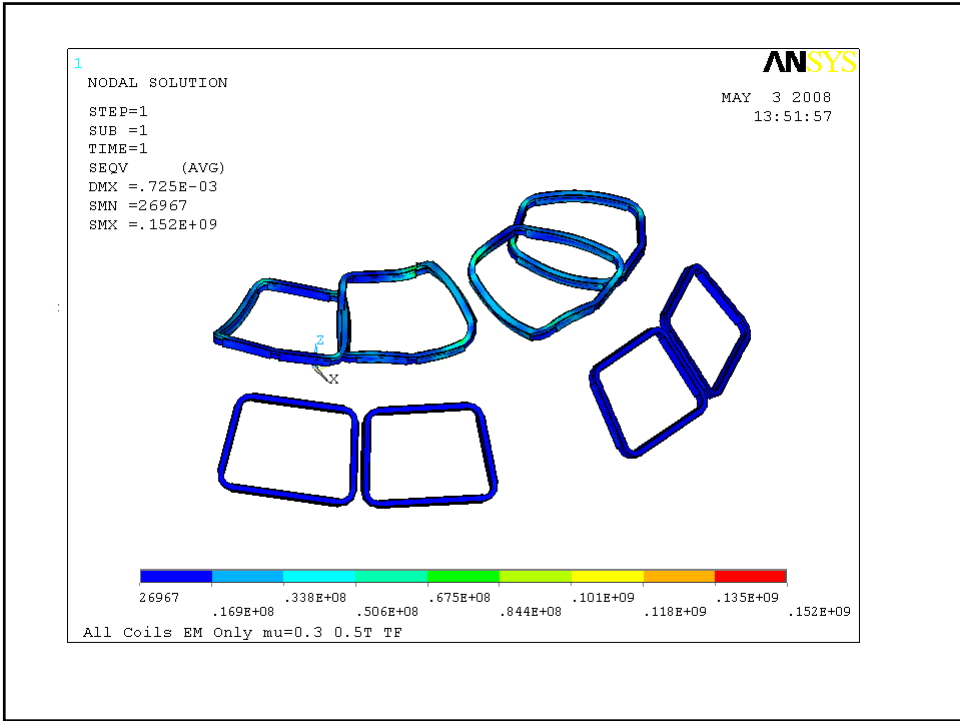
(Node) Stress Summary

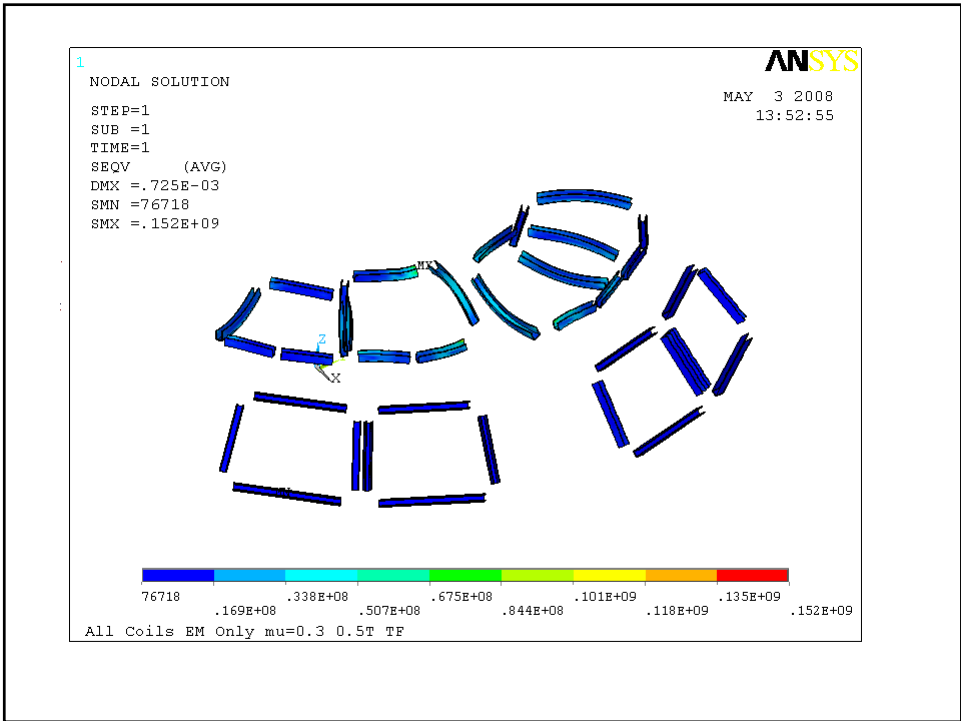
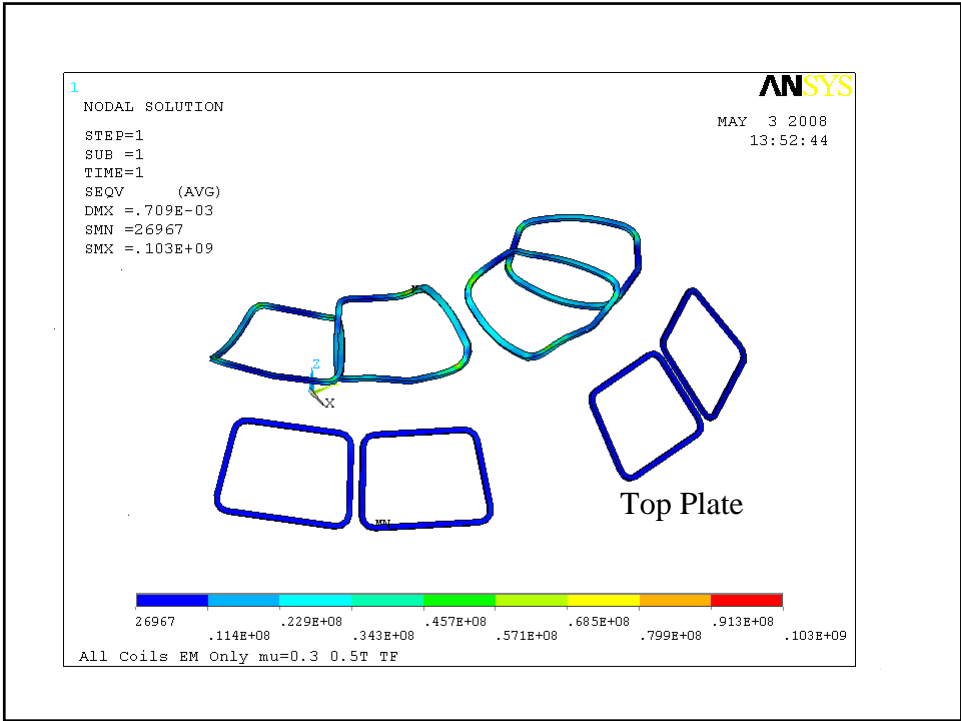
		Max Von Mises Stress							
		Cond Composite	Copper	Insulation Plate	U Channel				
No Friction Coil1	mu=0.0 CD+EM	32.5	71.5	8.1	113.0	186.0	Mpa		
		4.6	10.2	1.2	16.1	26.6	ksi		
