Fermilab

TS-SSC 91-194
10/7/91
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DCA311 and DCA312 Return End Coil Spring Rate

As part of the effort to understand the large increase in end force in DCA310 when the end bell was welded to the end plate, Gianni Tassotto and Wayne Koska had the end force on DCA311 and 312 measured as a function of how far the end loading screws were advanced. Two measurements were taken on DCA312, the first with the set screws at the lead (uninstrumented) end completely loose and the second with them tightened to a torque of 30 in-lbs. (approximately 300 lbs. per set screw). The data are shown in Tables I-III. The measured end force is plotted versus the applied torque in Figures 1-3. For DCA311, the 4 bullets track each other very closely and the force-torque relationship is quite linear with the exception of the break near 150 in-lbs when the torque wrench was changed. There is less reproducibility among the DCA312 bullets and only qualitative reproducibility between the two trials. Perhaps the threads are not in as good condition as on DCA311. However, the 312 bullets behave, on average, about the same as those in 311 and the spread among them (about +/-20%) seems acceptable.

The advance of the end loading screws was measured by noting the angle of the torque wrench. The data were recorded as positions on a clock face (e.g. "4:30") and the smallest increment measured was about 15 degrees ("0:30"). The angular advance data were converted to a linear displacement using the screw pitch of 16 threads per inch. Figures 4-6 show the end force as a function of displacement. The heavy line connects the average value of all force measurements at a given displacement. Because of the relatively coarse nature of the angle and therefore linear displacement measurement, often there are several force and torque points that are assigned the same displacement; all are included in the average. The data from 311 and the second test of 312 are approximately bi-linear with a break in the slope near 0.02 inches and 500 lbs per bullet. The data from the first measurement on 312 show a more continuous change in slope with displacement. The difference between the two measurements of 312 is comparable to the difference between the two magnets and this offers a good estimate of the experimental uncertainty. Table IV and Figure 7 compare the 4-bullet averages among the three measurement sets. The heavy line in Figure 7 is an average of the averages and gives the best estimate of the true spring rate of the return end of the coil.

The measured displacement is a sum of the deflections of the coil, the bullets and the end plate. At 3000 lbs per bullet the strain gauges read about 700 microstrain. They are about 1 inch long, so at the highest loads measured they deflect about 1 mil. On DD0012 the end force and end plate deflection under excitation were simultaneously measured[1]. A change in total end force of approximately 2000 lbs. resulted in a deflection of about 0.3 mils. The deflection of a disk restrained at its edge due to a force at its center scales as the square of the radius. Scaling the DD0012 result to the larger 50 mm magnet diameter and to 12000 lbs total force (3000 lbs per bullet) gives an end

plate deflection of about 3 mils. Thus about 90% of the deflection measured in these tests comes from the coil.

The bullets on DCA310 were preloaded to about 500 lbs each and after welding their load had increased to about 3500 lbs apiece. Based on the data in Figure 7, this corresponds to a deflection of the end plate due to the end bell welding of about 25 mils. It is believed[2] that the welders did not follow the specified procedure for welding the end plate, laying down a thicker bead than was specified. It is believed[2] that following the correct procedure could reduce the deflection by as much as 1/3, or 5-10 mils. It is planned (and agreed to by the welders) to follow the specifed welding procedure on DCA311. It is also planned to preload the bullets before welding to only 100 lbs each (10 in-lbs at the lead end). This corresponds to a reduction of the end plate to coil interference of about 10 mils. Thus the expected decrease in the final interference is 15-20 mils. From the data in Figure 7, this will result in a reduction of the final end force from the 3500 lbs per bullet observed in DCA310 to between 1000 and 2000 lbs per bullet.

REFERENCES

[1] J. Strait, et al., Tests of full scale SSC R&D dipole magnets, IEEE Trans. Mag. 25:1455 (1989).

[2] W. Higinbotham, private communication.

