TESLA WORKSHOP #2 11-Dec-91

SUMMARY GROUP #7; CRYOGENICS AND CRYOSTATS

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TESLA WORKSHOP #1

The first workshop centered on the choice of optimum frequency, 1500 vs. 3000MHz. Heat loads were dominated by the ability to get HOM loads out of the 2K system; total loads as high as 10W/m were being discussed.

The configuration was based on 28m modules with an active length of 20m; these were grouped into 250m sectors which could be independently warmed up or cooled down. The sectors were then combined into strings of up to 1km, which was limited by the heat load with two strings cooled by a 10kw refrigerator.

The 28m cryostat contained three refrigeration loops: 1) a 80K outer shield cooled by either LN2 or He gas, 2) a 13 to 15K inner shield loop, and 3) a 2K primary loop. The primary loop used a 2.8bar 2.2K supply header with branch JT valves for the 250m sector; the boil off gas was connected to a 300mm low pressure return header every 28m.

PRIOR TO TESLA WORKSHOP #2

A collaboration lead by Cornell and DESY worked on the parameters, concepts and problems from the first workshop to develop a 0.5 Tev conceptual design using 25Mv/m. The HOM problems drove the design frequency down and 1300MHz was chosen based on klystron availability. As part of this effort Horlitz developed a conceptual He distribution design and Trines developed it into a 12m cryostat conceptual design. Group #7 started it meeting with presentations of these two designs which then formed a starting point for their discussion.

REFRIGERATOR CONFIGURATION

The 0.5 Tev Linac has an active length of 20.7km; using a filling factor of 1/1.45, this gives us a physical length of 30km. Eight 10kw 2.0K refrigerators with a spacing of 3.7km are used; each is supplying two 1.85km strings, figure 1. These units are twice the size of the CEBAF refrigerator, which was felt to be the current limit of the cold compressor technology. Each refrigerator provides cooling for three refrigeration loops. The first loop uses 40K 20bar He to first absorb HOM power from stainless steel beam tubes every 12m and then cools the outer shield returning at 60K. The second loop uses 4.5K 3bar He to first cool superconducting quads and correctors, and to provide lead flow. It then cools the inner shield returning at about 5.5K and flashing in the return flow control JT valve providing liquid for the 4.5K subcooler. The third loop supplies 2.2K at 3bar to JT valves spaced every 144m, figure 2.

The concept of independent warm up and cool down sectors, which is a major part of the SSC design and was part of TESLA 1, was tentatively deleted. The majority felt that due to the low mass (but high liquid volume) and the lack of a large number of warm up cycles at HERA, it was not needed. The group did impose a six day repair cycle which when detailed calculations are done may force the sector to reappear.

140m SECTION COOLING

Table 1 shows the segmentation of the accelerator; each string is made of 12 144m sections. It was concluded that each 2K cooling loop should be independent as shown in figure 3. The inlet JT drops the pressure from 3 bar to 0.031 bar and is followed by a phase separator which reduces turbulence and produces stratified flow in the 100mm header. The liquid level is regulated to between 25 and 50mm at the outlet end by using the JT as a flow control valve; nominal flow being 20g/sec. At the outlet end gas is taken off the top and enters the 300mm header.

Table 1. Segmentation

Element	Length (m)		Filling Factor	Number/ Assemble	Total #
	Active	Physical			
CAVITY	1.038	1.385	79.9%	8	19,968
MODULE	8.31	12.00	74.2%	12	2,496
SECTION	99.7	144.0	74.2%	13	208
SECTOR	NA	NA	NA	NA	NA
STRING	1,296	1,872	74.2%	2	16
REFRIGERATOR	2,592	3,744	74.2%	8	8
LINAC	20,737	29,952	74.2%		

NOTE: Some of the numbers in this report have been adjusted after the meeting to make the design selfconsistent!

The instrumentation for vacuum and cryogenics is restricted to the ends of the section to limit costs as well as operator data over load. The concept of uncabled extra local sensors for trouble shooting was discussed as an option if needed.

There was a lengthy discussion on the segmentation of the vacuum system; the majority of the group concluded the insulating vacuum should have vacuum breaks every 144m with a controllable beam vacuum isolation valve.

CYROSTAT

In order to make TESLA affordable, we need to achieve major cost reductions in the cryostat which accounts for almost half of the module cost. This requires a cryostat closer to an SSC magnet than what has been used for cavities in the past.

