OH Coil Pre Load System
TF cold OH hot

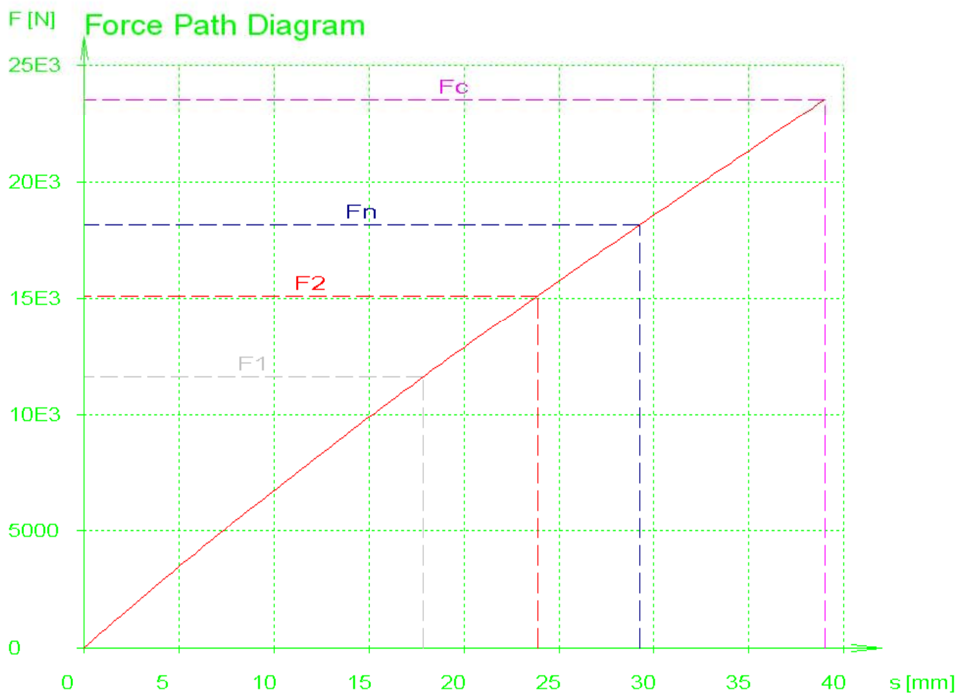
Calculations for most critical system scenario.
Pre load = 17.87 mm
OH thermal expansion = 6.0 mm
Total spring compression = 23.87 mm

Maximum obtained force on the OH coil
With 14 stacks = 15,113. x 14 = 211,582. N
(47,546. lbs.)

Life based on “Sigma II” is about 500,000 cycles.

FED4 - Disk Spring Calculation - 14 Stacks TF cold Oh Hot 2 26 Sp.fd4

File Edit View CAD Database Document OLE Help



Di = 30.5 mm
De = 60 mm
t = 3.5 mm
L0 = 5 mm

nf = 1
np = 26
Lc = 91 mm
L0 = 130 mm

Stainless Steel Required

E = 206000 MPa
mue = 0.3
rho= 7.85 kg/dm^3
sigma perm = 1230 MPa
(DIN 2092)

	0	1	2	n	c	
s	0.00	17.87	23.87	29.25	39.00	mm
L	130.00	112.13	106.13	100.75	91.00	mm
F	0	11608	15113	18153	23528	N
R	18566	15514	14895	14515	14245	N/mm
sigma I	0	-1554	-2029	-2434	-3121	MPa
sigma III	0	835	1085	1297	1650	MPa
si	0.00	0.69	0.92	1.13	1.50	mm
Li	5.00	4.31	4.08	5.00	0.00	mm
Fi	0	11608	15113	18153	23528	N

