Fermi National Accelerator Laboratory

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**Electrical Design Note for a
5000 ADC, 230 μ H
Power Supply Filter Choke**

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1.0 INTRODUCTION

Most high current iron core filter chokes for DC power supplies at Fermilab are constructed from magnet laminations. Sometimes these laminations need to be trimmed to yield the correct gap. Occasionally magnets are used as DC chokes. Both of these approaches are expensive. The large forward drop across a magnet often is unacceptable and makes it very expensive to operate. For instance, operating a B2 magnet for one year at 3000 ADC costs about \$34,000. A properly designed choke could cut this operating cost to about \$4,000. It would also take less space and cause less floor loading, but its inductance would also be smaller. Constructing a customized choke from magnet laminations is still rather expensive from a labor and iron cost point of view, but at least the losses can be controlled by proper design. In general, these types of chokes are not required to be made precisely. The coil and iron dimensions are not very critical as long as they can handle the current and as long as the iron does not saturate. Therefore, it is very reasonable to make chokes from commercially available, standard, tape wound silicon steel transformer cores. Many manufacturers, such as Arnold Engineering, and others make a large variety of sizes in 12 mill thick or thinner laminations (Fig. 3). Completed cut cores cost about \$1.83/lb (1992).

Several cores can be put in parallel to yield the required amount of iron cross section, and the required gap can be made by inserting a standard thickness G-10 shim between the cut core halves. The gap prevents iron saturation. The coil, with the iron cores around it, can be mounted in a steel cradle which holds the assembly together.

This type of design has several advantages.

1. The choke design can be customized easily because of the large variety of sizes of commercially available cores.
2. The cost of steel cores is low compared to customized laminations, except probably for mass production. No custom punching dies need to be made.
3. The magnetic properties of the steel cores are superior and well published.
4. The frequency response is superior.
5. Assembly is fast. A 2500 lbs choke and completed coil can be assembled in about 2 manweeks after some practice.
6. Losses and voltage drops can be controlled by making the proper design choices.

This note describes the design of a 5000 ADC, 230 μ H choke made from standard transformer cores. Five of these chokes have been made for CDF and MTF. NOTE: Special magnets can also be made using standard cores (Ref. 1).

2.0 CHOKE PARAMETER REQUIREMENTS

Both CDF and the Magnet Test Facility needed chokes to reduce the output voltage ripple of their 5000 A, 12 phase, unfiltered DC power supplies. Chokes rated about 200 μ H at 5000 ADC, with a properly chosen capacitor, will cause sufficient ripple reduction. The voltage drop across the choke should not exceed 3 V, because of circuit voltage limits at the installation site. Thus the required choke has to be as follows:

- 2.1 ~ 200 μ H at 5000 ADC
- 2.2 $\leq 0.6 \times 10^{-3} \Omega$ at 60° C
- 2.3 Cooling water ~ 1.5 GPM at $\Delta P = 100$ PSI

Comment:

The average coil operating temperature may be 60°C or less. The maximum inlet water temperature is 40°C maximum. The outlet cannot exceed 80°C, because the choke is protected against overtemperature (loss of cooling) with thermal switches (klixons) of 80°C. The coil insulation system is usually good for 140°C maximum, but a maximum operating temperature of 80°C is generally chosen in order to avoid cooling hose connection problems and possible steam formation at hotspots in the coil. The cooling water temperature will change according to a ratio of power versus flow rate as follows:

$$\Delta T \text{ } ^\circ\text{C} = \frac{3.8 \times \text{kW}}{\text{GPM}}$$

So, as a rule of thumb, we can say that with a practical cooling water temperature rise limit of 40°C, we need one GPM of cooling water flow for every 10 kW of coil losses.

3.0 CHOKE ELECTRICAL DESIGN

3.1 Steel Choice

For starters, choose a coil current density of 2000 A/inch² for the water cooled choke winding. This means that the steel cores have to have a winding space area of about:

$$\frac{5000}{2000} \times 1.25 \sim 3 \text{ inch }^2/\text{turn}$$

$$\frac{1}{1.25} = 0.8 \text{ is the estimated copper fill factor for the winding area}$$