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Table I

DCA311 BULLET TORQUE

Torque	Angle (degrees)				Displacement (inches)				Force (lbs)				theta		
(in-lbs)	Bullet 1	Bullet 2	Bullet 3	Bullet 4	Bullet 1	Bullet 2	Bullet 3	Bullet 4	Bullet 1	Bullet 2	Bullet 3	Bullet 4	(deg)	z(in)	Average
0	0	0	0	0	0.000	0.000	0.000	0.000	0	0	0	0	0	0.000	0
10	60	60	60	60	0.010	0.010	0.010	0.010	101	107	128	148	60	0.010	121
20	90	90	90	90	0.016	0.016	0.016	0.016	238	220	243	233	90	0.016	321
40	90	90	90	90	0.016	0.016	0.016	0.016	374	411	385	467	128	0.022	603
60	128	128	128	128	0.022	0.022	0.022	0.022	592	620	576	622	135	0.023	878
80	135	135	135	135	0.023	0.023	0.023	0.023	790	795	756	826	150	0.026	1251
100	135	135	135	135	0.023	0.023	0.023	0.023	991	975	902	990	180	0.031	1999
120	150	150	150	150	0.026	0.026	0.026	0.026	1201	1152	1048	1210	195	0.034	2370
140	150	150	150	150	0.026	0.026	0.026	0.026	1383	1353	1248	1412	210	0.036	2748
160	180	180	180	180	0.031	0.031	0.031	0.031	1666	2020	1806	1739	225	0.039	3076
160	180	180	180	180	0.031	0.031	0.031	0.031	1997	1997	2001	1968			
180	180	180	180	180	0.031	0.031	0.031	0.031	2222	2199	2179	2197			
200	195	195	195	195	0.034	0.034	0.034	0.034	2409	2354	2379	2336			
220	210	210	210	210	0.036	0.036	0.036	0.036	2574	2503	2511	2573			
240	210	210	210	210	0.036	0.036	0.036	0.036	2762	2751	2723	2777			
260	210	210	210	210	0.036	0.036	0.036	0.036	2970	2970	2867	2995			
265	225	225	225	225	0.039	0.039	0.039	0.039	3096	3097	3007	3104			

Table II

DCA312 A BULLET TORQUE

DCA312 End Loading (Lead end set screws set at 0 in-lbs.)

Torque	Angle (degrees)				Displacement (inches)				Force (lbs)				theta		
(in-lbs)	Bullet 1	Bullet 2	Bullet 3	Bullet 4	Bullet 1	Bullet 2	Bullet 3	Bullet 4	Bullet 1	Bullet 2	Bullet 3	Bullet 4	(deg)	z(in)	Average
0	0	0	0	0	0.000	0.000	0.000	0.000	0	0	0	0	0	0.000	0
20	60	60	60	60	0.010	0.010	0.010	0.010	259	192	211	240	60	0.010	226
40	90	90	90	90	0.016	0.016	0.016	0.016	404	420	455	484	90	0.016	441
60	105	105	105	105	0.018	0.018	0.018	0.018	612	578	595	638	105	0.018	689
80	120	120	105	120	0.021	0.021	0.018	0.021	788	742	781	831	120	0.021	867
100	150	120	105	150	0.026	0.021	0.018	0.026	874	888	930	1053	135	0.023	1244
120	150	120	120	150	0.026	0.021	0.021	0.026	971	1085	1060	1153	150	0.026	1134
140	165	150	135	165	0.029	0.026	0.023	0.029	1284	1179	1244	1403	165	0.029	1443
160	180	150	150	180	0.031	0.026	0.026	0.031	1484	1286	1422	1586	180	0.031	1752
180	195	165	165	195	0.034	0.029	0.029	0.034	1780	1505	1578	1770	195	0.034	1775
200	210	180	180	210	0.036	0.031	0.031	0.036	2148	1597	1756	1915	210	0.036	2032
220	225	180	180	225	0.039	0.031	0.031	0.039	2239	1801	1876	2168	225	0.039	2204
240	240	180	180	240	0.042	0.031	0.031	0.042	2529	1871	2048	2315	240	0.042	2422

Table III

DCA312 B BULLET TORQUE

DCA312 End Loading (Lead end set screws set at 30 in-lbs.)