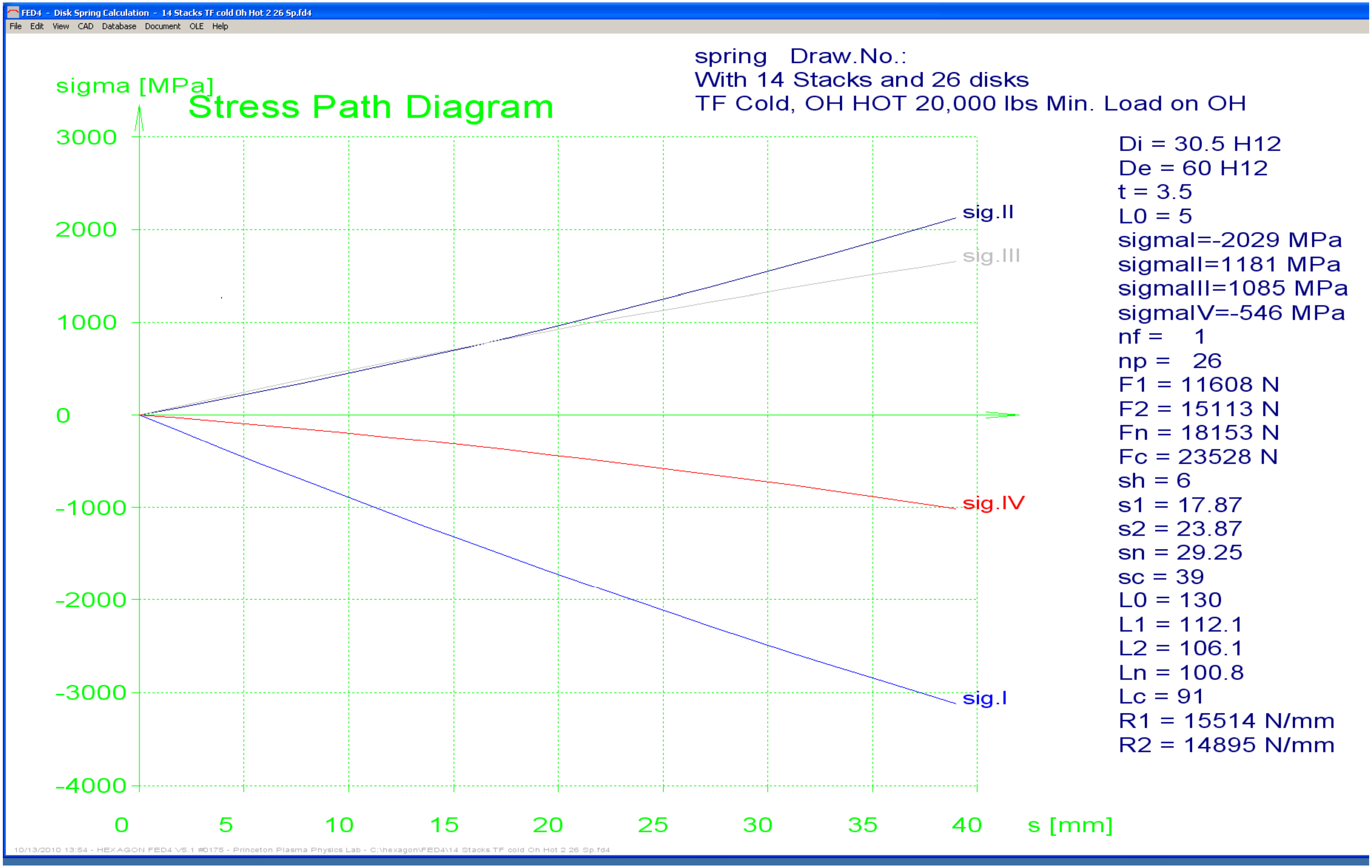
messages

- none -

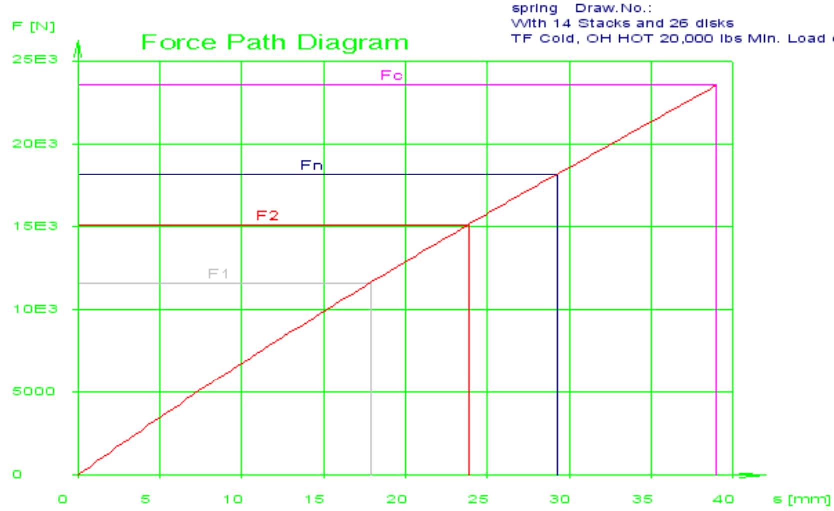
Pre Load = 17.87 mm
+OH hot = 6.0 mm
Total comp = 23.87 mm
Total Force/Stack =15113N
(Max operational force)