The winding space must be able to accommodate several turns, because the inductance increases with the square of the turns. However, more turns also require the gap to increase, because otherwise the steel would saturate at full DC current. Increasing the gap reduces the choke inductance linearly. Choose 1-1/4" x 1" copper with rounded corners and a 3/8" diameter cooling hole for the coil winding, because it is available as a leftover from the magnet factory. Each copper crosssection is 1.1in² and yields $\frac{5000}{2.2} = 2,270 \text{ A/inch}^2$ for two conductors in parallel at 5000 ADC. We are now ready to select a core from a catalogue. Arnold core #AA554 has a winding space of 11-1/4" x 2-1/2" ~ 28 inch² and can therefore accommodate 8 or 9 turns. The core has a steel crosssection of 2-11/16" x 4", or 69.35 x 10⁻⁴ m². This looks like a good choice. This core is easy to buy and weighs 98.5 lbs (or about 50 lbs / 1/2 core) and is therefore easy to handle.

We are now getting ready to calculate the inductance per core with 8 turns, but we first have to make a choice for the maximum magnetic field strength in the steel so that it

does not saturate. Choose $B = 13 \text{ kGauss}$ (1.3 Wb/m^2) maximum from published BH curves. The ampereturns needed to drive the flux through the steel of the cores can be neglected. The steel ampereturns at 13 kG are a very small fraction of the ampereturns needed to drive the same field through the choke gap. With these choices it is possible to calculate the gap and the inductance per core as follows:

$$\begin{aligned} B &\sim 1.3 \text{ Wb/m}^2 \\ N &= 8 \\ I &= 5000 \text{ A} \\ G &= ? \end{aligned}$$

How large a gap G is needed so that the core does not saturate? The cut core needs two gaps in series, one on each side. The gap can be calculated from:

$$\begin{aligned} B &= \mu_0 H & \mu_0 &= 4\pi \times 10^{-7} \text{ (mks system)} \\ & & H &= AT/m \end{aligned}$$

$$B = \frac{4\pi \times 10^{-7} \times 8 \times 5000}{2G} \sim 1.3$$

This yields $G = 1.93 \text{ cm}$. Select $G = 3/4"$ thick G10.

$$\text{Then: } B = \frac{4\pi \times 10^{-7} \times 8 \times 5000}{2 \times 0.75 \times 2.54 \times 10^{-2}}$$

$$B = 1.319 \text{ Wb/m}^2$$

The flux ϕ per core is the crosssectional area times the field strength.

$$\phi/\text{core} = 1.319 \times 69.35 \times 10^{-4}$$

$$\phi/\text{core} = 91.5 \times 10^{-4} \text{ Wb}$$

The inductance per core is the coupled flux per Ampere.

$$\text{Thus: } L/\text{core} = \frac{N\phi}{I}$$

$$L/\text{core} = \frac{8 \times 91.5 \times 10^{-4}}{5000}$$

$$L/\text{core} = 14.64 \times 10^{-6} \text{ H}$$

With 16 cores the inductance is:

$$L/16 \text{ cores} = 234 \times 10^{-6} \text{ H}$$

This looks reasonable and the coil can now be calculated. The steel cores can be arranged in two rows of eight cores. This is similar to the shell type, double core, single coil configuration shown in Fig. 3.

3.2 Coil Design

A preliminary design of the choke is shown in Drwg. #ATV090892CDF. The coil carries 5000 A, has 8 turns and uses two 1" x 1-1/4" copper conductors in parallel. Each conductor has a 3/8" diameter cooling waterhole and a copper crosssection of 1.1 inch². The current density in the copper is 2273 A/inch² at 5000A. Assume an average coil operating temperature of 60°C, which is about the worst case from a voltage drop point of view.

Properties of copper are mostly listed at 20°C and per cm³ or inch³, but it is handier to list them at operating temperature and sizes as below:

Typical Cu resistance at 60°C: $R_{60^{\circ}\text{C}} = 9.6771 \times 10^{-6} \Omega/\text{in}^2/\text{ft}$

Typical Cu weight: $W = 3.86 \text{ lbs/in}^2/\text{ft}$

Resistance temperature
coefficient per °C at 20°C: $\alpha = 0.00393$

With this information it is easy to calculate the coil.

$$I = 5000\text{A}$$

$$N = 8$$

Total Cu crosssection	= 2.2 inch ²
Coil average turn length	= 90"
Total coil weight	~ 516 lbs (120' of Cu)
Coil resistance at 60°C, $R_{60^{\circ}\text{C}}$	= $0.38 \times 10^{-3} \Omega$
Coil voltage drop at 5000A, 60°C	= 1.9 V
Coil losses at 5000A, 60°C	= 9.5 kW
Estimated flow at $\Delta P = 100 \text{ PSI}$	~ 10 GPM
Minimum needed flow at 40°C water temperature rise, or 20°C average coil temperature rise	= 1 GPM