The concept is to use the 300mm header as the support/alignment element with a center anchor post and two end flexible supports (or sliding posts) to provide for 15mm of thermal contraction. The cavities are aligned on the header, shields are attached and the entire assembly is slid into the vacuum vessel. The integration concepts of the cold quad and corrector into the module had not been fully developed.

Table 2. System Heat Load Budgets and Capacity

LOAD W/m active	2.0 K	5 K	50 K
STATIC LOAD	0.55	1.25	4.7
RF LOAD AT 2.0K	2.35		
COUPLER AC LOAD	0.10	0.10	0.5
HOM LOAD	0.48		1.8
CORRECTOR LEAD FLOW (1L/hr=5W)		0.10	
TOTAL W/m	3.5	1.5	7.0
REFRIGERATOR LOAD	9.026	3,759	18.145
REFRIGERATOR CAPACITY	10,000	7,500	25,000
MARGIN	111%	200%	138%

Table 3. Static Heat Load Budget

LOAD W/m active	2.0 K	5 K	50 K
RADIATION	0.05	0.35	2.00
SUPPORTS	0.05	0.20	0.70
COUPLERS	0.15	0.50	1.60
INSTRUMENTATION	0.10	0.05	0.05
VALVES & RELIEFS	0.10	0.05	0.05
UNALLOCATED	0.10	0.10	0.30
TOTAL W/m	0.55	1.25	4.70
MODULE TOTAL WATTS	4.57	10.39	39.05

The end fundamental power couplers must be able to provide for the 15mm of thermal contraction. Table 2 provides the total heat load budget and refrigeration capacity as provided by the different working groups. Table 3 in turn breaks down the static heat load budget for the individual component designers to use.

PRESSURE AND TEMPERATURE LIMITS

The cavity operating temperature depends on two factors: A) the cost optimum and B) ability to achieve gradient at chosen temperature. The gradient chosen was 25MV/m with a effective duty factor of 1.532%, which the refrigerators see as an effective gradient of 3.09MV/m, well below any cost optimum (ref. 1). Figure 4 shows the capital and operating cost minimums.

Superfluid heat transfer is required to achieve the high gradients, *i.e.*, we must operate below 2.177K.

We have therefore chosen 2.000K as the refrigerator operating temperature. The pressure drops of the system then give us 2.035K as the cavity operating temperature, Table 4. This provides us with more than a 0.1K safety margin and is not too far below the economic optimum.

The technology used to reach 2.0K is the cold compressor; the TESLA cold compressor would have to be a factor two larger capacity than those currently being commissioned at CEBAF.

Table 4. Delta T & Delta P Budget

2.0K RETURN T refrigerator:

	2.000 K	
DT height:	0.002 K	
DT 100mm:	0.003 K	20 g/sec
DT 300mm:	0.018 K	240 g/sec
DT subcooler:	0.012 K	
T cavity:	2.035 K	

2.2K SUPPLY:	0.2 BAR/Km MAX	3 BAR, 250 g/sec
4.5K SUPPLY:	0.1 BAR/Km MAX	3 BAR, 150 g/sec
5.5K RETURN:	0.1 BAR/Km MAX	3 BAR, 150 g/sec
50K SHIELD:	1.0 BAR/Km MAX	20 BAR, 70 g/sec

The refrigerator margin is always a significant cost issue. For refrigerators that use cold compressors this is a much bigger issue since they can not be efficiently run at reduced capacity. Current calculations indicate that the minimum CEBAF capacity is 70%, the load being provided by electric 2K heaters. If the physics requirement for energy is flexible, and since the RF load goes with the square of energy, we can use a 110% margin at 2.0K to minimize power consumption.

An alternate approach is to use extra stages of cold compression and/or variable interstage cooling. The absolute minimum number of stages is three. CEBAF uses four and should get turn down to 70%; five stages with some interstage cooling should provide some reasonable turn down, figure 2.

The 50K margin was chosen at 140% to allow for refrigerator degradation and high outer shield heat loads due to vacuum leaks. The 5K margin was chosen at 200% to deal with cold compressor efficiency, lead cooling, and inventory control liquefaction.

The pressure rating of the system is always a major area of controversy; the refrigeration and RF people want it higher, the cavity people want it lower to reduce Nb costs, and the cryostat people are in middle. Table 5 shows range of what the group felt was the optimum rating. The final choice must be based on a MTBF analysis to provide a minimum capital and operating cost as well as operating reliability.