Torque	Angle (degrees)				Displacement (inches)				Force (lbs)				theta		
(in-lbs)	Bullet 1	Bullet 2	Bullet 3	Bullet 4	Bullet 1	Bullet 2	Bullet 3	Bullet 4	Bullet 1	Bullet 2	Bullet 3	Bullet 4	(deg)	z(in)	Average
0	0	0	0	0	0.000	0.000	0.000	0.000	38	35	39	47	0	0.000	40
20	90	90	90	90	0.016	0.016	0.016	0.016	231	217	211	281	90	0.016	235
40	120	120	120	105	0.021	0.021	0.021	0.018	407	425	388	463	105	0.018	463
60	150	135	135	150	0.026	0.023	0.023	0.026	672	597	611	655	120	0.021	407
80	165	135	135	165	0.029	0.023	0.023	0.029	915	741	834	846	135	0.023	855
100	165	135	135	165	0.029	0.023	0.023	0.029	1107	889	993	1124	150	0.026	962
120	165	135	135	165	0.029	0.023	0.023	0.029	1346	992	1186	1343	165	0.029	1194
140	180	150	150	180	0.031	0.026	0.026	0.031	1504	1181	1338	1513	180	0.031	1710
160	180	165	165	180	0.031	0.029	0.029	0.031	1782	1210	1491	1617	188	0.033	2061
180	195	165	180	180	0.034	0.029	0.031	0.031	2052	1360	1652	1762	195	0.034	2185
200	195	180	180	180	0.034	0.031	0.031	0.031	2254	1540	1939	1953	210	0.036	2342
220	210	180	188	195	0.036	0.031	0.033	0.034	2382	1836	2183	2166	225	0.039	2634
240	225	188	195	210	0.039	0.033	0.034	0.036	2549	1939	2303	2326	240	0.042	2869
260	225	195	210	210	0.039	0.034	0.036	0.036	2672	2152	2550	2418	255	0.044	3166
265	225	210	225	210	0.039	0.036	0.039	0.036	2771	2101	2558	2475			
	225	210	225	210	0.039	0.036	0.039	0.036	2734	2128	2600	2465			
	240	210	225	225	0.042	0.036	0.039	0.039	2936	2229	2588	2588			
	240	225	225	225	0.042	0.039	0.039	0.039	2788	2474	2729	2714			
	240	240	240	240	0.042	0.042	0.042	0.042	2940	2565	2876	2860			
	255	255	240	240	0.044	0.044	0.042	0.042	2865	3467	3016	2974			

Table IV

DCA311			DCA312 (LE=0)			DCA312 (LE=30)			Average		
theta (deg)	z(in)	<F> (lbs)	theta (deg)	z(in)	<F> (lbs)	theta (deg)	z(in)	<F> (lbs)	theta (deg)	z(in)	<F> (lbs)
0	0.000	0	0	0.000	0	0	0.000	40	0	0.000	13
60	0.010	121	60	0.010	226	90	0.016	235	60	0.010	173
90	0.016	321	90	0.016	441	105	0.018	463	90	0.016	332
128	0.022	603	105	0.018	689	120	0.021	407	105	0.018	576
135	0.023	878	120	0.021	867	135	0.023	855	120	0.021	637
150	0.026	1251	135	0.023	1244	150	0.026	962	135	0.023	993
180	0.031	1999	150	0.026	1134	165	0.029	1194	150	0.026	1115
195	0.034	2370	165	0.029	1443	180	0.031	1710	165	0.029	1318
210	0.036	2748	180	0.031	1752	188	0.033	2061	180	0.031	1820
225	0.039	3076	195	0.034	1775	195	0.034	2185	195	0.034	2110
			210	0.036	2032	210	0.036	2342	210	0.036	2374
			225	0.039	2204	225	0.039	2634	225	0.039	2638
			240	0.042	2422	240	0.042	2869			
						255	0.044	3166			