This coil will work. The coil is wound on a winding fixture, after which B stage tape is applied around the two copper conductors in parallel. After that the coil receives a ground wrap and is cured on the winding fixture. For reference see drawings 5525-ME-274925 through -274929. There was some keystoning at the coil bends that needed to be

removed. The leads of the coil are made long for ease of connection at the installation site. Copper flags are brazed to the leads for power connections.

4.0 CHOKE ASSEMBLY

The choke is assembled in a shop and requires the use of a small crane. Two rows of eight cores are banded around the coil, with two G-10 shims used as spacers to create the gap. The winding surface walls of the cores are lined with a medium-hard rubber material and the cores are shimmed for a snug fit around the coil before banding (Fig. 3). The cores are separated by a thin piece of DMD (or other insulation material) to prevent possible iron shorts across the lamination of adjacent cores. After this, the cores are put in a cradle (Drwg. ATV010892CDF, Sh 5). A similar cradle is put on the top and both cradles are thereafter welded together with side plates. The banding buckles fall in the cavity under the side plates between the top and bottom caps. Stops are installed to prevent the assembly and the coil from sliding inside. The cores are not all equal in size and there are cavities under some cores as they sit in the "box". One gallon of epoxy is therefore poured in the bottom cradle. After the bottom epoxy is cured, the choke is turned over and another gallon of epoxy is poured in at the previous top cradle. This secures the cores and completes the assembly of the chokes. The assembly of the chokes was done at MAB. The coils were made at the Magnet Factory.

5.0 DRAWINGS

The following is a list of drawings for the choke:

#ATV010892CDF, SH1	- Power supply choke for CDF 5000ADC, 230 μ H, 0.4 Ω
#ATV010892CDF, SH2	- same as above
#ATV010892CDF, SH5	- Power supply choke for CDF core cradle
#ATV010892CDF, SH6	- Power supply choke for CDF spacer and nameplate
5525-ME-274925	- Conventional magnet facility choke coil - coil assembly
5525-ME-274926	- Conventional magnet facility choke coil - coil crosssection
5525-ME-274527	- Conventional magnet facility choke coil - shims
5525-ME-274528	- Conventional magnet facility choke coil - winding fixture
5525-ME-274929	- Conventional magnet facility choke coil - curing fixture

6.0 TESTING

The following were tested:

1)	Cooling flow	- 3.8 GPM at $\Delta P \sim 75$ PSI
2)	Pressure test	- 375 PSI for 15 min
3)	Hi-potential test 2500 Vdc, 1 min	- > 2500 M Ω
4)	DC resistance	- $0.23 \times 10^{-3} \Omega$ at $\sim 20^\circ\text{C}$
5)	Inductance	- > 230 μH ⁽¹⁾

(1) The results of the inductance test were not meaningful. The measured values at low operating current were on the order of 460 mH. This is probably caused by flux bypassing the gap via the banding buckles and the steel cradle spacer. These parts will saturate at higher currents, but testing at high current was not practical in the assembly area.

7.0 COST

The cost of the winding/curing fixture was \$4300.00 excluding design cost.

Material cost per choke:

16 Cores	-	\$2940.00	
2 cradles, 2 side plates, miscellaneous	-	\$ 175.00	
516 lbs copper (free from stock)	-	\$1500.00	(estimated value)
Total material	~	<u>\$5000.00</u>	

The labor cost for winding and curing of the coil is not precisely known, but is about \$7,500.00. Choke assembly takes about 2 manweeks.

8.0 COMMENTS

The design of this choke or similar chokes is easily modified by changing the gap, the number of turns, or the number of cores. For instance, we could put all windings in series and end up with 16 turns at 2500A. This would yield a 0.92 milliHenry choke at 2500 ADC.

Another interesting idea is to vary the thickness of the G-10 shims installed in different cores. A smaller gap causes the inductance per core to increase, but also causes it to saturate at a

lower d.c. current value. For instance, cutting the gap in half causes the inductance to increase by a factor of two, but also causes saturation at half of the original gap saturation current..