For TESLA there are a number of major issues that are driving the design to higher pressure rating in addition to the normal refrigeration issues. The RF desire is for a stiffness of 5Hz/mBAR to reduce the resonant frequency change due to the electromagnetic pressure and to reduce its vibration sensitivity due to ground motion and to accelerator pulsing. A higher pressure also greatly simplifies the cryostat design by reducing the number of relief valves and the requirement for larger interconnect piping.

MISCELLANEOUS PARAMETERS

Table 6 provides a number of other miscellaneous parameters that the group felt was important. The current cryogenic design is a gravity fed and therefore the pipe diameters limit the incline.

Table 5. Maximum Allowable Working Pressure

CAVITY AND 300mm HEADER:			
	HOT:	2 to 4 BAR	Nb YIELD LIMIT
	COLD:	3 to 6 BAR	BELLOWS LIMIT
PIPING:		20 BAR	
CRYOSTAT:		2 BAR	SET RELIEF LOWER

Table 6. Miscellaneous Parameters

MAXIMUM ACCELERATOR INCLINE:	0.02%		
COOLDOWN TIME:	1 DAY 300 to 5K, 1 DAY FILL		
WARM UP TIME:	3 DAYS		
MAXIMUM TEMPERATURE GRADIENTS:	TBD	GOAL	2 K: >50 K 5 K: 295 K 50 K: 250 K

There was a disagreement on how important fast warm up is. Fermilab has had 75 partial warm up for repairs while HERA which is just starting up has had almost none. This led to a compromise for a six day repair cycle.

AREAS THAT REQUIRE ADDITIONAL WORK

A) The current design for the cryostat has the fundamental power coupler entering the cavity outside of the liquid He bath. This may cause the cavity to quench. SACLEY will be testing this over the next six months.

B) The alignment requirements and their requirements for the cryostat supports needs to be understood.

C) R&D in the windows is required.

D) A failure mode analysis must be done.

E) The detailed design of the relief valve system needs to be done. The current design requires reliefs to the surface every 1872m.

F) The cooldown and warm up stresses must be analyzed.

G) The issue of whether the cavities should mounted above or below the 300mm header should be reviewed.

REFERENCES

1. "Cryogenic Optimization for Cavity Systems," D. Proch and C. H. Rode, Proceedings of the 1989 IEEE Particle Accelerator Conference, 89CH2669-0, 589, (1989).