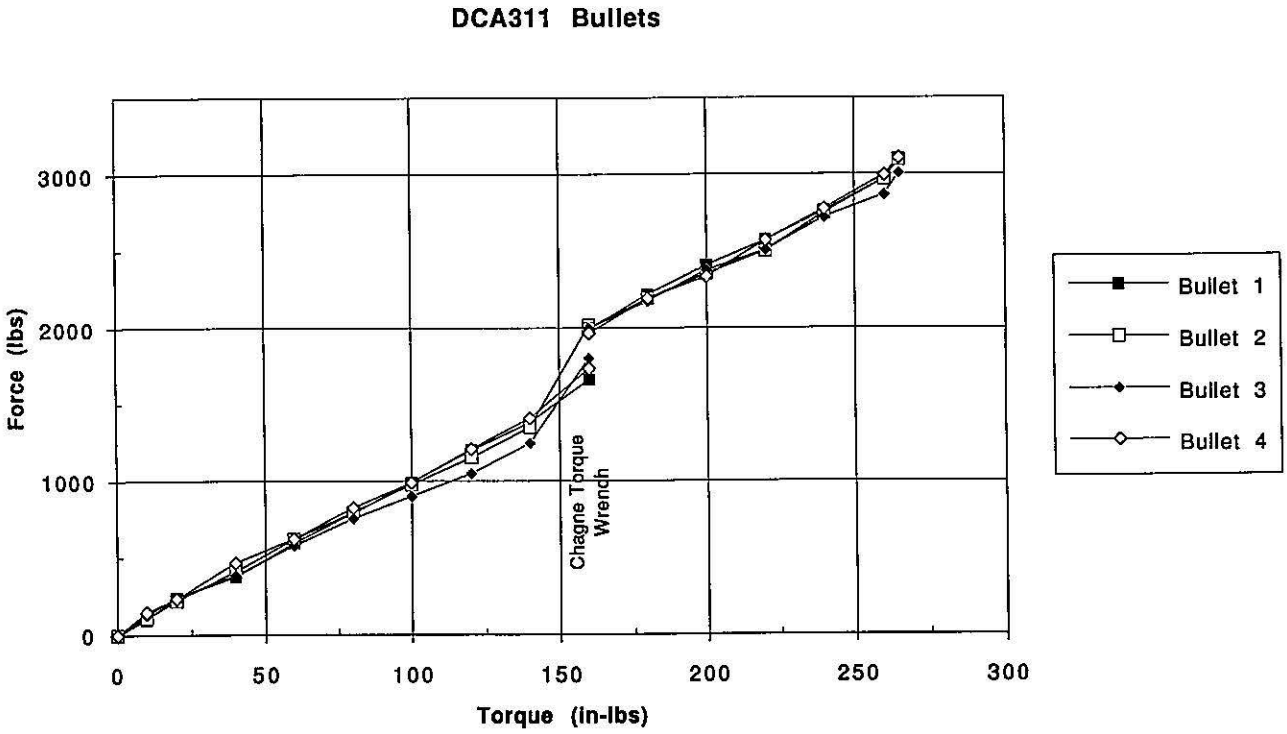

Figure 1

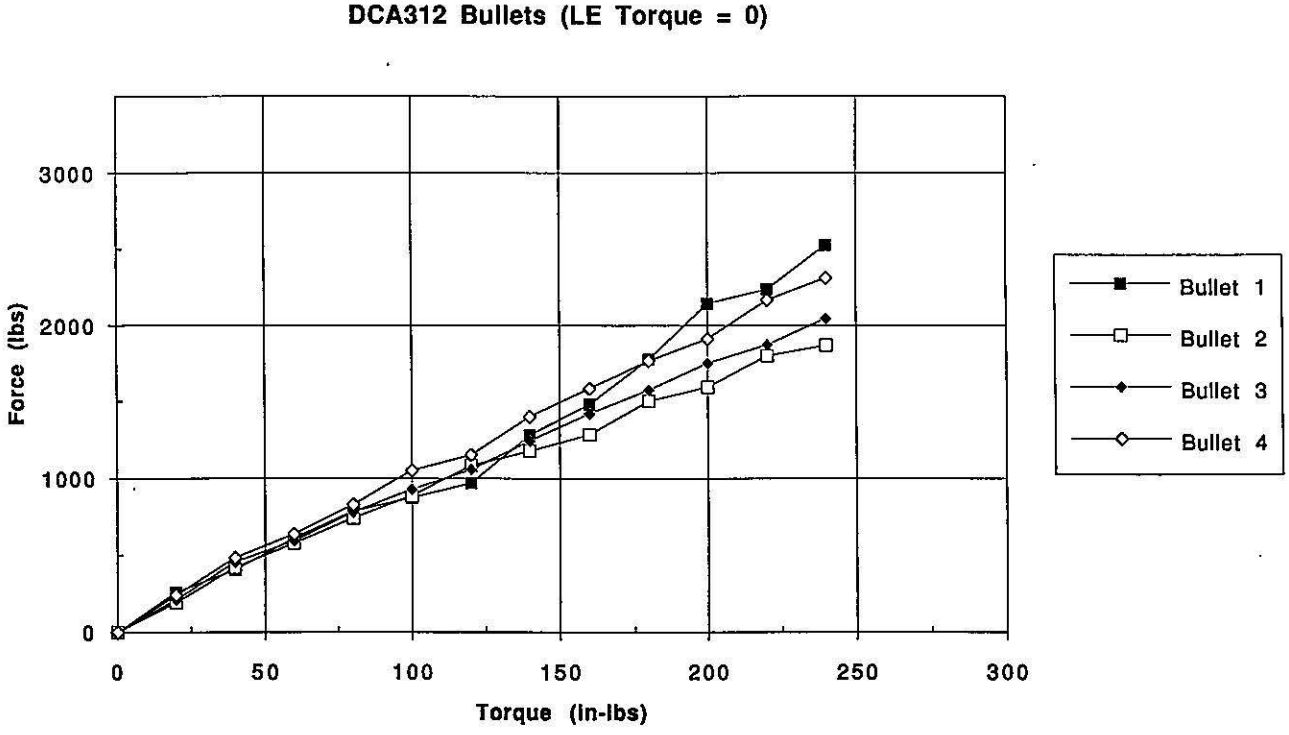

Figure 2

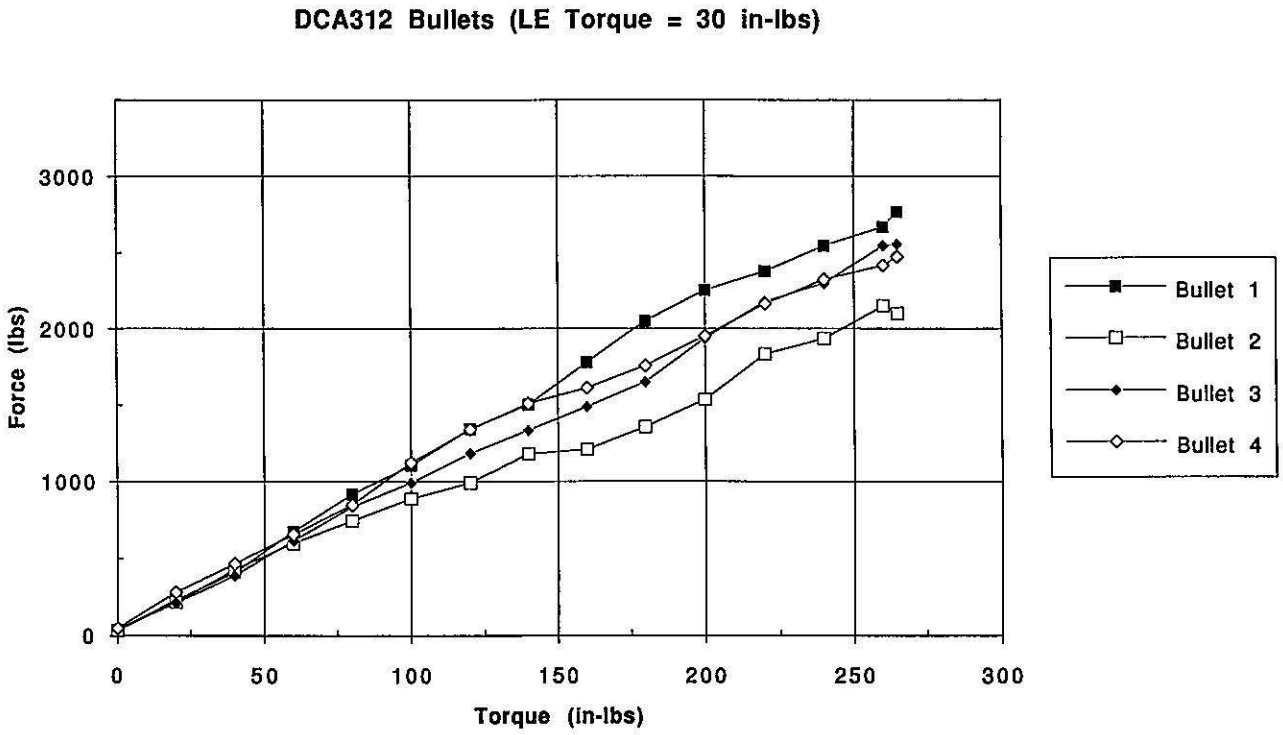
DCA312 Bullets (LE Torque = 30 in-lbs)
Force (lbs)
3000
2000
1000
0
0
50
100
150
200
250
300
Torque (in-lbs)
Bullet 1
Bullet 2
Bullet 3
Bullet 4

