BABAR
Superconducting Solenoid Quench Protection Review

October 17, 1996

BABAR

Babar Characters TM & © L. de Brunhoff

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3 BABAR Solenoid - P. Fabbricatore

4 Quench Analysis - P. Valente

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AVERY READY INDEX™ INDEXING SYSTEM

Quench Protection Review

Thursday October 17, 1996
Orange Room
Agenda

9:00 - 9:30	Introduction	T. O'Connor (LLNL)
9:30 - 10:00	BABAR Solenoid	P. Fabbricatore (INFN)
10:00 - 11:00	Quench Analysis	P. Valente (Ansaldo)
11:00 - 12:00	Quench Protection	P. Valente (Ansaldo)
12:00 - 1:00	Working Lunch - Orange Room	
1:00 - 2:00	Quench Protection (Cont. if necessary)	P. Valente (Ansaldo)
2:00 - 3:00	Discussion	All

LAWRENCE LIVERMORE NATIONAL LABORATORY

7000 East Ave., P.O. Box 808, L-287, Livermore, CA 94550
Email: toconnor@llnl.gov Phone: (510) 423-8781
Fax: (510) 422-6747 (verify, 510-423-7533)

October 11, 1996

Dr. Steve St. Lorant
P.O Box 4349, M/S 20
Stanford Linear Accelerator Center
Stanford, CA 94309

Dear Dr. St. Lorant:

Thank you for agreeing to participate in the Quench Protection Review of the superconducting solenoid for the BABAR Detector scheduled for October 17, 1996 at Stanford Linear Accelerator Center. This review is part of our normal preparation before procuring the solenoid.

The charge to the review group is:

1. Is the quench analysis complete?
2. Is the BABAR solenoid adequately protected during a quench?
3. Is there anything that could be done to improve the protection?
4. Is adequate testing being planned?
5. Is there enough redundancy in the quench protection system?
6. Have we overlooked anything?

Stewart Shen has agreed to be the lead reviewer, and the full membership is attached.

The review agenda and maps of the area are enclosed. If documentation is available before the review I will send you a copy of it.

Yours in appreciation,

Thomas G. O'Connor
Magnet Co-System Manager

cc: B. Bell (SLAC)
D. Hitlin (SLAC)
L. Keller (SLAC)
V. Luth (SLAC)

List of Reviewers:

Dr. Steve St. Lorant
P.O Box 4349, M/S 20
Stanford Linear Accelerator Center
Stanford, CA 94309
(415) 926-2671

Dr. Stewart Shen
Lawrence Livermore Nat. Lab
P.O. Box 808, L-287
Livermore, CA 94550
(510) 423-4826
(510) 422-6747 (fax)

Dr. Jon Zbasnik
Lawrence Livermore Nat. Lab
P.O. Box 808, L-643
Livermore, CA 94550
(510) 423-5634
(510) 422-2477 (fax)

Introduction

Thomas G. O'Connor

Accelerator Technologies Engineering Group
Lawrence Livermore National Laboratory

October 17, 1996
BABAR Superconducting Solenoid Quench Protection Review
Stanford Linear Accelerator Center

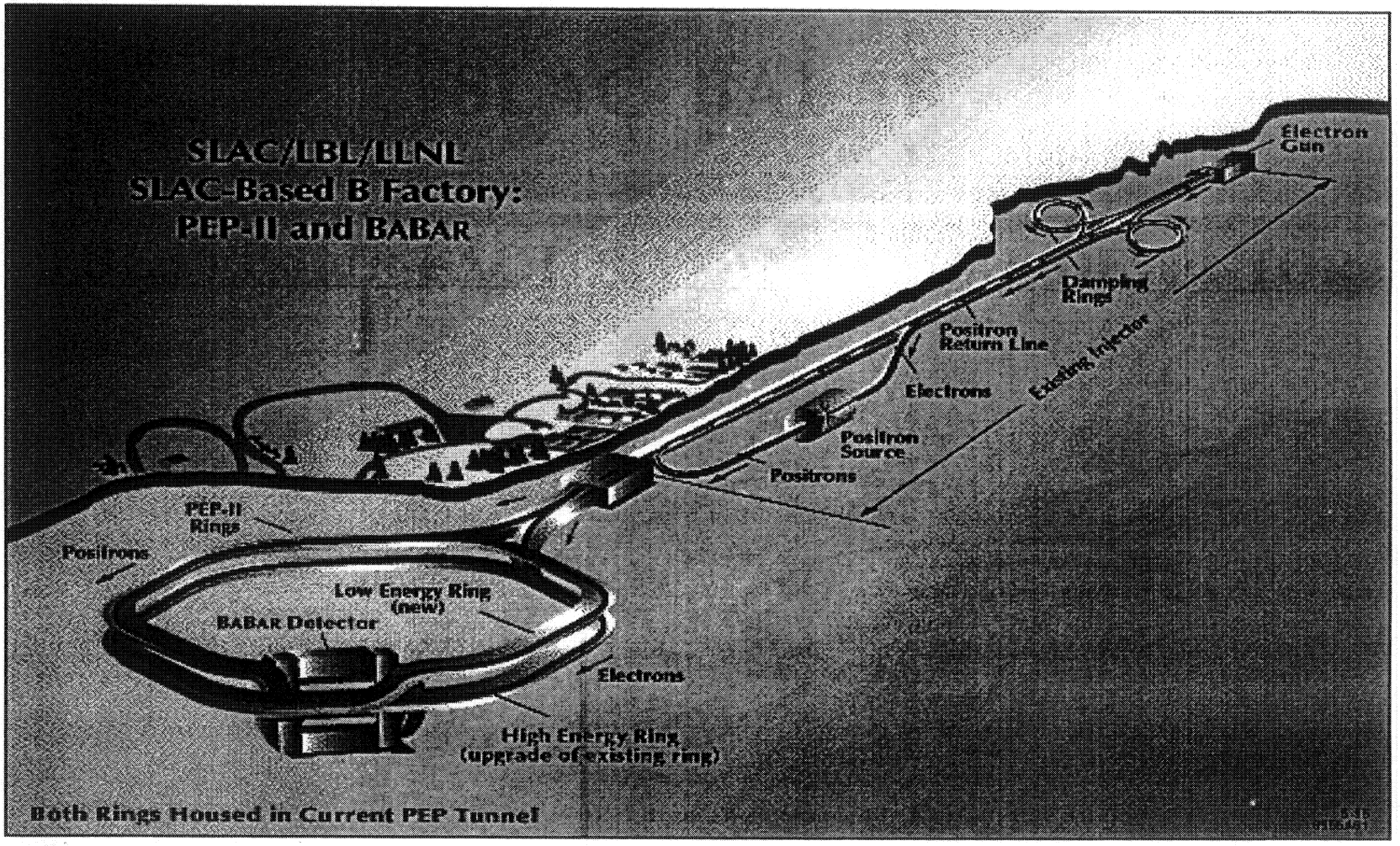
SLAC- BABAR

Outline

- Overview of SLAC
- Purpose of the BABAR Detector
- List of BABAR Collaborators
- Magnet System Group
- Magnet System Schedule
- Charge to the Reviewers

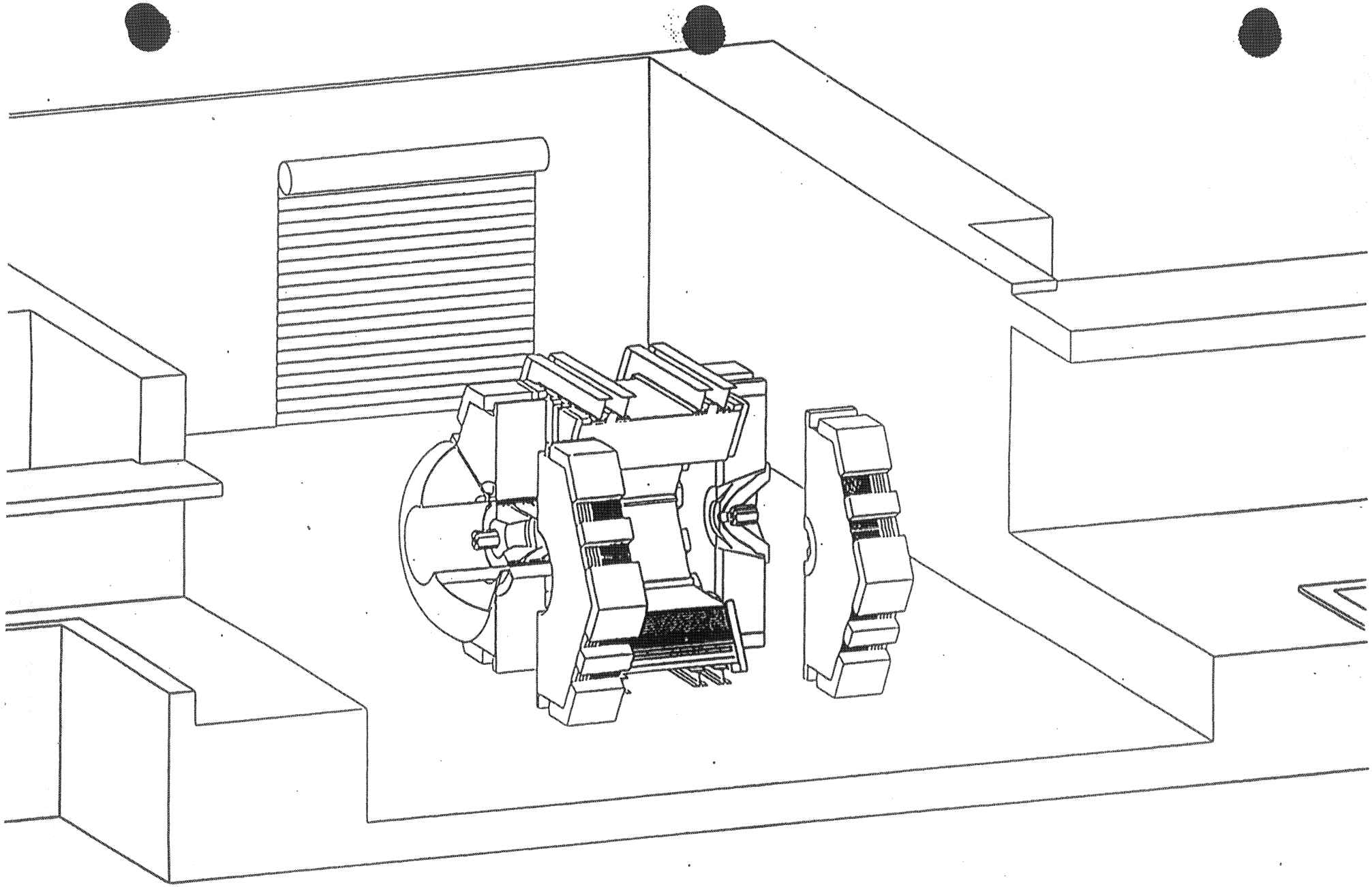
SLAC- BABAR

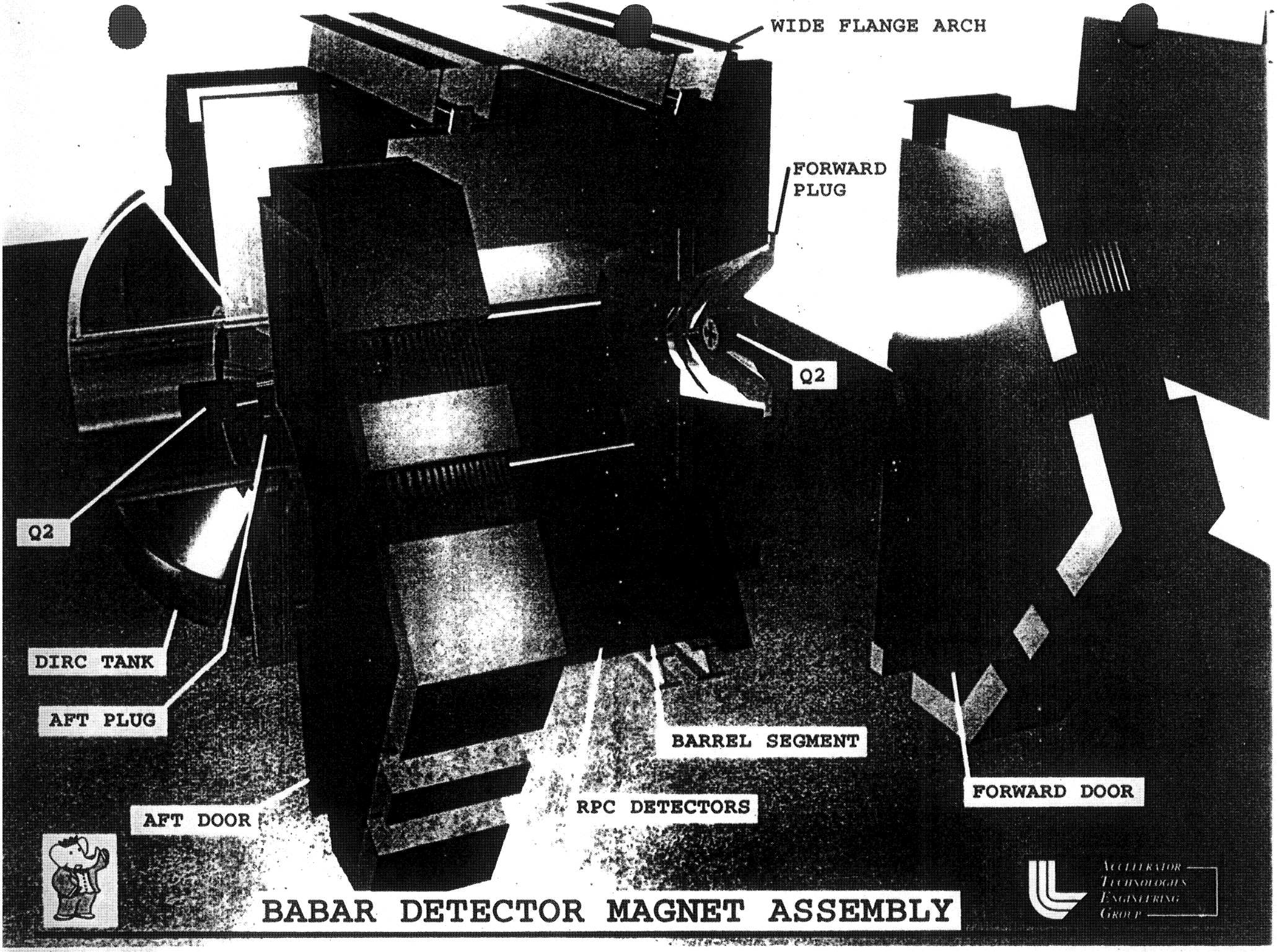
THE PEP-II (B-FACTORY) AND BABAR DETECTOR

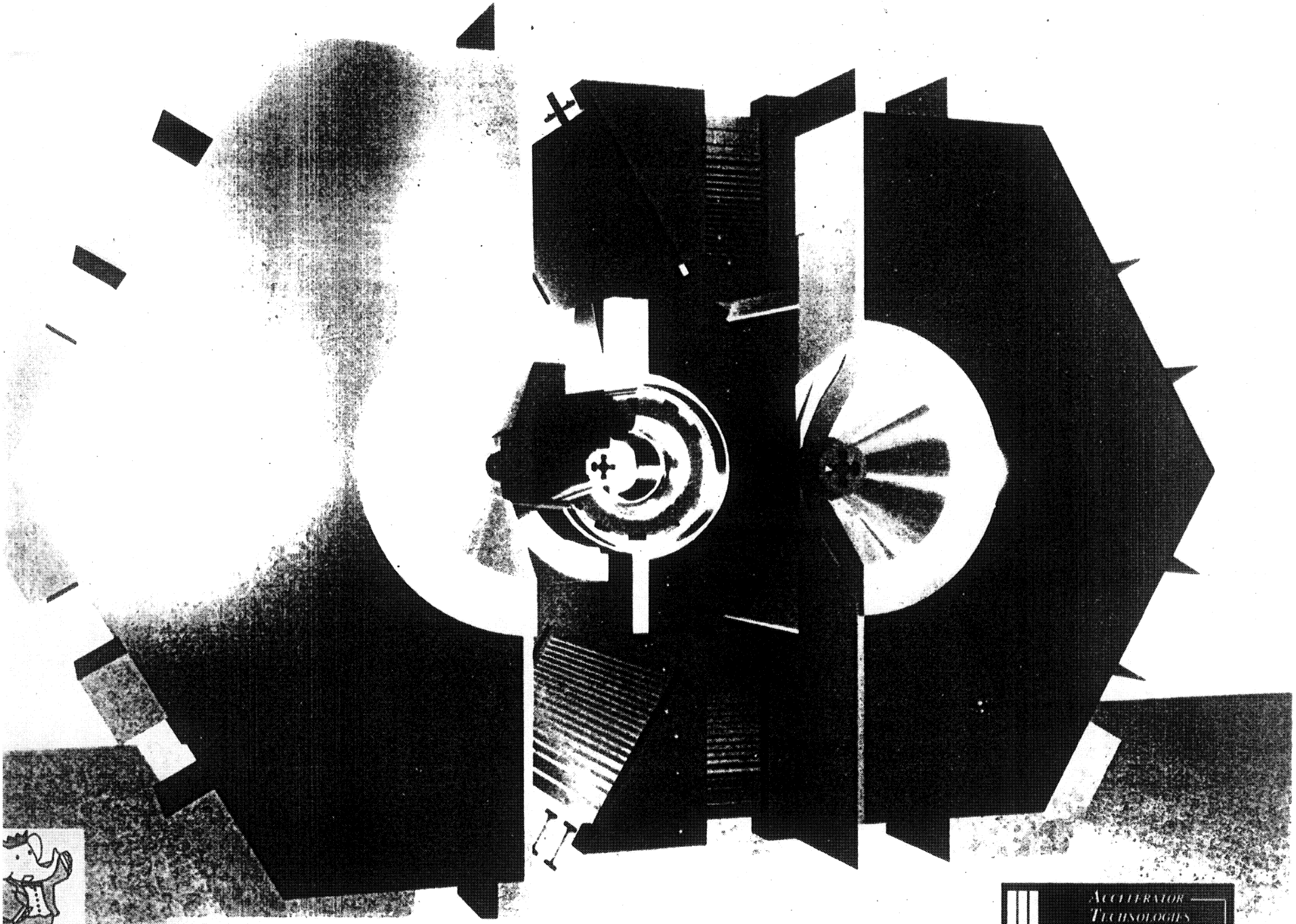


Purpose of the BABAR Detector

- Shortly after the Big Bang there were nearly equal amounts of matter and anti-matter. We are now trying to understand why the universe is composed mostly of matter.
- We believe the answer to this question can be found by studying the decay of B and anti-B mesons (B^0 *and* $\bar{B}^0$ --> BABAR)

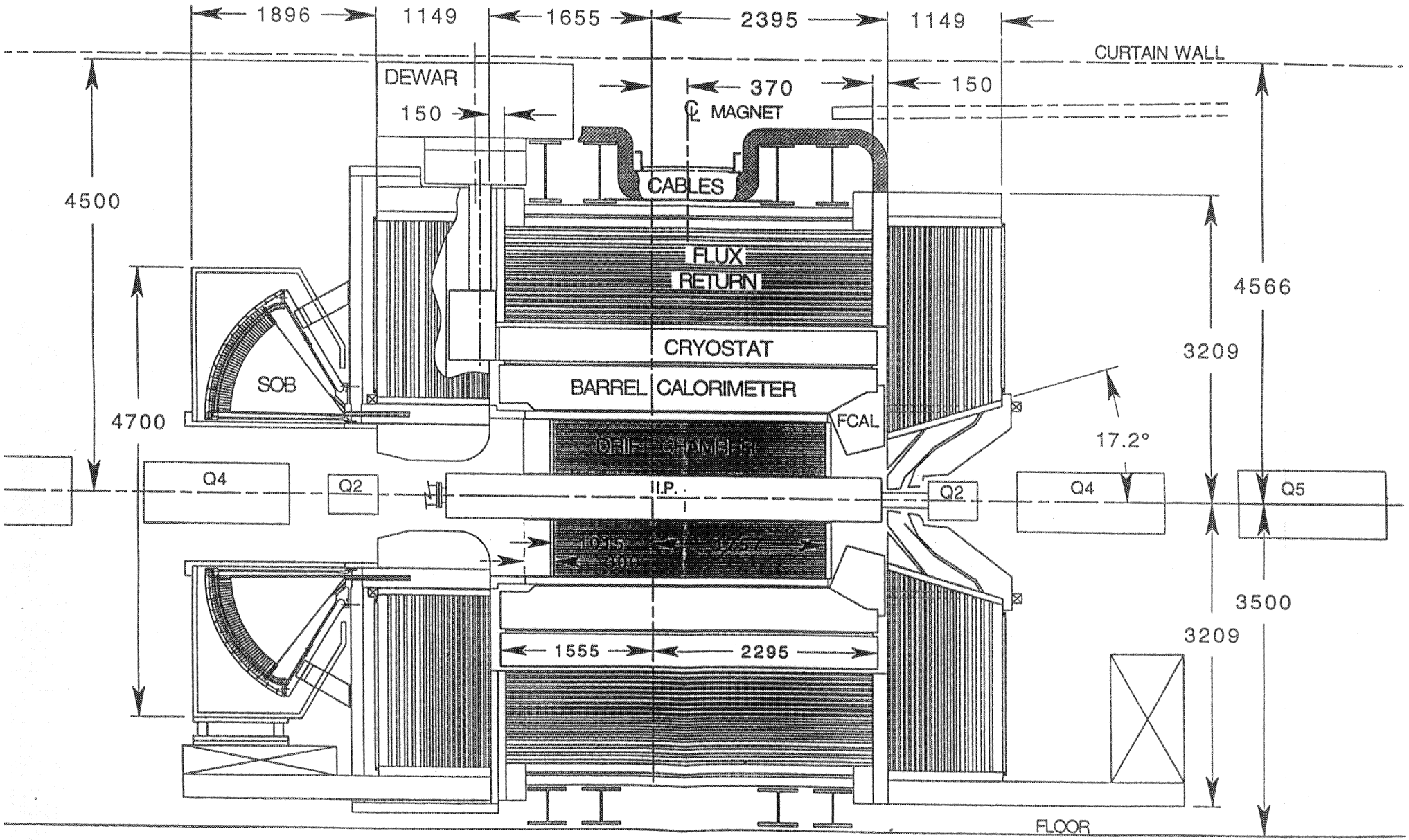



WIDE FLANGE ARCH
FORWARD PLUG
Q2
Q2
DIRC TANK
AFT PLUG
BARREL SEGMENT
FORWARD DOOR
RPC DETECTORS
AFT DOOR
BABAR DETECTOR MAGNET ASSEMBLY
ACCELERATOR TECHNOLOGIES ENGINEERING GROUP



BABAR DETECTOR MAGNET ASSEMBLY

ACCELERATOR
TECHNOLOGIES
ENGINEERING
GROUP



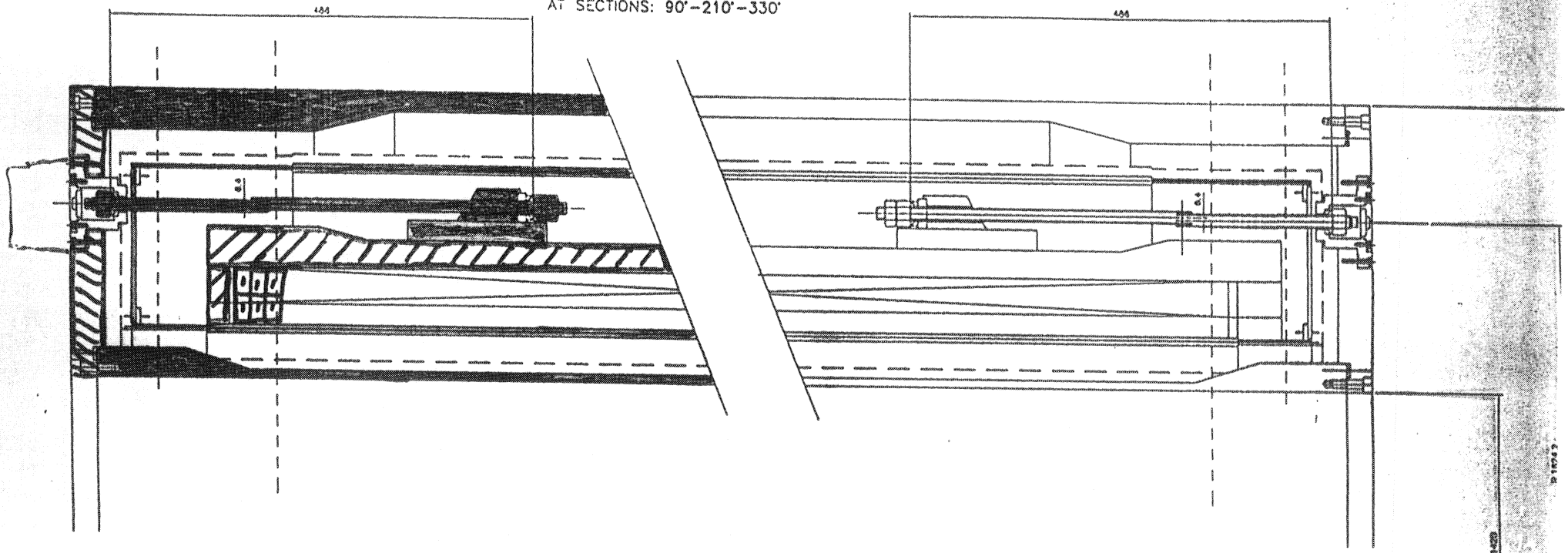
HJK-4/15/96

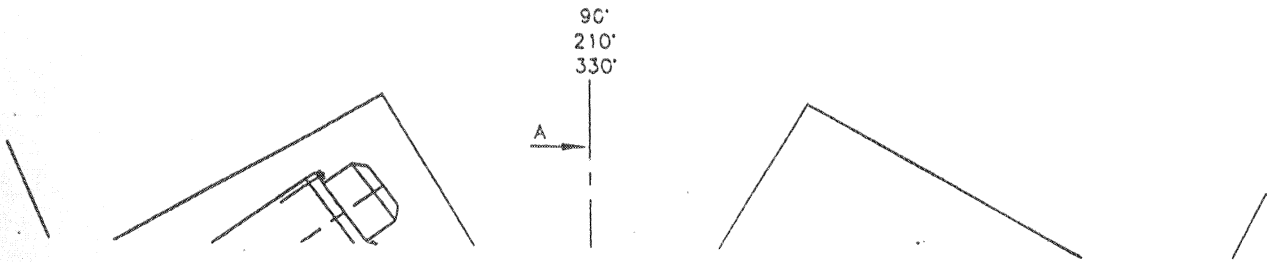
BaBar Detector Assembly

SEZ.A-A

SEZIONI A: 90°-210°-330°

AT SECTIONS: 90°-210°-330°





The BABAR Collaboration

10 Countries
78 Institutions
530 Collaborators

January 1996

USA [33/256]

California Institute of Technology
UC, Davis
UC, Irvine
UC, Los Angeles
UC, San Diego
UC, Santa Barbara
UC, Santa Cruz
U of Cincinnati
U of Colorado
Colorado State
U of Iowa
Iowa State U
LBNL
LLNL
U of Louisville
U of Maryland
U of Massachusetts, Amherst
MIT
U of Mississippi
Mount Holyoke College
Northern Kentucky U
U of Notre Dame
ORNL/Y-12
U of Pennsylvania
Prairie View A&M
Princeton
Rutgers
SLAC
U of South Carolina
Stanford U
U of Texas at Dallas
Vanderbilt
U of Wisconsin

Canada [7/25]

U of British Columbia
Carleton U and CRPP
McGill U
U de Montréal
TRIUMF
U of Victoria
York U

China [4/19]

Beijing Glass Research Inst.
Inst. of High Energy Physics, Beijing
Shanghai Inst. of Ceramics (SICCAS)
Tsinghua U, Beijing

France [5/56]

LAPP, Annecy
LAL Orsay
LPNHE des Universités Paris 6/7
Ecole Polytechnique
CEA, DAPNIA, CE-Saclay

Germany [2/12]

Ruhr U Bochum
Technische U Dresden

Italy [13/80]

INFN, Bari and U di Bari
INFN, Ferrara
Lab. Nazionali di Frascati dell' INFN
INFN, Genova and U di Genova
INFN, Milano
INFN, Napoli and U di Napoli
INFN, Padova
INFN, Pavia and U. di Pavia
INFN, Pisa, U di Pisa & Scuola Normale
INFN, Roma and U "La Sapienza"
INFN, Superiore di Sanita', Roma
INFN, Torino and U di Torino
INFN, Trieste and U di Trieste

Norway [1/3]

U of Bergen

Russia [2/28]

Budker Institute, Novosibirsk
JINR, Dubna

United Kingdom [10/48]

U of Bristol
Brunel University
U of Edinburgh
U of Lancaster
U of Liverpool
Imperial College
Queen Mary & Westfield College
Royal Holloway & Bedford New College
U of Manchester
Rutherford Appleton Laboratory

Taiwan [1/3]

Academia Sinica

BABAR

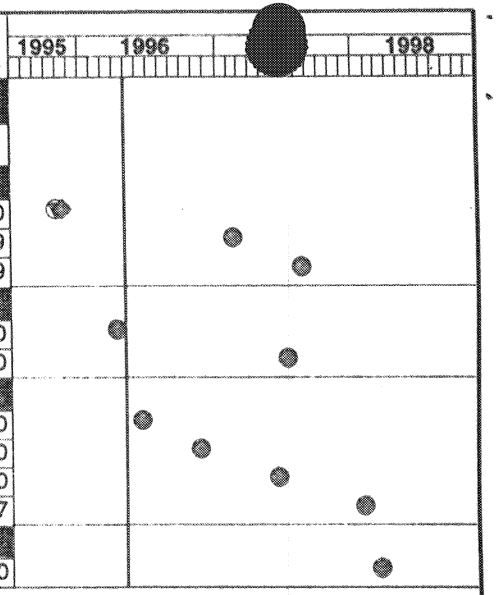
Babar IN and © L. de Brunhoff

SLAC- BABAR

Magnet System Group

- Robert Bell (SLAC) - BABAR Project Engineer
- Orrin Fackler (LLNL) - Magnet Physicist
- Jack Heck (ORNL) - End Door Lead Engineer
- Lewis Keller (SLAC) - Magnet Physicist
- Jim Krebs (SLAC) - Integration Engineer
- Harvey Lynch (SLAC) - BABAR Integration Physicist
- Steve McGrath (ORNL) - Structural Analyst
- Thomas O'Connor (LLNL) - Magnet Co-System Manager
- Nancy Yu (SLAC) - Structural Analyst

Activity ID	Activity Description	Baseline Variance	Projected Finish	Total float	Baseline Finish	TF -1 Mo.	TF -2 Mo.	TF -3 Mo.
Milestone Level 3 - BABAR Management								
1.6 MAGNET SYSTEM								
1.6.1 SUPERCONDUCTING SOLENOID								
B6SS09	PLACE SOLENOID ORDER- 10% Pymt (10%M) - Italy	-10	14NOV95A		31OCT95	0	0	0
B6SS24A	SOLENOID IMPREGNATED	0	13FEB97	32	13FEB97	31	9	59
B6SS30A	SOLENOID ARRIVES @ SLAC	0	15AUG97	31	15AUG97	31	0	59
1.6.3 CRYOGENICS								
B6LH13A	PLACE ORDER FOR LHe SYSTEM	0	09APR96A		09APR96	0	0	0
B6LH23A	LHe SYSTEM COMMISSIONED (Pymt 15%M) GPP	0	08JUL97	59	08JUL97	0	0	0
1.6.6 FLUX RETURN								
B6FR51	ORDER FLUX RET BRRL & END CAPS-10% pymt (10%M)	0	11JUN96	-29	11JUN96	0	0	0
B6FR54A	1st IRON BLOCK COMPLETE FOR FLUX RETURN	0	15NOV96	42	15NOV96	0	0	0
B6FR59A	FLUX RETURN ARRIVES @ SLAC - 10% Pymt (10%M)	0	13JUN97	-10	13JUN97	0	0	0
B6FR63A	FLUX RETURN ASSY COMPLETE @ SLAC (18%M)	0	29JAN98	63	29JAN98	138	138	77
1.6.7 INSTL FIXTURES & TEST EQUIPMENT								
B6FR147A	MAGNET MAPPING COMPLETE	0	13MAR98	22	13MAR98	0	0	0



Project Start	03APR95
Project Finish	29APR98
Data Date	30APR96
Plot Date	24MAY96

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Early Bar
Progress Bar
Critical Activity

BBAR:M160

Sheet 1 of 1

1.6 MAGNET SYSTEM
Level 3 Milestone Schedule
Status as of April 30, 1996

SLAC- BABAR

The charge to the review group is:

- Is the quench analysis complete?
- Is the BABAR solenoid adequately protected during a quench?
- Is there anything that could be done to improve the quench protection?
- Is there enough redundancy in the quench protection system?
- Is adequate testing of the quench protection system being planned?
- Have we overlooked anything?