Saturation causes the inductance to decrease to a low value. We can imagine a simplified saturation effect and say that the inductance becomes zero after saturation and that the steel abruptly saturates. Each core of the 5000 A choke would then contribute $14.6 \times 10^{-6} \text{H}$ to the total choke below the saturation current and none above saturation, as shown in Fig. 1.

Figure 1: Simplified inductance per core.

Now imagine that we use different gaps in the 16 cores as follows:

	Gap	Core Saturating Current Amp	Contribution to Inductance Below Saturation μH
4 Cores	$2 \times 3/4$	5000	58.4
4 Cores	$0.8 \times 2 \times 3/4$	4000	83.0
4 Cores	$0.6 \times 2 \times 3/4$	3000	97.0
4 Cores	$0.4 \times 2 \times 3/4$	2000	146.0

This yields a total choke inductance of:

Operating Current AMP	Total Choke Inductance μH
5000	58
4000	141
3000	238
2000	384

The inductance of this tapered gap choke as a function of the current is plotted in Figure 2.

Figure 2: Tapered gap choke

Other combinations can be made. This is interesting, because power supply ripples are about twice as large (12 phase unfiltered) at medium output voltage than at full output. The ripple filter choke inductance can therefore be smaller at high power supply output. Lighter weight tapered gap chokes could therefore be just as effective, when used as power supply ripple filter chokes.

9.0 ACKNOWLEDGEMENT

The assembly of the chokes was coordinated by John Juneau at MAB. He did an excellent job.

10.0 REFERENCES

- (1) TM1605, A.T. Visser, July 1989, A novel flattop current regulated energy discharge type pulsed power supply and magnet yielding 4.4 kGaussmeter for 6 milliseconds.

BANDING DATA

Core Strip Width (in.)	Core Cross-Section (D x E) - in ²	Band Size (in.)	No. Bands Required	Seal Dimension (in.)	Banding Force (lb.)
Any	.188 or less	3/16 x .006	1	3/16 x 1/4	37.5
3/8 or larger	.188 to .375	3/8 x .006	1	3/8 x 3/8	75
3/8 to 1-1/2	.375 to .75	3/8 x .012	1	3/8 x 3/8	150
1-5/8 or larger		3/8 x .006	2	3/8 x 3/8	75
1/2 to 1-1/8	.75 to 1.5	3/8 x .012	1	3/8 x 3/8	150
1-1/4 or larger		3/8 x .012	2	3/8 x 3/8	150
3/4 or larger	1.5 to 3.0	3/4 x .023	1	7/8 x 1-7/8	600
3/4 or larger	3.0 to 4.25	3/4 x .035	1	7/8 x 1-7/8	900
2 or larger	4.25 to 6.0	3/4 x .023	2	7/8 x 1-7/8	600
3-1/4 or larger	6.0 to 9.0	3/4 x .023	3	7/8 x 1-7/8	600
3-1/4 or larger	9.0 to 13.5	3/4 x .035	3	7/8 x 1-7/8	900

Figure 3

ENGINEERING NOTE	SECTION	PROJECT	SERIAL CATEGORY	PAID
POWER SUPPLY CHOKE FOR CDF	EEO	CDF	KEPHART	1
5000AOC, 230 VAC, 0.4 A			NAME A.T. VANDER	
			DATE 1/8/92	REVISION DATA
				PREL.

DRW# ATVO10892CDF
SH 1
REF 9204 ED 173037

CHOKE
 $B = \mu_0 H$, $N = 8$, $I = 5000 A$
 $B = \frac{4\pi \times 10^{-7} \times 8 \times 5000}{2 \times 0.75 \times 2.54 \times 10^{-2}} = 1.319 \frac{Wb}{m^2}$
 $\Phi = BA$ (NEGLECT IRON AT)
 $\Phi_{CORE} = 1.319 \times 69.35 \times 10^{-4} = 91.49 \times 10^{-6} Wb$
 $L_{CORE} = \frac{N\Phi}{I} = \frac{8 \times 91.49 \times 10^{-6}}{5000}$
 $L_{CORE} = 14.64 \times 10^{-6} H$
 $L_{16 CORES} = 234.2 \times 10^{-6} H$ (UP TO 5000 ADC)