TESLA REFRIGERATION LAYOUT

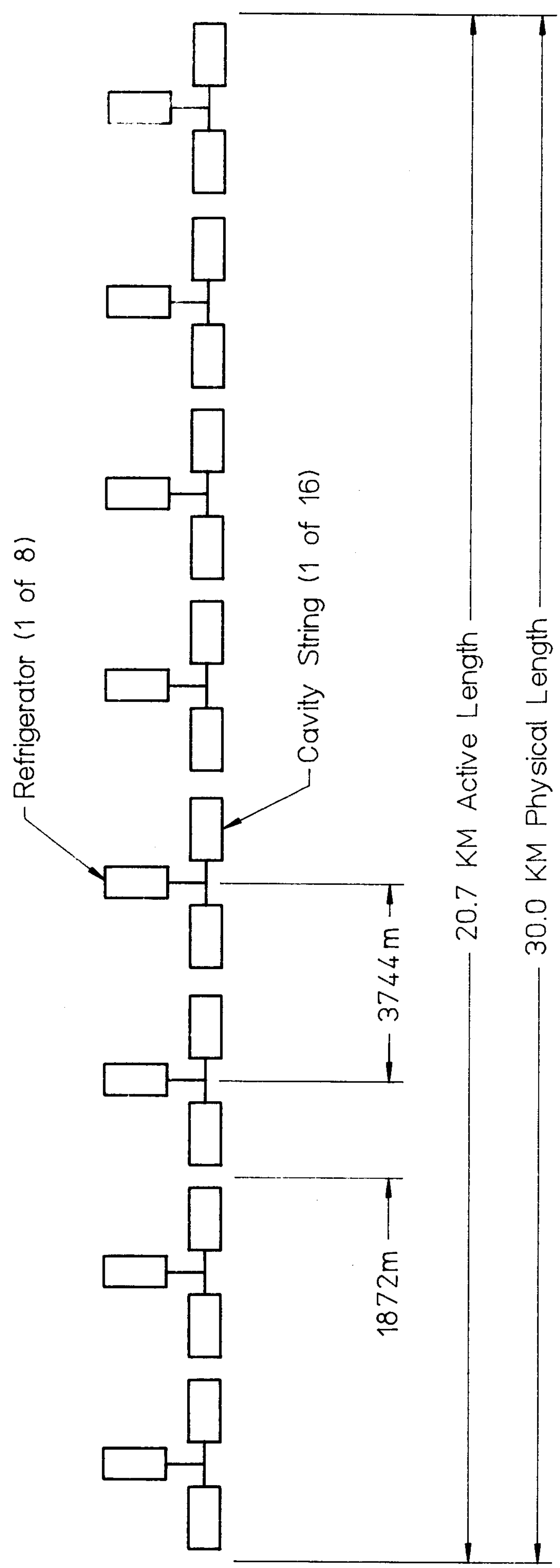

FIGURE 1

/usr4/wbs/7/CHR_MISC/tesla_fig1

TESLA 1872M CAVITY STRING COOLING

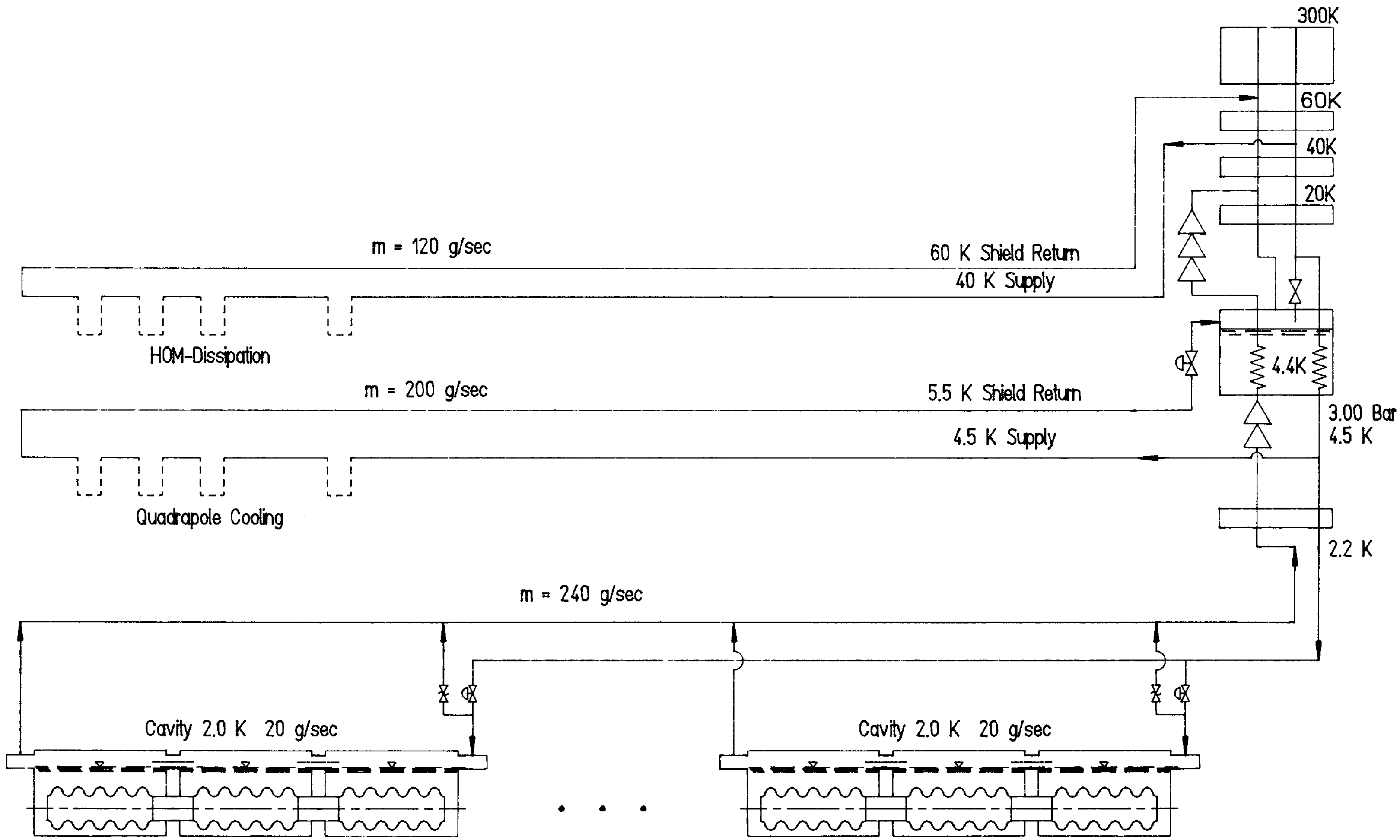