Quench Analysis

P. Valente
(Ansaldo)

QUENCH ANALYSIS

- PROTECT
  - Multi-layer quench code
  - Inductive coupling
  - Thermal coupling
- ANSYS
  - To know stress intensity starting from temperature calculated using "protect"

4 CASES ANALYZED

(ALL WITH QUENCH STARTING FROM INTERNAL LAYER)

1. Central point with protection
2. Central point without protection
3. End point without protection
4. End point with protection

QUENCH starting from INTERNAL RADIUS, CENTRAL POINT;
WITH PROTECTION (Rdump=0.068 Ohm);
aluminium cylinder on esternal radius

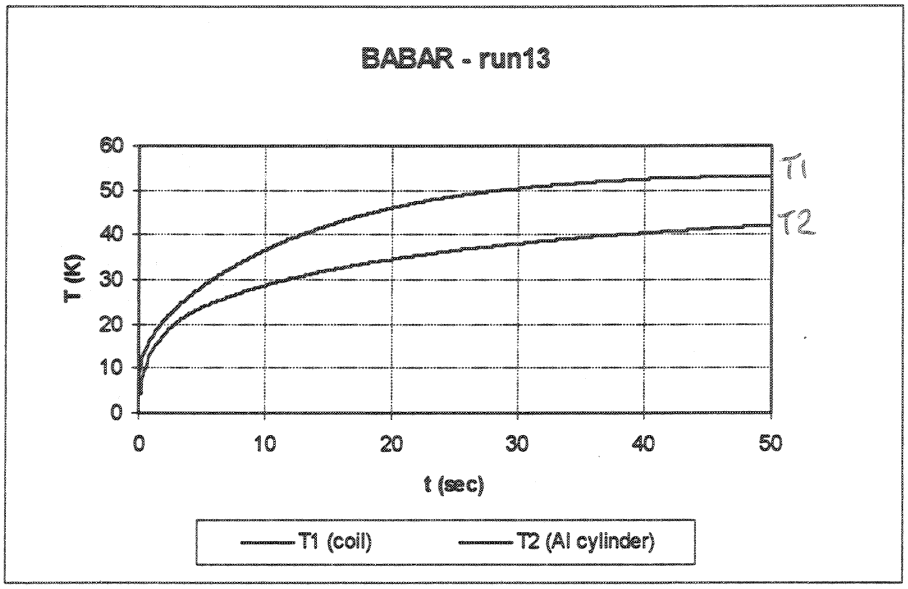


Fig. 1.1) - plot of maximum temperature (versus time) in coil and cylinder:

final Tmax of coil = **53 Kelvin**
final Tmax of Al cylinder = 42 Kelvin

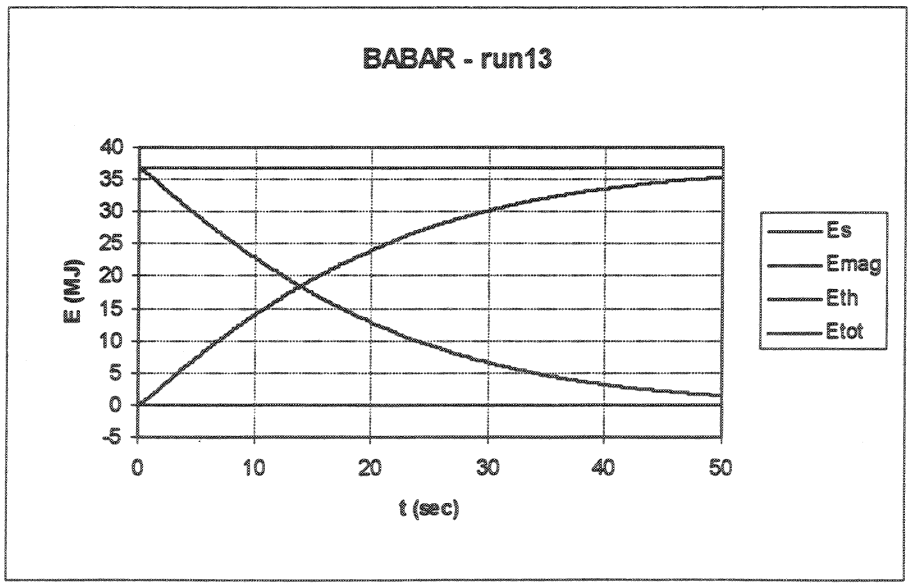


Fig. 1.2) - Energy plot:
E_{mag}= Magnetic energy, E_{th}=thermal energy, E_{tot}=total energy=E_{mag}+E_{th}

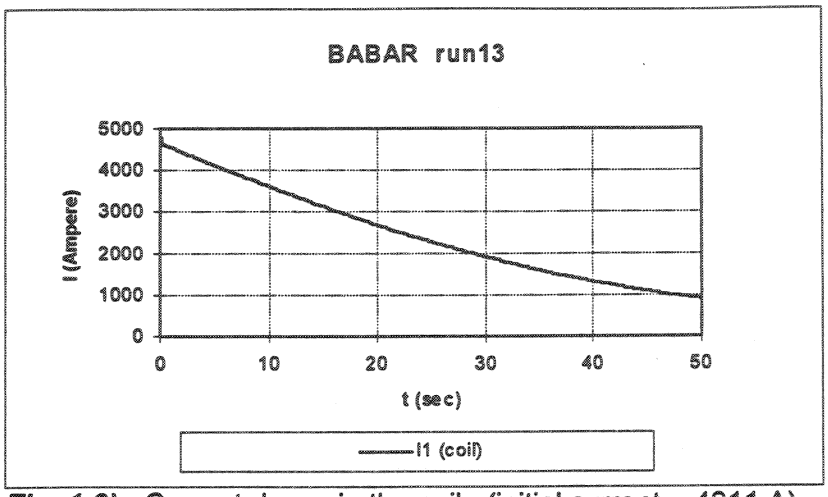


Fig. 1.3) - Current decay in the coil (initial current = 4811 A)

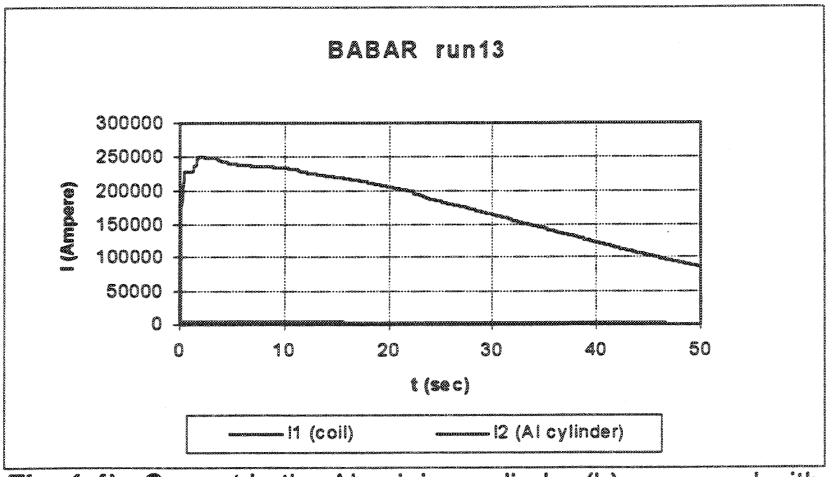


Fig. 1.4) - Current in the Aluminium cylinder (I_2) compared with current in the coil (I_1): I2,max = 251000 A, at t ≅ 2 sec.

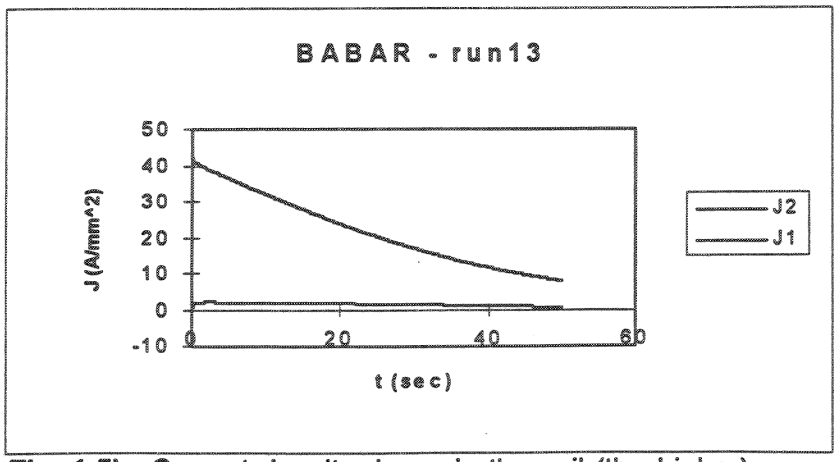


Fig. 1.5) - Current density decay in the coil (the higher) compared with current density in the Aluminium cylinder (the lower)

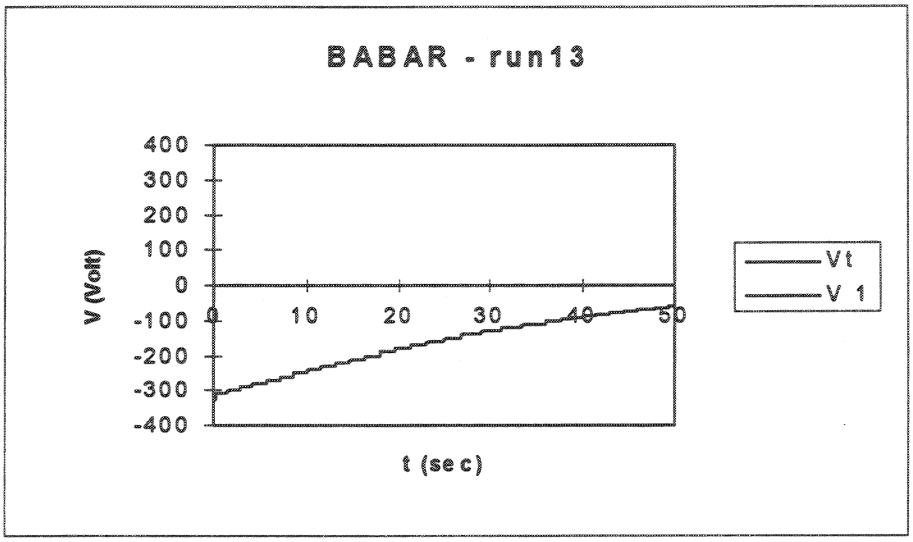


Fig. 1.6) - Voltage plot

Vo= - (4811 A) * (0.068 Ohm) = - 327 Volt

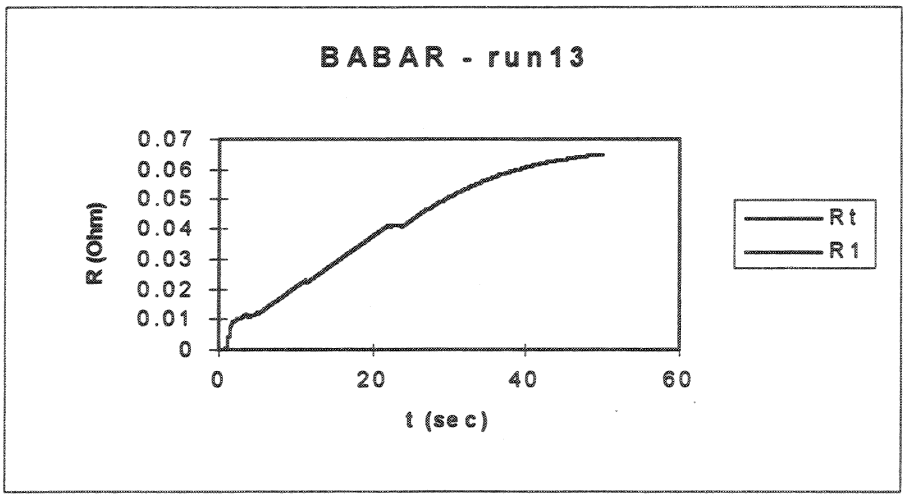


Fig. 1.7) - Growing resistance in the coil

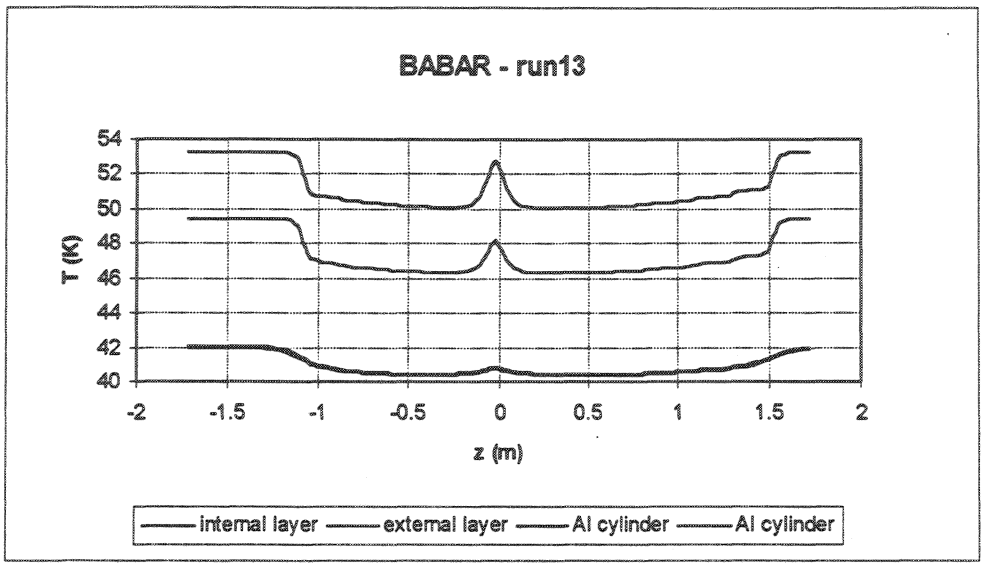


Fig. 1.8) - Axial temperature distribution at the "final" time (t=50 sec from the quench start)

QUENCH starting from INTERNAL RADIUS, CENTRAL POINT;
WITHOUT PROTECTION (Rdump=0.0001 Ohm for the calculation);
aluminium cylinder on esternal radius

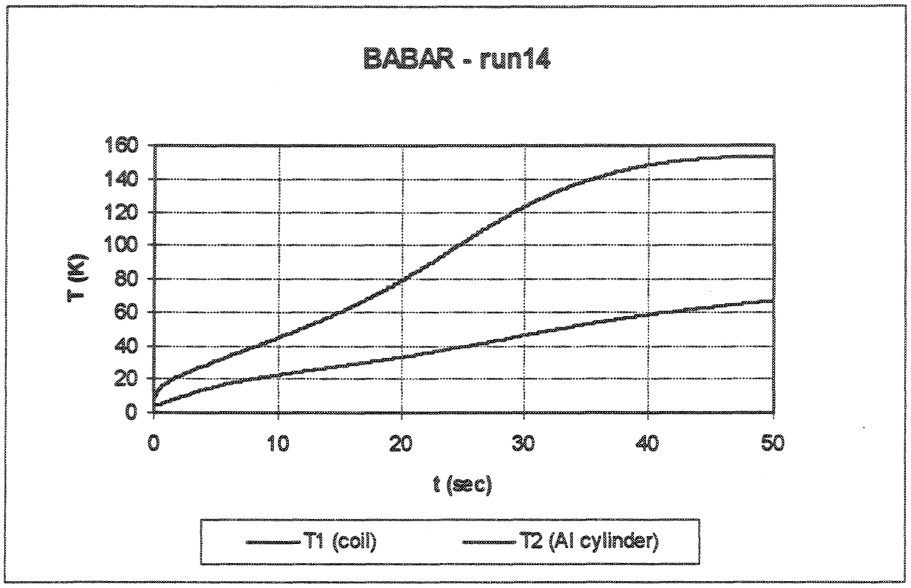


Fig. 2.1) - plot of maximum temperature (versus time) in coil and cylinder:

final Tmax of coil = **154 Kelvin**
final Tmax of Al cylinder = 67 Kelvin

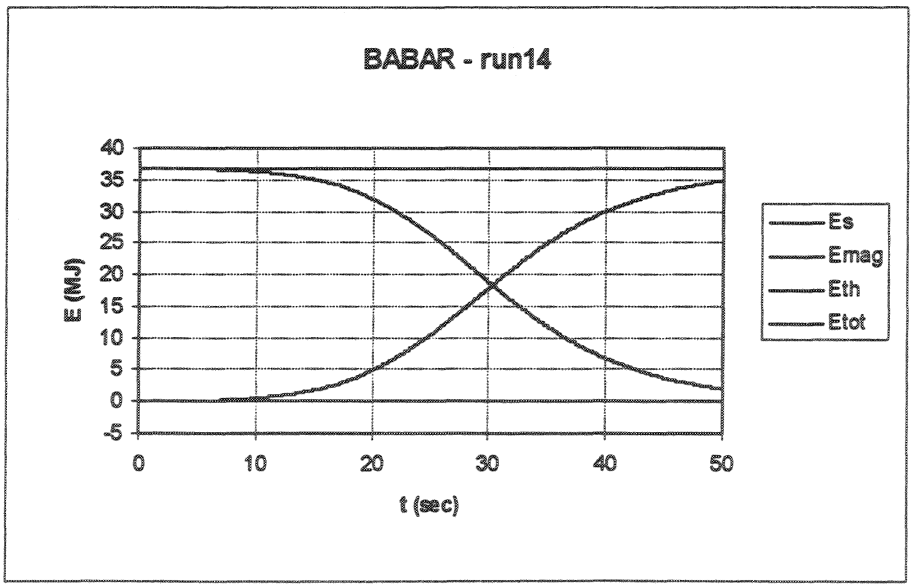


Fig. 2.2) - Energy plot:
E_{mag}= Magnetic energy, E_{th}=thermal energy, E_{tot}=total energy=E_{mag}+E_{th}

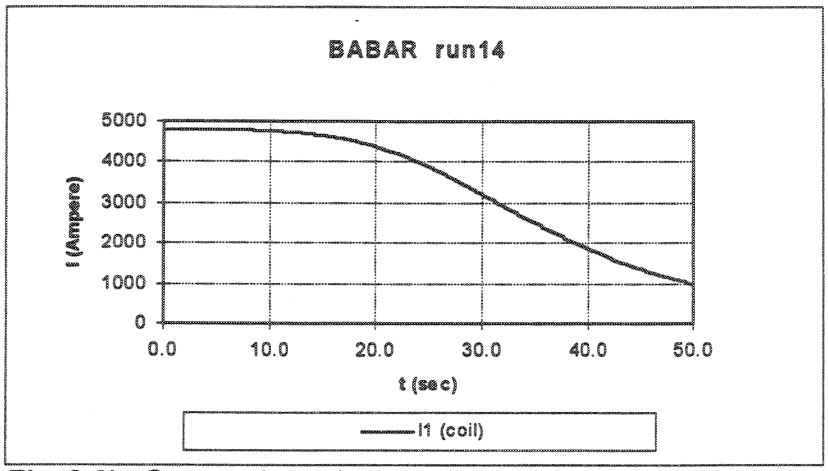


Fig. 2.3) - Current decay in the coil (initial current = 4811 A)

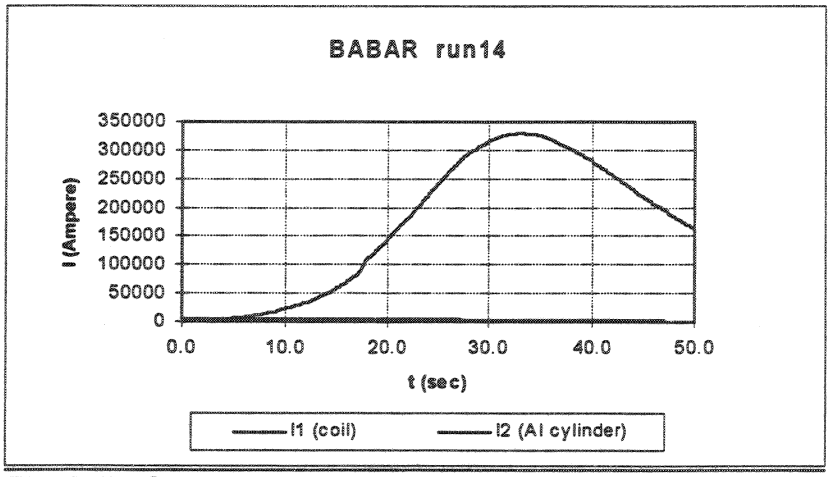
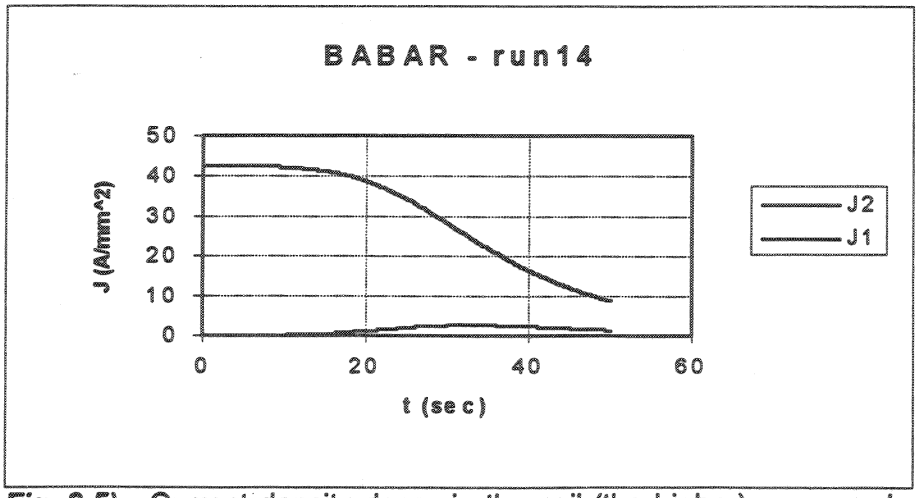


Fig. 2.4) - Current in the Aluminium cylinder (I_2) compared with current in the coil (I_1): I2,max = 330000 A, at t ≅ 33 sec.



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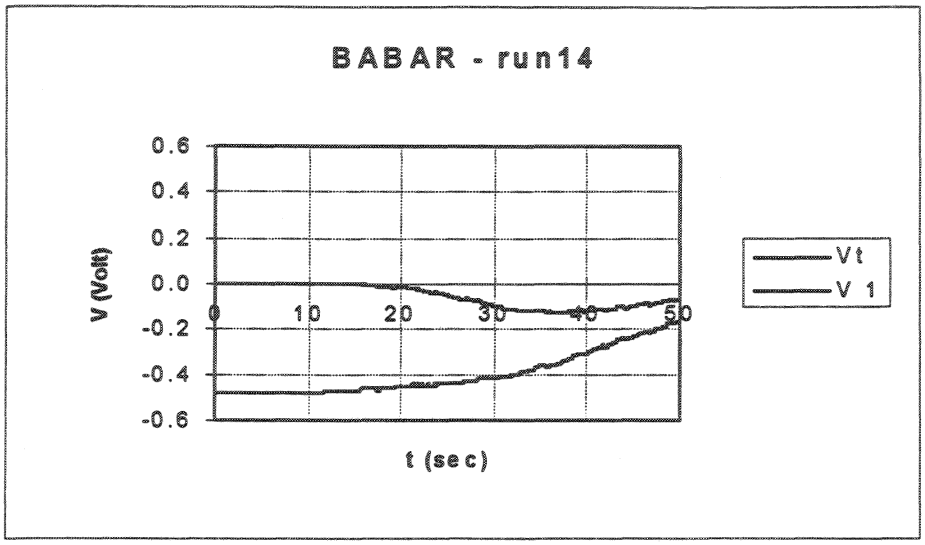


Fig. 2.6) - Voltage plot

Vo= - (4811 A) * (0.0001 Ohm) = - 0.48 Volt

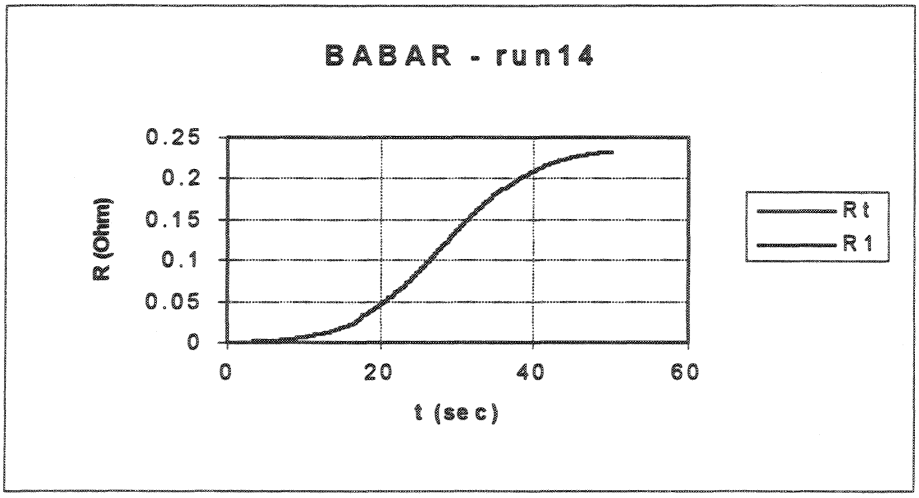
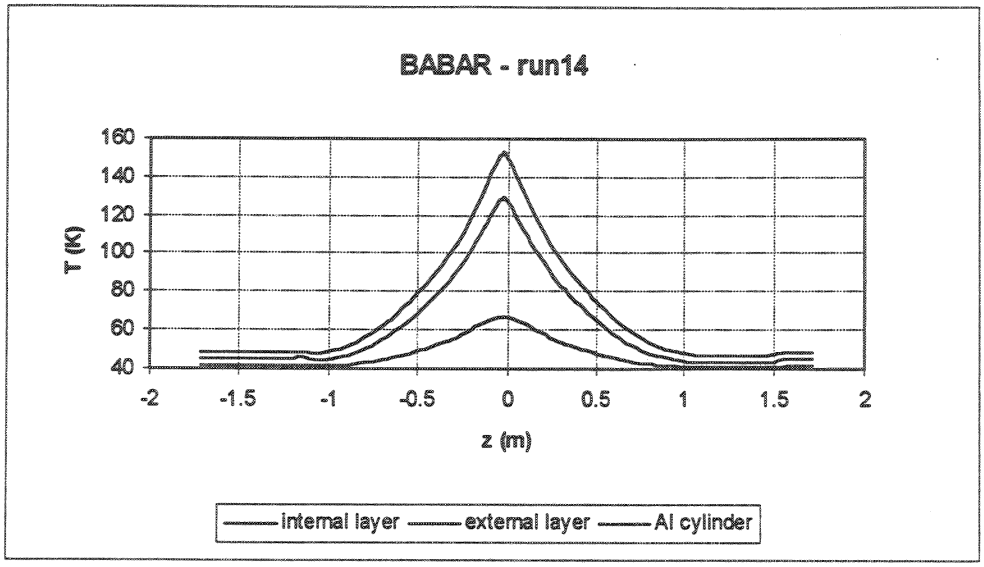


Fig. 2.7) - Growing resistance in the coil



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QUENCH starting from INTERNAL RADIUS, END POINT;
WITHOUT PROTECTION (Rdump=0.0001 Ohm for the calculation);
aluminium cylinder on esternal radius

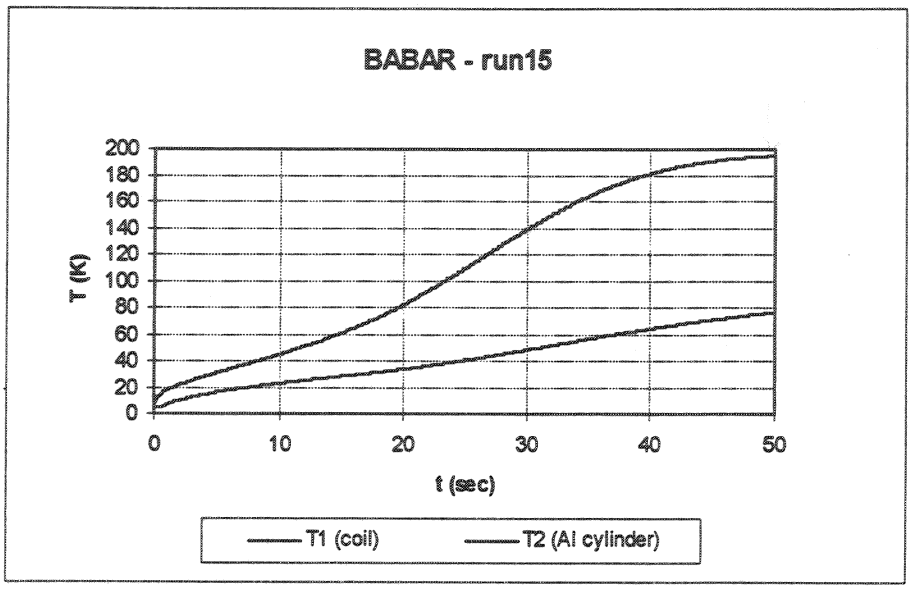
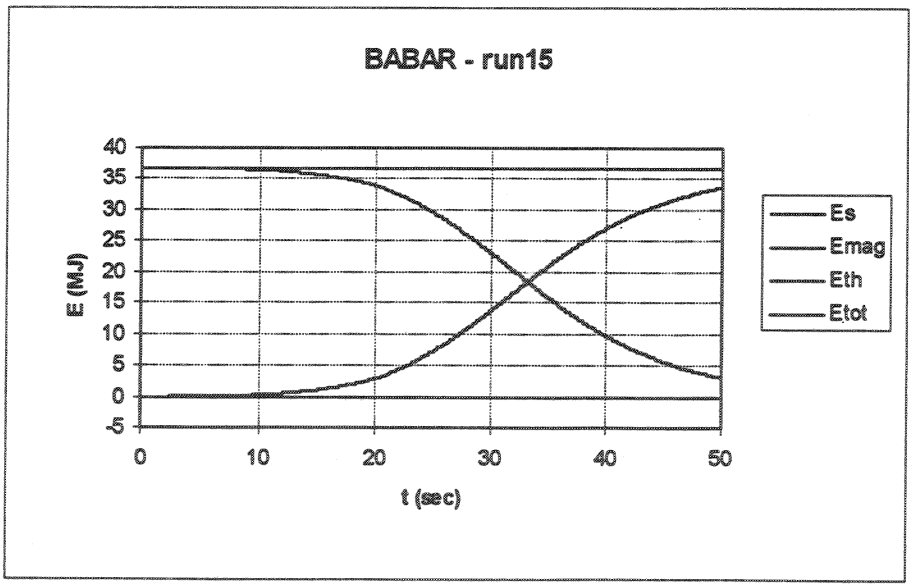


Fig. 3.1) - plot of maximum temperature (versus time) in coil and cylinder:

final Tmax of coil = **195 Kelvin**
final Tmax of Al cylinder = 77 Kelvin



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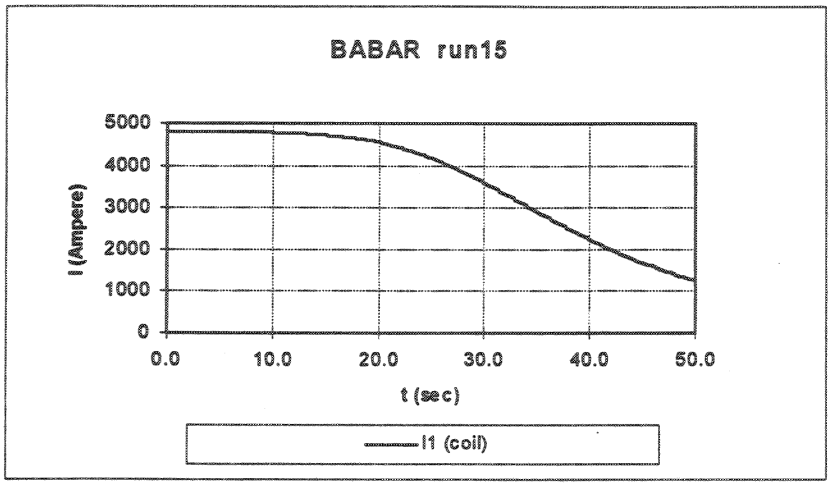

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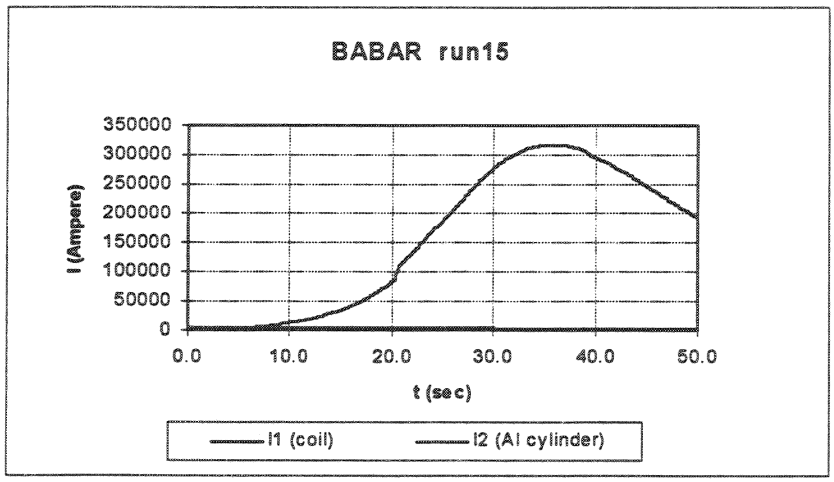


Fig. 3.4) - Current in the Aluminium cylinder (I_2) compared with current in the coil (I_1): I2,max = 318000 A, at t ≅ 36 sec.