COIL AVERAGE TURN LENGTH 90°
 CU CROSS $= 1.1 \text{ mm}^2$, 4.3 LB/FT
 CU $R_{20^\circ C} = 8 \times 10^{-6} \Omega/FT$
 $R_{COIL 20^\circ C} = \frac{1}{2} \times 8 \times 90 \times 10^{-6} = 3.6 \times 10^{-3} \Omega$
 $R_{COIL 60^\circ C} = 0.84 \times 10^{-3} \times 1.1 \times 10^{-3} \times 0.0093 = 0.98 \text{ m}\Omega$
 $V_{COIL AT 5000A} = 1.9 V$
 COIL LOSSES $= 9.43 \text{ KW AT } 5000A$
 NEEDED COOLING $\sim 1 \text{ GPM AT } 27 \sim 38^\circ C$
 CU LENGTH/WINDING $\sim 60 \text{ FT}$, 258 LBS
 FLOW/WINDING $\sim 5 \text{ GPM AT } 27 \sim 100 \text{ PSI}$
 TOTAL COIL: WEIGHT $\sim 516 \text{ LBS}$ CU, 10AFT
 FLOW $\sim 10 \text{ GPM AT } 27 \sim 100 \text{ PSI}$ (PARALLEL WATER)
 KLIYON - $80^\circ C$ AT PART.
 TOTAL STL: WEIGHT $\sim 1576 \text{ LBS}$
 TOTAL INDUCTOR $\sim 2500 \text{ mH}$ AT $27 \sim 100 \text{ PSI}$

FIRMILAS ENGINEERING NOTE	SECTION	PROJECT	SERIAL CATEGORY	PAGE
	FED	COF	MEPHART	2
	SUBJECT: POWER SUPPLY CHOWS FOR COF			
NAME		DATE		
A.T. VISSER		1/8/92		
REVISION DATA				

DRW 8.37V010842 CDF
(PR-34) SH 2

COIL: 16 TURNS $1 \frac{1}{4} \times 1$ WITH $3/8$ HOLE CU
2 TURNS IN PARALLEL
INSULATION $1/8$ TURN
B-STAGE FIBERGLASS 2T, HALTAMP
GROUND WRAP

SEE SH 1
FOR CONNECTION

*CHECK WITH MAGNET
CHECK FIT IN CORE OF FINISHED COIL

REF 9204 ED 173051

ENGINEERING NOTE	SECTION	PROJECT	SERIAL CATEGORY	PAUL
	EE-3	LDF	WEPHART	4
	SUBJECT POWER J. RAY CHOKER FOR LDF CHOKER POWER TERMINAL			
	NAME: AT VISOR DATE: 1/2/92 REVISION DATE:			

DRW# ATN010892CDF
JH-4

REF 4204ED 173051

ENGINEERING NOTE POWER SUPPLY CHOME FOR CDF CORE CABLE	REGION	PROJECT	SERIAL CATEGORY	PALE
	EEO	CDF	WEPHART	5
	NAME		DATE	
	A.T. VILNER		1/18/72	
REVISION DATE				

BRW 43TV012892CDF
JH5

REMOVE BURR, SCALE, RUIT
REF 9204 ED173051

REV.	DESCRIPTION	DATE	BY
A	REVISIONS AND WINDING POSITION	5.1.8	5.1.8
B	CONDUCTOR WRAP AND CONDUCTOR WRAP	5.1.8	5.1.8
C	CONDUCTOR WRAP AND CONDUCTOR WRAP	5.1.8	5.1.8