Figure 3

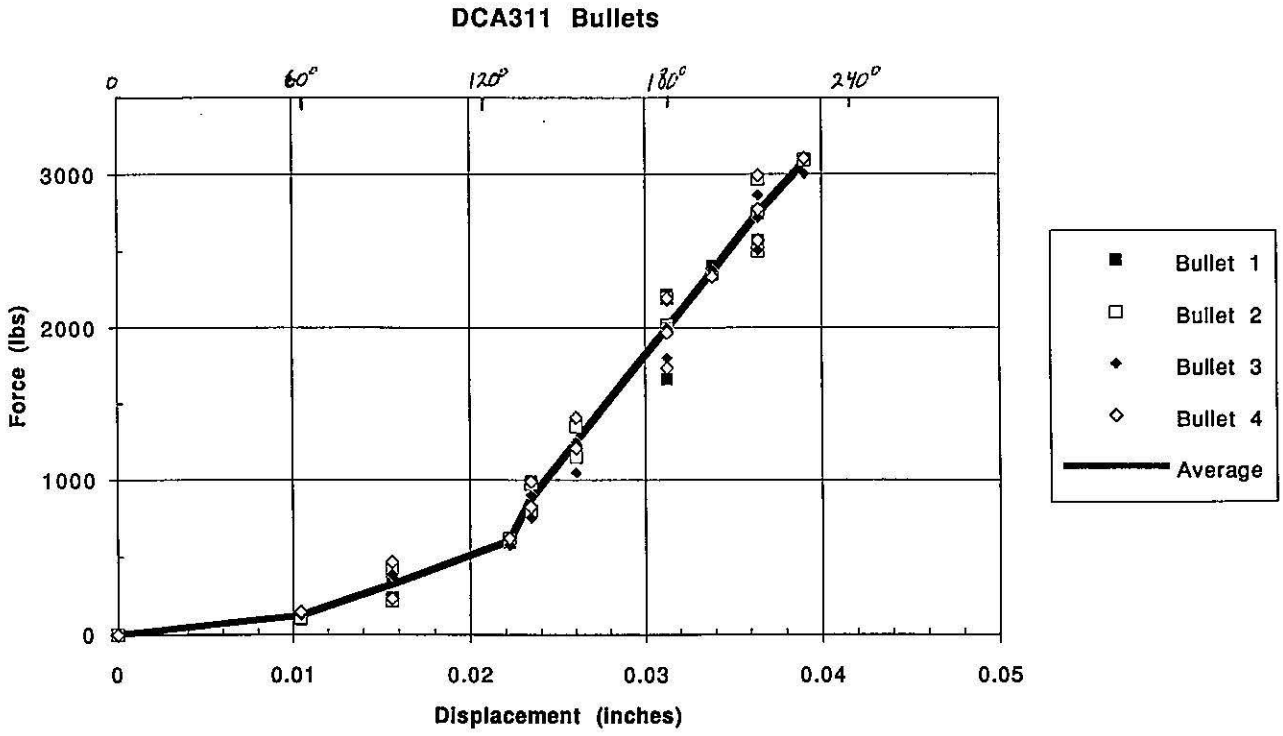

Figure 4