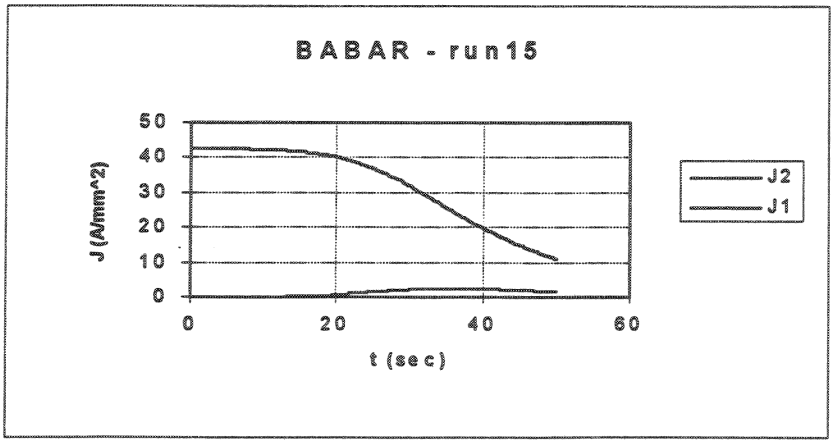


Fig. 3.5) - Current density decay in the coil (the higher) compared with current density in the Aluminium cylinder (the lower)

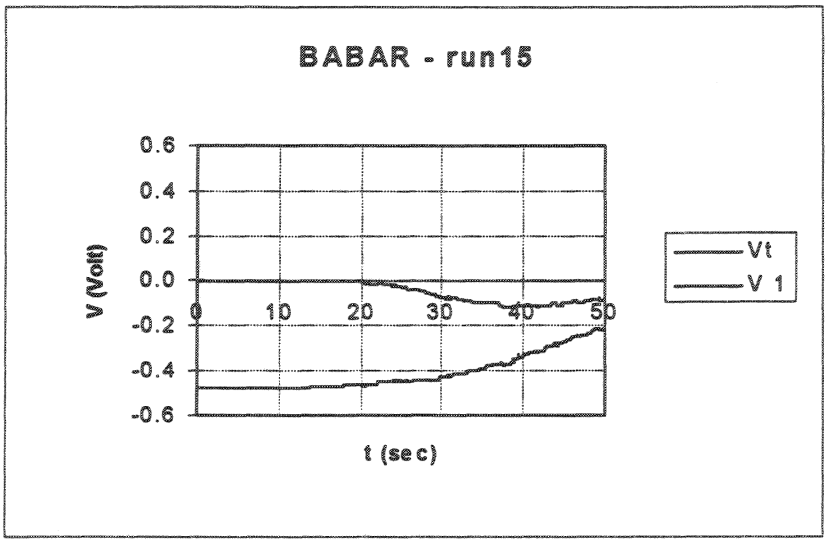
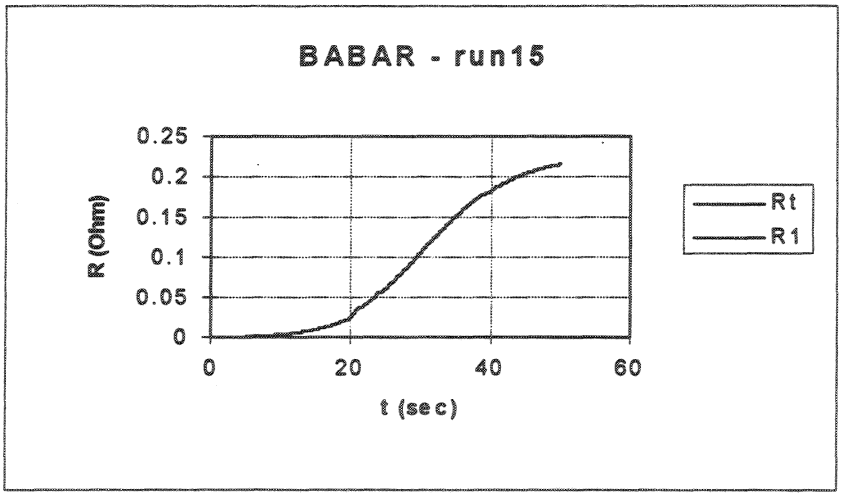


Fig. 3.6) - Voltage plot

Vo= - (4811 A) * (0.0001 Ohm) = - 0.48 Volt



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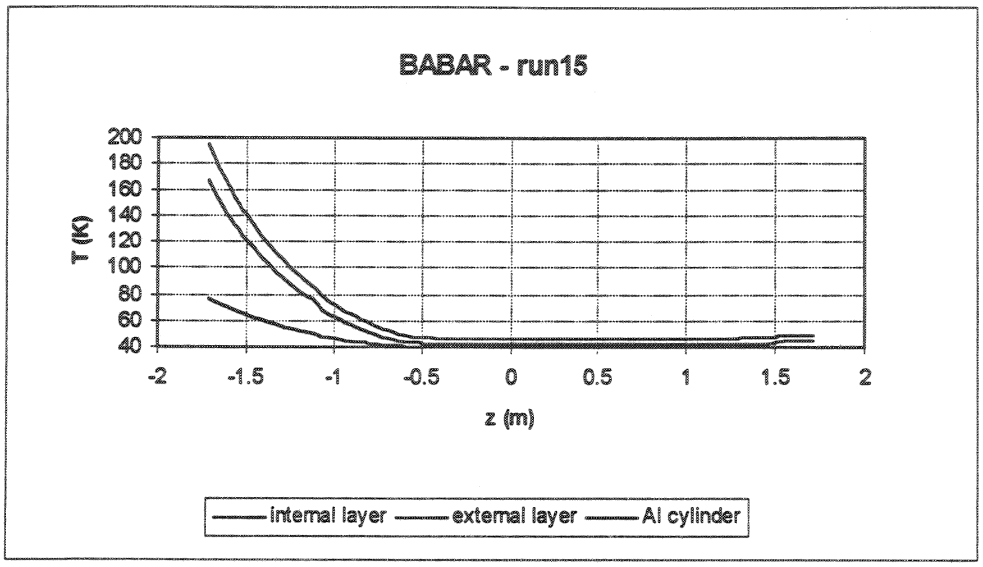

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QUENCH starting from INTERNAL RADIUS, END POINT;
WITH PROTECTION (Rdump=0.068 Ohm);
aluminium cylinder on esternal radius

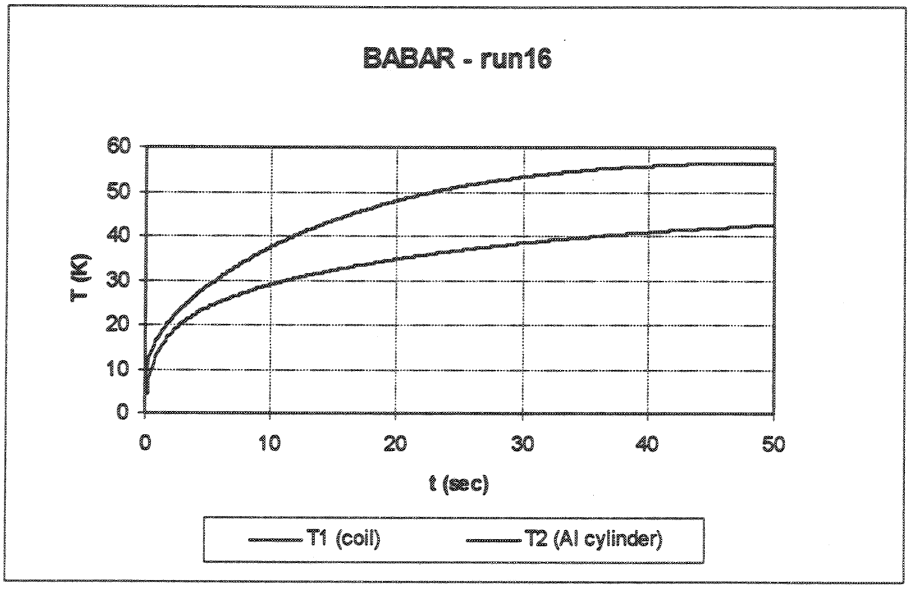


Fig. 4.1) - plot of maximum temperature (versus time) in coil and cylinder:

final Tmax of coil = **57 Kelvin**
final Tmax of Al cylinder = 43 Kelvin

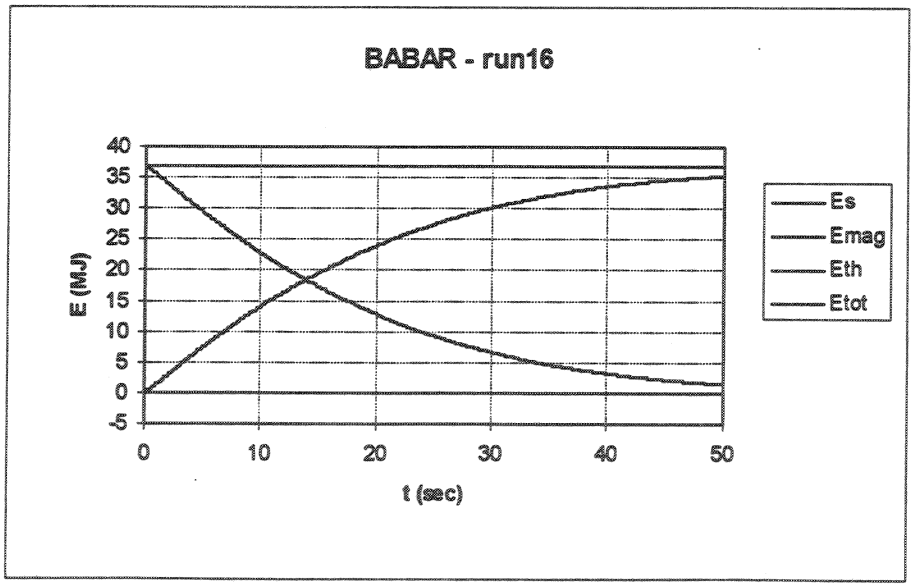


Fig. 4.2) - Energy plot:
E_{mag}= Magnetic energy, E_{th}=thermal energy, E_{tot}=total energy=E_{mag}+E_{th}

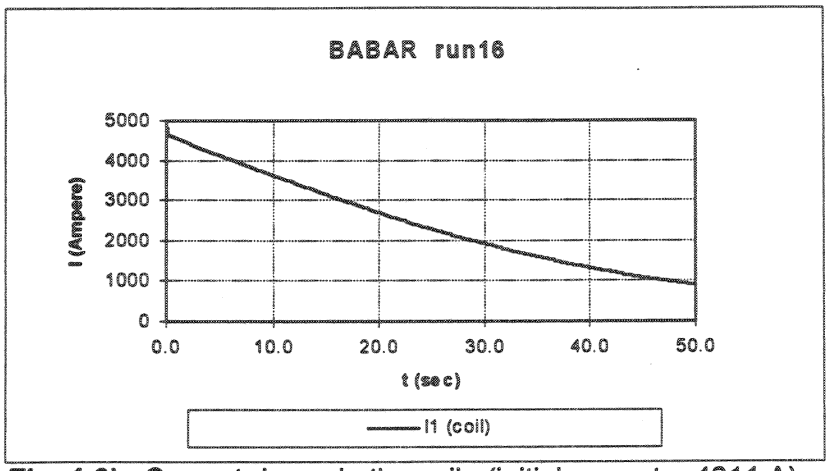


Fig. 4.3) - Current decay in the coil (initial current = 4811 A)

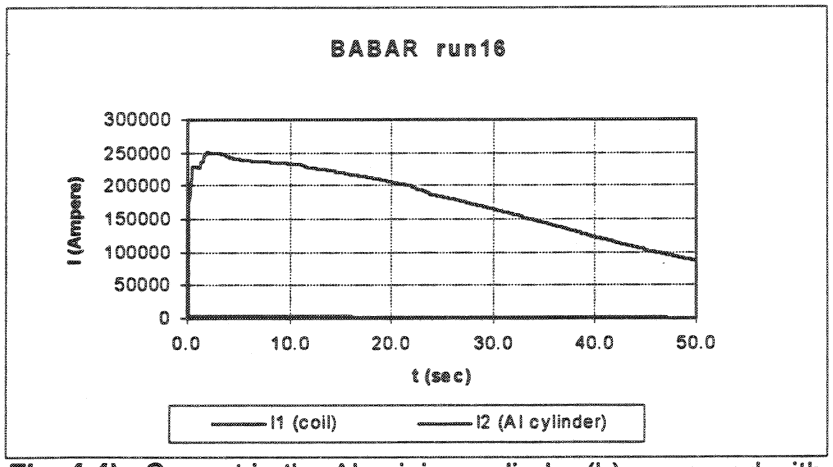


Fig. 4.4) - Current in the Aluminium cylinder (I_2) compared with current in the coil (I_1): I2,max = 229000 A, at t ≅ 1 sec.

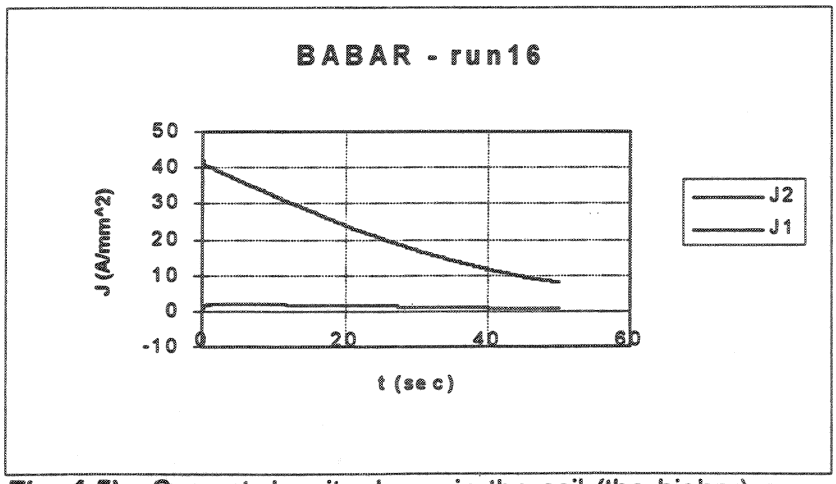


Fig. 4.5) - Current density decay in the coil (the higher) compared with current density in the Aluminium cylinder (the lower)

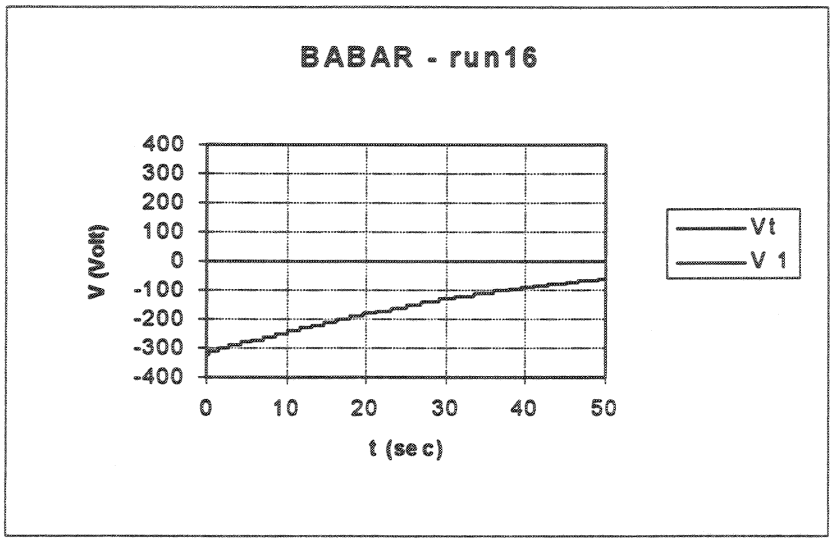


Fig. 4.6) - Voltage plot

Vo= - (4811 A) * (0.068 Ohm) = - 327 Volt

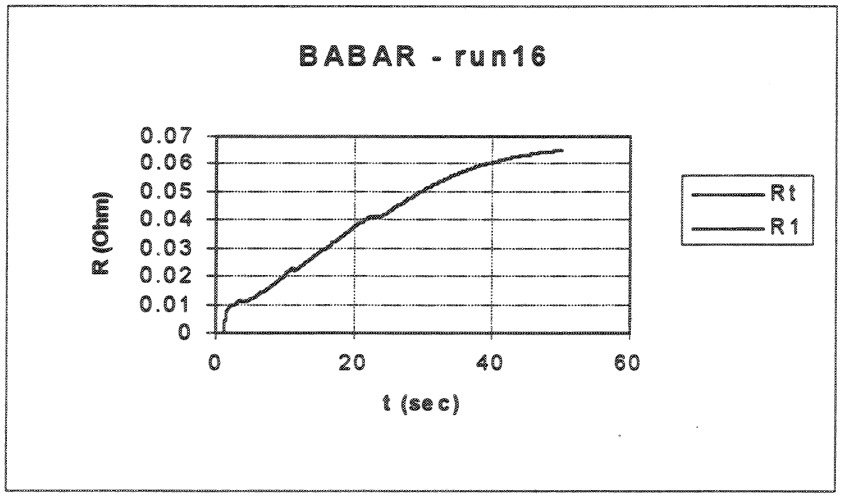


Fig. 4.7) - Growing resistance in the coil

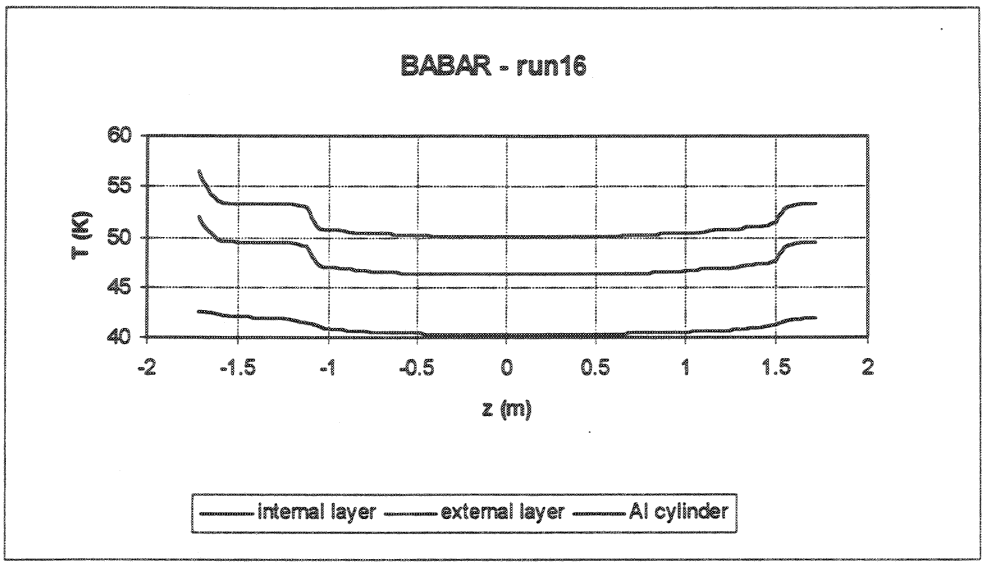
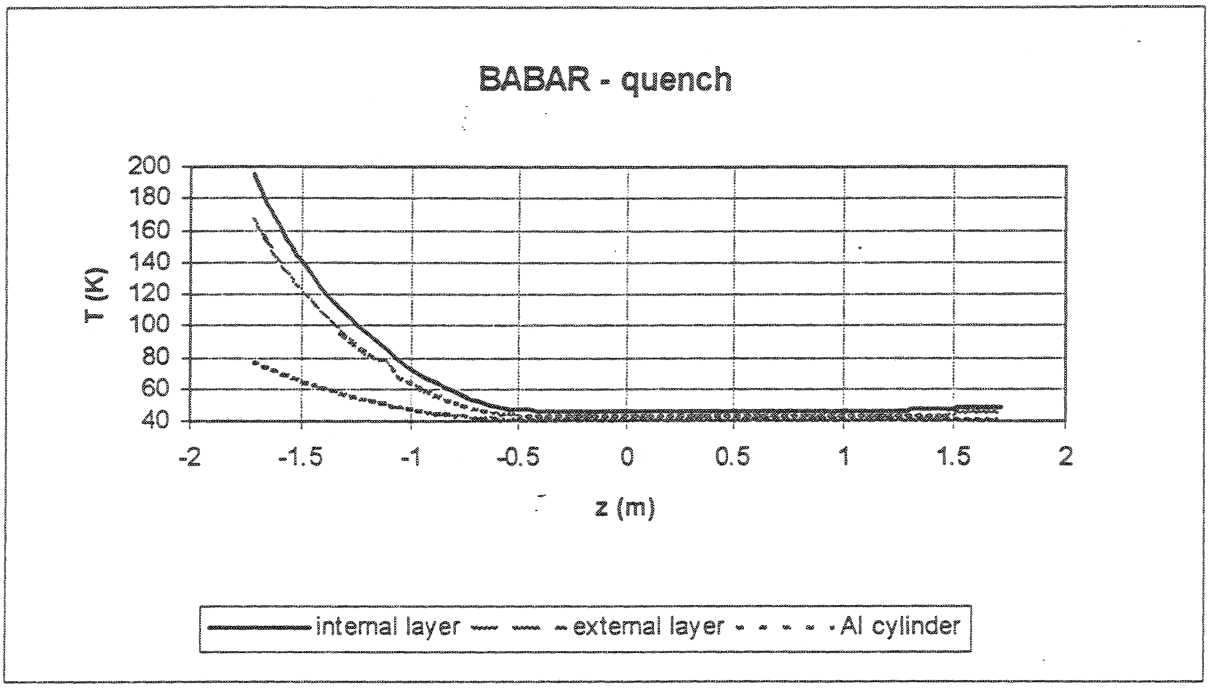
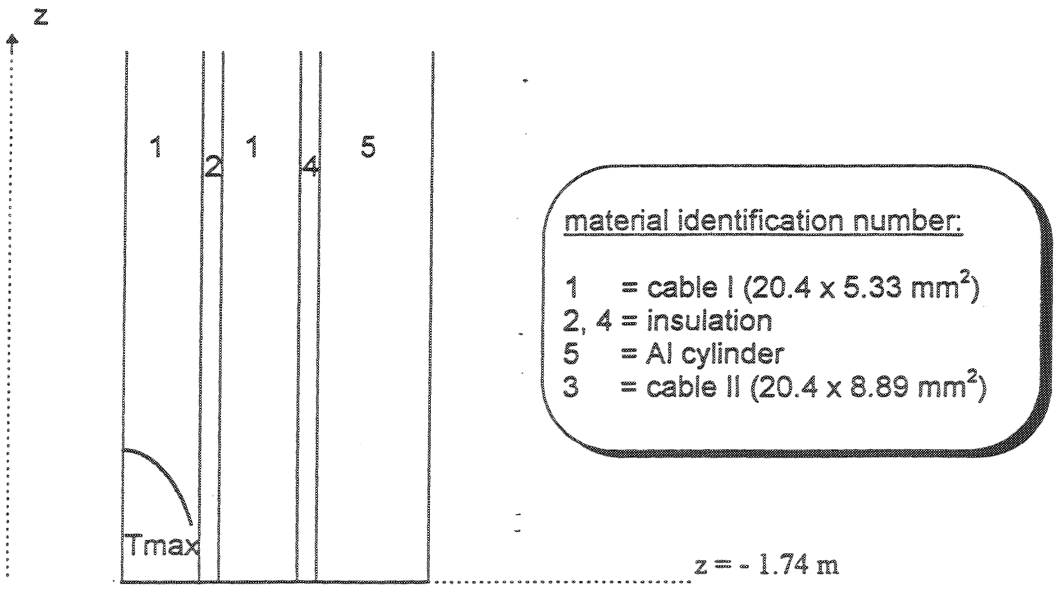


Fig. 4.8) - Axial temperature distribution at the "final" time (t=50 sec from the quench start)



1) - TEMPERATURE DISTRIBUTION AT THE END OF QUENCH ANALYSIS (t= 50 SEC);
QUENCH STARTED FROM INTERNAL RADIUS, END OF COIL,
WITHOUT PROTECTION RESISTANCE;
Z = COIL AXIS, MIDPLANE AT Z=0.



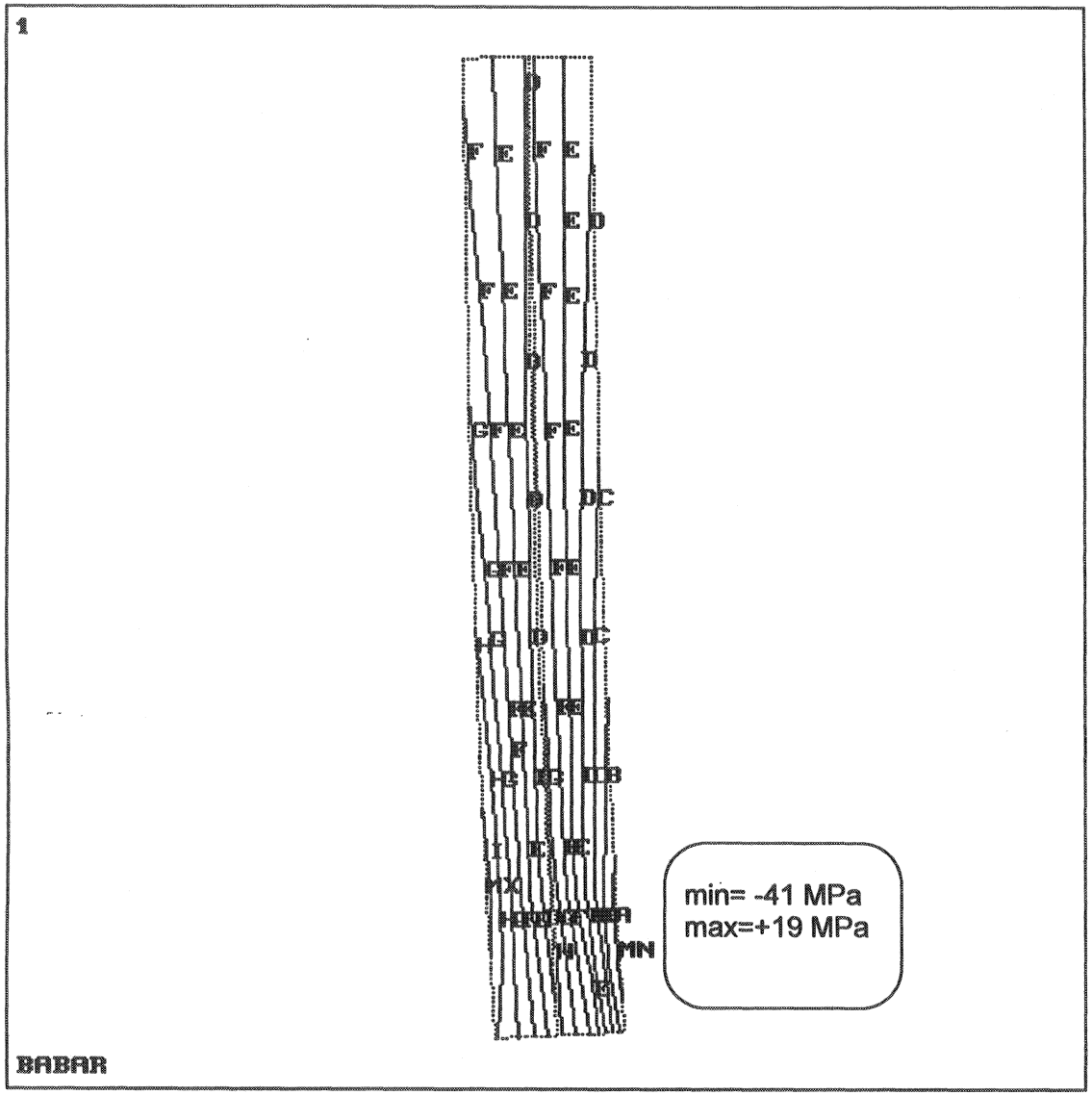
ANSYS SHELL MODEL

stress (MPa)	mat.1 (lateral cable)	mat.2 (interlayer insulation)	mat.3 (central cable)	mat.4 insulation on external radius of coil	mat.5 Al - cylinder
Sx (radial)	-5, +7	- 5, + 8	-0.04, +0.6	-7, +1	-13, +5
Sy (axial)	Comp **- 40**, +19	- 8, + 9	- 2, +0.8	- 4, + 4	- 28, + **52**
Sz (hoop)	**- 44**, +3	- 12, + 3	- 2, +1	- 4, + 15	Tension +0.3, + **77**
Sxy (shear)	-3, +8	- 0.5, + 3	-0.3, +0.04	-0.8, + 19	-5, +7
Sint (intensity)	------	------	------	------	90

indicates Lorentz forces?

FULL - RANGE STRESS TABLE FOR T_{ref} = 4 Kelvin STRESS ANALYSIS

(WORST QUENCH TEMPERATURE DISTRIBUTION)

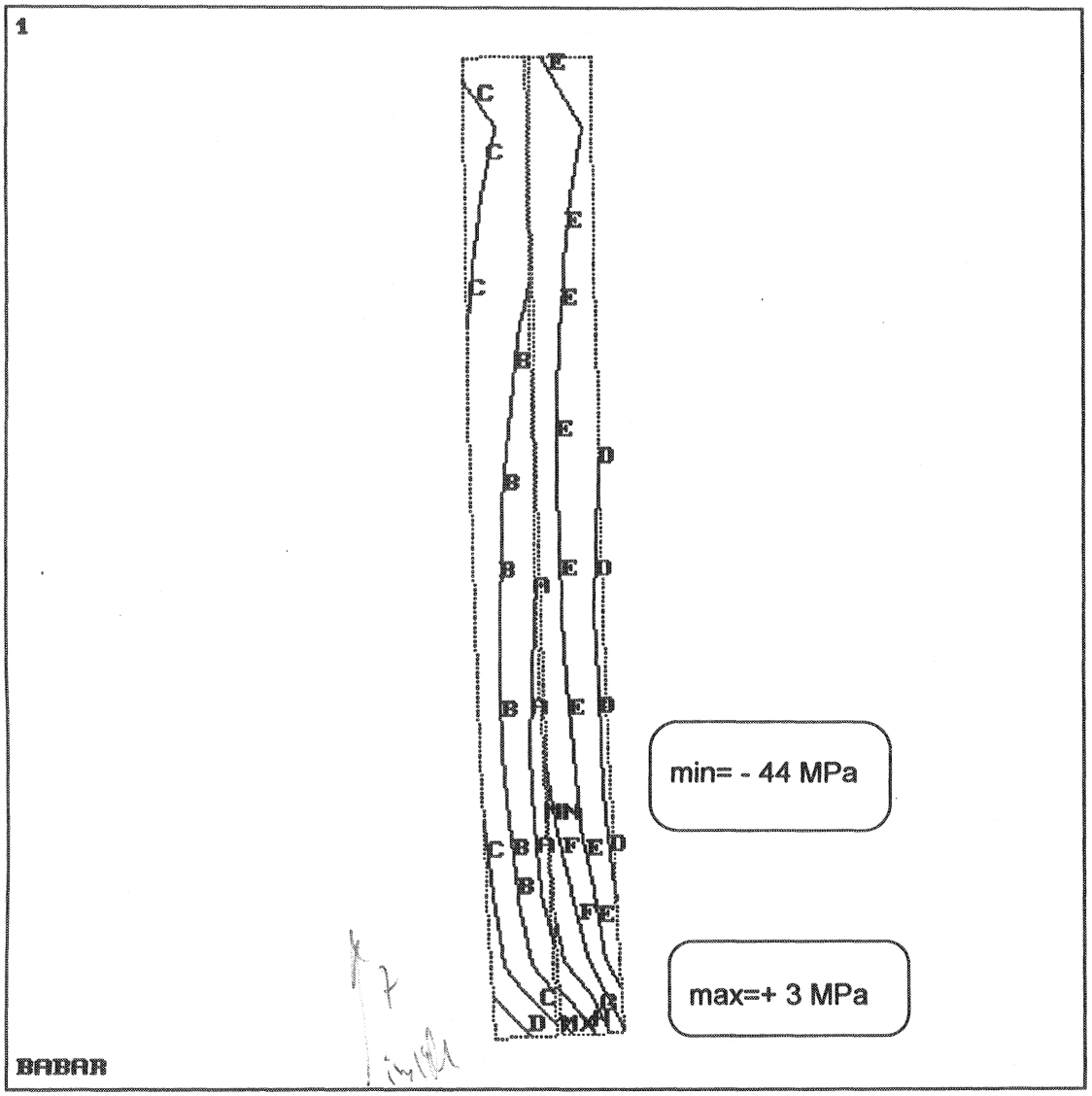


ANSYS 5.1
SEP 11 1996
13:55:47
PLOT NO. 1
NODAL SOLUTION
STEP=1
SUB =1
TIME=1
SY (AVG)
RSYS=0
DMX =0.001817
SMN =-0.405E+08
SMX =0.189E+08
A =-0.372E+08
B =-0.306E+08
C =-0.240E+08
D =-0.174E+08
E =-0.108E+08
F =-0.421E+07
G =0.239E+07
H =0.900E+07
I =0.156E+08

min= -41 MPa
max=+19 MPa

full range:
min= - 41 MPa
max=+19 MPa

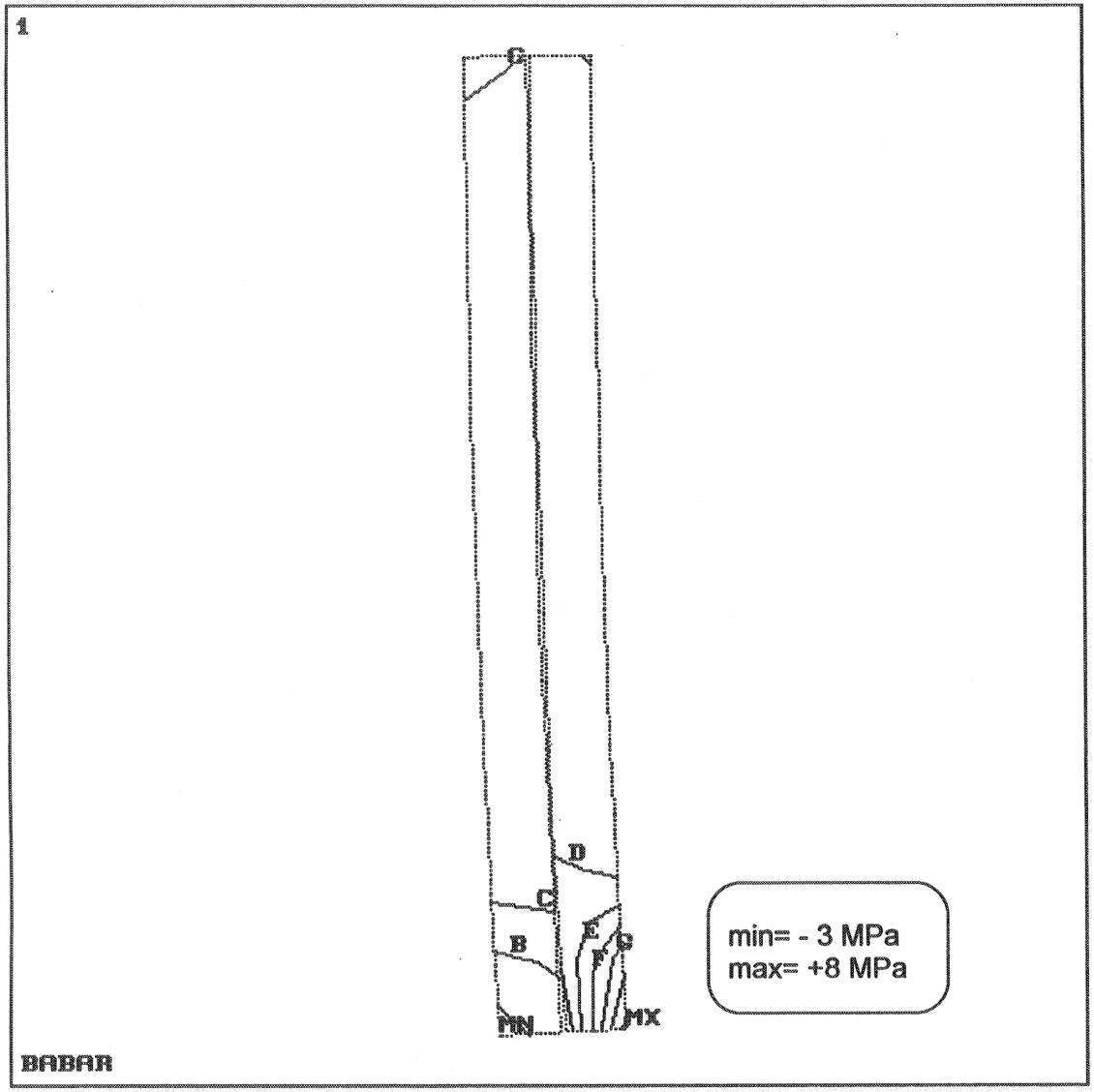
Tref = 4 K - axial stress in the coil (warm end)



ANSYS 5.1
SEP 11 1996
13:55:50
PLOT NO. 2
NODAL SOLUTION
STEP=1
SUB =1
TIME=1
SZ (AVG)
RSYS=0
DMX =0.001817
SMN =-0.440E+08
SMX =0.294E+07
A =-0.414E+08
B =-0.362E+08
C =-0.310E+08
D =-0.257E+08
E =-0.205E+08
F =-0.153E+08
G =-0.101E+08
H =-0.488E+07
I =331727

full range:
min= - 44 MPa
max= +3 MPa

Tref = 4 K - hoop stress in the coil (warm end)

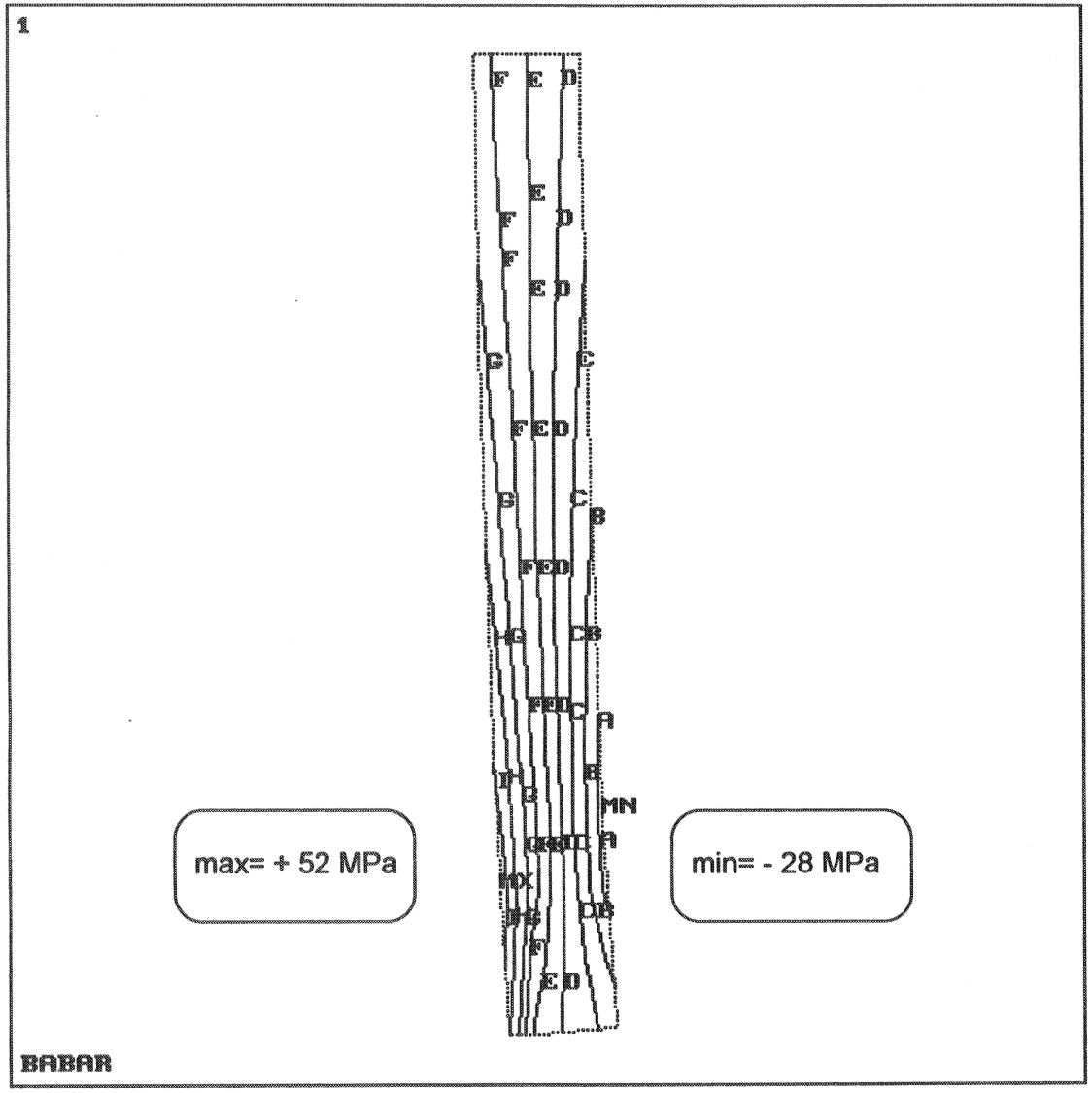


ANSYS 5.1
SEP 11 1996
13:55:57
PLOT NO. 3
NODAL SOLUTION
STEP=1
SUB =1
TIME=1
SXY (AVG)
RSYS=0
DMX =0.001817
SMN =-0.275E+07
SMX =0.764E+07
A =-0.218E+07
B =-0.102E+07
C =132910
D =0.129E+07
E =0.244E+07
F =0.360E+07
G =0.475E+07
H =0.591E+07
I =0.706E+07

min= - 3 MPa
max= +8 MPa

full range:
min= - 3 MPa
max= +8 MPa

Tref = 4 K - shear stress in the coil (warm end)