10/13/2010 13:19 - HEXAGON FED4 V5.1 #0175 - Princeton Plasma Physics Lab - C:\hexagon\FED4\14 Stacks TF cold Oh Hot 2 26 Sp.fd4

start Microsoft PowerPoint ... FED4 - Disk Spring C... 1:19 PM


FED4 - Disk Spring Calculation - 14 Stacks TF cold Oh Hot 2 26 Sp.fd4
File Edit View CAD Database Document OLE Help
spring Draw.No.:
With 14 Stacks and 26 disks
TF Cold, OH HOT 20,000 lbs Min. Load on OH
sigma [MPa]
Stress Path Diagram
3000
2000
1000
0
-1000
-2000
-3000
-4000
0 5 10 15 20 25 30 35 40
s [mm]
sig.II
sig.III
sig.IV
sig.I
Di = 30.5 H12
De = 60 H12
t = 3.5
L0 = 5
sigmaI=-2029 MPa
sigmaII=1181 MPa
sigmaIII=1085 MPa
sigmaIV=-546 MPa
nf = 1
np = 26
F1 = 11608 N
F2 = 15113 N
Fn = 18153 N
Fc = 23528 N
sh = 6
s1 = 17.87
s2 = 23.87
sn = 29.25
sc = 39
L0 = 130
L1 = 112.1
L2 = 106.1
Ln = 100.8
Lc = 91
R1 = 15514 N/mm
R2 = 14895 N/mm
10/13/2010 13:54 - HEXAGON FED4 V5.1 #0175 - Princeton Plasma Physics Lab - C:\hexagon\FED4\14 Stacks TF cold Oh Hot 2 26 Sp.fd4

spring Draw.No.:
With 14 Stacks and 26 disks
TF Cold, OH HOT 20,000 lbs Min. Load on OH



Di = 30.5 H12
De = 60 H12
t = 3.5
L0 = 5
sigmaI=-2029 MPa
sigmaII=1181 MPa
sigmaIII=1085 MPa
sigmaIV=-546 MPa
nf = 1
np = 26
F1 = 11608 N
F2 = 15113 N
Fn = 18153 N
Fc = 23528 N
sh = 6
s1 = 17.87
s2 = 23.87
sn = 29.25
sc = 39
L0 = 130
L1 = 112.1
L2 = 106.1
Ln = 100.8
Lc = 91
R1 = 15514 N/mm
R2 = 14895 N/mm

spring Draw.No.:
With 14 Stacks and 26 disks
TF Cold, OH HOT 20,000 lbs Min. Load on OH

SINGLE DISK SPRING			
inside diameter	Di	mm	30.5 H12
outside diameter	De	mm	60 H12
thickness	t	mm	3.5
length	L0	mm	5
weight	m	g	57.61
usable spring travel sn=0.75*h0	sin	mm	1.125
max. spring travel h0=sc	sic	mm	1.5
spring force with sn=0.75*sc	Fin	N	18153
No. of springs per package	nf		1
No. of spring packages	np		26

Length mm	Sp.travel mm	Load N	Sigma MPa
L0 = 130.00			
L1 = 112.13	s1 = 17.87	F1 = 11607.78	sigma1 = 835
	sh = 6.00	Fh = 3504.78	sigmah = 250
L2 = 106.13	s2 = 23.87	F2 = 15112.57	sigma2 = 1085
Ln = 100.75	sn = 29.25	Fn = 18152.58	sigman = 1297
Lc = 91.00	sc = 39.00	Fc = 23528.21	sigmac = 1650

	Date	Name
Compl.	08/25/2010	P. Rogoff
Check		
Stand.		

Disk Spring

Cond.	Modification	Date	Name
a	Initial Design	08/26/2010	P. R.

Princeton Plasma Physics Lab

Page

Pg.