	EM Only	19.9	43.8	5.0	44.2	34.1	Mpa		
		2.8	6.3	0.7	6.3	4.9	ksi		
	CD Only	25.0	55.0	6.3	106.0	198.0	Mpa		
		3.6	7.9	0.9	15.1	28.3	ksi		
Friction Coil1	mu=0.3 CD+EM	27.4	60.3	6.9	120.0	196.0	Mpa		
		3.9	8.6	1.0	17.1	28.0	ksi		
	EM Only	23.1	50.8	5.8	72.7	54.9	Mpa		
		3.3	7.3	0.8	10.4	7.8	ksi		
	CD Only	24.5	53.9	6.1	96.3	174.0	Mpa		
		3.5	7.7	0.9	13.8	24.9	ksi		
Friction All Coils	mu=0.3 CD+EM	33.9	74.6	8.5	166.0	257.0	Mpa		
		4.8	10.7	1.2	23.7	36.7	ksi		
	EM Only	22.9	50.4	5.7	79.2	116.0	Mpa		
		3.3	7.2	0.8	11.3	16.6	ksi		
	CD Only	25.5	56.1	6.4	117.0	188.0	Mpa		
		3.6	8.0	0.9	16.7	26.9	ksi		

Element Average Stress at Max Location drops from 257 to 76.4 MPa