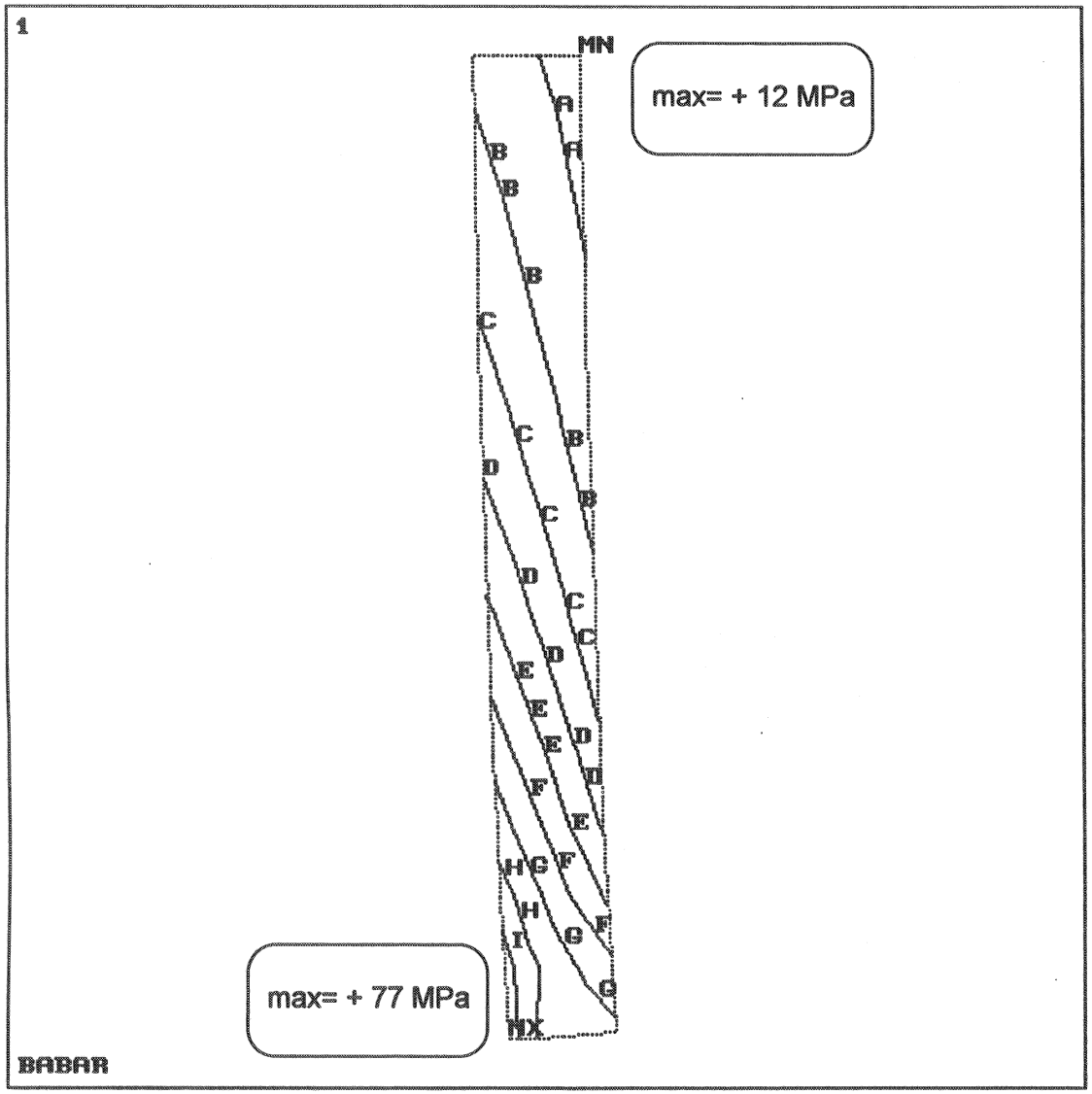
ANSYS 5.1
SEP 11 1996
13:56:22
PLOT NO. 4
NODAL SOLUTION
STEP=1
SUB =1
TIME=1
SY (AVG)
RSYS=0
DMX =0.001785
SMN =-0.284E+08
SMX =0.523E+08
A =-0.239E+08
B =-0.149E+08
C =-0.597E+07
D =0.299E+07
E =0.120E+08
F =0.209E+08
G =0.299E+08
H =0.388E+08
I =0.478E+08

max= + 52 MPa

min= - 28 MPa

full range:
min= - 28 MPa
max= +52 MPa

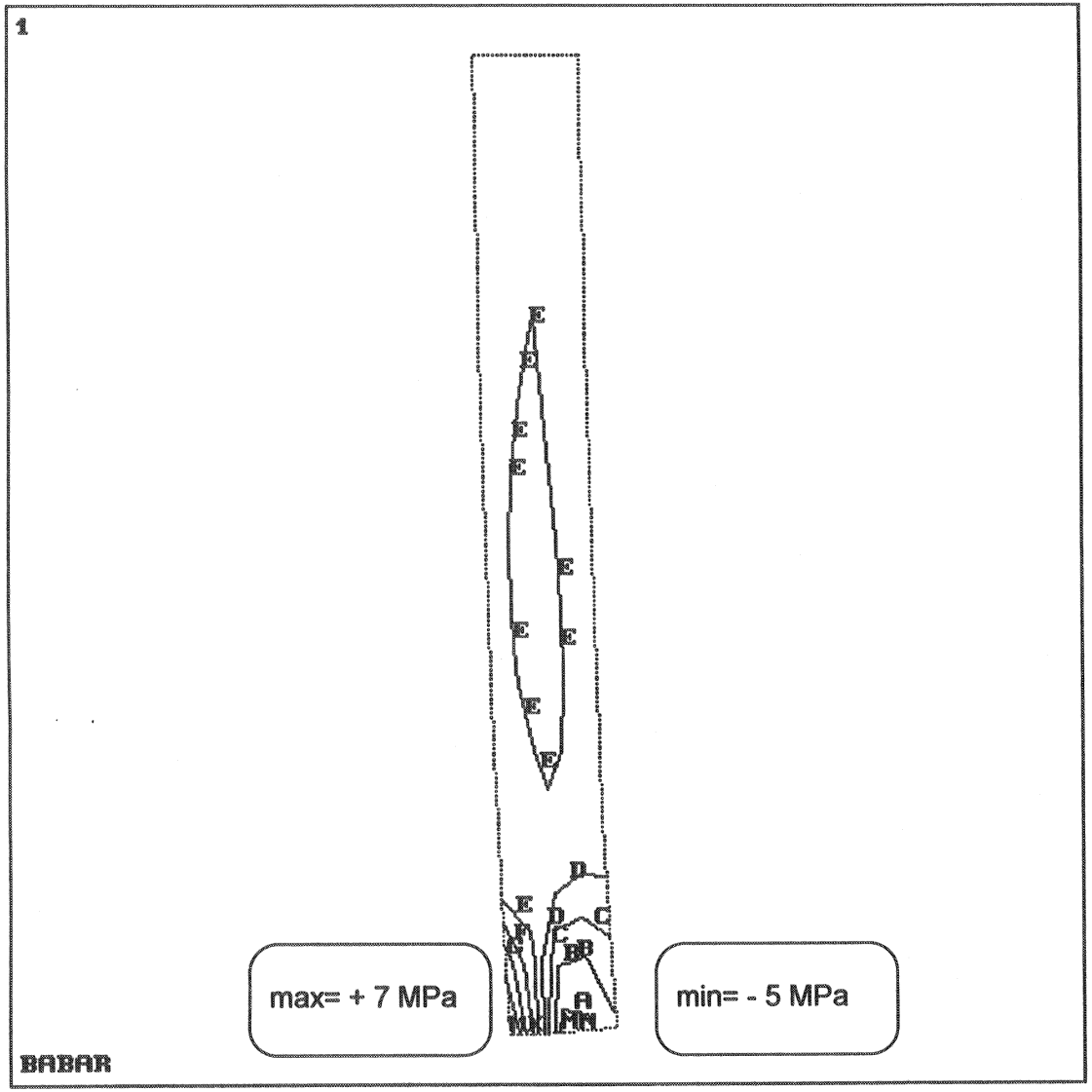
Tref=4 K - axial stress in the Al-cylinder (warm end)



ANSYS 5.1
SEP 11 1996
13:56:27
PLOT NO. 5
NODAL SOLUTION
STEP=1
SUB =1
TIME=1
SZ (AVG)
RSYS=0
DMX =0.001785
SMN =0.120E+08
SMX =0.769E+08
A =0.156E+08
B =0.229E+08
C =0.301E+08
D =0.373E+08
E =0.445E+08
F =0.517E+08
G =0.589E+08
H =0.661E+08
I =0.733E+08

full range:
min= + 0.3 MPa
max= + 77 MPa

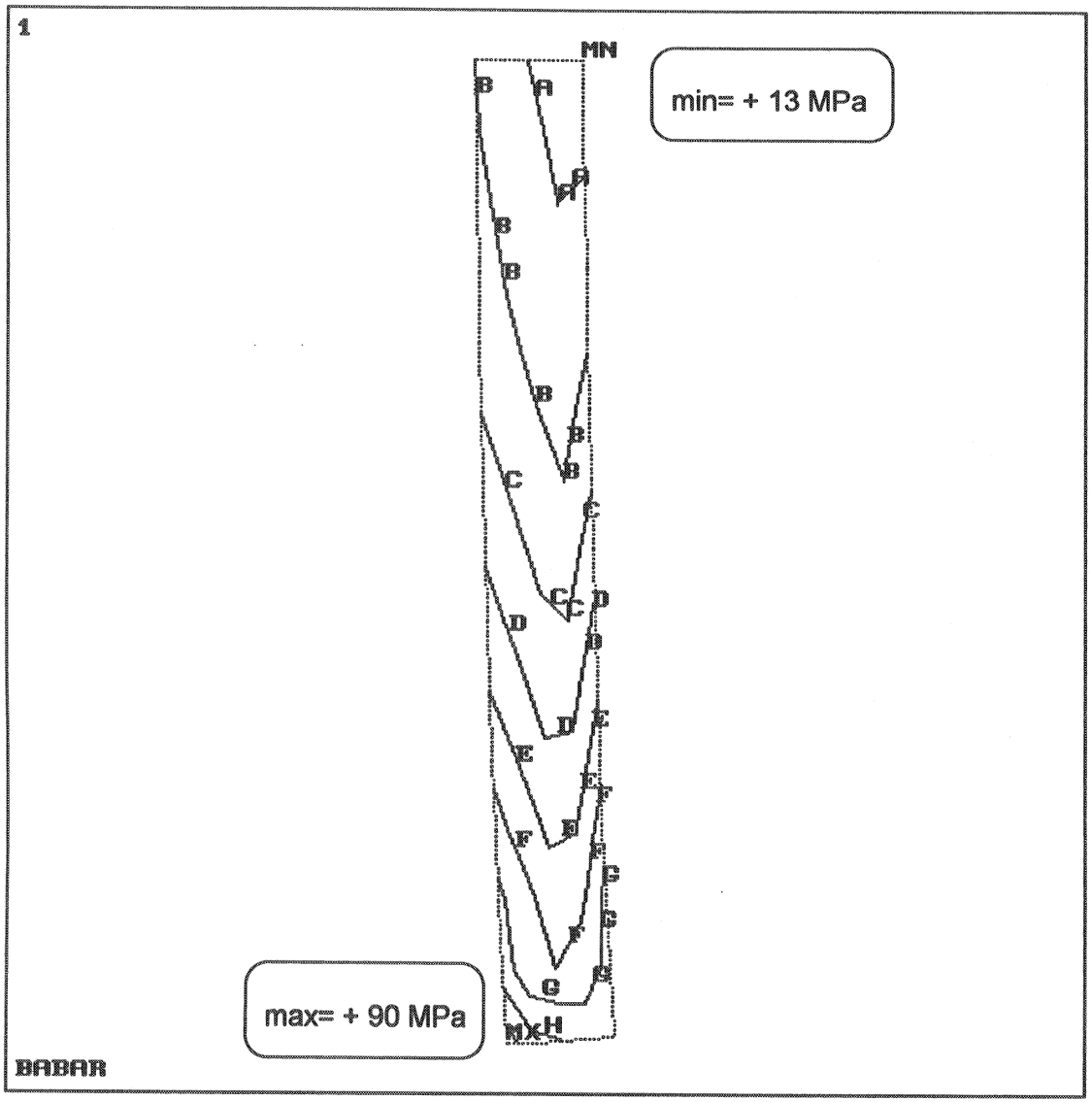
Tref = 4 K - hoop stress in the Al-cylinder (warm end)



ANSYS 5.1
SEP 11 1996
13:56:32
PLOT NO. 6
NODAL SOLUTION
STEP=1
SUB =1
TIME=1
SXY (AVG)
RSYS=0
DMX =0.001785
SMN =-0.505E+07
SMX =0.684E+07
A =-0.439E+07
B =-0.307E+07
C =-0.175E+07
D =-427333
E =893435
F =0.221E+07
G =0.353E+07
H =0.486E+07
I =0.618E+07

full range:
min= - 5 MPa
max= + 7 MPa

Tref = 4 K - shear stress in the Al-cylinder (warm end)



ANSYS 5.1
SEP 11 1996
13:56:36
PLOT NO. 7
NODAL SOLUTION
STEP=1
SUB =1
TIME=1
SINT (AVG)
DMX =0.001785
SMN =0.134E+08
SMX =0.896E+08
A =0.177E+08
B =0.261E+08
C =0.346E+08
D =0.431E+08
E =0.515E+08
F =0.600E+08
G =0.685E+08
H =0.769E+08
I =0.854E+08

full range:
min= + 0.3 MPa
max= + 90 MPa

Tref = 4 K - stress intensity in the Al-cylinder (warm end)

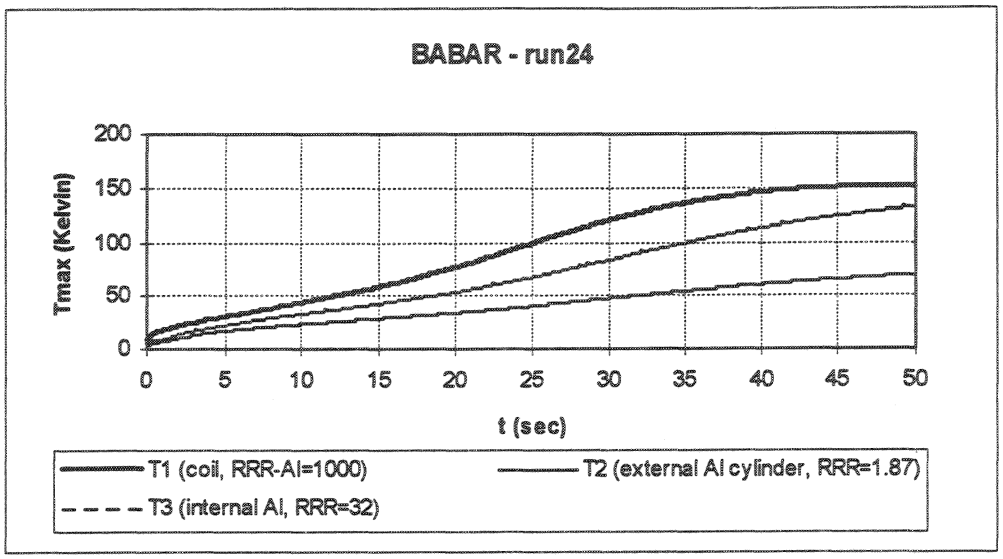
THE STRESS INTENSITY IS SO MUCH

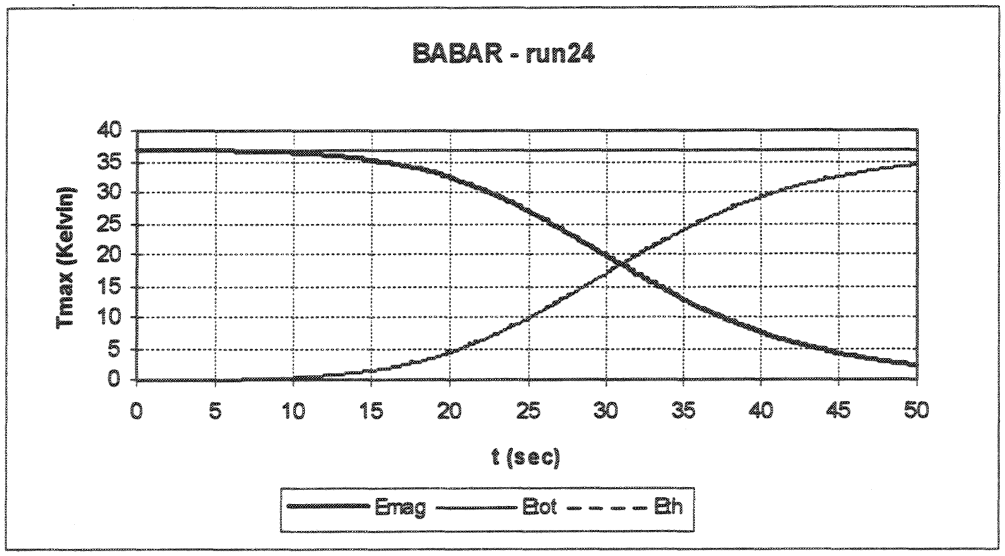
ANOTHER ANALYSIS WAS MADE TRYING TO REDUCE THE MAX TEMPERATURE DURING QUENCH USING:

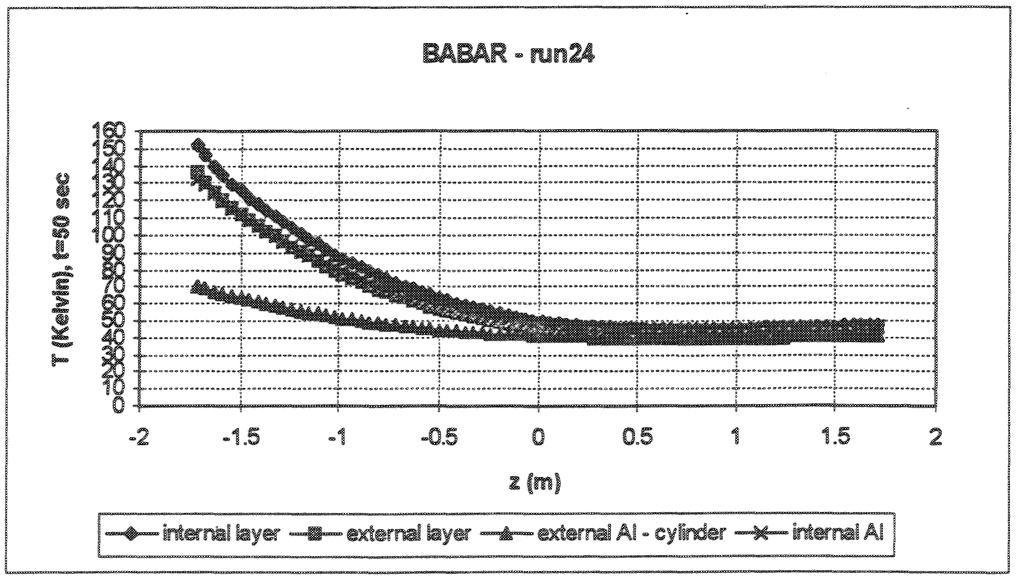
LONGITUDINAL ALUMINUM STRIPS

WITH DIFFERENT RRR TYPES

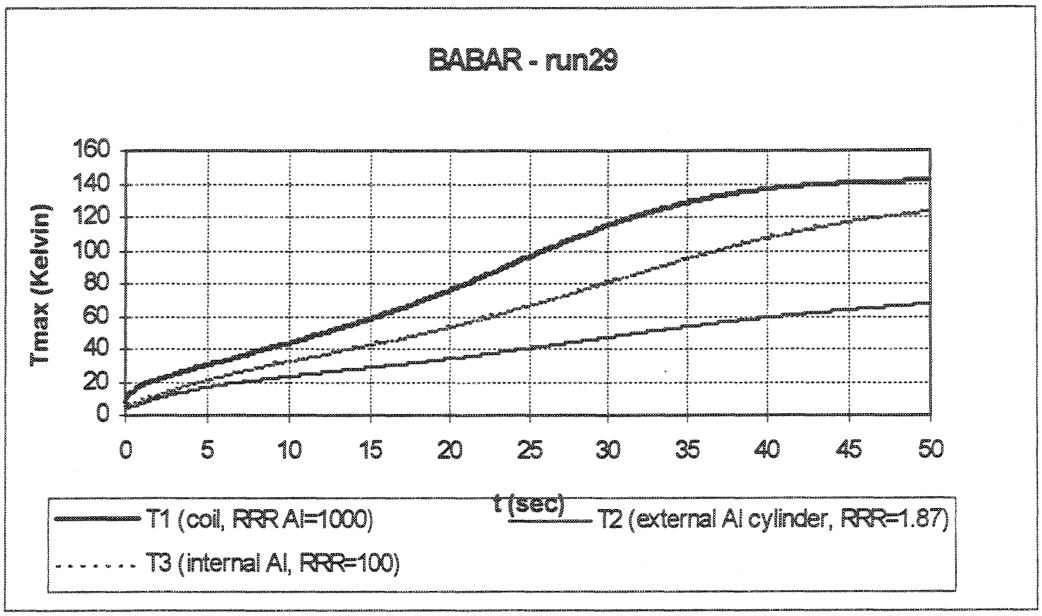
aluminum strips - RRR=32
(Al 1100)

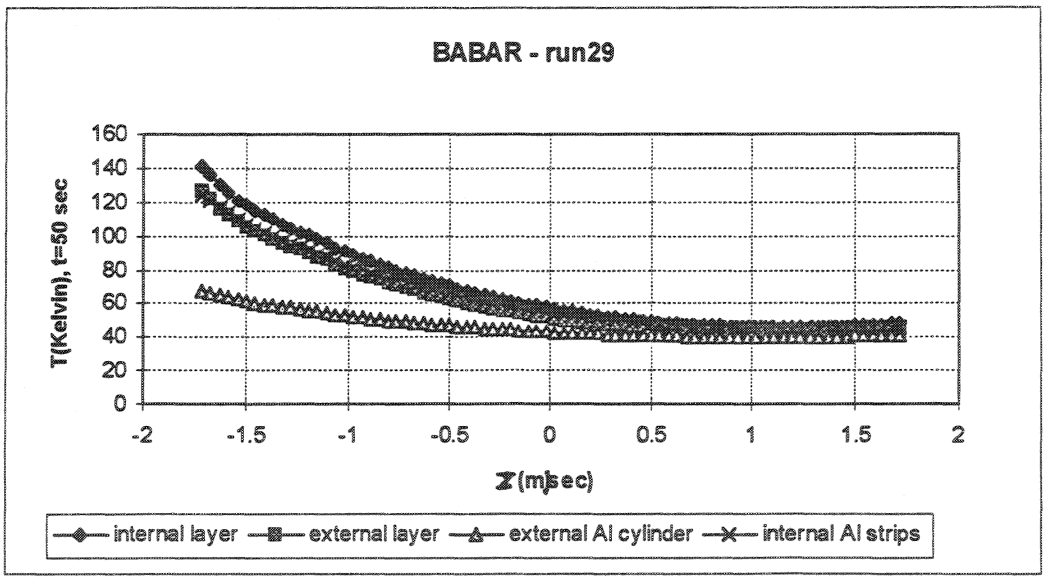




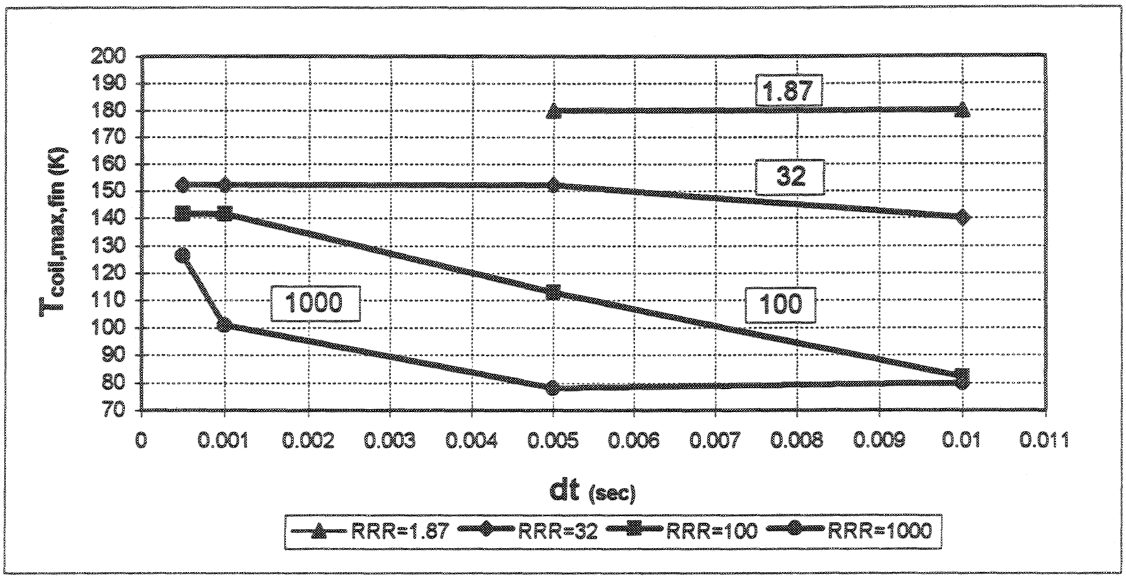


aluminum strips - RRR=100





dt (sec)	Tcoil,max,finale (K)			
	RRR=1.87	RRR=32	RRR=100	RRR=1000
5.00E-04		152	141.5	126.5
1.00E-03		152	141.5	101
5.00E-03	180	152	113	78
1.00E-02	180	140	82	80



INFLUENCE OF ALUMINUM STRIPS PLACED ON INTERNAL RADIUS OF COIL

(1 mm thickness+1 mm insulation)

Tref=4 K

RRR=32 (=Al 1100, 99% pure)

mat.1 (cable)	mat.5 (Al cylinder on external radius)
Sy = -27, +13 MPa Sz = -29, +6 MPa	Sy = -19, +35 MPa Sz = +0.3, +56 MPa Sint,max = 65 MPa

---

RRR=100

mat.1 (cable)	mat.5 (Al cylinder on external radius)
Sy = -23, +11 MPa Sz = -25, +6 MPa	Sy = -16, +30 MPa Sz = +0.3, +47 MPa Sint,max = 54 MPa

USING STRIPS THE STRESS INTENSITY IS VERY MUCH REDUCED

ANSALDO would use:

ALUMINUM 1050 or 1060 (99.5 % purity, easy to find), 1 mm thick

RRR should be between 32 and 100 (we have not found the data till now).

Such stress intensity is, in any case, due to a protection system failure.

Instead of testing the system without protection, is not better to be sure that the protection system works properly?

Quench Protection

P. Valente
(Ansaldo)

QUENCH PROTECTION SYSTEM

- QUENCH DETECTOR
  - PREAMPLIFIER
  - MAIN MODULE

- BREAKERS
- DUMP RESISTOR
- HARD WIRED SYSTEM

QUENCH DETECTOR

Action time less than 5 msec

PREAMPLIFIER

- Balanced bridge (only signal due to modification of resistance caused by a quench produce unbalancing)
- Input protected by high voltage through zener diodes
- Signals are converted from single ended to differential

MAIN MODULE

- Modular amplification (gain 25 - 1250). With max. gain unbalancing signal is ~ 1 mVolt
- 2 types of thresholds:
  - Absolute value
  - Integrated value (in case of low quench propagation velocity)

HOW TO IMPROVE QUENCH PROTECTION SYSTEM SECURITY?

QUENCH DETECTOR preamplifier

- LESS NOISE WITH:

  Amagnetic metallic box (shield)

  Differential signal

  Very close to the magnet

  Twisted wires from voltage taps

- POWER SUPPLY under batteries

- SECURITY LOGIC

  RELAYS ARE N.O. (in normal operation are excited closed)

- SAFE IN CASE OF ELECTRICAL LEADS RUPTURE (dead line used)

  (both for connection or power supply)

- CONNEY CONNECTORS (screwed) between preamplifier e quench detector

- N. 2 BREAKERS UNDER BATTERY (action time 80 msec)
- FUSE (thin wire) to safe the system against short circuit
- DIFFERENT PROTECTIONS
  - QD1 → MAGNET
  - QD2 → MAGNET + BUS BARS (more noisy)
  - N. 2 VOLTAGE COMPARATOR → BUS BARS + and BUS BARS - (less noisy)

- HARD WIRED SYSTEM

It is an electronic system that in case of alarm open the breakers, passing through the quench detector main module.

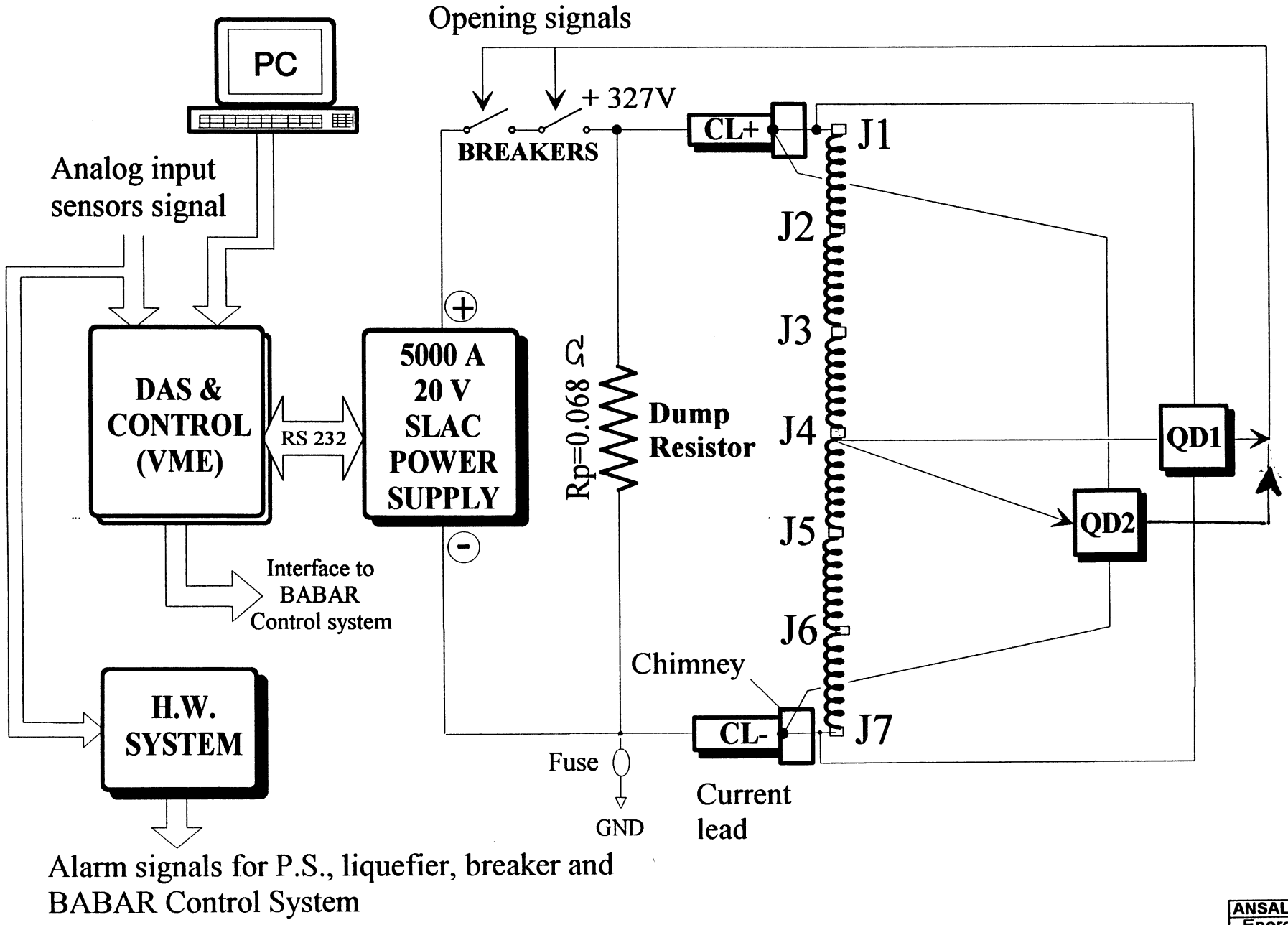
It has in input some analogic or digital signal and the output is an AND of digital signals (for analogic signals they are compared to a threshold).