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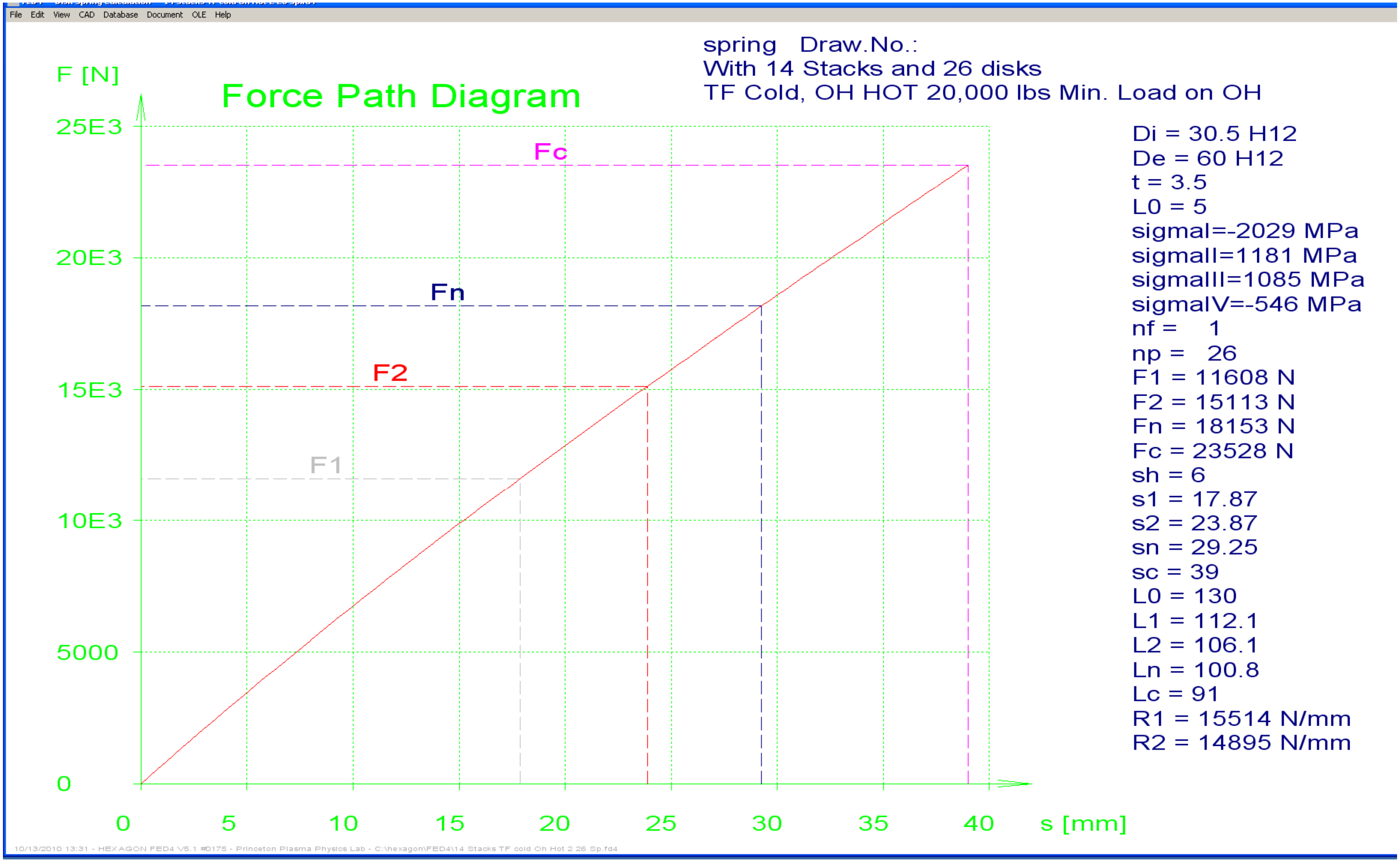