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120	121	122	123	124	125	126	127	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	144	145	146	147	148	149	150	151	152	153	154	155	156	157	158	159	160	161	162	163	164	165	166	167	168	169	170	171	172	173	174	175	176	177	178	179	180	181	182	183	184	185	186	187	188	189	190	191	192	193	194	195	196	197	198	199	200	201	202	203	204	205	206	207	208	209	210	211	212	213	214	215	216	217	218	219	220	221	222	223	224	225	226	227	228	229	230	231	232	233	234	235	236	237	238	239	240	241	242	243	244	245	246	247	248	249	250	251	252	253	254	255	256	257	258	259	260	261	262	263	264	265	266	267	268	269	270	271	272	273	274	275	276	277	278	279	280	281	282	283	284	285	286	287	288	289	290	291	292	293	294	295	296	297	298	299	300	301	302	303	304	305	306	307	308	309	310	311	312	313	314	315	316	317	318	319	320	321	322	323	324	325	326	327	328	329	330	331	332	333	334	335	336	337	338	339	340	341	342	343	344	345	346	347	348	349	350	351	352	353	354	355	356	357	358	359	360	361	362	363	364	365	366	367	368	369	370	371	372	373	374	375	376	377	378	379	380	381	382	383	384	385	386	387	388	389	390	391	392	393	394	395	396	397	398	399	400	401	402	403	404	405	406	407	408	409	410	411	412	413	414	415	416	417	418	419	420	421	422	423	424	425	426	427	428	429	430	431	432	433	434	435	436	437	438	439	440	441	442	443	444	445	446	447	448	449	450	451	452	453	454	455	456	457	458	459	460	461	462	463	464	465	466	467	468	469	470	471	472	473	474	475	476	477	478	479	480	481	482	483	484	485	486	487	488	489	490	491	492	493	494	495	496	497	498	499	500	501	502	503	504	505	506	507	508	509	510	511	512	513	514	515	516	517	518	519	520	521	522	523	524	525	526	527	528	529	530	531	532	533	534	535	536	537	538	539	540	541	542	543	544	545	546	547	548	549	550	551	552	553	554	555	556	557	558	559	560	561	562	563	564	565	566	567	568	569	570	571	572	573	574	575	576	577	578	579	580	581	582	583	584	585	586	587	588	589	590	591	592	593	594	595	596	597	598	599	600	601	602	603	604	605	606	607	608	609	610	611	612	613	614	615	616	617	618	619	620	621	622	623	624	625	626	627	628	629	630	631	632	633	634	635	636	637	638	639	640	641	642	643	644	645	646	647	648	649	650	651	652	653	654	655	656	657	658	659	660	661	662	663	664	665	666	667	668	669	670	671	672	673	674	675	676	677	678	679	680	681	682	683	684	685	686	687	688	689	690	691	692	693	694	695	696	697	698	699	700	701	702	703	704	705	706	707	708	709	710	711	712	713	714	715	716	717	718	719	720	721	722	723	724	725	726	727	728	729	730	731	732	733	734	735	736	737	738	739	740	741	742	743	744	745	746	747	748	749	750	751	752	753	754	755	756	757	758	759	760	761	762	763	764	765	766	767	768	769	770	771	772	773	774	775	776	777	778	779	780	781	782	783	784	785	786	787	788	789	790	791	792	793	794	795	796	797	798	799	800	801	802	803	804	805	806	807	808	809	810	811	812	813	814	815	816	817	818	819	820	821	822	823	824	825	826	827	828	829	830	831	832	833	834	835	836	837	838	839	840	841	842	843	844	845	846	847	848	849	850	851	852	853	854	855	856	857	858	859	860	861	862	863	864	865	866	867	868	869	870	871	872	873	874	875	876	877	878	879	880	881	882	883	884	885	886	887	888	889	890	891	892	893	894	895	896	897	898	899	900	901	902	903	904	905	906	907	908	909	910	911	912	913	914	915	916	917	918	919	920	921	922	923	924	925	926	927	928	929	930	931	932	933	934	935	936	937	938	939	940	941	942	943	944	945	946	947	948	949	950	951	952	953	954	955	956	957	958	959	960	961	962	963	964	965	966	967	968	969	970	971	972	973	974	975	976	977	978	979	980	981	982	983	984	985	986	987	988	989	990	991	992	993	994	995	996	997	998	999	1000	1001	1002	1003	1004	1005	1006	1007	1008	1009	1010	1011	1012	1013	1014	1015	1016	1017	1018	1019	1020	1021	1022	1023	1024	1025	1026	1027	1028	1029	1030	1031	1032	1033	1034	1035	1036	1037	1038	1039	1040	1041	1042	1043	1044	1045	1046	1047	1048	1049	1050	1051	1052	1053	1054	1055	1056	1057	1058	1059	1060	1061	1062	1063	1064	1065	1066	1067	1068	1069	1070	1071	1072	1073	1074	1075	1076	1077	1078	1079	1080	1081	1082	1083	1084	1085	1086	1087	1088	1089	1090	1091	1092	1093	1094	1095	1096	1097	1098	1099	1100	1101	1102	1103	1104	1105	1106	1107	1108	1109	1110	1111	1112	1113	1114	1115	1116	1117	1118	1119	1120	1121	1122	1123	1124	1125	1126	1127	1128	1129	1130	1131	1132	1133	1134	1135	1136	1137	1138	1139	1140	1141	1142	1143	1144	1145	1146	1147	1148	1149	1150	1151	1152	1153	1154	1155	1156	1157	1158	1159	1160	1161	1162	1163	1164	1165	1166	1167	1168	1169	1170	1171	1172	1173	1174	1175	1176	1177	1178	1179	1180	1181	1182	1183	1184	1185	1186	1187	1188	1189	1190	1191	1192	1193	1194	1195	1196	1197	1198	1199	1200	1201	1202	1203	1204	1205	1206	1207	1208	1209	1210	1211	1212	1213	1214	1215	1216	1217	1218	1219	1220	1221	12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REV	DESCRIPTION	DATE