INPUT SIGNAL:

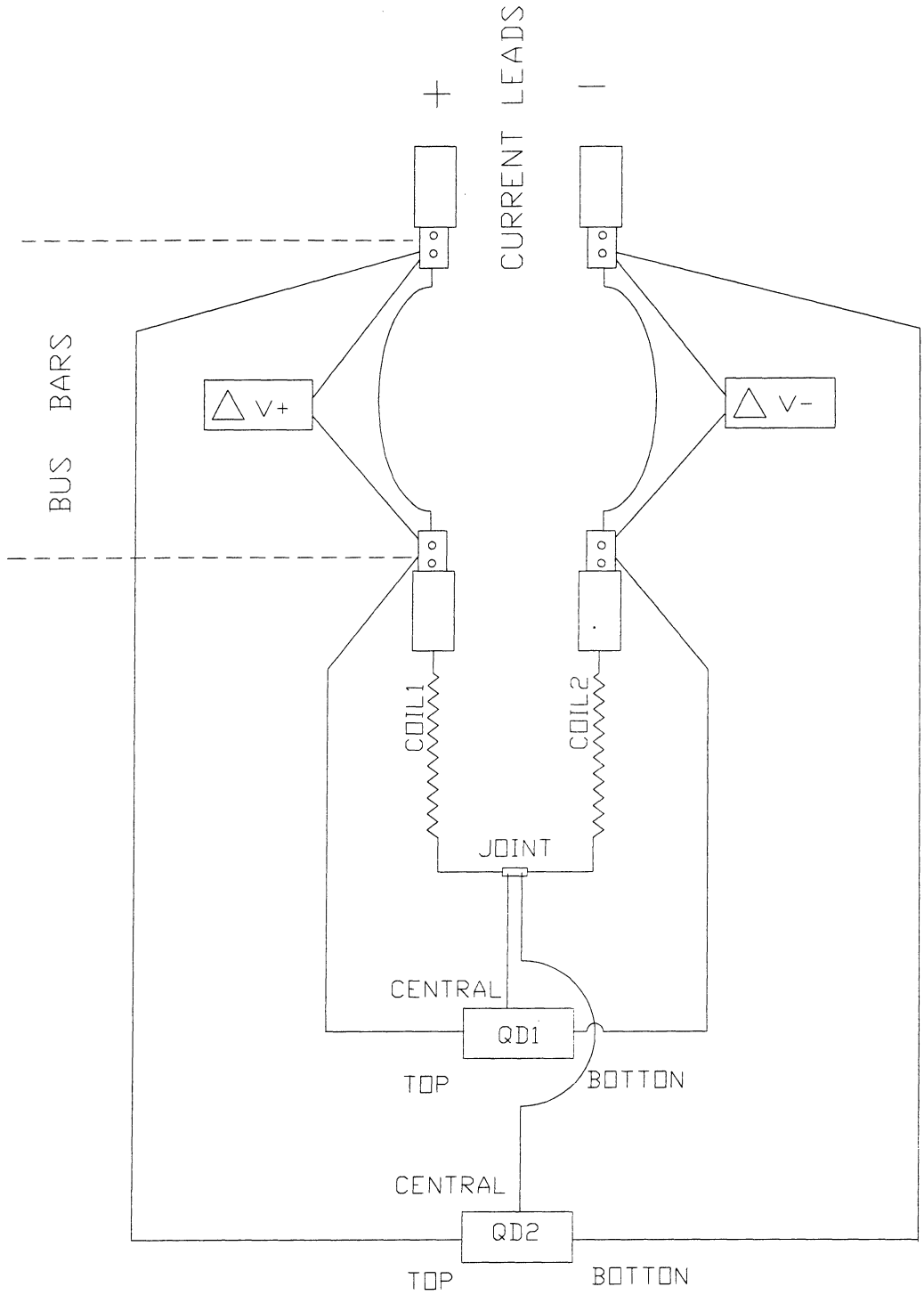
- Push button
- Helium level
- Vacuum
- QD1
- QD2
- Power supply failure
- Bus bar + voltage
- Bus bar - voltage
- Current leads + voltage drop
- Current leads + voltage drop
- Current leads - voltage drop

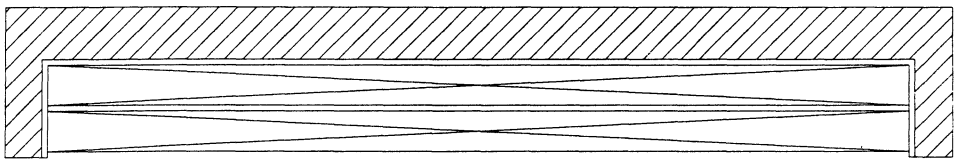
These alarms would be activated only in case of bad function of the Process Control System. In fact all these signal are acquired by that system (VME) and there are two level of software alarms that would be active before the hardwired system would work.

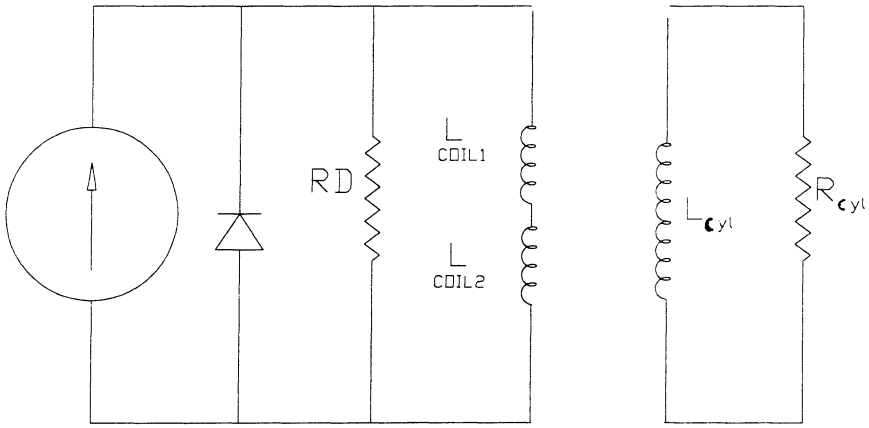
BABAR PROTECTION CONTROL SYSTEM



ANSALDO
Energia


CURRENT LEADS
+
−
BUS BARS
V+
V−
COIL1
COIL2
JOINT
CENTRAL
QD1
TOP
BOTTON
CENTRAL
QD2
TOP
BOTTON




RD
L
COIL1
L
COIL2
L
cyl
R
cyl

BaBar Co.l

Quench Review

P. Fabbricatore

THE SUPERCONDUCTING SOLENOID FOR BABAR EXPERIMENT AT PEPII

1) BRIEF HISTORY

2) COIL CHARATERISTICS

3) PRESENT STATUS

4) SCHEDULE

Overall coil parameters

Central Induction	1.5T
Conductor peak field	2.5T
Uniformity in the tracking region	± 3%
Winding Length	3470 mm *warm* 3455 mm *cold*
Winding mean radius	1530.2 mm *warm* 1524.4 mm *cold*
Amp turns	4.97 10^6
Operating current	4582 A (4800)
Inductance	2.584 H
Stored Energy	29 MJoule
The coil is made by two conductors forming 3 regions with different current density. Layers Number of turns	 2 1085
Total length of conductor	10500 m

CONDUCTOR

Conductor type	Pure Al-stabilised co-extruded
Aluminium RRR	> 1000
Thin conductor unit lengths	2 x 1840 m 2 x 1860 m
Thin conductor unit lengths	2 x 1820 m 2 x 1840 m
Dimensions at 300 K: Bare	4.93 and 8.49 x 20 mm2
Conductor Overall current density Central region Side regions	 29 A/mm^2 48 A/mm^2
Superconducting cable	Rutherford
Dimensions	6.4 x 1.4 mm^2
Strands diameter	0.8 mm
Number of strands	16
Cu/Sc	1.1
Filament diameter	40 μm
Ic(B=2.5, T=4.5)	11730 A

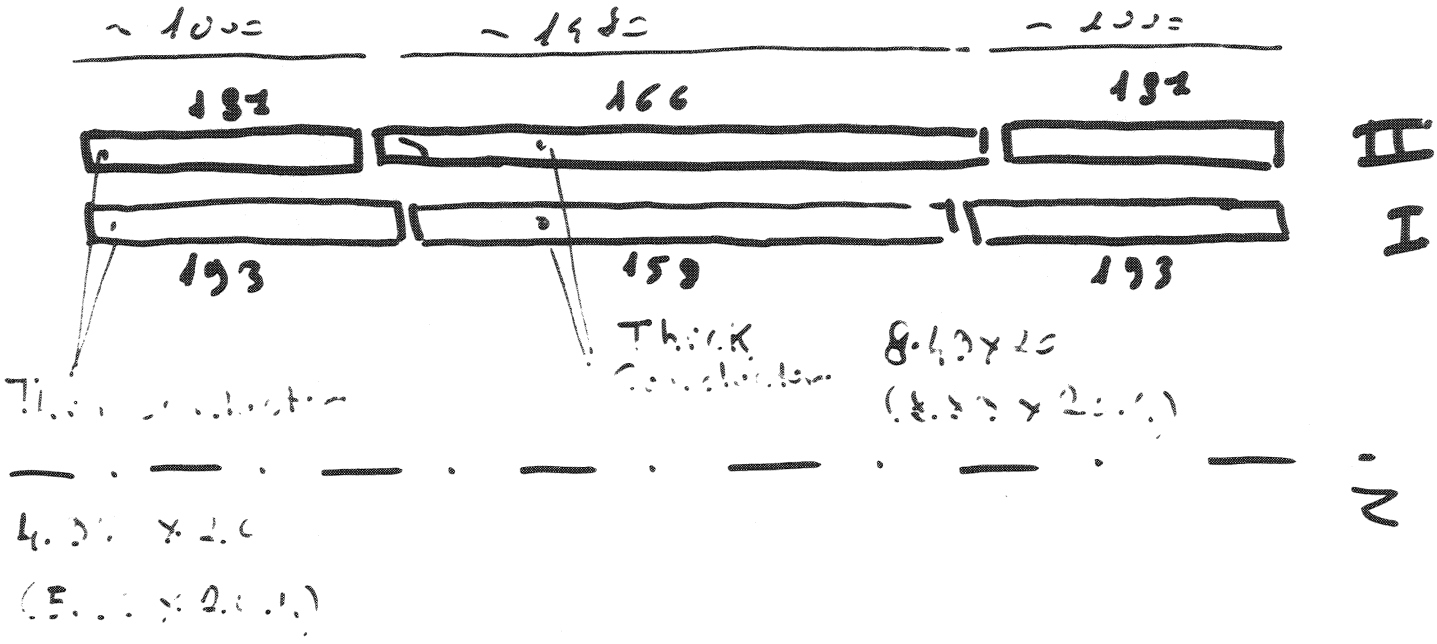
4550 Cu.
4800 Cu

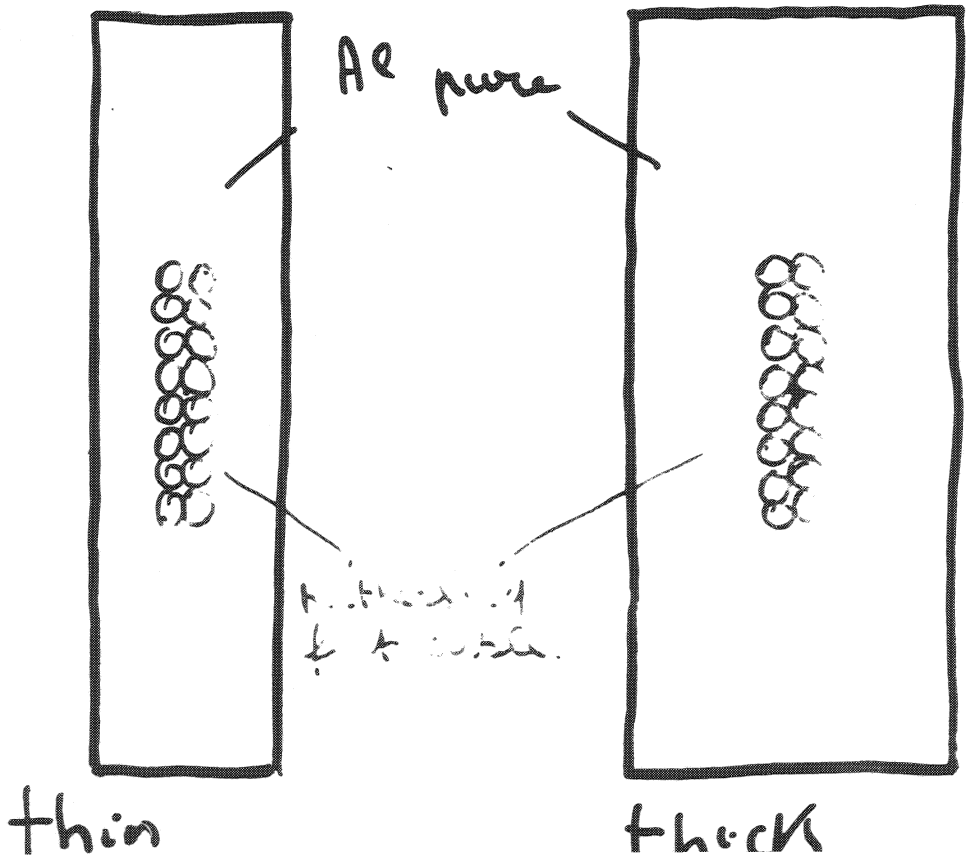
Jc (B~5, T=4.2K) ≥ 3000 A/mm²

Winding

2 layers (from stability)

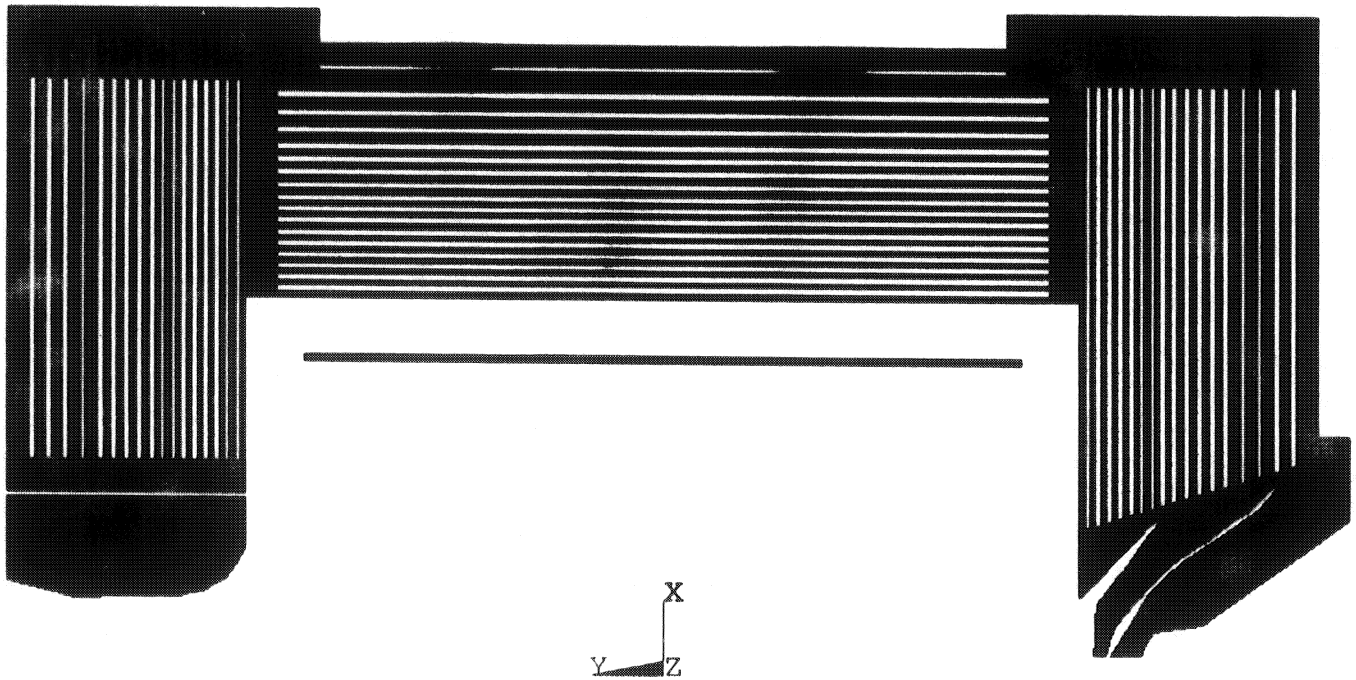
2. current densities (B uniformity in D.C.)





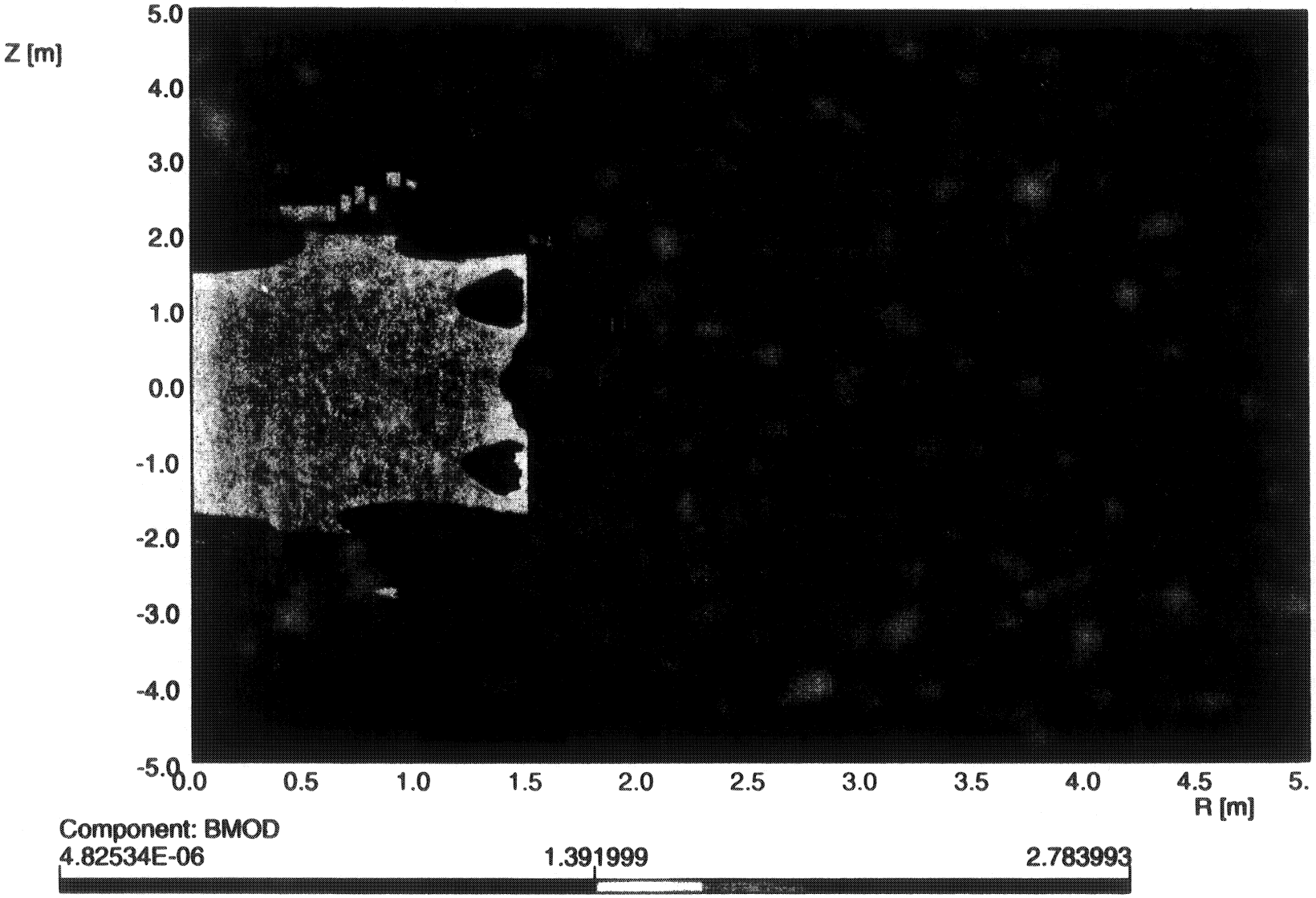
Main characteristics of some thin solenoids

	CDF	ZEUS	CLEO II	ALEPH	BaBaR
Location	FNL	DESY	CORNEL	CERN	SLAC
Manufacturer and year of completion	Hitachi 1984	Ansaldo 1988	Oxford 1987	SACLAY 1986	Ansaldo 1997
Central Field (T)	1.5	1.8	1.5	1.5	1.5
Inner Bore (m)	2.86	1.85	2.88	4.96	3.02
Length (m)	5	2.5	3.48	7	3.48
Stored Energy (MJ)	30	12.5	25	137	30
Current (A)	5000	5000	3300	5000	4582
Total weight (t)	11	2.5	7.0	60	7.8
Radiation Length	0.85	0.9	-	1.6	1.4 max
Conductor overall dimensions (mm)	3.89 x 20	4.30 x 15 5.56 x 15	5 x 16	3.6 x 35	4.93 x 20 8.49 x 20
Overall Current density A/mm^2	64	78 60	42	40	49 28



ANSYS 5.2
OCT 15 1996
19:20:09
PLOT NO. 1
AREAS
MAT NUM

ZV =1
DIST=3.576
XF =1.659
YF =-.0767
A-ZM=90
Z-BUFFER
EDGE



Component: BMOD
4.82534E-06 1.391999 2.783993

UNITS

Length	: m
Flux density	: T
Field strength	: A m^{-1}
Potential	: Wb m^{-1}
Conductivity	: S m^{-1}
Source density	: A m^{-2}
Power	: W
Force	: N
Energy	: J
Mass	: kg

PROBLEM DATA
BABARNEW.ST;1
Linear elements
Axi-symmetry
Modified R*vec pot.
Magnetic fields
Static solution
Scale factor = 1.0
20974 elements
10603 nodes
146 regions

15/Oct/96 16:49:32 Page 4

OPERA-2d
Pre and Post-Processor 1.603

1

ANSYS 5.2
OCT 15 1996
19:31:38
PLOT NO. 1
NODAL SOLUTION
STEP=2
SUB =1
TIME=2
BSUM (AVG)
SMN =.406E-08
SMX =2.626

.406E-08
.291741
.583481
.875222
1.167
1.459
1.75
2.042
2.334
2.626

AREAS
MAT NUM

ZV =1
DIST=5.5
XF =2.5
A-ZM=90
EDGE

Forces

- Not symmetric iron (z)
- Net axial force 50 t backward
- Ø force for coil disp. 3.5 cm forward
- The coil is 2.5 cm displ. (free) with respect the iron

± 1 cm axial disp. still possible

- 25 t axial magn. force
- 20 t transv. force
- Weight
- Seismic 0.2 g transv.

  1.6 g vert.

1) BRIEF HISTORY

- **OCTOBER 1994 - MARCH 1995**

  INFN Genova and RAL performed the conceptual Design

- **MARCH 1995**

  Design Review in SLAC

- **JUNE 1995**

  Design revised following the reccommendations of Review Committee

- **JUNE 1995**

  Specifications

- **JUNE 1995**

  Tender

- **JULY 1995**

  Order placed to ANSALDO ENERGIA (Genova)
  Choice between ANSALDO and OXFORD proposals
  Review Committee

- **OCTOBER 1995**

  First informal meeting SLAC-INFN-ANSALDO

- **JANUARY 1996**

  I formal Review (first design)

- **APRIL 1996**

  II formal Review (Engineering Design)

- **SEPTEMBER 1996**

  II Informal meeting SLAC-INFN-ANSALDO

- **OCTOBER 1996**

  II formal Review

CRITICAL LINES

SUPPORTING CYLINDER	October 18th 1996
CONDUCTOR	October 2nd / Nov . 11th Dec. 2nd 1996
CRYOSTAT	February 28th 1997

IMPORTANT DATES

WINDING	from Oct. 23rd 1996 to Jan. 22 nd 1997
ASSEMBLY	from Mar. 3rd 1997 to May 15th 1997
TEST in Ansaldo	within June 23rd 1997
COIL AT S.F.	Sept. 8th 1997

Lawrence Livermore National Laboratory, University of California

Dr. Stewart S. Shen
P.O. Box 808, L-287, Livermore, CA 94551-9900 USA
Phone: (510) 423-4826
Telefax: (510) 424-3532
E-Mail: shen@maverick.llnl.gov

Dec. 13, 1996

Hi Steve and Jon:

I have just recived the packet containing the info we requested in the first Quench Protection Review Meeting on 10/17. Please study them.

After New Year, I will contact you to arrange a meeting at LLNL in the week of 1/13.
Thanks

Sincerely,

Stewart S. Shen
ATEG
Applied Research Engineering Division

LAWRENCE LIVERMORE NATIONAL LABORATORY

7000 East Ave., P.O. Box 808, L-287, Livermore, CA 94550
Email: toconnor@llnl.gov Phone: (510) 423-8781
Fax: (510) 422-6747 (verify, 510-423-7533)

November 5, 1996

Dear Solenoid Group:

The review of the Quench Protection System held on October 17, 1996 went very well. The reviews felt the we have a good quench protection system and that there is enough redundancy in the system to adequately protect the superconducting solenoid. Before the reviewers write up their report they have requested that we send them the information listed below. After they have had time to review this new information we will have a conference call to discuss it some time during the week of December 18, 1996.

The list includes the person or group responsible for obtaining the information and a brief description of the requested information. The responses to these questions are attached.

1) INFN - Detailed field plots of the maximum field in the conductor OK
2) INFN - MPZ analysis - analysis already complete, P. Fabbricatore will write a summary of the results. OK
3) Ansaldo - Re-run quench analysis with an RRR of 500, what is the effect of the lower RRR. OK
4) Ansaldo - Re-run the stress analysis of the for time = 30 sec. What is the effect of high temperature gradient at approx. 75% current. Use the quench results from Run15 (no dump resistor and quench from one end) OK
5) Ansaldo - Has your quench protection code been calibrated? If not the reviewers would like it to be bench marked against some know quench problem
6) Ansaldo - The values of all mechanical, thermal and electrical properties used in your quench and stress analysis. OK
7) Ansaldo - what is the heat treatment of the 5083 Aluminum winding cylinder. For example "T6" Ans: 5083-0
8) O'Connor - The review committee wanted to see the detailed design of the joints.
9) Ansaldo - Could the joint between the two layers (J4) be eliminated. This joint is in the high field region where quench is likely to start from. What happens if the quench propagates equally on both layers. The voltage taps looking at the change in voltage between the two layers may not detect a quench of this kind for some time.

Yours in appreciation,

Thomas G. O'Connor
Magnet Co-System Manager

BABAR MAGNET PEAK FIELD AT THE WINDING

To perform this simulation, the old model (not updated with the new forward door geometry and the new B-H curves) was used.
The winding is the one given by ANSALDO (see Fig. 1-1) with a current I=4530 A (the resultant magnetic field is 1.5017 T).

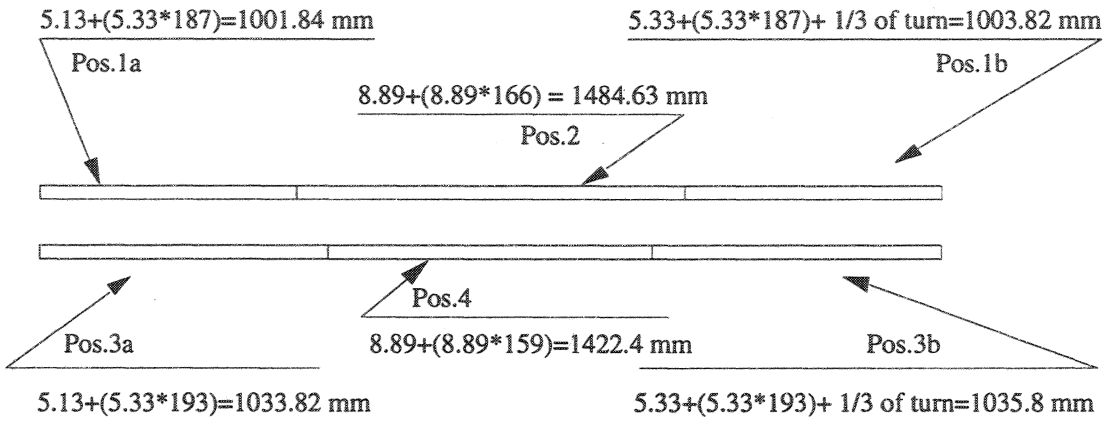


Fig. 1-1 Basic design of BABAR winding

At first the winding was modelised in rectangular shape 8 mm width (the width of the Rutherford cable), with the correct current density shared in all the sections (see Fig. 1-2); with this model the resultant peak field on the winding is 1.88 T. But in this way all the obtained results are correct unless the field on the winding; to get this result it is needed to take into account the self field.
So twenty turns of the backward end coils, the regions where the maximum magnetic field was found, was modeled separately: with the self field correction the peak field on the winding becomes 2.065 T.

No changes in iron – cutting.

At 5083 cylinder.

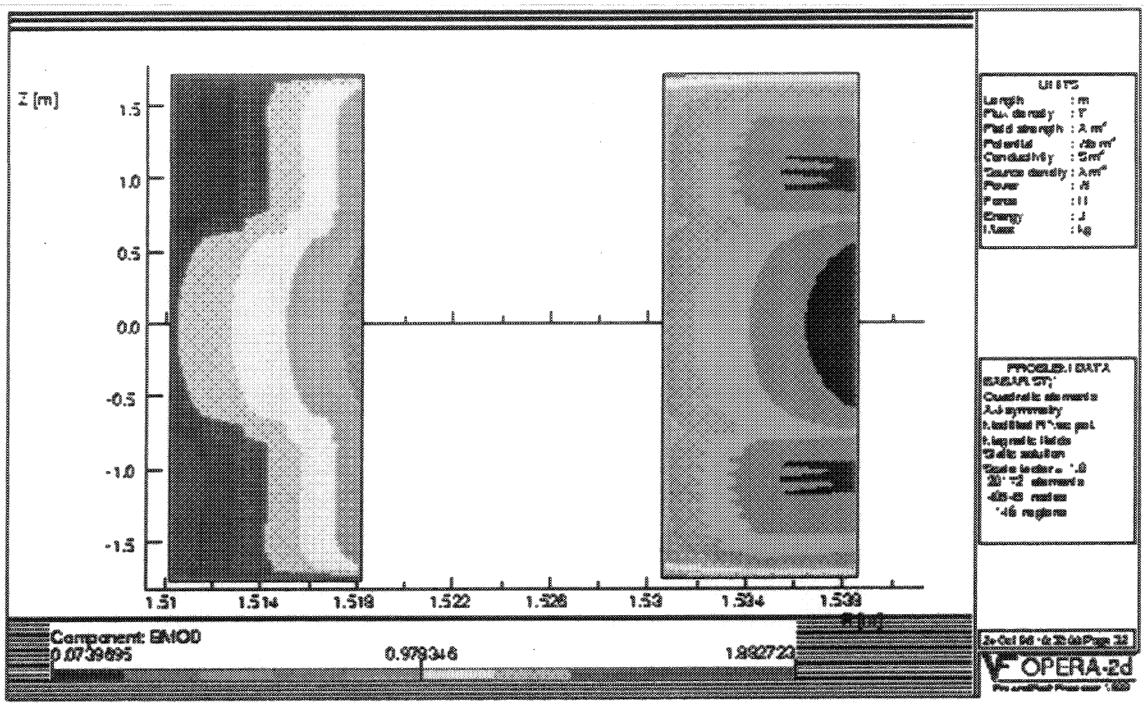


Fig. 1-2 Field on the winding modeled in rectangular shape

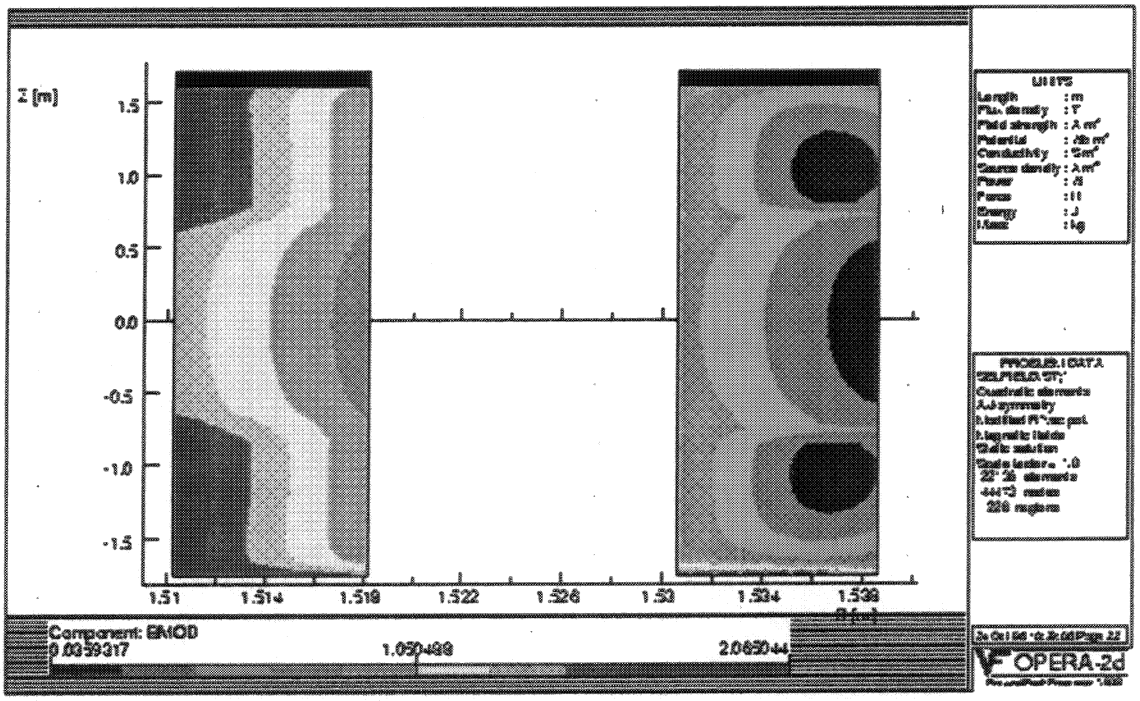


Fig. 1-3 Field on the winding wih the backward end coils modeled as they are BABAR magnet peak field at the winding

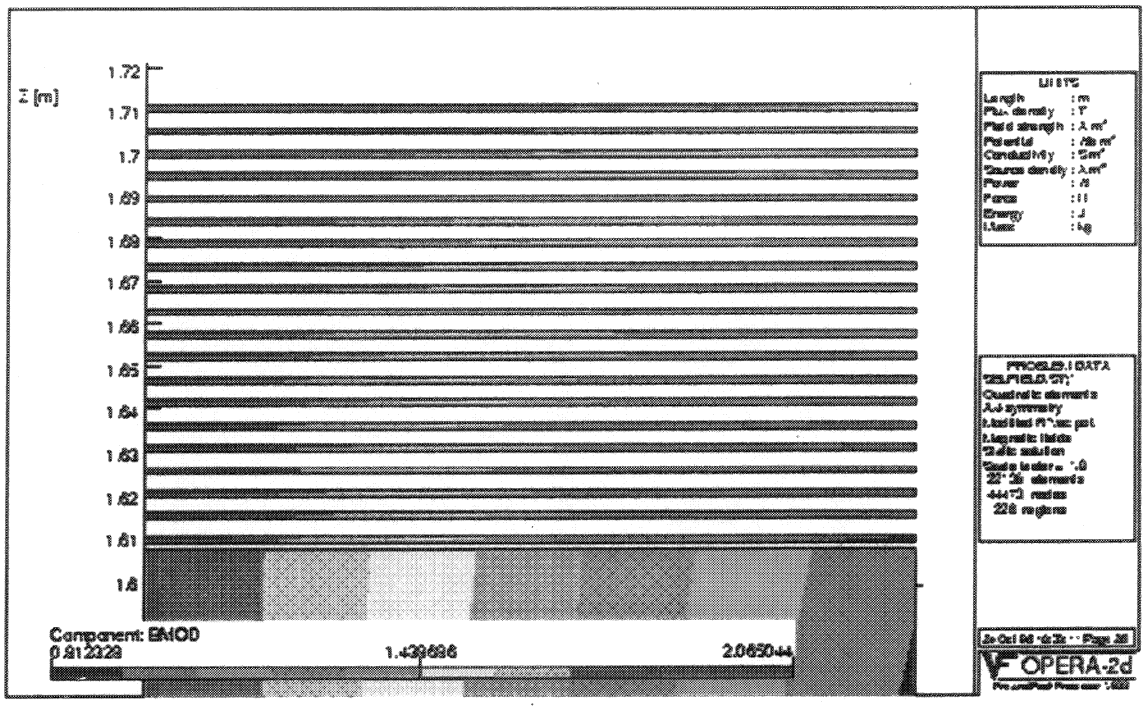


Fig. 1-4 Particular of the field in one backward end coil

Minimum Propagation Zone for BABAR winding

L. Boldi (Istituto Nazionale di Fisica Nucleare - Genova)
Genova 13 November, 1996

These simulations analyse the Minimum Quench Energy and the Minimun Propagation Zone for the BaBar two layers 's model.

In fig.1 and in table 1 are showed the dimensions of cable and the main parameters used for computations.

The whole magnet is represent as the model in fig.2, due to the symmetry only a quarter of geometry was considered.