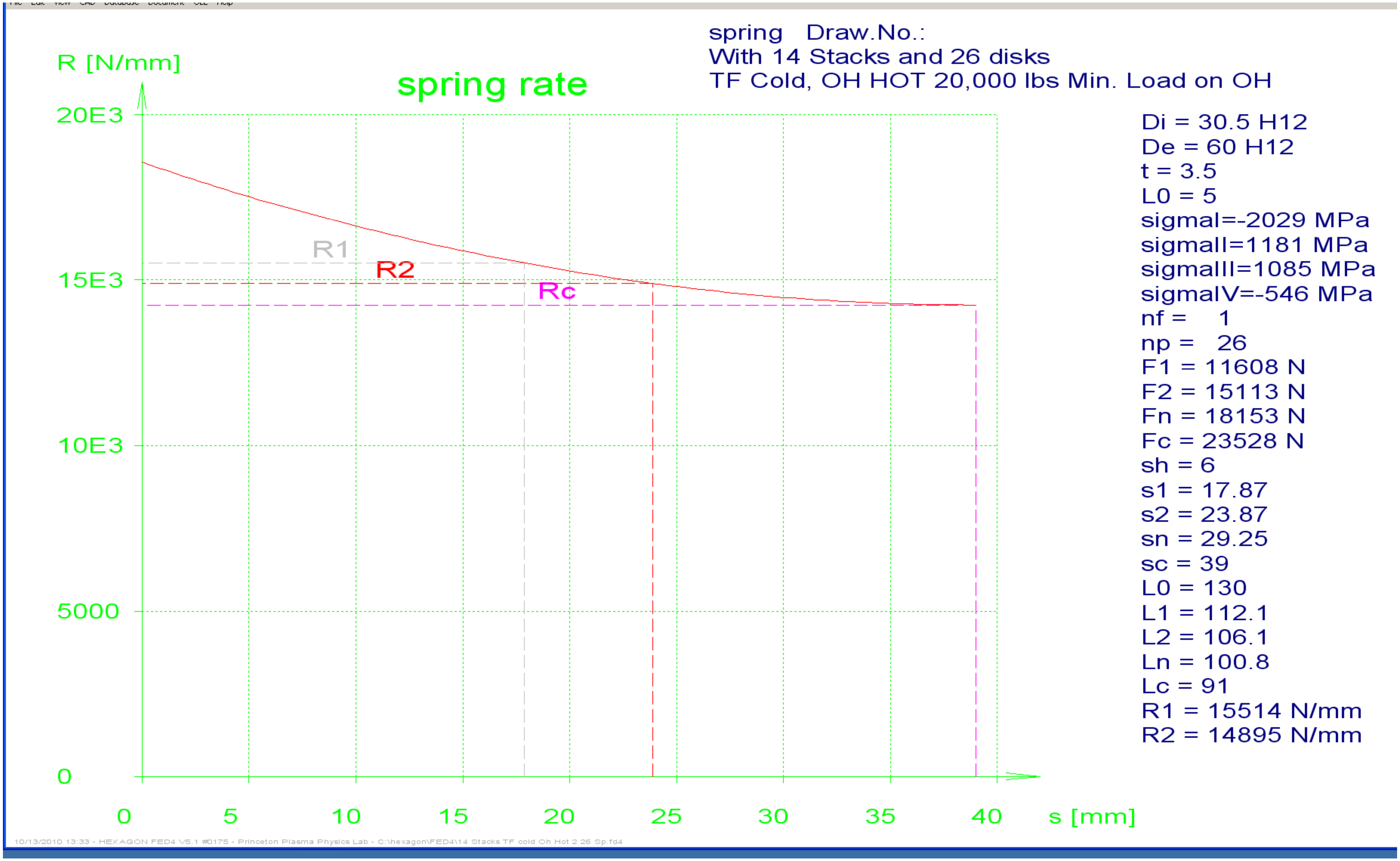
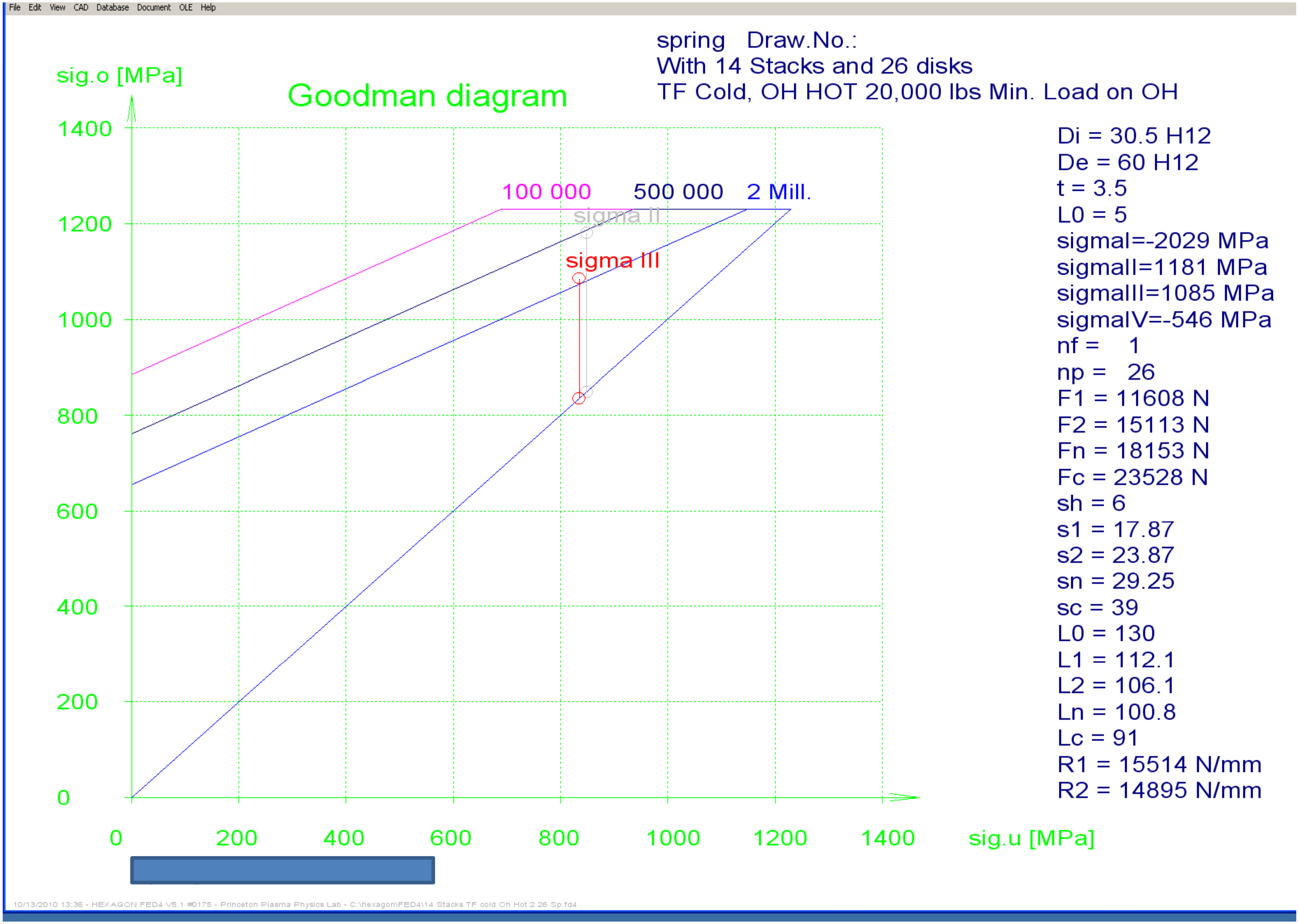
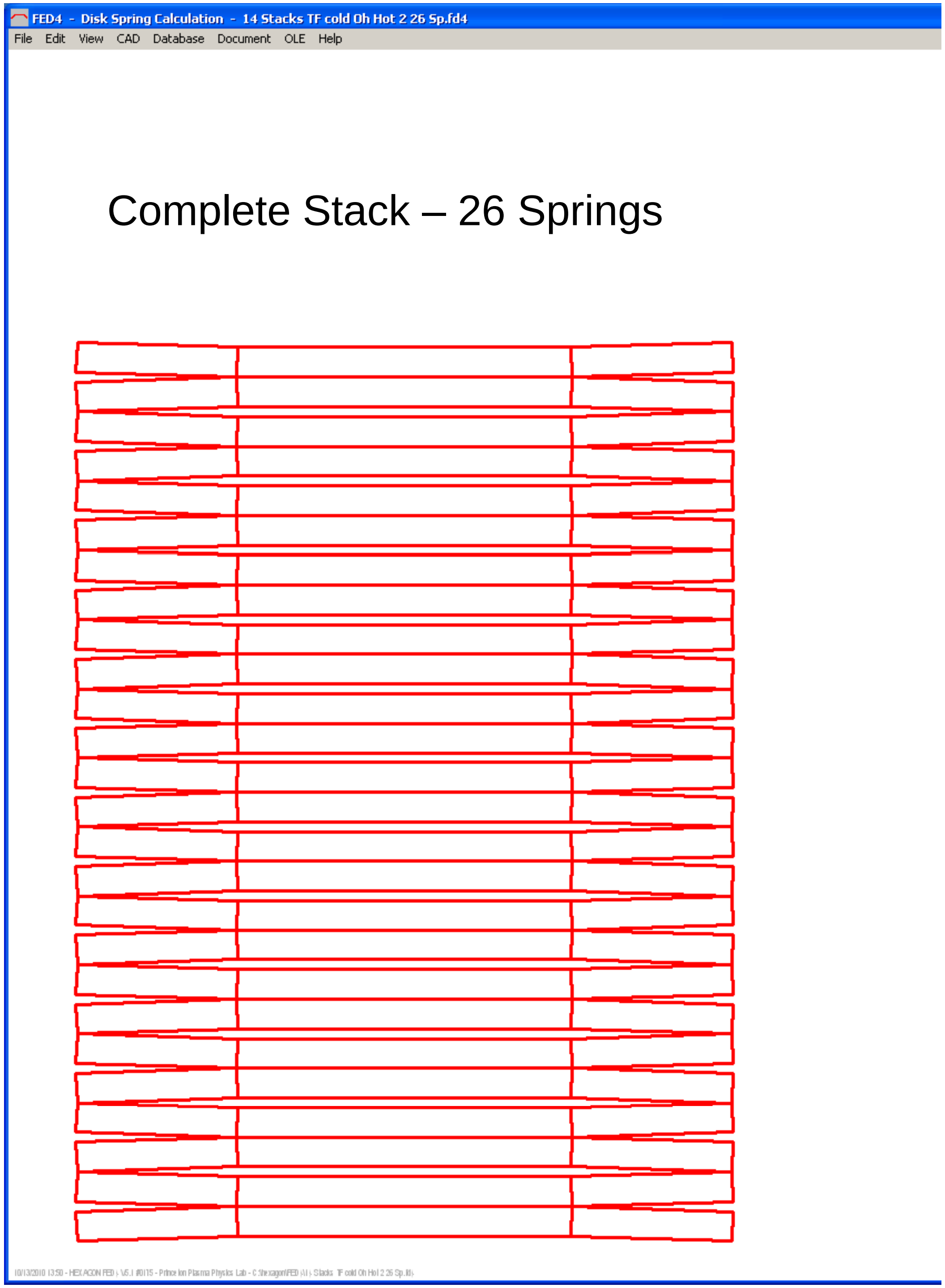