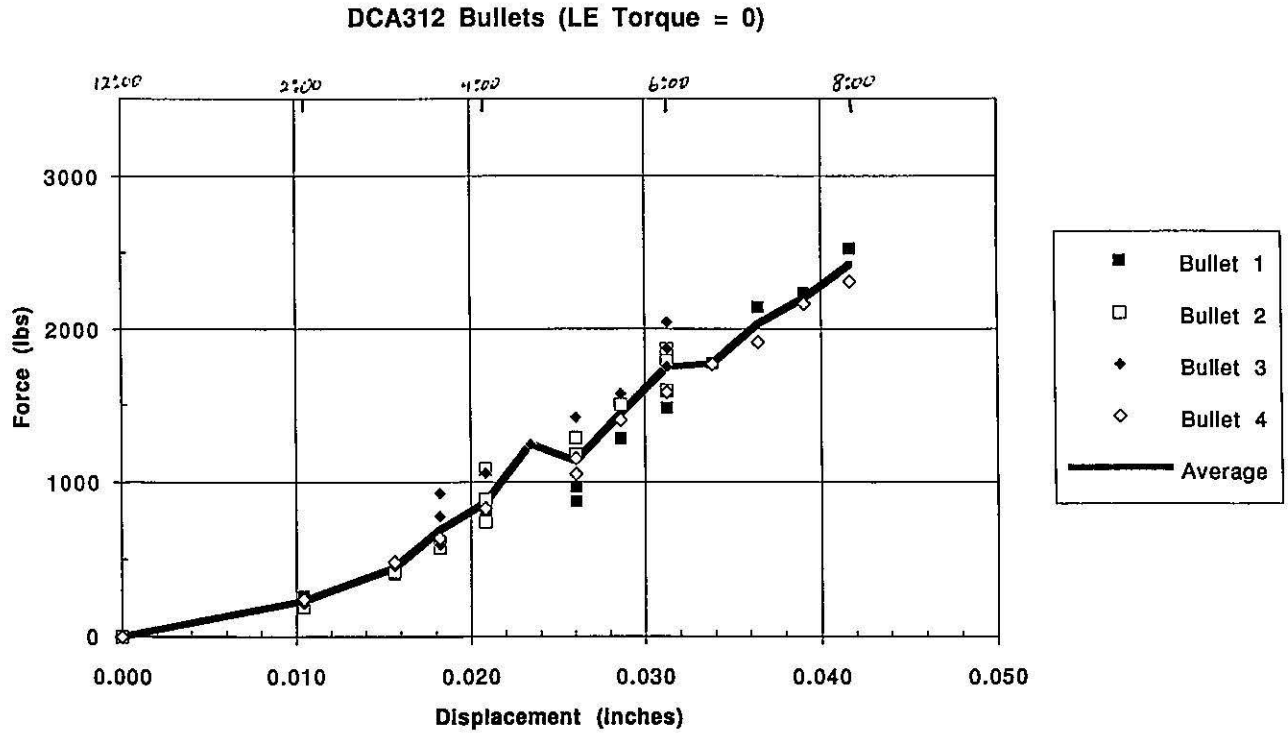

Figure 5

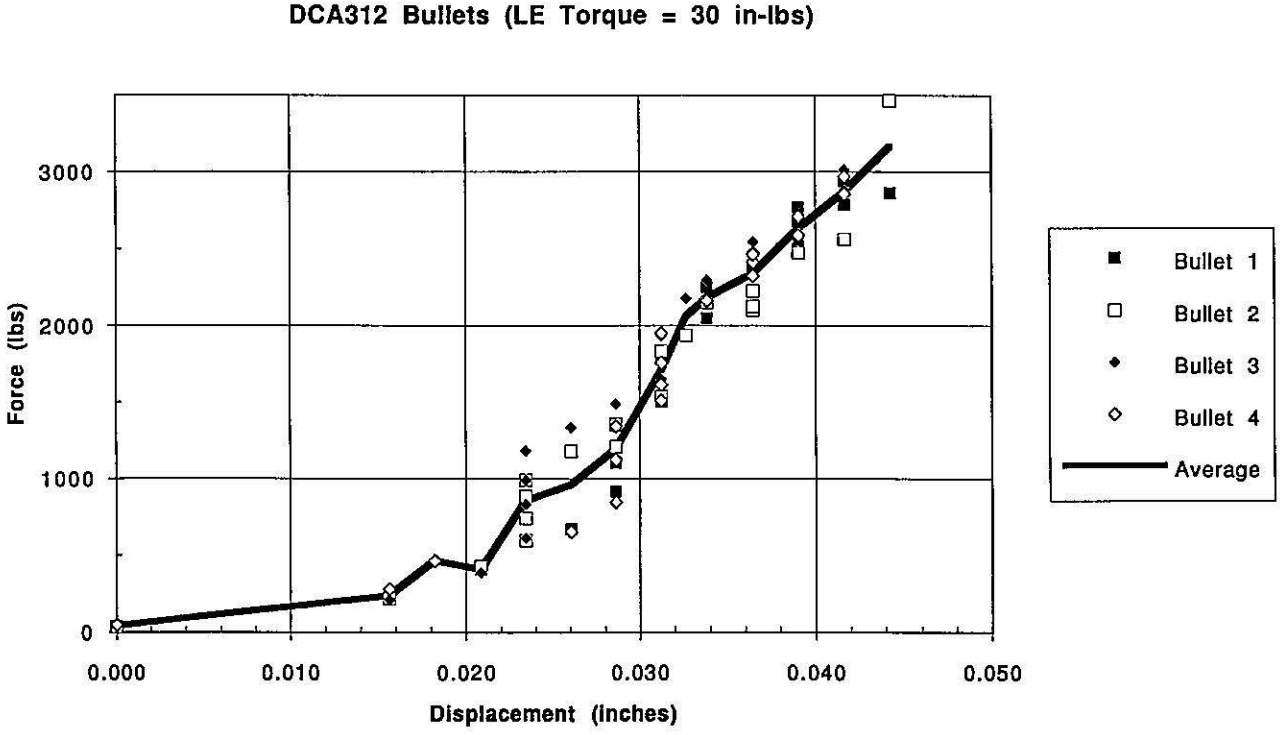