The time evolution of transited zone in conductor, after a heat disturbance (Δz = 1 cm , Δt = 10 msec), allows to say that MPZ is about 0.7 m and its duration time is ~ 250 msec, while the MQE is about 1.5 J (case with current diffusion effect, fig. 3). (Computed.) Adiabatic. (check calculations)

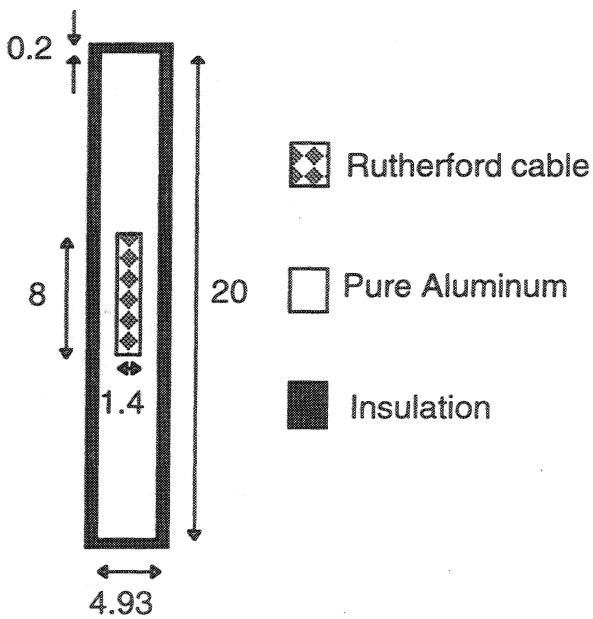


Fig. 1 BaBar cable (dimensions in mm).

Table 1

First layer		Second layer	
Magnetic field	2.5 T	Magnetic field	1.4 T
Sharing temperature	6.6 K	Sharing temperature	7.05 K
Critical temperature	8.2 K	Critical temperature	8.67 K
Current	5000 A	Nominal temperature	4.5 K

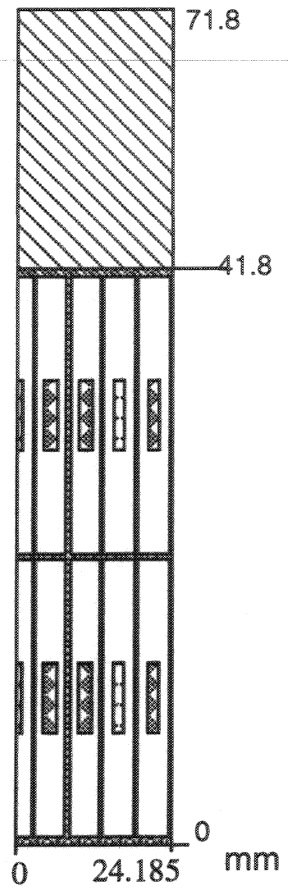


Fig. 2 Model of Babar two layers.

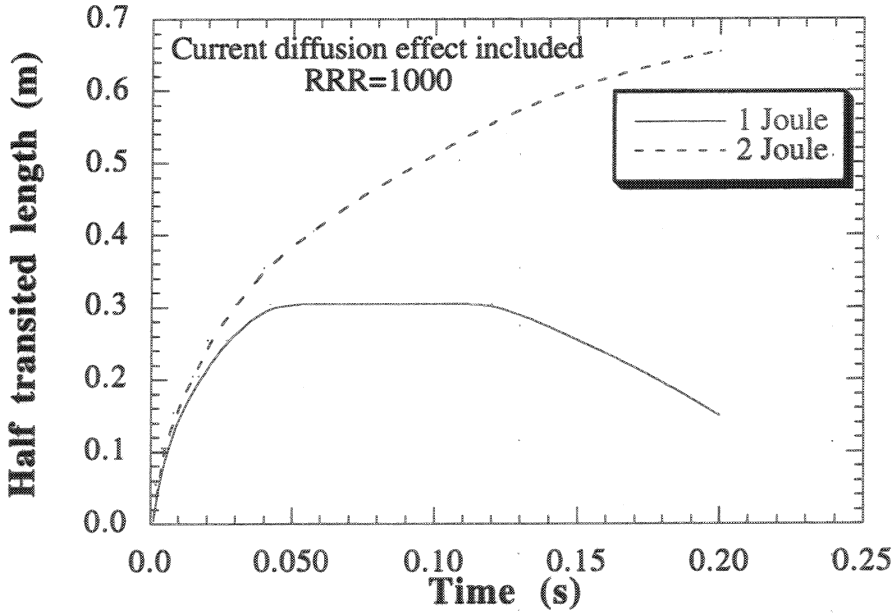


Fig.3 Half transited zone length versus time

ADVANCEMENTS IN QUENCH ANALYSIS

WORST CASE OF QUENCH = START FROM ONE END OF COIL,
WITHOUT DUMP RESISTOR

3 **A** - STRESS VALUES FOR INTERMEDIATE TIME DURING QUENCH (t=30 sec from quench start), WHEN CURRENT IS STILL 75%

4 **B** - WHAT HAPPENS IF RRR=500 FOR ALUMINUM OF CABLE (INSTEAD OF RRR=1000)

1 **C** - CHECK OF OUR QUENCH COMPUTATION CODE WITH ANOTHER MAGNET, SIMILAR TO BABAR, WHERE QUENCH MEASUREMENTS HAD BEEN MADE

ANSALDO-SLAC MEETING 7-8 Nov. 1996

@ 50 sec Zero current, No Aluminum strips

stress (MPa)	mat.1 (lateral cable)	mat.2 (interlayer insulation)	mat.3 (central cable)	mat.4 insulation on external radius of coil	mat.5 Al - cylinder
Sx (radial)	-5, +7	- 5, + 8	-0.04, +0.6	-7, +1	-13, +5
Sy (axial)	- 40, +19	- 8, + 9	- 2, +0.8	- 4, + 4	- 28, + 52
Sz (hoop)	- 44, +3	- 12, + 3	- 2, +1	- 4, + 15	+0.3, + 77
Sxy (shear)	-3, +8	- 0.5, + 3	-0.3, +0.04	-0.8, + 19	-5, +7
Sint (intensity)	------	------	------	------	90

- FULL - RANGE STRESS TABLE FOR T_{ref} = 4 Kelvin STRESS ANALYSIS (WORST QUENCH TEMPERATURE DISTRIBUTION)

σ_{weld} for 5083 Al = ? σ_{allow} for 5083 Al ≃ 100 MPa

5083-0 σ_{yield} " " ≃ 200 MPa

RRR=32 (=Al 1100, 99% pure) axial Strips 1mm thick 30cm wided 1mm of insulation

mat.1 (cable)	mat.5 (Al cylinder on external radius)
from -40 to Sy = -27, +13 MPa Sz = -29, +6 MPa	Sy = -19, +35 MPa Sz = +0.3, +56 MPa Sint,max = 65 MPa

Table 4.2)

RRR=100 Strips

mat.1 (cable)	mat.5 (Al cylinder on external radius)
Sy = -23, +11 MPa Sz = -25, +6 MPa	Sy = -16, +30 MPa Sz = +0.3, +47 MPa Sint,max = 54 MPa

- Quench from one end of coil, no dump resistor
- No aluminum strips
- → t=30 sec from quench start (75% current)

THERMAL (Tref=4 K)

minima & maxima	mat.1 (lateral cable)	mat.2 (interlayer insulation)	mat.3 (central cable)	mat.4 (insulation)	mat.5 (aluminum containment cylinder)
Sx (MPa)	-3, +3	-3, +4	-0.03, +0.3	-6, +1	-8, +3
Sy (MPa)	**-22, +11**	-7, +1	-2, +0.4	-5, -0.4	**-17, +30**
Sz (MPa)	**-29, +3**	-10, -0.9	-2, +0.7	-2, +5	**-0.5, +44**
Sxy (MPa)	-2, +4	-0.2, +3	-0.2, +0.02	-0.5, +10	-3, +4
Sint (MPa)	---	---	---	---	

Axial

CURRENT

minima & maxima	mat.1 (lateral cable)	mat.2 (interlayer insulation)	mat.3 (central cable)	mat.4 (insulation)	mat.5 (aluminum containment cylinder)
Sx (MPa)	-2, -0.2	-2, +0.1	-0.8, +0.2	-0.9, +0.05	-0.7, +0.1
Sy (MPa)	**-12, +0.09**	-6, -1	-5, +4	-5, -1	**-15, +0.8**
Sz (MPa)	**+15, +28**	+7, +13	+14, +23	+6, +13	**+12, +30**
Sxy (MPa)	-0.5, +1	-0.7, +1	-0.8, +2	-0.9, +1	-0.8, +1
Sint (MPa)	16, 38	8, 19	16, 28	8, 18	15, 36

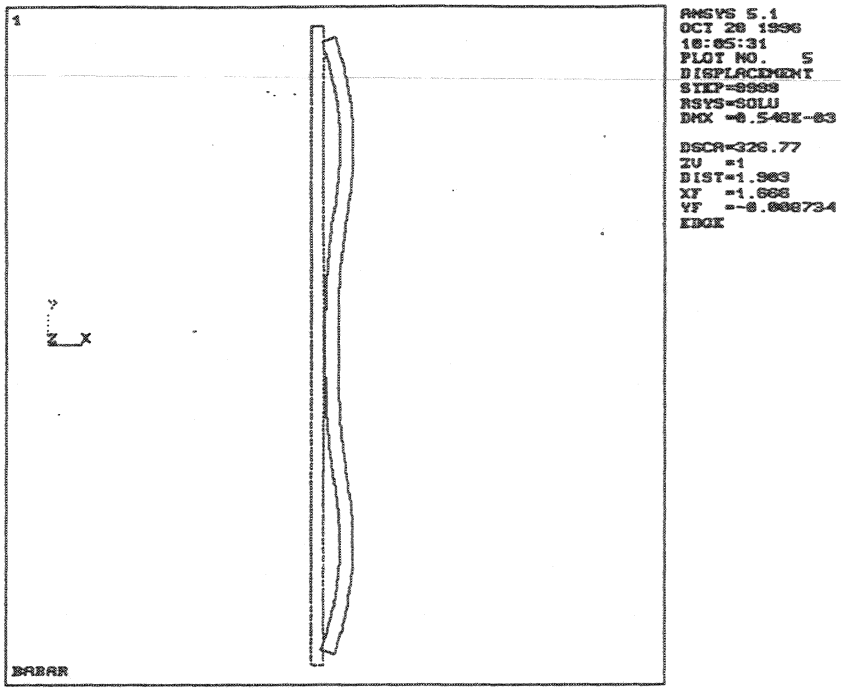
THERMAL+CURRENT

minima & maxima	mat.1 (lateral cable)	mat.2 (interlayer insulation)	mat.3 (central cable)	mat.4 (insulation)	mat.5 (aluminum containment cylinder)
Sx (MPa)	-3, +1	-4, +2	-0.6, +0.2	-6, +0.5	-9, +3
Sy (MPa)	**-23, +8**	-12, -1	-7, +3	-7, -2	**-17, +28**
Sz (MPa)	**-8, +28**	+0.7, +12	-13, +23	+6, +14	**+13, +66**
Sxy (MPa)	-2, +4	-0.7, +3	-1, +2	-1, +10	-3, +3
Sint (MPa)	---	---	---	---	17, 74

from -40

y from +3

{75% current} +{ temperature distribution from quench at t=30 sec}



If quench started from an intermediate point of the coil (not the centre, not one end) corresponding to one of the humps in the deformed model ?

Conservative valuation: the most unfavourable combination of the components is

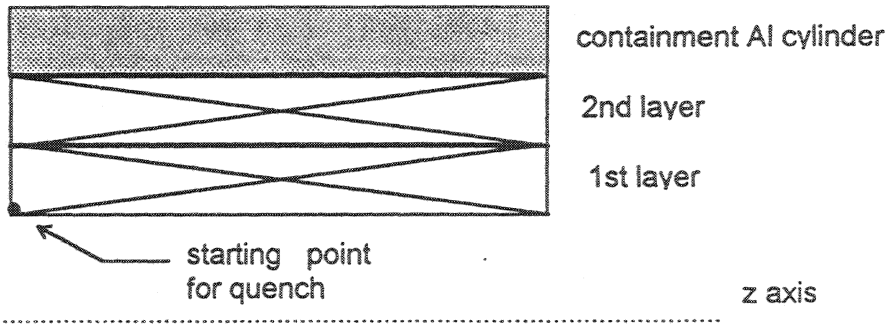
axial	COIL, Sy	-22 -12	=	-34 MPa
hoop	COIL, Sz	+3 +28	=	+31 MPa
	CYLINDER, Sy	-17 -15	=	-32 MPa
	CYLINDER, Sz	+44, +30	=	+74 MPa = 44 + 30 from worst case on previous page

(5)

EFFECT OF RRR=500 FOR ALUMINUM OF CABLES

(PREVIOUS RUNS: RRR=1000)

QUENCH STARTING FROM INTERNAL RADIUS OF COIL, ONE END



RRR of containment cylinder aluminum: 1.87 (Al 5083 alloy)
RRR of aluminum in cables: now is 500
aluminum strips are absent in this comparison

1) dump resistor is present (Rdump=0.068 Ω)

⇒ "final" maximum temperature is *higher*

WORSE

A little more energy is dissipated inside the coil, but the part which is dissipated outside in the dump resistor is still predominant.

RRR=**1000**: Tcoil,max,final= **57 K**
RRR=**500**: Tcoil,max,final= **60 K**

2) dump resistor is absent (Rdump=0.0001 Ω for the computation)

⇒ "final" maximum temperature is *lower*

BETTER

Propagation speed is a little higher for the RRR=500 case, at low temperatures.

RRR=**1000**: Tcoil,max,final= **195 K**
RRR=**500**: Tcoil,max,final= **178 K**

If dump resistor is not present it is better if the RRR is lower

(6)

"FINAL" = at t=50 sec from quench start (for this magnet)

- WE SAY "**THE END OF QUENCH**" TO MEAN A TIME WHEN:

  1) - ALMOST ALL MAGNETIC ENERGY HAS BEEN TRANSFORMED INTO THERMAL ENERGY

  2) - MAXIMUM TEMPERATURE IN THE COIL HAS REACHED A SATURATION VALUE

  3) - THE HIGHEST TEMPERATURE GRADIENT IS PRESENT (BEFORE TEMPERATURE IN THE COIL GOES TOWARDS UNIFORMITY, THAT IS BEFORE MAXIMUM TEMPERATURE SATURATION VALUE SPREADS THROUGHOUT THE COIL).

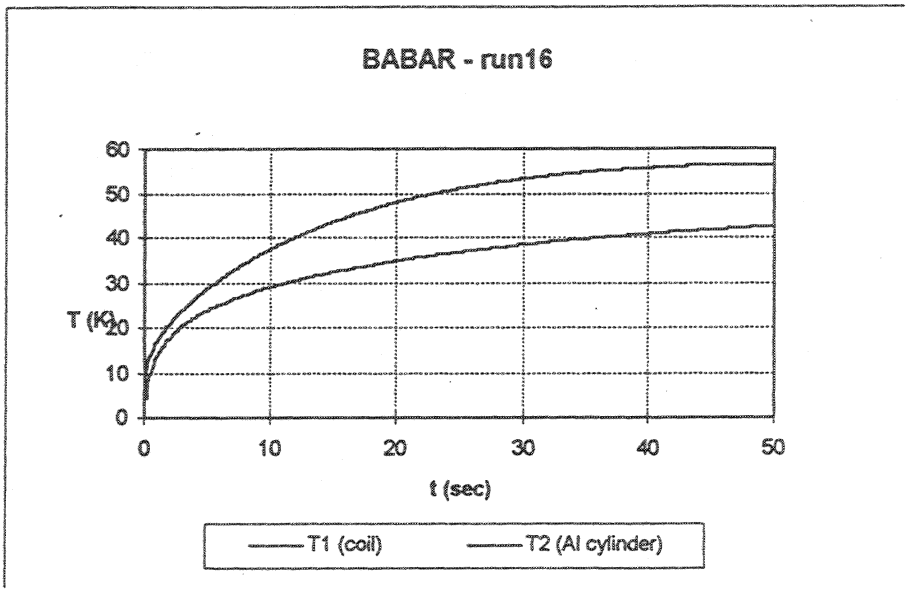
---

(7)

plot of maximum temperature (versus time) in coil and cylinder:

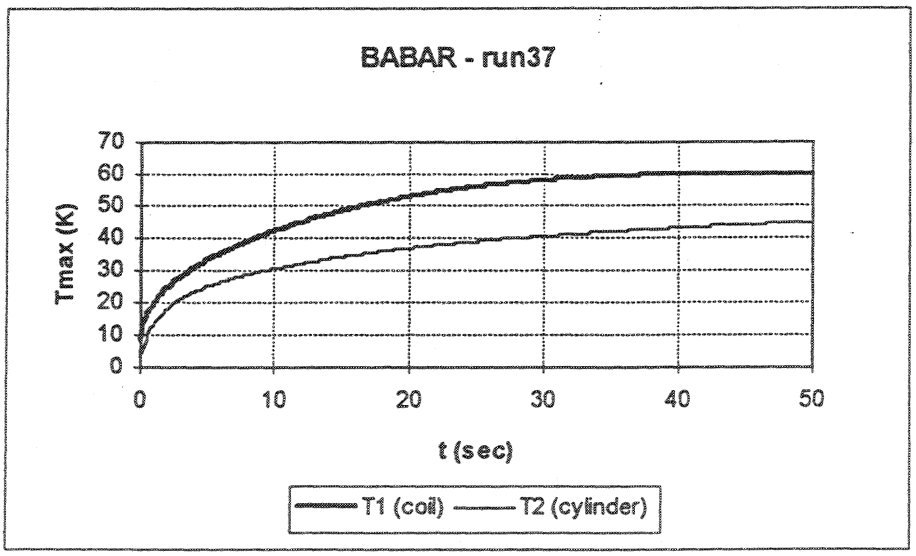
Rdump = 0.068 Ω

RRR=1000



final Tmax of coil = **57 Kelvin**
final Tmax of Al cylinder = 43 Kelvin

RRR=500



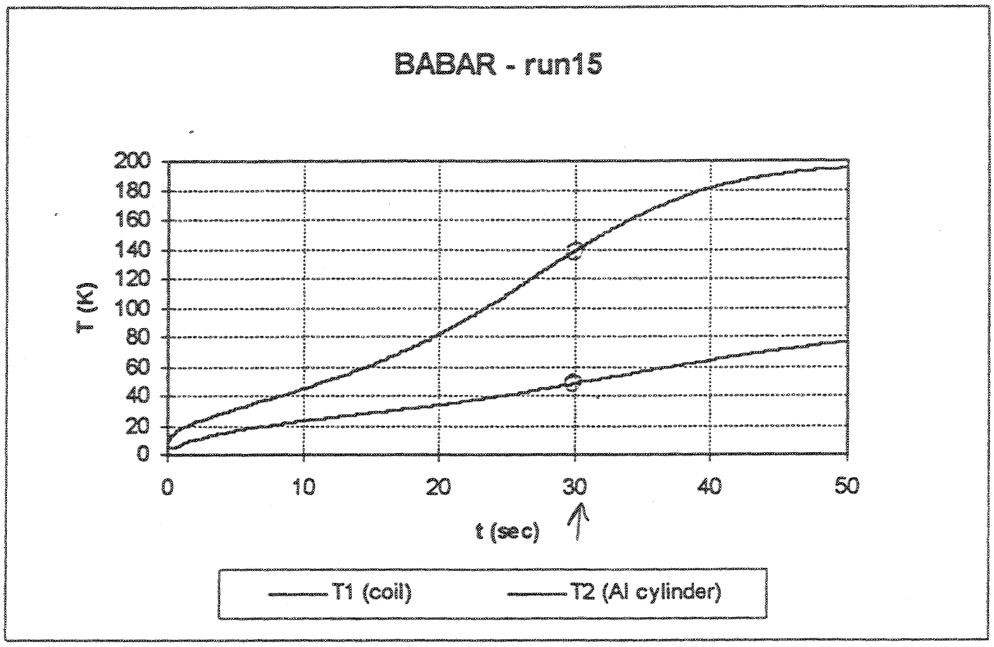
final Tmax of coil = **60 Kelvin**
final Tmax of Al cylinder = 45 Kelvin

(8)

plot of maximum temperature (versus time) in coil and cylinder:

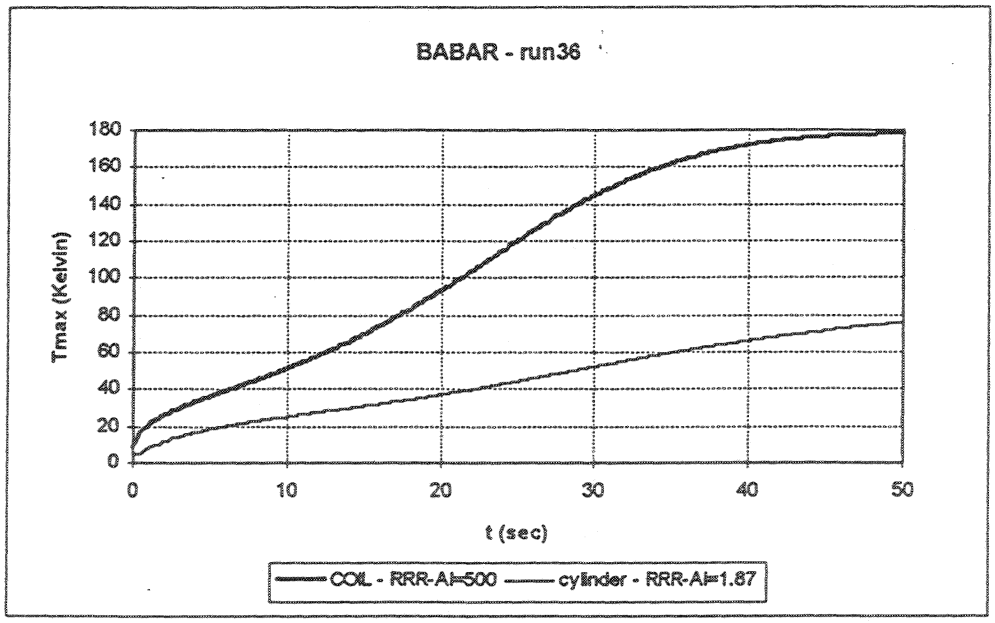
Rdump = 0.0001 Ω without dump resistor

RRR=1000



final Tmax of coil = 195 Kelvin
final Tmax of Al cylinder = 77 Kelvin

RRR=500



final Tmax of coil = 178 Kelvin
final Tmax of Al cylinder = 76 Kelvin

Propagation velocity according to Wilson:

["Superconducting magnets", Martin N. Wilson, Clarendon Press Oxford 1983, equation (9-17) restricted to adiabatic process]

$$v = \frac{J}{C} \cdot \left(\frac{\rho K}{Ts - To} \right)^{0.5}$$

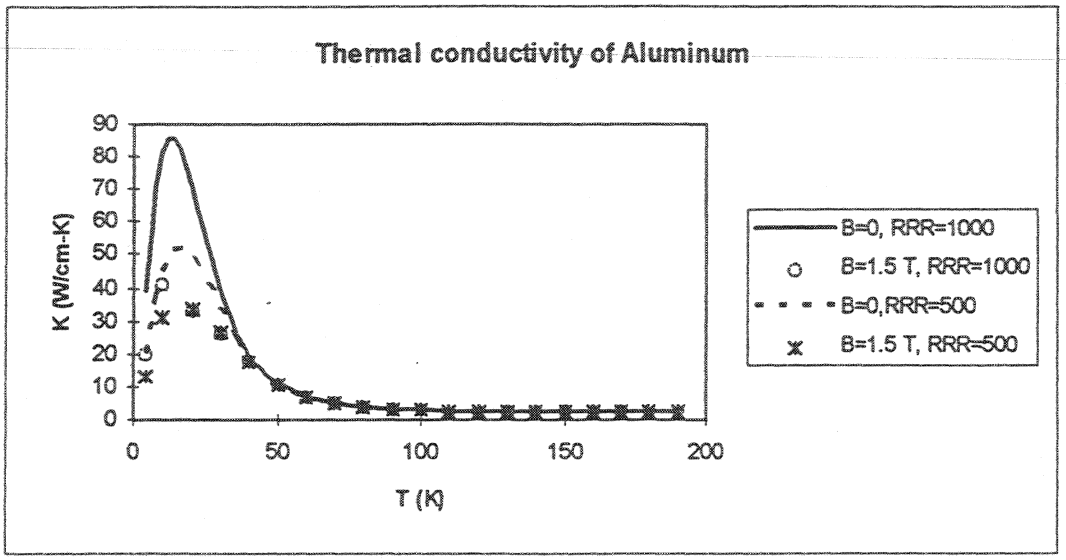
J = current density
C = specific heat (indipendent from RRR)
ρ = electrical resistivity
K = thermal conductivity
Ts = mean temperature
To = 4.2 K

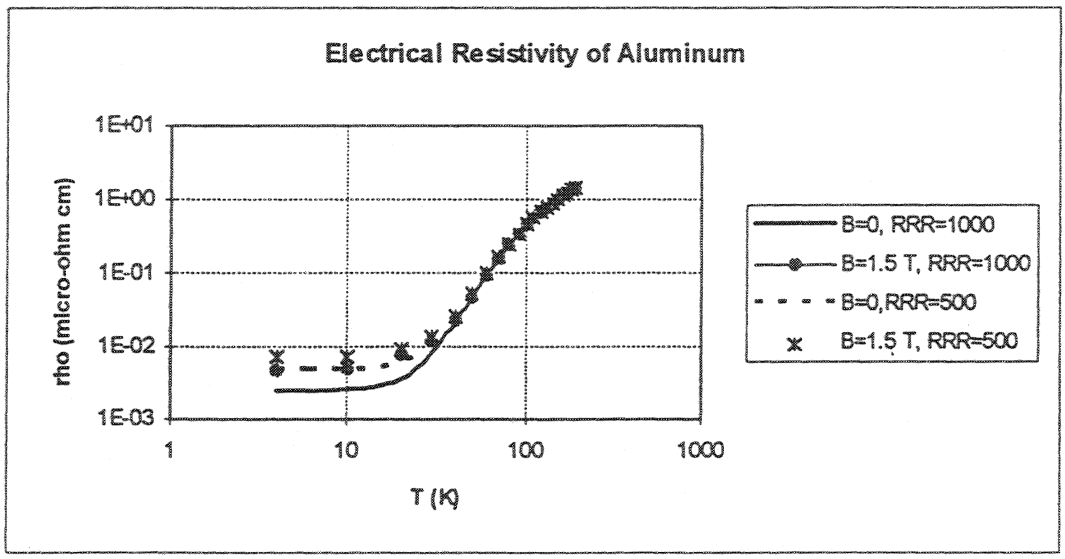
Maximum ratio for speed (see last graph page 7):

v(RRR=500) / v(RRR=1000) =**1.10 (peak)** for T=20K

propagation velocity **+0% ÷ +10%** for RRR=500 compared with RRR=1000
maximum temperature of coil = **-9%** for RRR=500 compared with RRR=1000

10

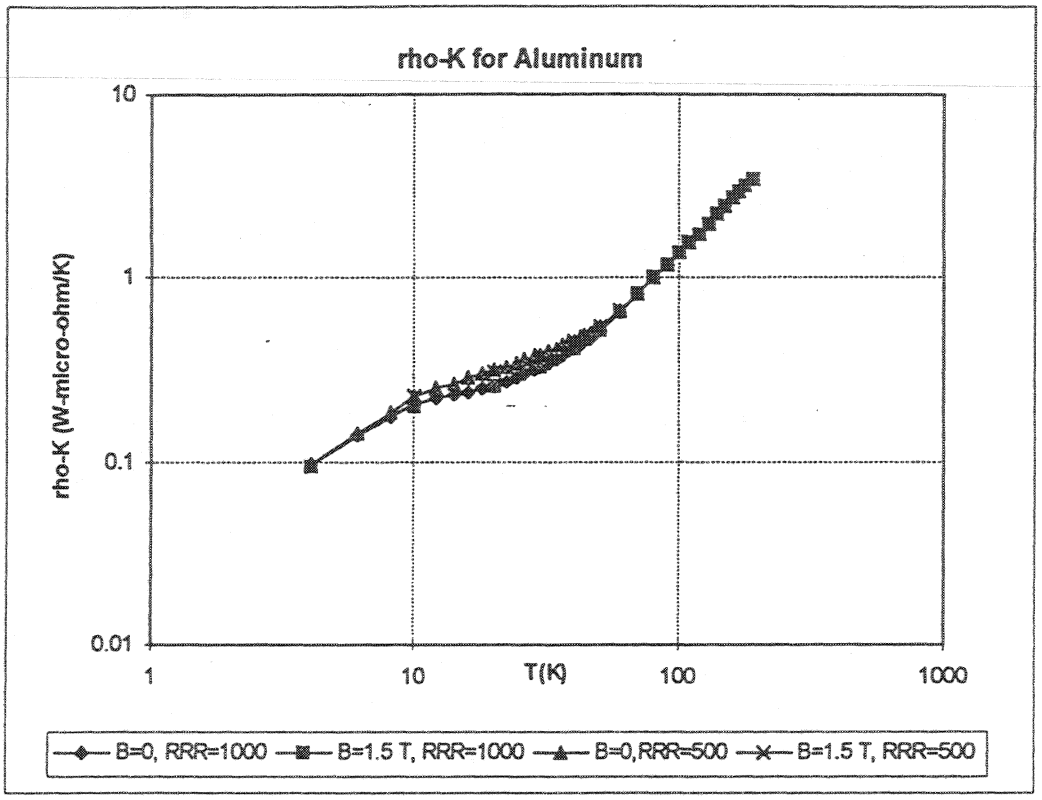


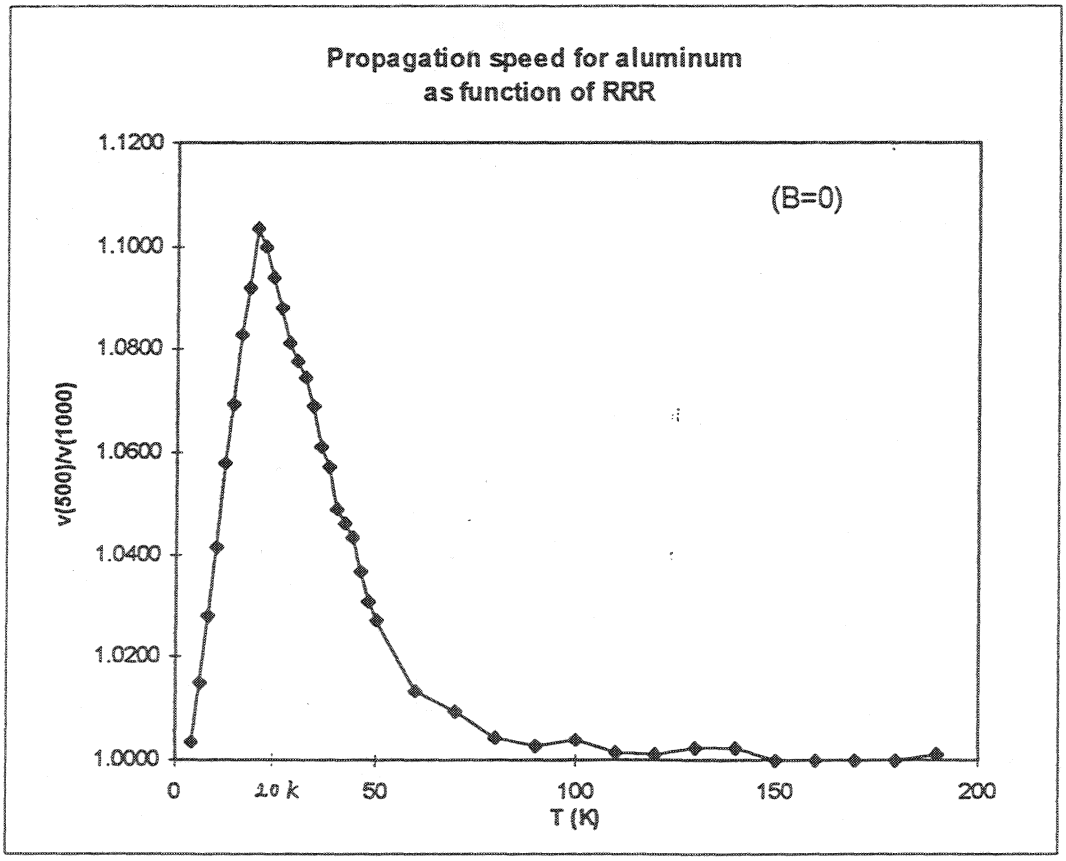


higher RRR ⇒ higher thermal conductivity,
lower electrical resistivity

(max. effect at low temperatures)

(11)





No difference between RRR of 1000 + 500

(12)

CHECK OF QUENCH COMPUTATION CODE : THIN SOLENOID MODEL FOR ZEUS PROJECT

("Quench behaviour of a thin solenoid", Bonito Oliva, MT-11, p.285)

check?