FIGURE 2

/wbs/7/CHR_MISC/tesla_fig2

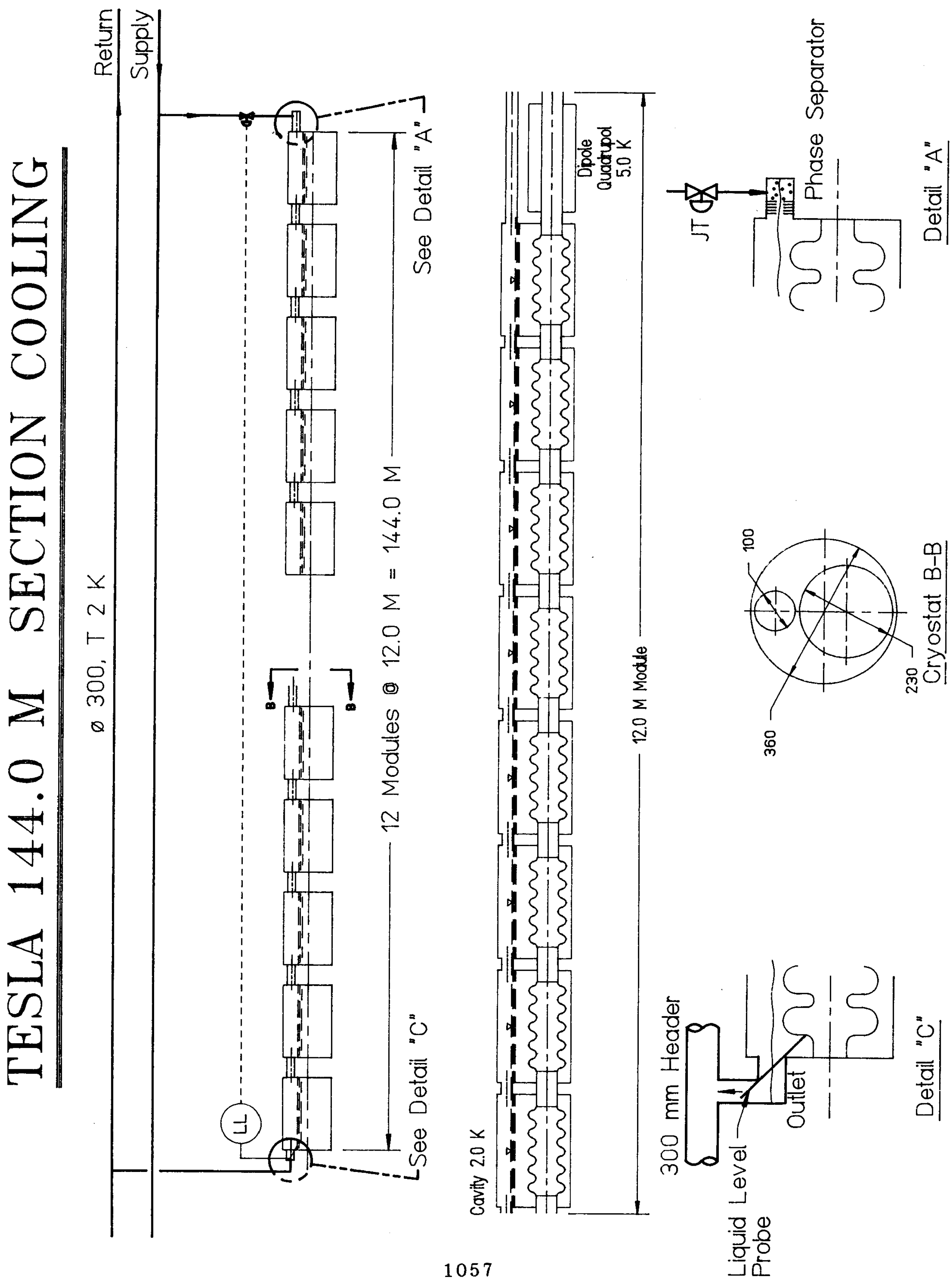

FIGURE 3

/usr4/wbs/7/CHR_MISC/tesla_fig3

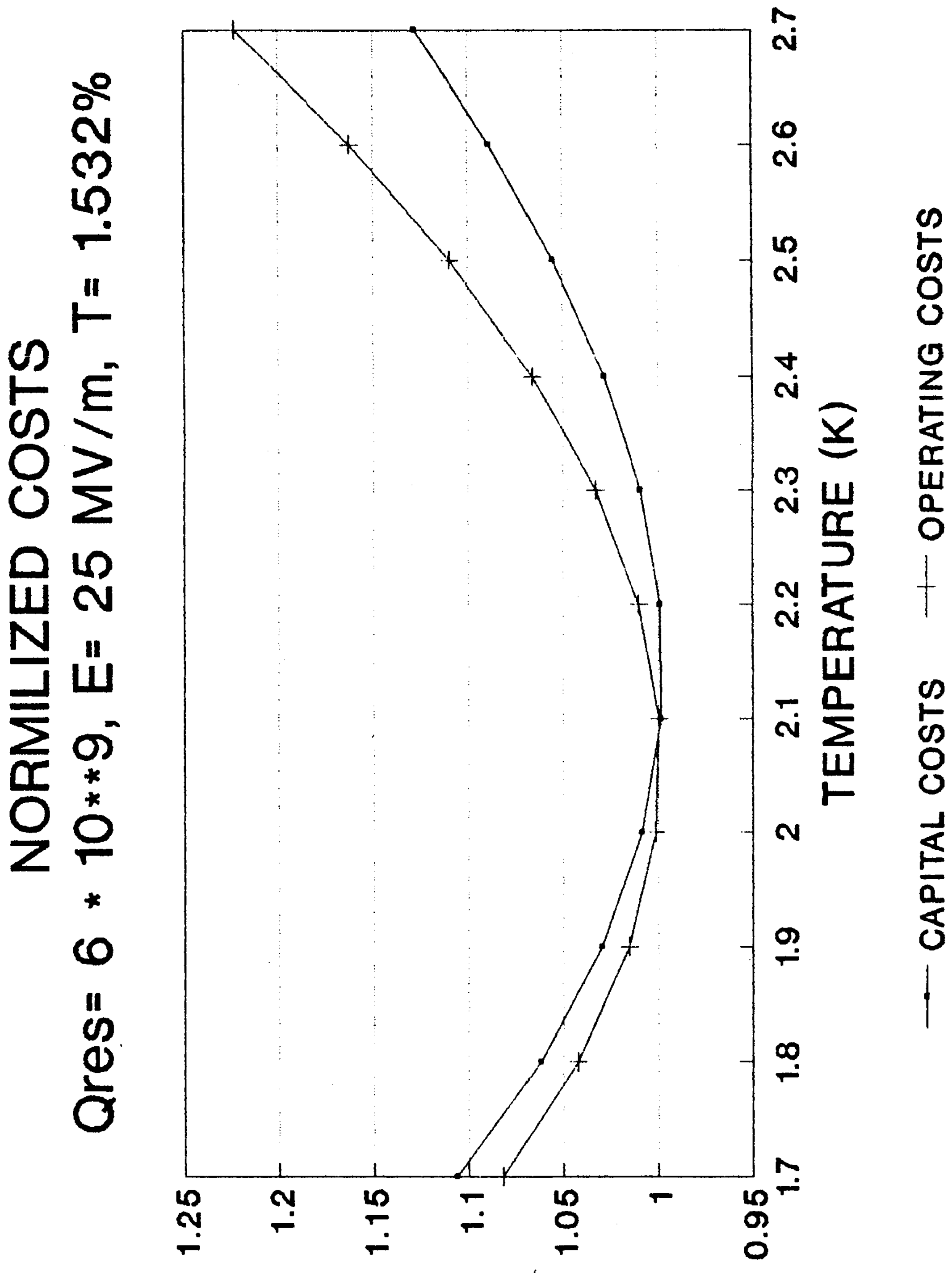
NORMILIZED COSTS
Qres= 6 * 10**9, E= 25 MV/m, T= 1.532%
1.25
1.2
1.15
1.1
1.05
1
0.95
1.7
1.8
1.9
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
TEMPERATURE (K)
CAPITAL COSTS
OPERATING COSTS

FIGURE 4