Figure 6

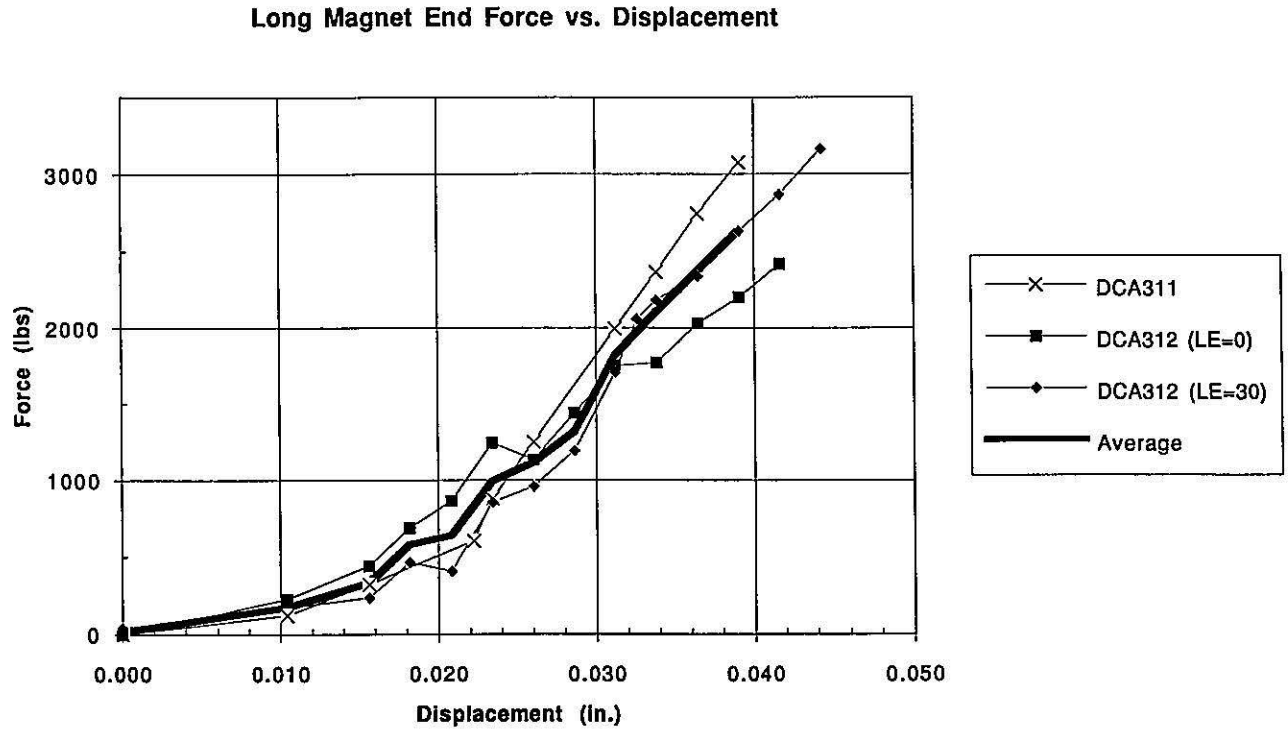

Figure 7