File Edit View CAD Database Document OLE Help
spring Draw.No.:
With 14 Stacks and 26 disks
TF Cold, OH HOT 20,000 lbs Min. Load on OH
Force Path Diagram
F [N]
25E3
20E3
15E3
10E3
5000
0
Fc
Fn
F2
F1
0
5
10
15
20
25
30
35
40
s [mm]
Di = 30.5 H12
De = 60 H12
t = 3.5
L0 = 5
sigmaI=-2029 MPa
sigmaII=1181 MPa
sigmaIII=1085 MPa
sigmaIV=-546 MPa
nf = 1
np = 26
F1 = 11608 N
F2 = 15113 N
Fn = 18153 N
Fc = 23528 N
sh = 6
s1 = 17.87
s2 = 23.87
sn = 29.25
sc = 39
L0 = 130
L1 = 112.1
L2 = 106.1
Ln = 100.8
Lc = 91
R1 = 15514 N/mm
R2 = 14895 N/mm
10/13/2010 13:31 - HEXAGON FED4 V5.1 #0175 - Princeton Plasma Physics Lab - C:\hexagon\FED4\14 Stacks TF cold Oh Hot 2 26 Sp.fd4


spring Draw.No.:
With 14 Stacks and 26 disks
TF Cold, OH HOT 20,000 lbs Min. Load on OH
spring rate
R [N/mm]
20E3
15E3
10E3
5000
0
0
5
10
15
20
25
30
35
40
s [mm]
R1
R2
Rc
Di = 30.5 H12
De = 60 H12
t = 3.5
L0 = 5
sigmaI=-2029 MPa
sigmaII=1181 MPa
sigmaIII=1085 MPa
sigmaIV=-546 MPa
nf = 1
np = 26
F1 = 11608 N
F2 = 15113 N
Fn = 18153 N
Fc = 23528 N
sh = 6
s1 = 17.87
s2 = 23.87
sn = 29.25
sc = 39
L0 = 130
L1 = 112.1
L2 = 106.1
Ln = 100.8
Lc = 91
R1 = 15514 N/mm
R2 = 14895 N/mm
10/13/2010 13:33 - HEXAGON FED4 V5.1 #0175 - Princeton Plasma Physics Lab - C:\hexagon\FED4\14 Stacks TF cold Oh Hot 2 26 Sp.fd4