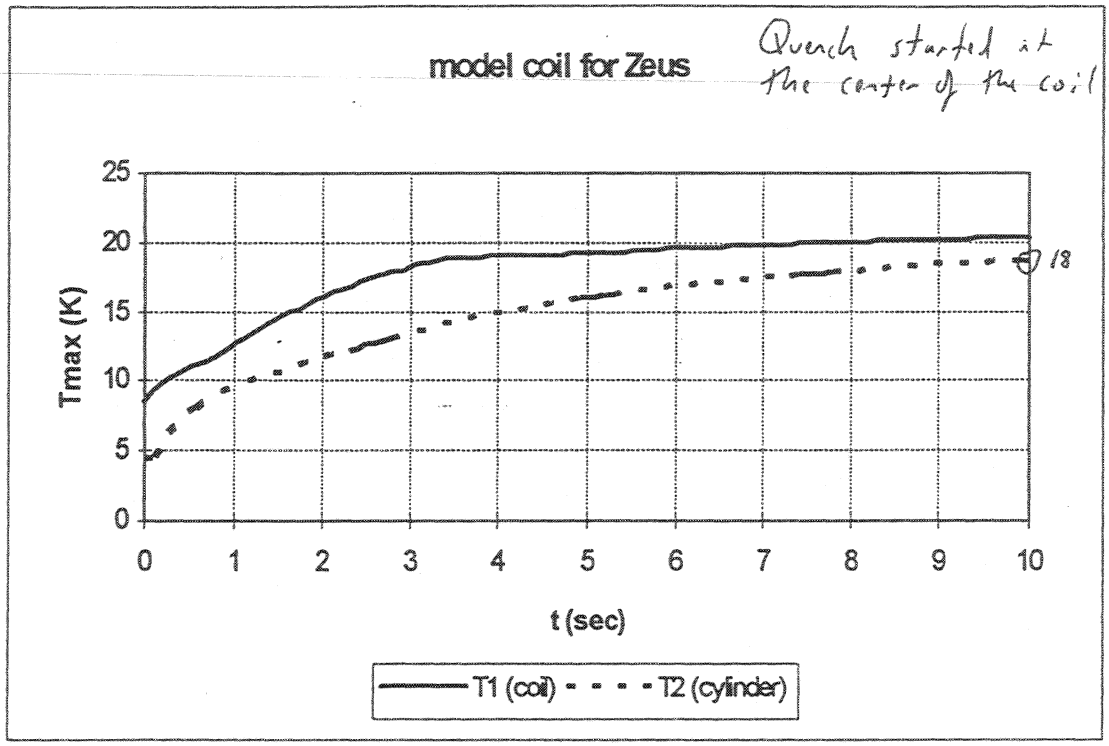
INPUT PARAMETERS:

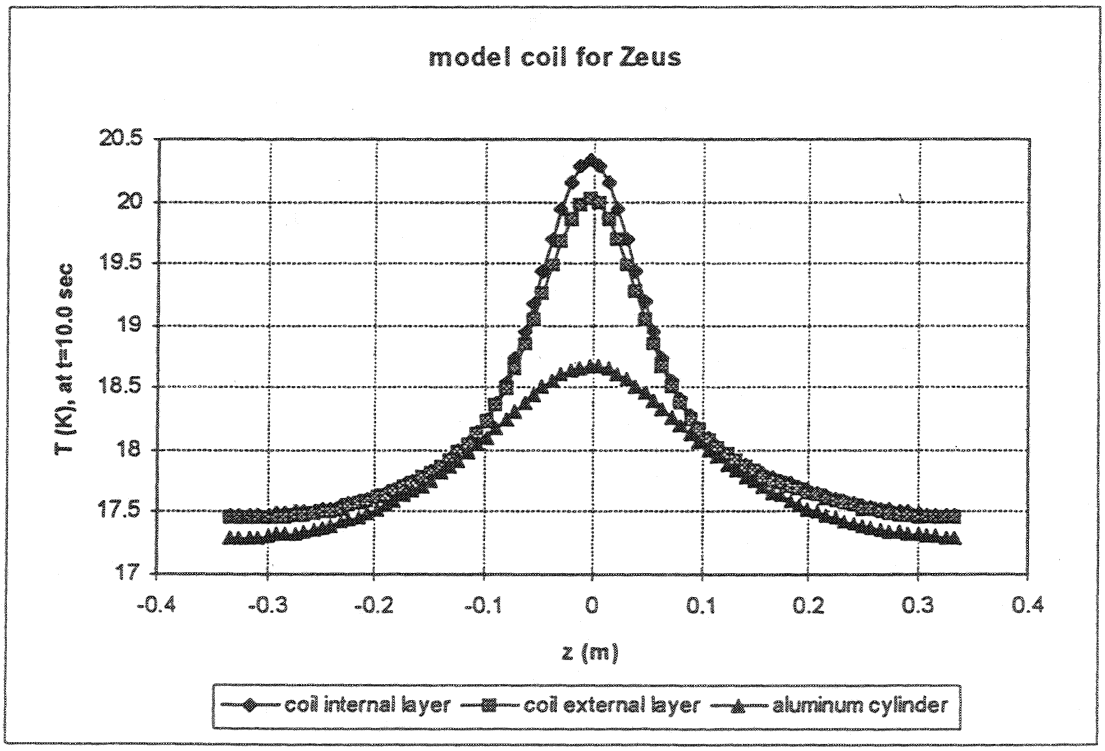
2 layers NbTi + aluminum cylinder

coil internal diameter	= 760 mm
coil external diameter	= 824 mm
coil length	= 677 mm
cylinder thickness	= 18 mm
number of turns for layer	= 140
coil-cylinder insulation thickness	= 1 mm
turn-to-turn insulation thickness	= 0.5 mm
no interlayer	
bare conductor	= 4.3 mm x15 mm
Rutherford cable (10 strands)	= 1.8 mm x 5 mm
Cu / NbTi ratio	= 1.1 : 1
filament diameter	= 40 μm
aluminum for cylinder: alloy 5083	(RRR=1.87)
aluminum for cables: pure 99.996%	(RRR ≅ 1000)
design current:	5000 A
maximum reached current:	3200 A
dump resistor:	3.6 mOhm

RESULTS TO BE COMPARED:

	REFERENCE	OUR CODE RESULT
coil inductance	43 mH	45.9 mH
cylinder inductance	$0.6 \cdot 10^{-6}$ H	$0.65 \cdot 10^{-6}$ H
mutual inductance	$1.6 \cdot 10^{-6}$ H	$1.61 \cdot 10^{-6}$ H
final temperature of coil and cylinder	12 to 19 K	coil: 20 K cylinder: 19 K
final resistance of coil	0.4 mOhm	0.3 to 0.5 mOhm





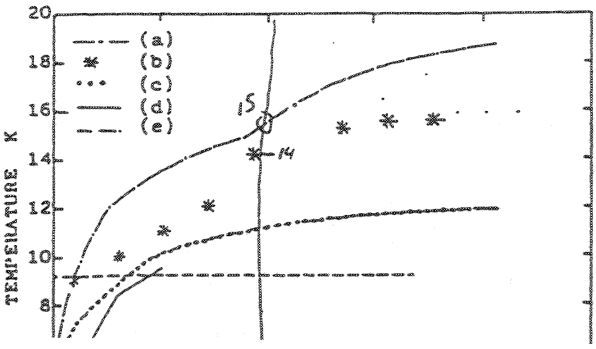


FIGURE 10 - Temperature evolution after breaker opening
(a) cylinder temperature (calculation A)
(b) experimental cylinder temperature
(c) cylinder and coil temperature (calculation B)
(d) coil temperature calculated from experimental data

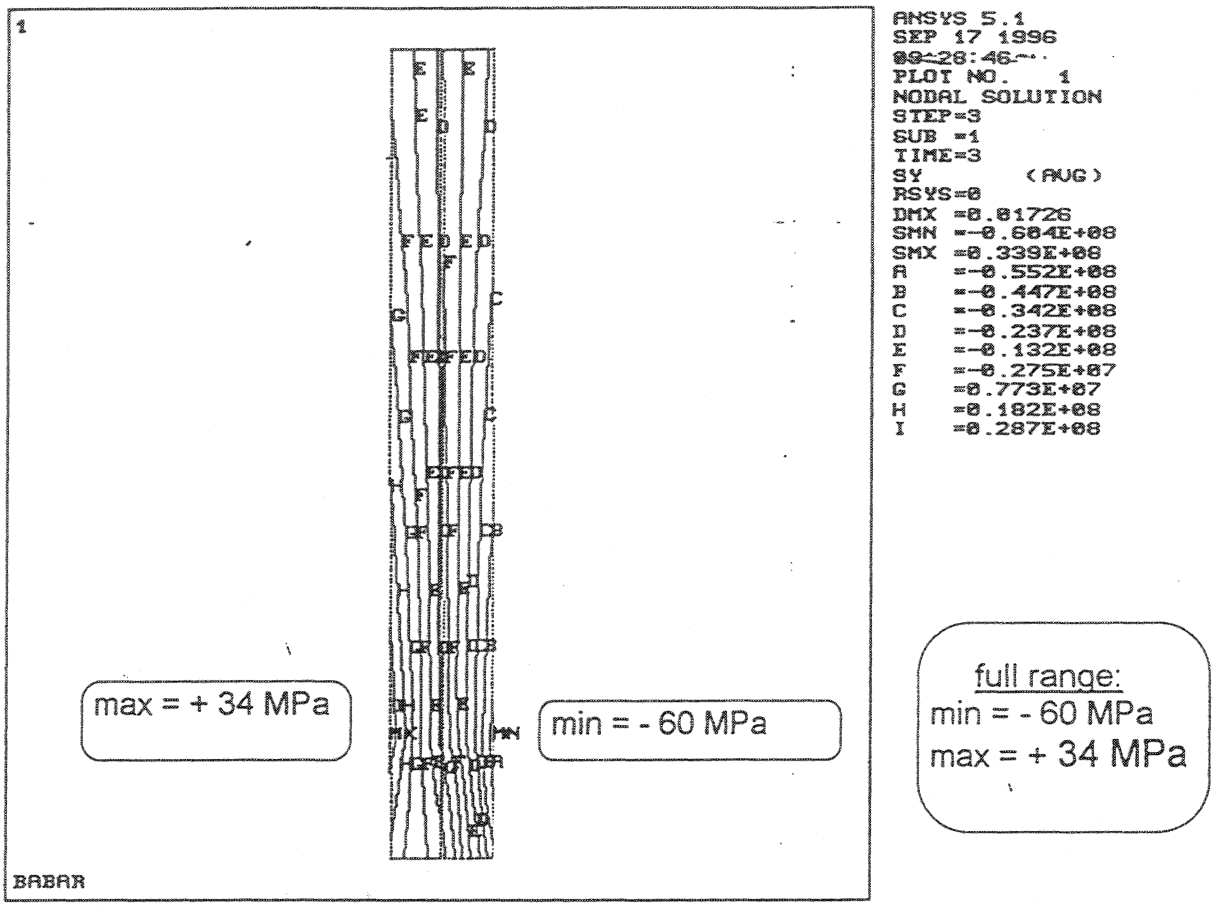


Fig. 3.1.1) - axial stress in the coil (warm end) for T_{ref}=450 K

Notes:
Coil in compression on external side, tension on internal side.
Compare with ***Fig.3.1.4***).

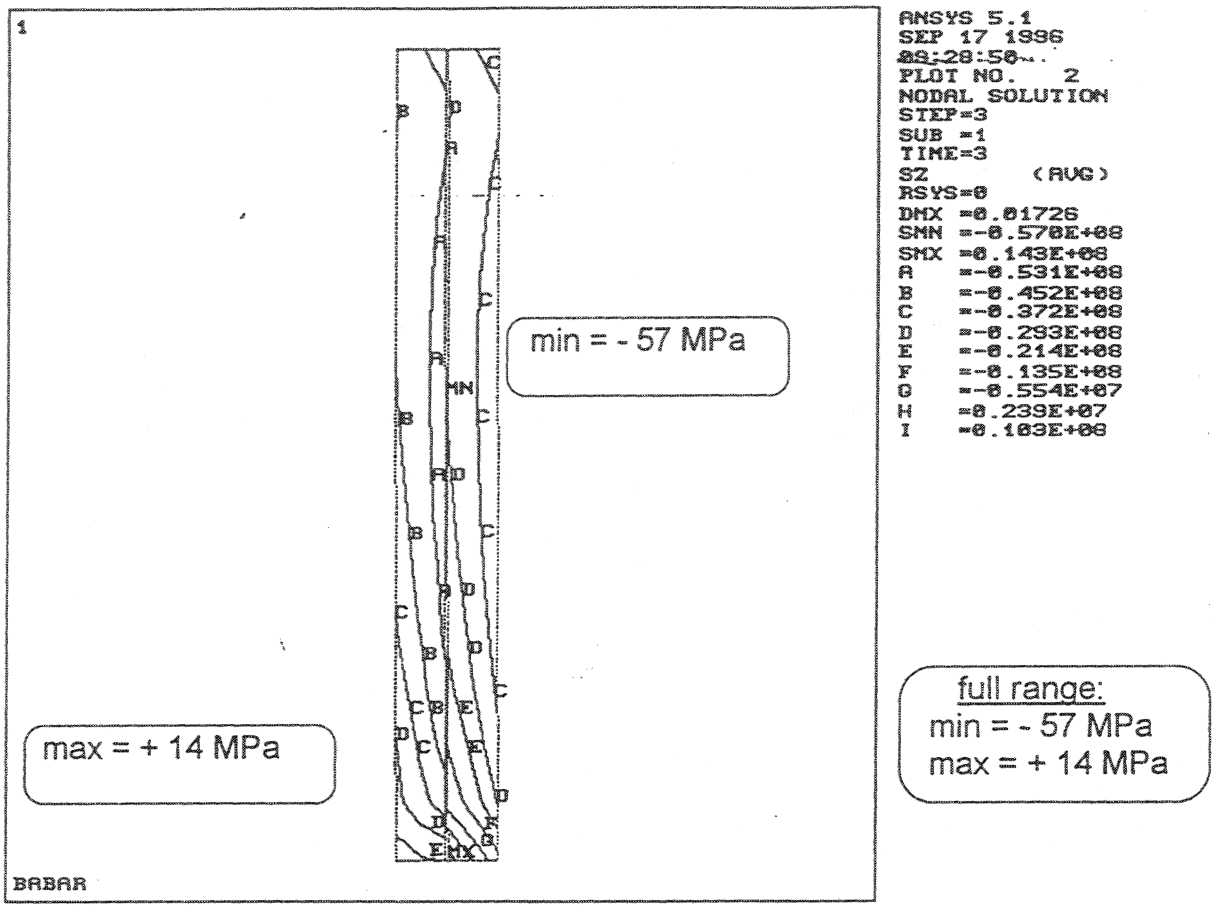


Fig. 3.1.2) - hoop stress in the coil (warm end) for T_{ref}=450 K

Notes:
Coil is almost all in compression, especially on external side (near containment cylinder)

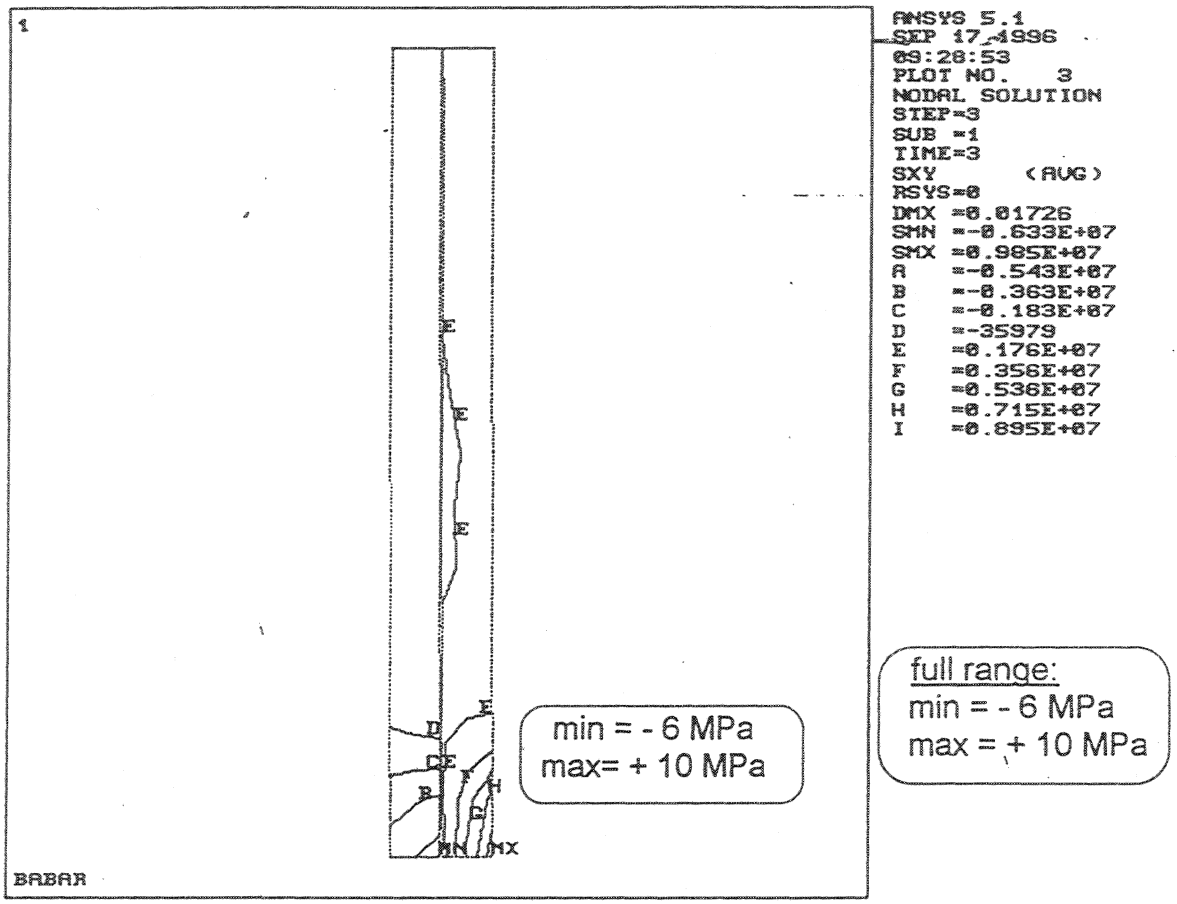


Fig. 3.1.3) - shear stress in the coil (warm end) for T_{ref} = 450 K -

Notes:
Min. and Max. are just localised peaks.
Throughout the rest of the model shear stress is about zero (lines D-E).

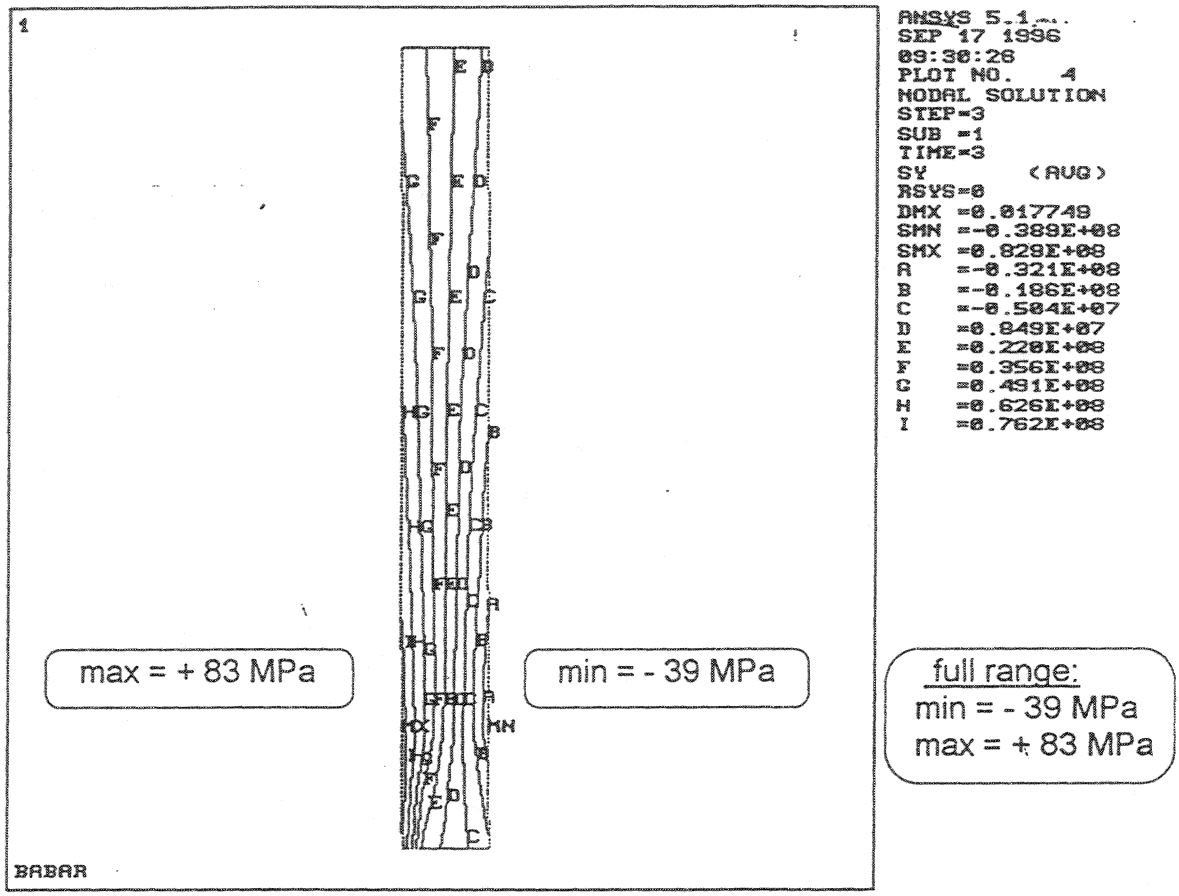


Fig. 3.1.4) - axial stress in the Aluminum cylinder (warm end) for T_{ref}=450 K

Notes:
Containment cylinder is in tension at the internal side (near the coil, which in turn is in compression: see ***Figure 3.1.1***).

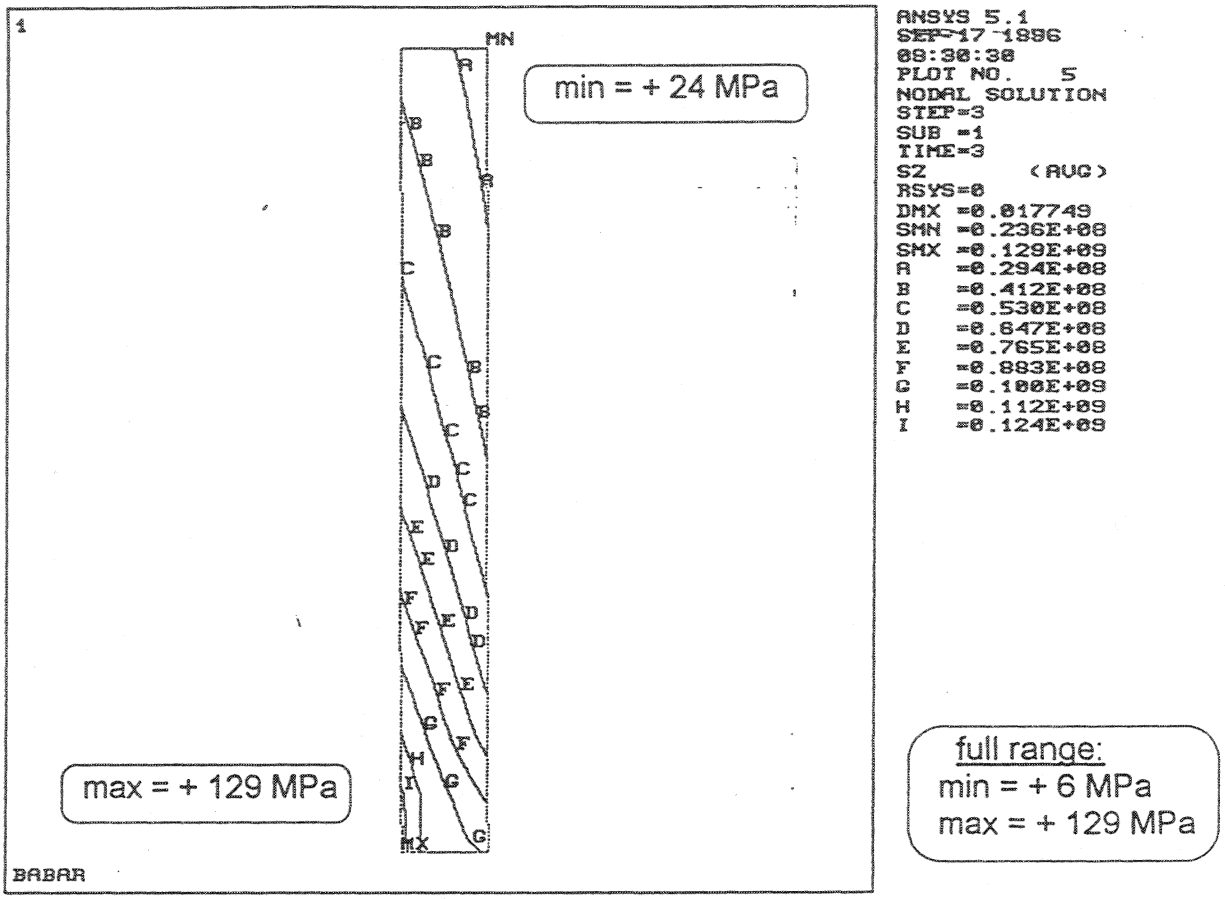


Fig. 3.1.5)- hoop stress in the aluminum cylinder (warm end) for T_{ref}=450 K

Notes:
Containment cylinder is in tension, with a maximum at the warmest point.
Compare with ***Fig. 3.1.2*** (coil in compression).

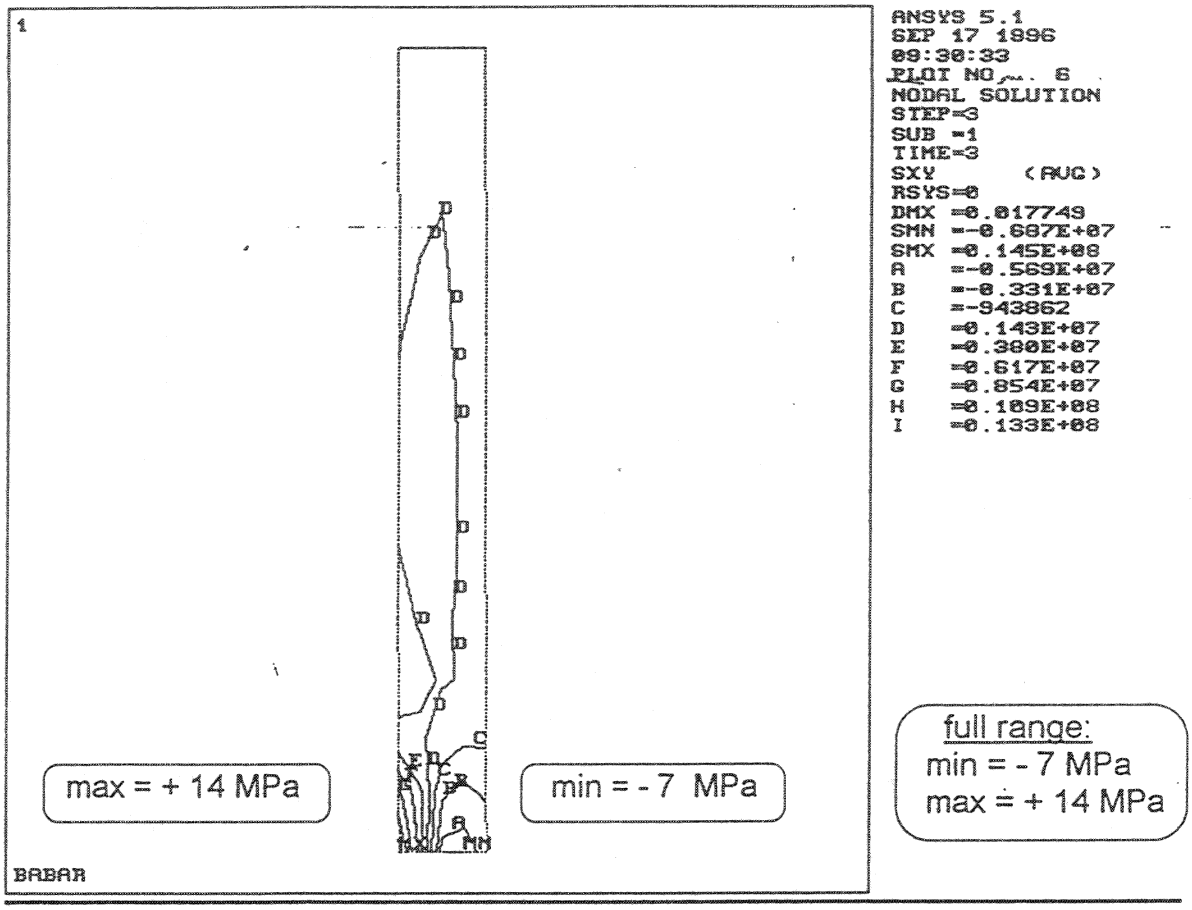


Fig. 3.1.6) - shear stress in the Aluminum cylinder (warm end) for Tref=450 K

Notes:
Min. and Max. are just localised peaks.
Throughout the rest of the model shear stress is about zero (lines C-D).

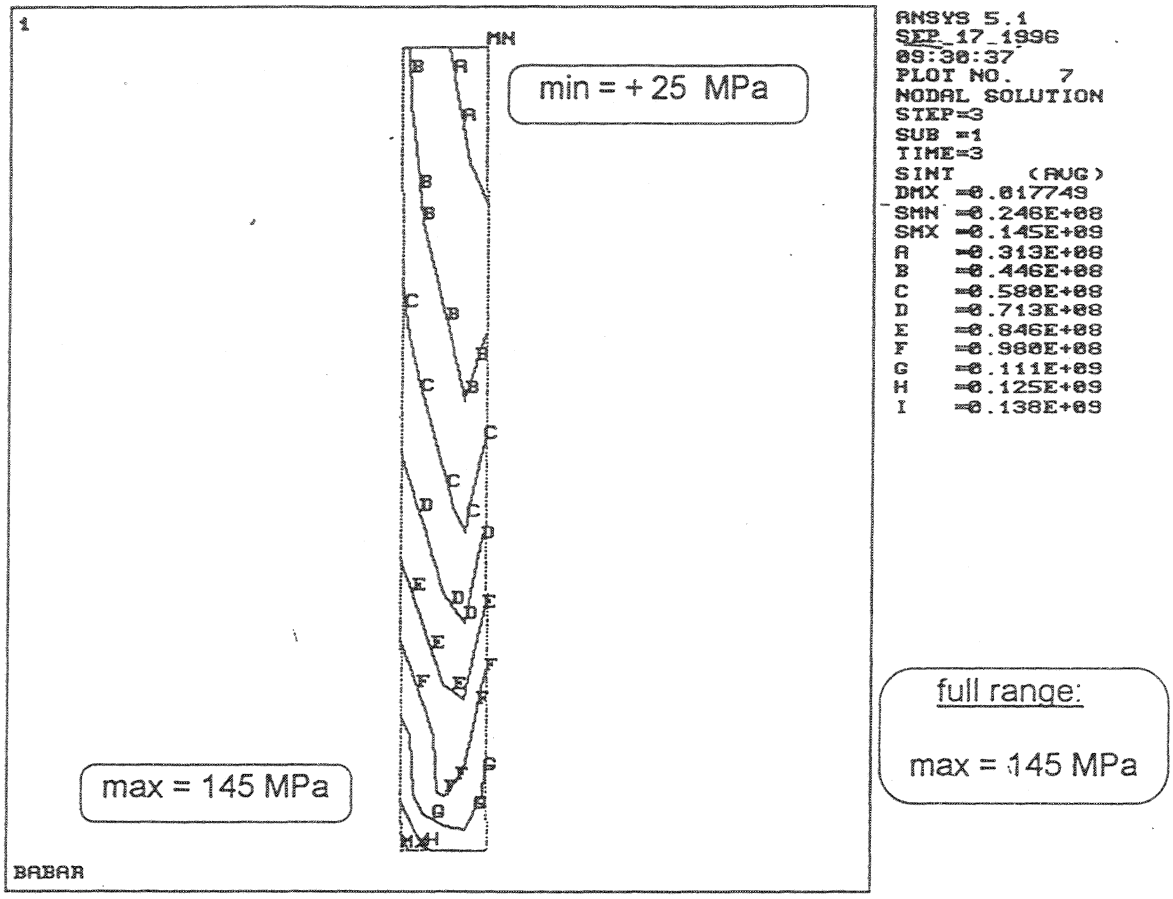


Fig. 3.1.7) - stress intensity in the Aluminum cylinder (warm end) for T_{ref} = 450 K

Notes:
Stress intensity map is similar to hoop stress map (***Fig. 3.1.5***).

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MITTENTE *FROM*	Sig. / Mr. : P. VALENTE Ufficio / Office : PMA/CRSP Tel. n. / Phone No. : 010/6556722
OGGETTO *SUBJECT*	BaBar Mechanical, thermal and electrical properties used in quench and sterss analysis
	Enclosed are what in subject. P. Valente

Appendix III

MATERIAL PROPERTIES

A. Superconducting Materials

The Jc critical current density in A/mm^2 at 2.2 and 4.2 K and the critical temperature Tc for NbTi and Nb3Sn conductors are listed below in tables III-1, III-2.

Table III-1 Jc and Tc of NbTi

Bc2=10.6 T1=4.2 TCR=9.2 Pincon=326.923E6

B	Tc	J(2.2K)	J(4.2K)	B	Tc	J(2.2K)	J(4.2K)
.00	9.20	4293.	3465.	6.00	6.70	2331.	1504.
.20	9.12	4228.	3400.	6.20	6.61	2266.	1438.
.40	9.05	4162.	3335.	6.40	6.51	2201.	1373.
.60	8.97	4097.	3269.	6.60	6.41	2135.	1308.
.80	8.90	4031.	3204.	6.80	6.32	2070.	1242.
1.00	8.82	3966.	3138.	7.00	6.22	2005.	1177.
1.20	8.74	3901.	3073.	7.20	6.12	1939.	1112.
1.40	8.66	3835.	3008.	7.40	6.02	1874.	1046.
1.60	8.58	3770.	2942.	7.60	5.92	1808.	981.
1.80	8.50	3705.	2877.	7.80	5.81	1743.	915.
2.00	8.43	3639.	2812.	8.00	5.71	1678.	850.
2.20	8.34	3574.	2746.	8.20	5.60	1612.	785.
2.40	8.26	3508.	2681.	8.40	5.50	1547.	719.
2.60	8.18	3443.	2615.	8.60	5.39	1481.	654.
2.80	8.10	3378.	2550.	8.80	5.28	1416.	588.
3.00	8.02	3312.	2485.	9.00	5.17	1351.	523.
3.20	7.94	3247.	2419.	9.20	5.05	1285.	458.
3.40	7.85	3181.	2354.	9.40	4.94	1220.	392.
3.60	7.77	3116.	2288.	9.60	4.82	1155.	327.
3.80	7.68	3051.	2223.	9.80	4.70	1089.	262.
4.00	7.60	2985.	2158.	10.00	4.58	1024.	196.
4.20	7.51	2920.	2092.	10.20	4.45	958.	131.
4.40	7.42	2855.	2027.	10.40	4.33	893.	65.
4.60	7.34	2789.	1962.	10.60	4.20	828.	
4.80	7.25	2724.	1896.	10.80	4.07	762.	
5.00	7.16	2658.	1831.	11.00	3.93	697.	
5.20	7.07	2593.	1765.	11.20	3.80	631.	
5.40	6.98	2528.	1700.	11.40	3.65	566.	
5.60	6.89	2462.	1635.	11.60	3.51	501.	
5.80	6.79	2397.	1569.	11.80	3.36	435.	

Table II-2 Jc and Tc of NbsSn

NI,API,BC2T1E1I,T1I,TCRMI,E1I,PINCONI,Strain/1400,1800,25.00,4.20,18.0,-.002,1.13e11,-.002/

B	Tc	J(2.2)	J(4.2)	B	Tc	J(2.2)	J(4.2)
.20	16.27	43807.	40227.	12.20	5.96	1727.	1372.
.60	15.16	24547.	22482.	12.60	5.76	1610.	1267.
1.00	14.40	18446.	16848.	13.00	5.57	1499.	1168.
1.40	13.77	15116.	13769.	13.40	5.39	1394.	1075.
1.80	13.24	12921.	11735.	13.80	5.20	1295.	988.
2.20	12.76	11321.	10252.	14.20	5.02	1201.	905.
2.60	12.32	10083.	9102.	14.60	4.84	1113.	828.
3.00	11.92	9084.	8174.	15.00	4.67	1029.	755.
3.40	11.54	8252.	7401.	15.40	4.49	950.	687.
3.80	11.18	7545.	6744.	15.80	4.32	875.	623.
4.20	10.84	6933.	6175.	16.20	4.15	804.	563.
4.60	10.52	6396.	5676.	16.60	3.99	738.	507.
5.00	10.21	5919.	5232.	17.00	3.82	675.	454.
5.40	9.91	5492.	4836.	17.40	3.66	616.	405.
5.80	9.63	5106.	4477.	17.80	3.50	560.	359.
6.20	9.35	4756.	4152.	18.20	3.34	507.	317.
6.60	9.08	4435.	3855.	18.60	3.18	458.	278.
7.00	8.82	4141.	3582.	19.00	3.02	412.	242.
7.40	8.57	3869.	3331.	19.40	2.87	369.	208.
7.80	8.33	3617.	3098.	19.80	2.72	328.	178.
8.20	8.09	3384.	2883.	20.20	2.56	291.	150.
8.60	7.85	3166.	2683.	20.60	2.41	256.	125.
9.00	7.62	2963.	2496.	21.00	2.27	223.	102.
9.40	7.40	2773.	2322.	21.40	2.12	193.	82.
9.80	7.18	2595.	2159.	21.80	1.97	166.	64.
10.20	6.97	2428.	2006.	22.20	1.83	141.	49.
10.60	6.76	2270.	1863.	22.60	1.69	118.	35.
11.00	6.55	2122.	1729.	23.00	1.54	97.	24.
11.40	6.35	1983.	1602.	23.40	1.40	79.	15.
11.80	6.15	1851.	1484.	23.80	1.26	62.	9.
12.00	6.05	1788.	1427.	24.00	1.19	55.	6.