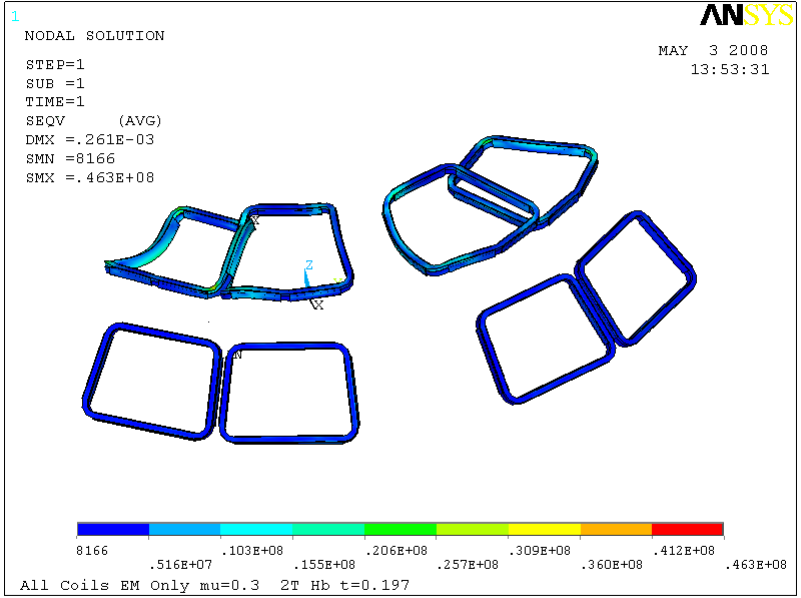
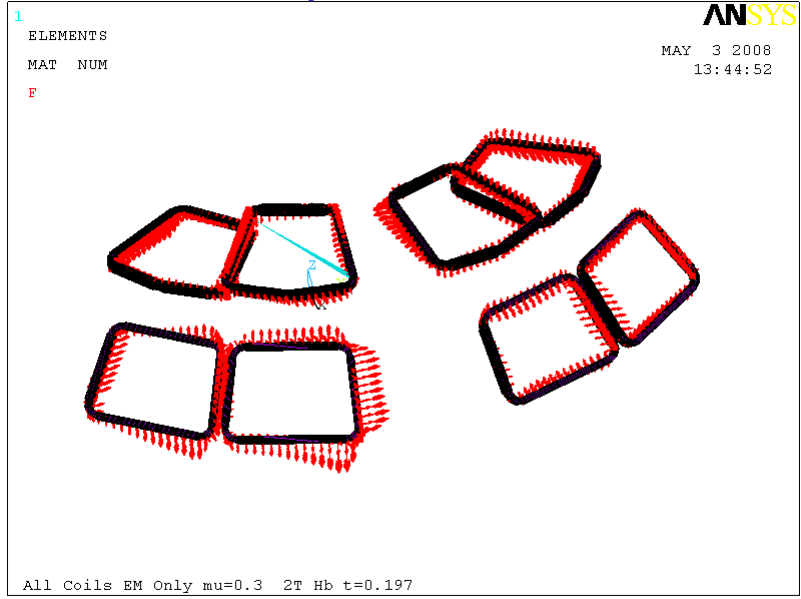
All Coils EM Only mu = 0.3 0.5 TF

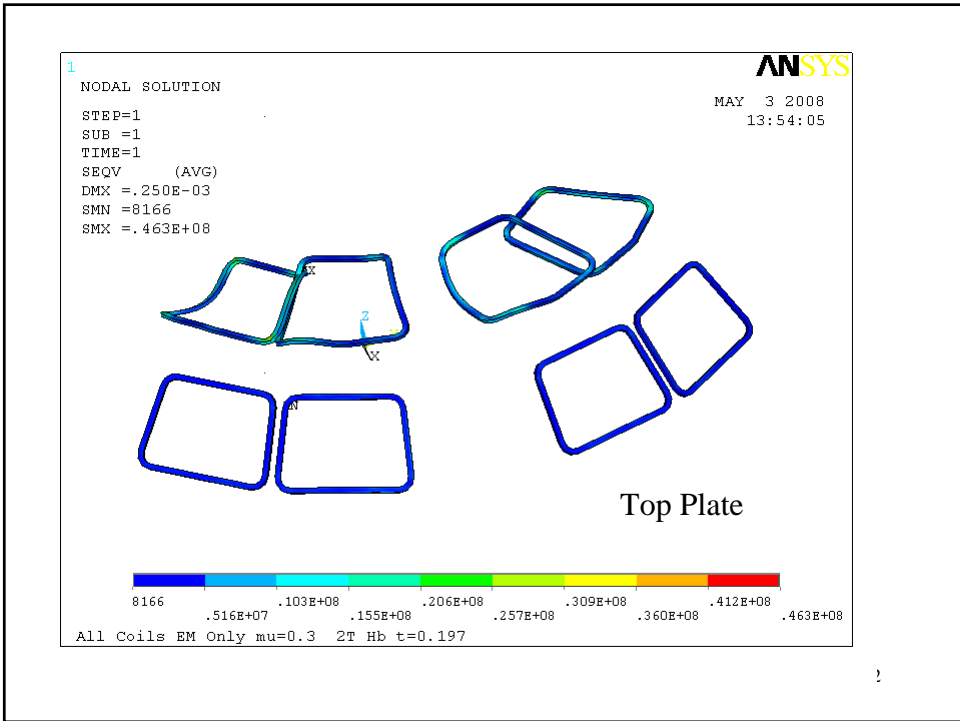
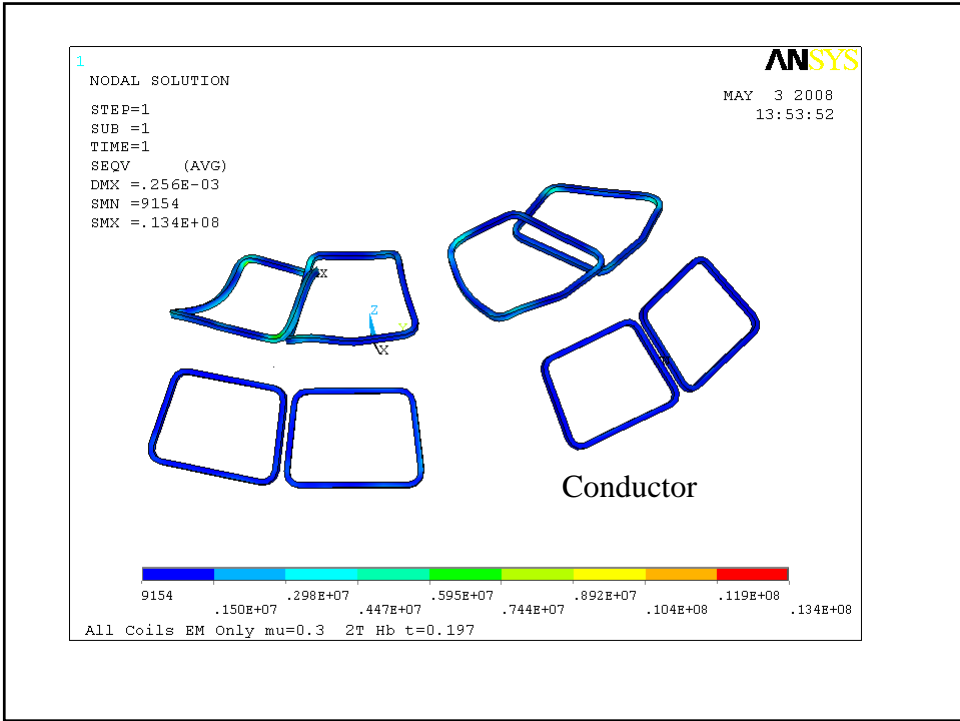


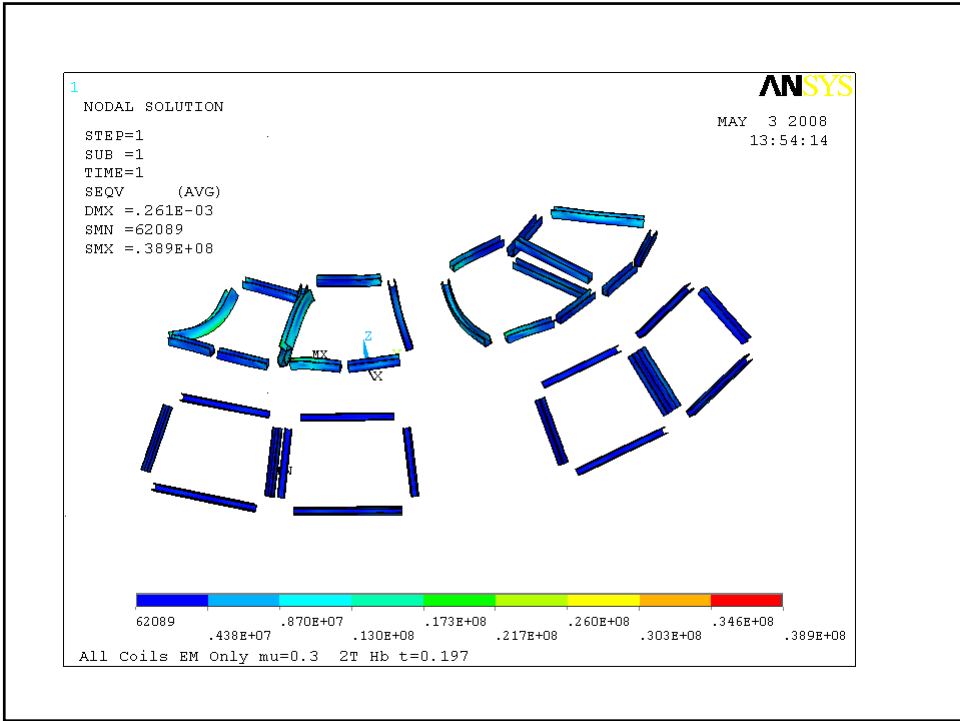




All Coils EM Only $\mu = 0.3$ 2T HB $t=0.197s$







Comparison of EM Scenarios

Friction	mu=0.3 EM Only	Max Von Mises Stress						Mpa ksi			
		All Coils	Cond Composite	Copper	Insulation Plate	U Channel					
iota=0.19		22.9	3.3	50.4	7.2	5.7	0.8	79.2	11.3	116.0	16.6
0.5T TF		24.1	3.4	53.0	7.6	6.0	0.9	103.0	14.7	152.0	21.7
2T HB t=0.197s		13.4	1.9	29.5	4.2	3.4	0.5	46.3	6.6	38.9	5.6