File Edit View CAD Database Document OLE Help
spring Draw.No.:
With 14 Stacks and 26 disks
TF Cold, OH HOT 20,000 lbs Min. Load on OH
sig.o [MPa]
Goodman diagram
1400
1200
1000
800
600
400
200
0
100 000
500 000
2 Mill.
sigma II
sigma III
0
200
400
600
800
1000
1200
1400
sig.u [MPa]
Di = 30.5 H12
De = 60 H12
t = 3.5
L0 = 5
sigmaI=-2029 MPa
sigmaII=1181 MPa
sigmaIII=1085 MPa
sigmaIV=-546 MPa
nf = 1
np = 26
F1 = 11608 N
F2 = 15113 N
Fn = 18153 N
Fc = 23528 N
sh = 6
s1 = 17.87
s2 = 23.87
sn = 29.25
sc = 39
L0 = 130
L1 = 112.1
L2 = 106.1
Ln = 100.8
Lc = 91
R1 = 15514 N/mm
R2 = 14895 N/mm
10/13/2010 13:36 - HEXAGON FED4 V5.1 #0175 - Princeton Plasma Physics Lab - C:\hexagon\FED4\14 Stacks TF cold Oh Hot 2 26 Sp.fd4

Complete Stack – 26 Springs



This is provided as a check of above “HEXAGON” calculations.