ITEM	PART NO.	DESCRIPTION OR SIZE	QTY.
PARTS LIST			
1	AXIS	AXIS	2-5-92
2	AXIS	AXIS	2-5-92
3	AXIS	AXIS	2-5-92
4	AXIS	AXIS	2-5-92
5	AXIS	AXIS	2-5-92
6	AXIS	AXIS	2-5-92
7	AXIS	AXIS	2-5-92
8	AXIS	AXIS	2-5-92
9	AXIS	AXIS	2-5-92
10	AXIS	AXIS	2-5-92
11	AXIS	AXIS	2-5-92
12	AXIS	AXIS	2-5-92
13	AXIS	AXIS	2-5-92
14	AXIS	AXIS	2-5-92
15	AXIS	AXIS	2-5-92
16	AXIS	AXIS	2-5-92
17	AXIS	AXIS	2-5-92
18	AXIS	AXIS	2-5-92
19	AXIS	AXIS	2-5-92
20	AXIS	AXIS	2-5-92
21	AXIS	AXIS	2-5-92
22	AXIS	AXIS	2-5-92
23	AXIS	AXIS	2-5-92
24	AXIS	AXIS	2-5-92
25	AXIS	AXIS	2-5-92
26	AXIS	AXIS	2-5-92
27	AXIS	AXIS	2-5-92
28	AXIS	AXIS	2-5-92
29	AXIS	AXIS	2-5-92
30	AXIS	AXIS	2-5-92
31	AXIS	AXIS	2-5-92
32	AXIS	AXIS	2-5-92
33	AXIS	AXIS	2-5-92
34	AXIS	AXIS	2-5-92
35	AXIS	AXIS	2-5-92
36	AXIS	AXIS	2-5-92
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41	AXIS	AXIS	2-5-92
42	AXIS	AXIS	2-5-92
43	AXIS	AXIS	2-5-92
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98	AXIS	AXIS	2-5-92
99	AXIS	AXIS	2-5-92
100	AXIS	AXIS	2-5-92

PERM NATIONAL ACCELERATOR LABORATORY			
UNITED STATES DEPARTMENT OF ENERGY			
CONVENTIONAL MAGNET FACILITY			
CHOKE-COIL			
COIL CROSS SECTION			
SCALE	1/2" = 1"	DATE	5-5-92
DESIGNED BY	D. RISSMAN	CHECKED BY	D. RISSMAN
DRAWN BY	D. RISSMAN	APPROVED BY	D. RISSMAN
DATE	5-5-92	DATE	5-5-92
REV	1	REV	1

10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200
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REV.	DESCRIPTION	DRAWN	DATE
		APPD.	DATE

ITEM	PART NO.	DESCRIPTION OR SIZE	QTY.
PARTS LIST			
UNLESS OTHERWISE SPECIFIED		ORIGINATOR	
XX	XXX	ANGLES	DRAWN
1.03	+	+	CHECKED
1. BREAK ALL SHARP EDGES .02 MAX.		APPROVED	
2. DO NOT SCALE DRAWING.		USED ON	ME-274928
3. DIMENSIONS BASED UPON ANST Y14.5M-1982		MATERIAL	ALUM. 6061-T6
4. MAX. ALL MACH. SURFACES 125
FERMI NATIONAL ACCELERATOR LABORATORY UNITED STATES DEPARTMENT OF ENERGY			
CONVENTIONAL MAGNET FACILITY CHOKE-COIL SHIMS			
SCALE	FILMED	DRAWING NUMBER	REV.
FULL		5525-MA-274927	
CREATED WITH I-DEAS 4.1		USER NAME: D. RISSMAN

DETAIL 2

DETAIL 3

DETAIL 4

DETAILS

[illegible]