	A	B	C	D
3				
4		Calcs Based on the SCHNORR data formulas.		
5				
6		Note: These calculations are for SCHNORR #15900		
7				
8				
9		De - Ouside diameter	60	mm
10		Di - Inside diameter	30.5	mm
11				
12		pi	3.14	
13		1/pi	0.3185	
14		3/pi	0.9554	
15		6/pi	1.9108	
16				
17		del=De/Di Schnorr Formula #2	1.9672	
18				
19		Indel=In(De/Di)	0.6766	
20				
21		del-1	0.9672	
22		del+1	2.9672	
23				
24				
25				
26		(del-1/del)^2	0.2417	
27		(del+1)/(del-1)	3.0678	
28		(2/Indel)	2.9559	
29				
30				
31		K1 =1/pi(((del-1/del)^2))/((del+1)/((del-1)-(2/Indel))) Formula #3	0.6879	
32				
33		K2=6/pi(((del-1)/(Indel))-1)))/(Indel) Formula #4	1.2129	
34				
35		K3=3/pi(del-1/Indel) Formula #5	1.3657	
36				
37		K4=1 since thikness is less than 6 mm Formula #6 (see chapter	1	
38				
39				
40		FORCE and STRESS Calculations		
41				
42				
43				
44		lo= total height	5.004	mm
45		ho= lo-t	1.499	mm
46		t=average spring thickness	3.505	mm

Calculations based on the “SCHNORR” catalogue equations for a single disk at maximum compression.
s = .918 mm

Stack compression
In this case:
s = 23.87 mm.

Or (.918x26) =
23.87 mm
Force = 15164 N

See Slide #2

47	s= deflection of the single spring (from 75% of ho))	0.918	mm
48	E= modulus for steel	206000	N/mm^2
49	mu= Poisson's ratio	0.3	
50	1-mu^2	0.91	
51	4E/(1-mu^2)	905494.505	
52	t^4/(K1*de^2)	0.06094519	
53	s/t	0.26191155	
54	ho/t	0.42767475	
55	s/2t	0.13095578	
56			
57	Formula #8a	15164.64	N
58			
59	Formula #9 Stresses at the center of rotation (point OM)	-1124.08	N/mm^2
60	(should be less then -1600N/mm^2)		
61	t^2/(K1*de^2)	0.00496093	
62			
63	formula #10 Stress at point (I)	-2030.27	N/mm^2
64			
65			
66	formula #11 Stress at point (II)	1183.42482	N/mm^2
67			
68			
69	formula #12 Stress at point (III)	1086.30	N/mm^2
70			
71	1/del	0.50833333	
72	(K2-2K3)	-1.5185995	
73	(ho/t-s/2t)	0.29671897	
74			
75	Formula #13 Stress at point (IV)	-547.32	N/mm^2
76			
77	t^3/(K1*de^2)	0.01738807	
78			
79	Formula #14 Spring Rate (dF/ds)	14953.84	N/mm
80			
81	Formula #15 Spring Work (Integral from 0 to s, of F*ds)	7218.36	N-mm
82			
83	2E/(1-mu^2)	452747.253	
84	t^5/(K1*de^2)	0.2136129	
85			
86	**Basic requirements for a good Disk spring design**		
87	**For the above basic equations to work**		
88			
89	This Spring is linear because ho/t=.428 (since for ho/t<0.4 are lii	slightly non-LINEAR	
90			
91	del=De/Di=2.3923 and it should be between 1.75 and 2.5	O.K.	
92	Outside diameter De, Inside diameter Di		

ho/t=(lo-t)/t=.428 and it should be between 0.4 to 1.3 O.K.

ho=lo-t cone height, t=disk thickness

De/t=17.12 and it should be between 16. and 40. O.K.

Conclusion: This spring under the constant load of 3790.0 N is O.K.

Basic machine operation requirements:

1) TF coil inner leg maximum thermal expansion was calculated at 8.4mm
2) OH coil requires a preload of 20,000.0 lbs total or 7,413.3 N (12 St) per stack. Must calculate the required deflection (s) for the preload force?
3) OH coil thermal expansion was calculated at 6.0mm

So, the total each spring stack travel is = 8.4+6.0+calculated from minimum preload

For Fatigue predictions, using fatigue life diagrams for disk springs, one requires the Pre and Maximum loads stresses at points II or III (depending on del and ho/t).