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Specific heat vs Temperature

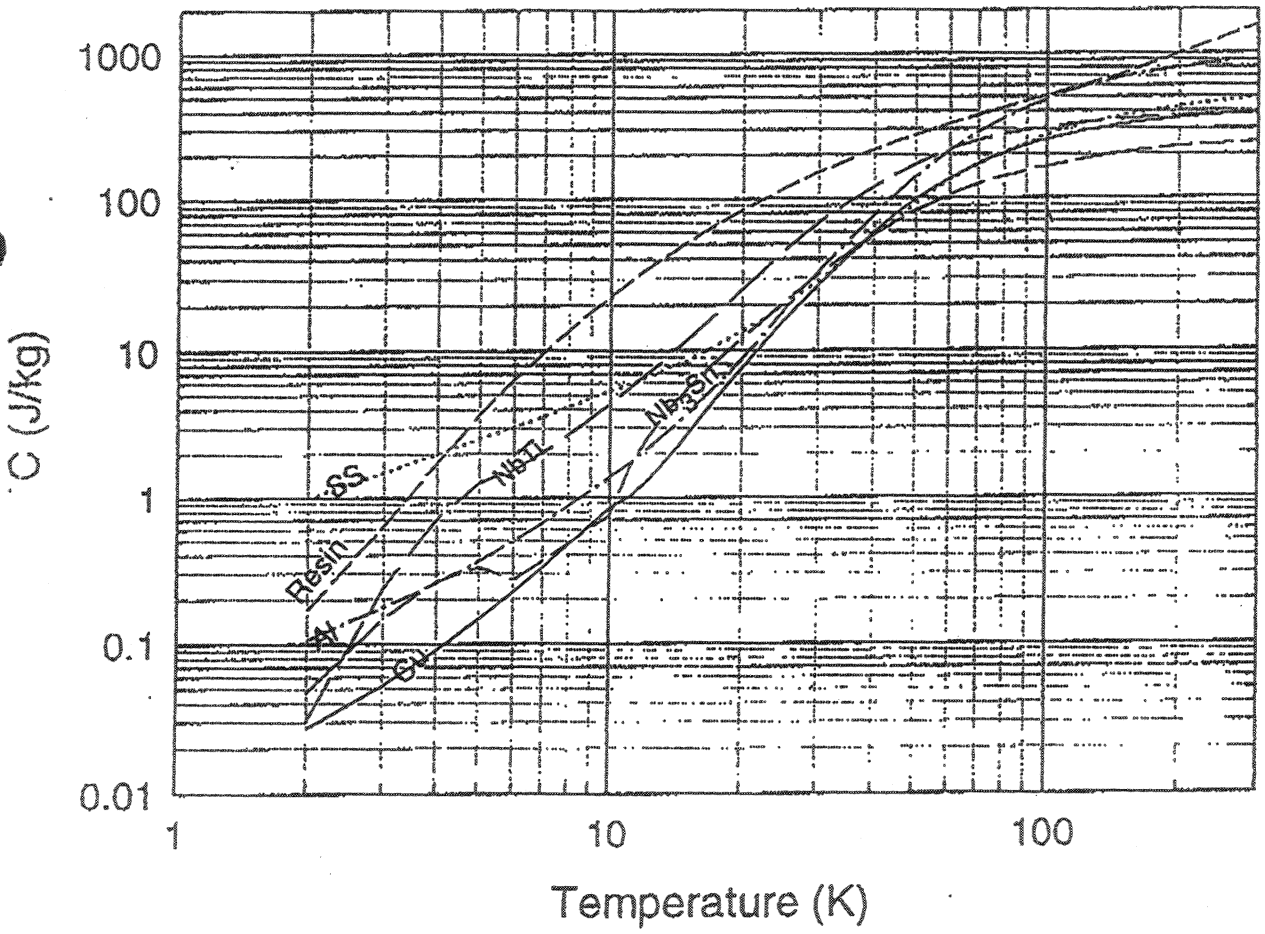

Fig III-1 Specific heat for all materials used in the code *Protect*.

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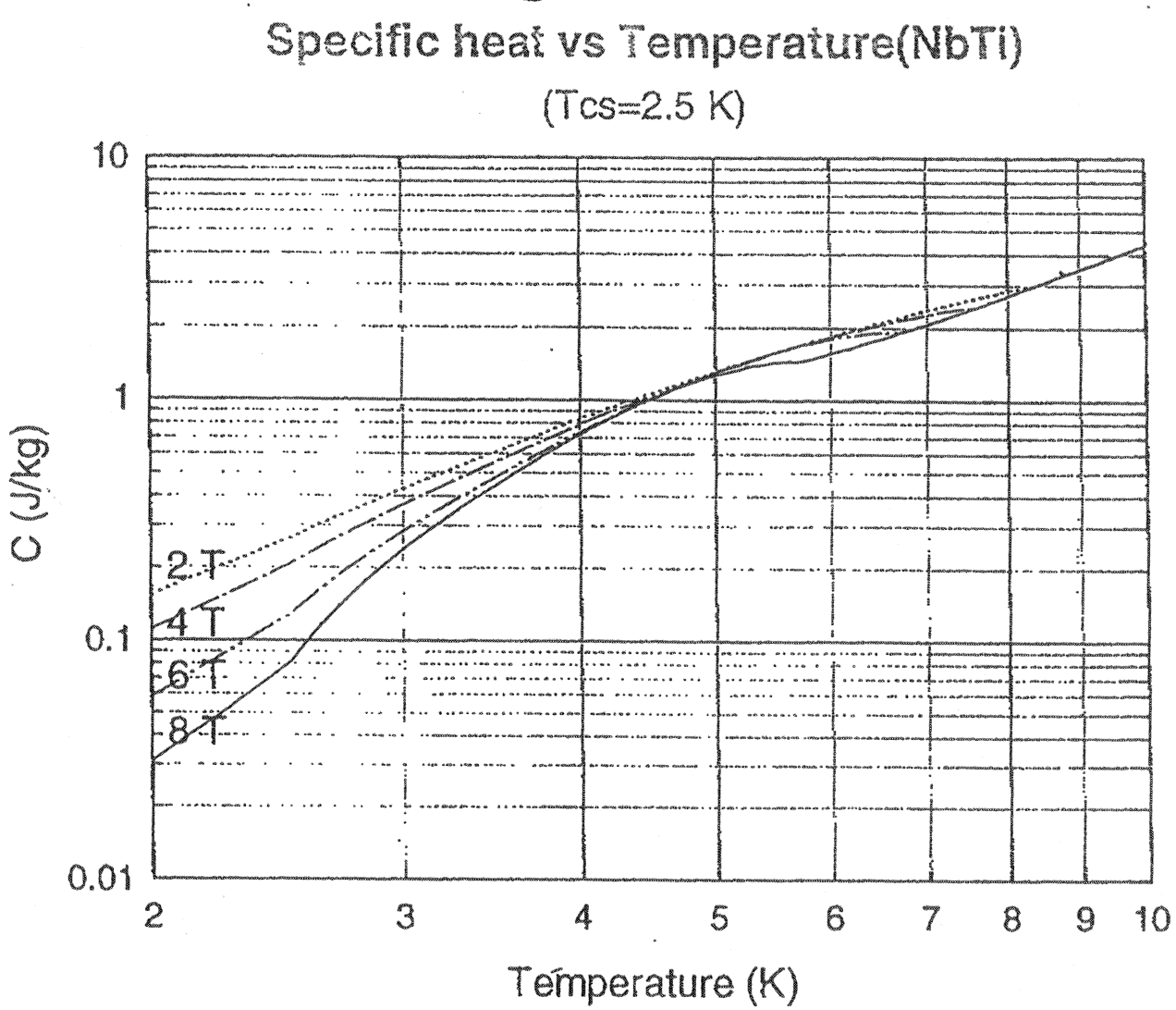

Fig III-2 Specific heat of NbTi as function of current sharing temperature, material temperature and field.

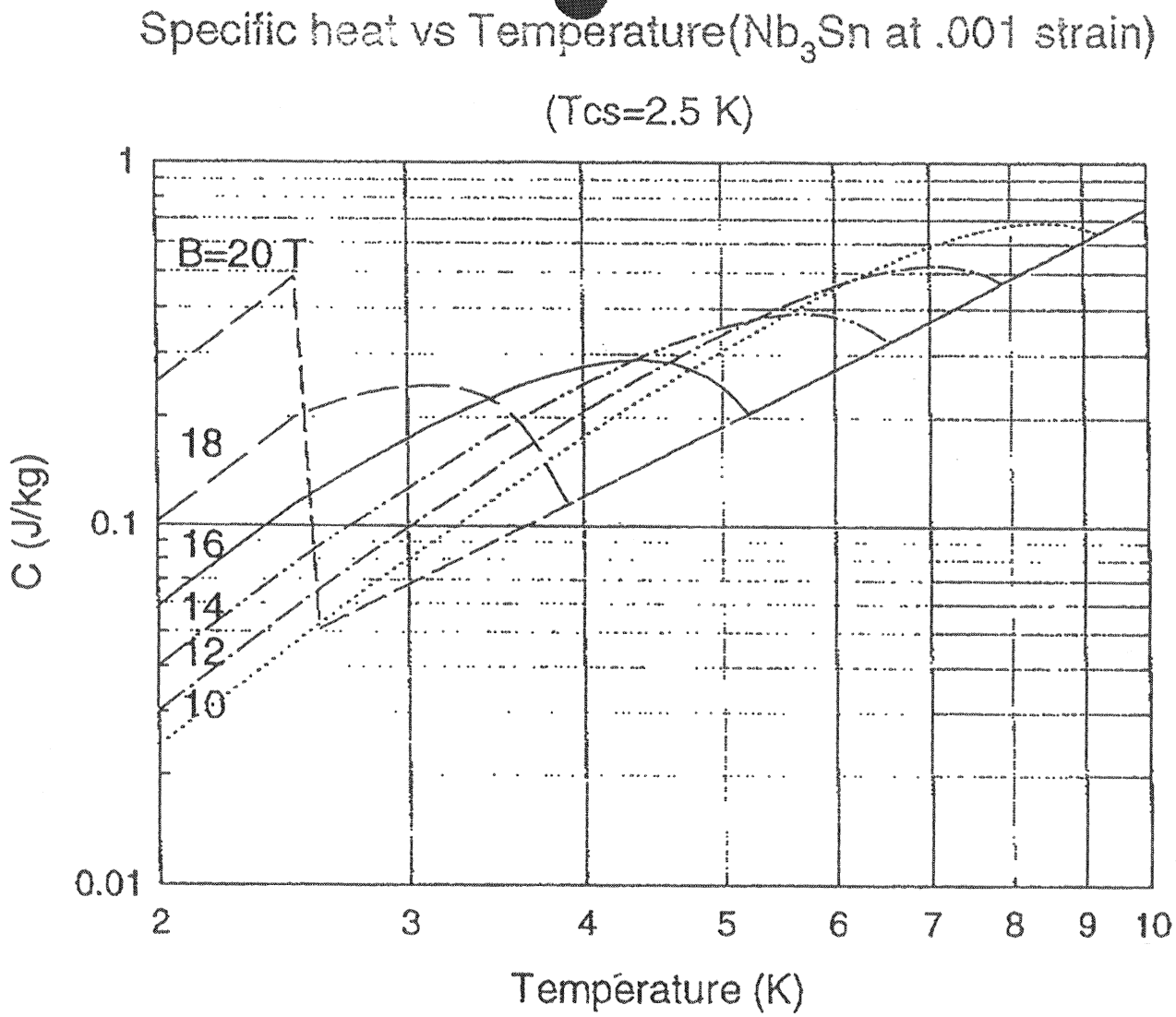

Fig. III-3 Specific heat of Nb_3Sn vs. T as function of current sharing temperature, and field.

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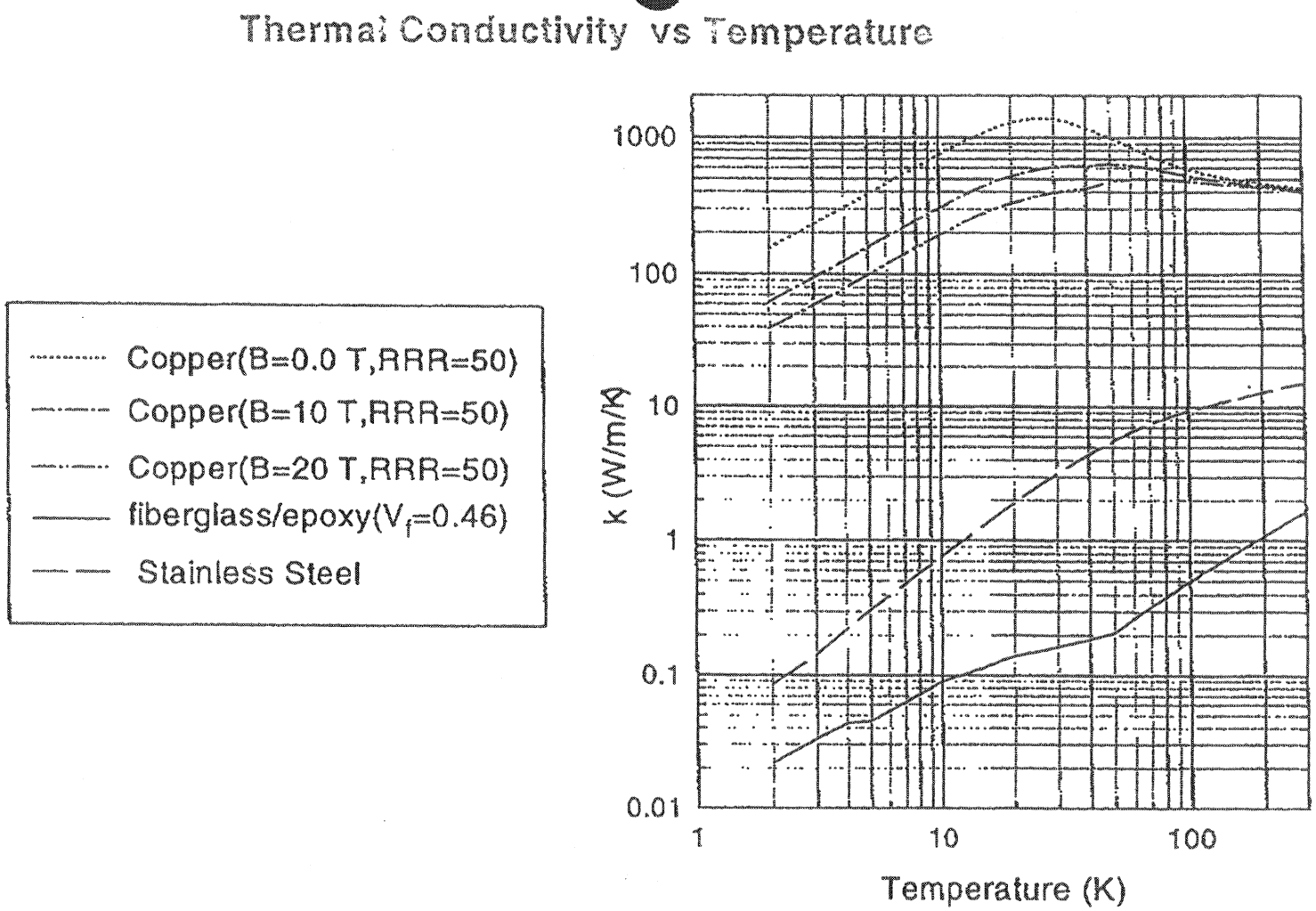

Fig. III-4 Thermal conductivities of the materials used in the code *Protect*.

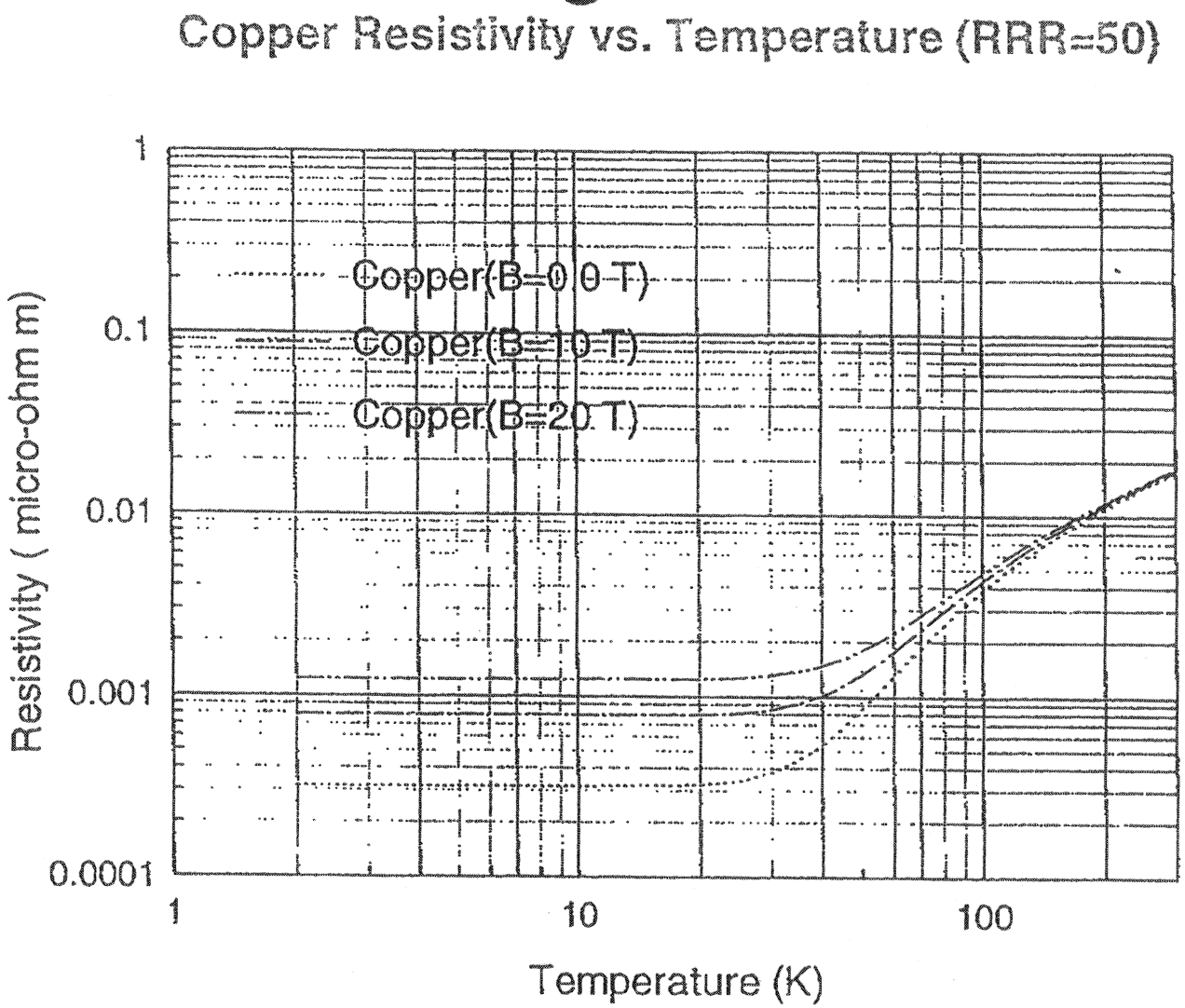

Fig. III-5 Electrical resistivity of copper as function of temperature and field.

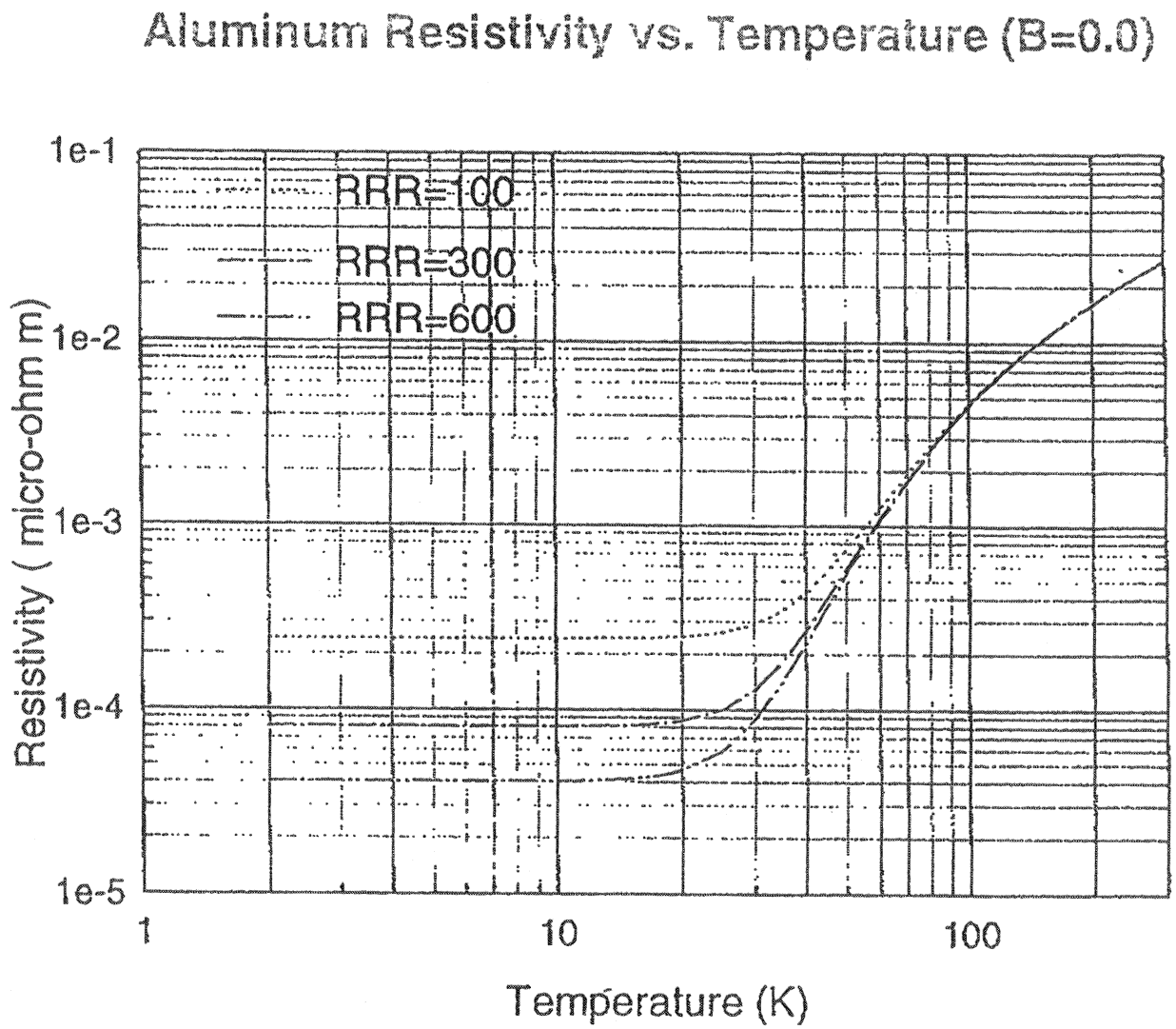

Fig. III-6 Electrical resistivity of Aluminum as function of temperature and RRR.

3.1) - Reference temperature = 450 K

Material properties are the same which were reported in (*Ref.1*), except for thermal expansion coefficients which have been recalculated (the uncorrected coefficients give similar stress values, a little lower for aluminum).

properties at T = 4K, 77 K, 295 K;
x=radial component, y=axial component, z=hoop component

	mat.1 (cable I)	mat.2, mat.4 (insulation)	mat.3 (cable II)	aluminum-alloy cylinder
E [GPa] (elasticity modulus)	Ex=72.9,71.8,64.3 Ey=68.9,67.4,59.8 Ez=74.4,73.5,66.2	Ex=29.1,27.0,22.4 Ey=35.9,33.7,28.0 Ez=35.9,33.7,28.0	Ex=74.1,73.0,65.5 Ey=72.1,70.8,63.3 Ez=75.7,74.8,67.4	Ex=Ey=Ez= 77.7, 77.2, 70.1
ν (Poisson's ratio)	0.34, 0.34, 0.35	0.21, 0.19, 0.15	0.34, 0.34, 0.35	0.327,0.328, 0.338
α [K^{-1}] (thermal expansion, mean coefficient)	17.8e-6, 20.8e-6, 24.2e-6	α_x = 29.9e-6, 34.0e-6, 38.0e-6 $\alpha_y = \alpha_z$ = 9.02e-6, 10.0e-6, 10.0e-6	17.8e-6, 20.8e-6, 24.2e-6	17.9e-6, 20.9e-6, 24.2e-6

$$\alpha_{mean}(T, Tref) := \frac{1}{(Tref - T)} \cdot \frac{L(Tref) - L(T)}{L(Tref)}$$

$$\Updownarrow$$

$$L(T) = L(Tref) \cdot \left(1 - \alpha_{mean} \cdot (Tref - T)\right)$$

Taking into account a reference temperature Tref = 450 K, stress by thermal expansion is dominated by a contribution due to the {T = 4 K} operative situation, to which the temperature distribution due to the quench is added.

For this reason we think the {Tref=4 K} analysis (next chapter) is more significant, showing the stress distribution to be superimposed when the quench happens, no matter what the base stress-state is.

However, the stress values in this computational case (Tref=450 K) are reported in the following *Table 3.1* and *Figures 3.1.1 to 3.1.7*.

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3.2) - Reference temperature = 4 K

Material properties are the same of chapter *3.1*), except for thermal expansion coefficients which have been recalculated for reference temperature Tref = 4 K, basing on *Ref. 3 and 4*.

properties at T = 4K, 77 K, 295 K;
x=radial component, y=axial component, z=hoop component

	mat.1 (cable I)	mat.2, mat.4 (insulation)	mat.3 (cable II)	aluminum-alloy cylinder
E [GPa] (elasticity modulus)	Ex=72.9,71.8,64.3 Ey=68.9,67.4,59.8 Ez=74.4,73.5,66.2	Ex=29.1,27.0,22.4 Ey=35.9,33.7,28.0 Ez=35.9,33.7,28.0	Ex=74.1,73.0,65.5 Ey=72.1,70.8,63.3 Ez=75.7,74.8,67.4	Ex=Ey=Ez= 77.7, 77.2, 70.1
ν (Poisson's ratio)	0.34, 0.34, 0.35	0.21, 0.19, 0.15	0.34, 0.34, 0.35	0.327,0.328, 0.338
α [K^{-1}] (thermal expansion, mean coefficient)	0, 3.16e-6, 14.4e-6	α_x =0, 12.1e-6, 19.4e-6 $\alpha_y = \alpha_z$ =0,4.9e-6,9.2e-6	0, 3.16e-6, 14.4e-6	0, 3.55e-6, 14.5e-6

$$\alpha_{mean}(T, Tref) := \frac{1}{(Tref - T)} \cdot \frac{L(Tref) - L(T)}{L(Tref)}$$

$$\Updownarrow$$

$$L(T) = L(Tref) \cdot \left(1 - \alpha_{mean} \cdot (Tref - T)\right)$$

Note that alpha coefficient is always defined as positive.
If Tref>T, L(Tref)>L(T). This is the case Tref=450 K, for example.
If Tref<T, L(Tref)<L(T). This is the present case, Tref=4 K.

In the following pages, *Table 3.2)* shows maxima and minima for the whole model; *Figures 3.2.1 to 3.2.7* show stress components in the coil and the containment cylinder.

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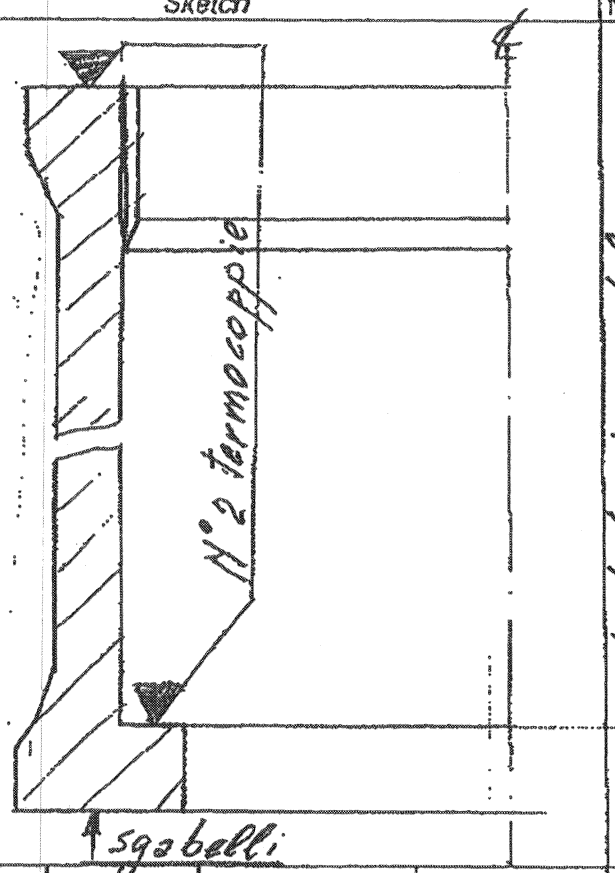
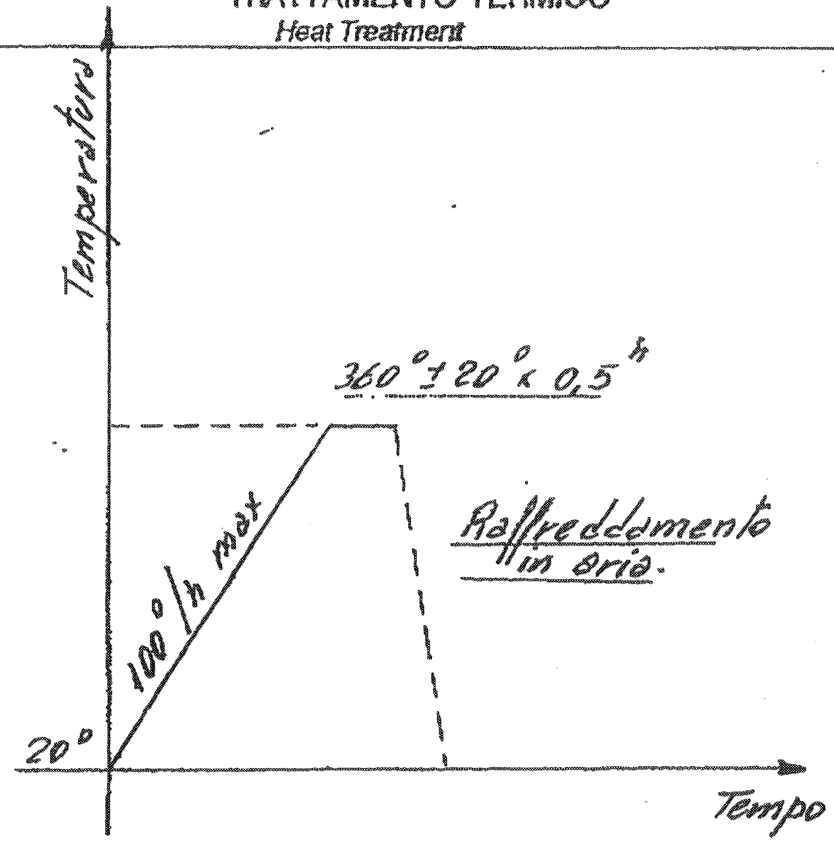
	Sig. / Mr. :	T. O'CONNOR cc. P. FABBRICATORE
	Fax n. / Fax no. :	313358 / 0015104226747
MITTENTE *FROM*	Sig. / Mr. :	P. VALENTE
	Ufficio / Office :	PMA/CRSP
	Tel. n. / Phone No. :	010/6556722
OGGETTO *SUBJECT*		BaBar HEAT TREATMENT PLANNING
	Enclosed are what in subject. P. Valente	

ANSALDO
Ansaldo Energia s.p.a
Stabilimento MILANO

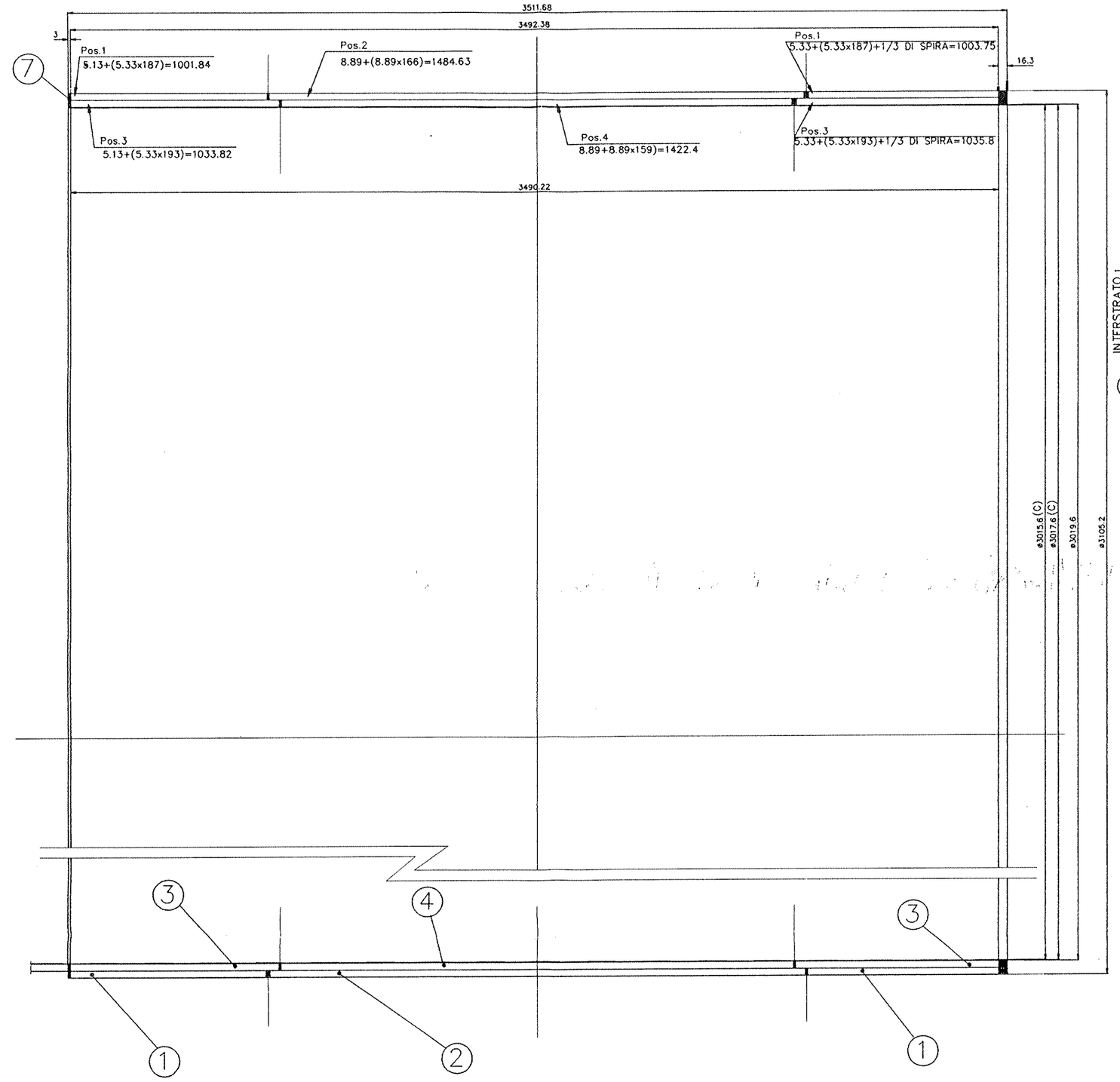
PIANO DI TRATTAMENTO TERMICO
Heat Treatment Planning

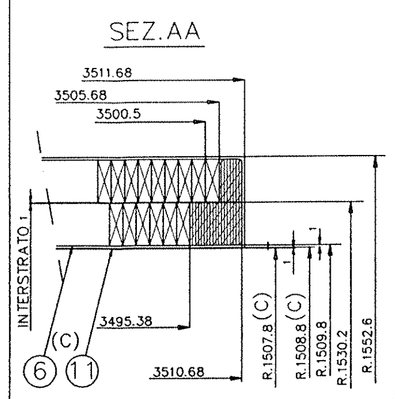
Commessa : 00U4EM
~~Coupon N°~~ : *

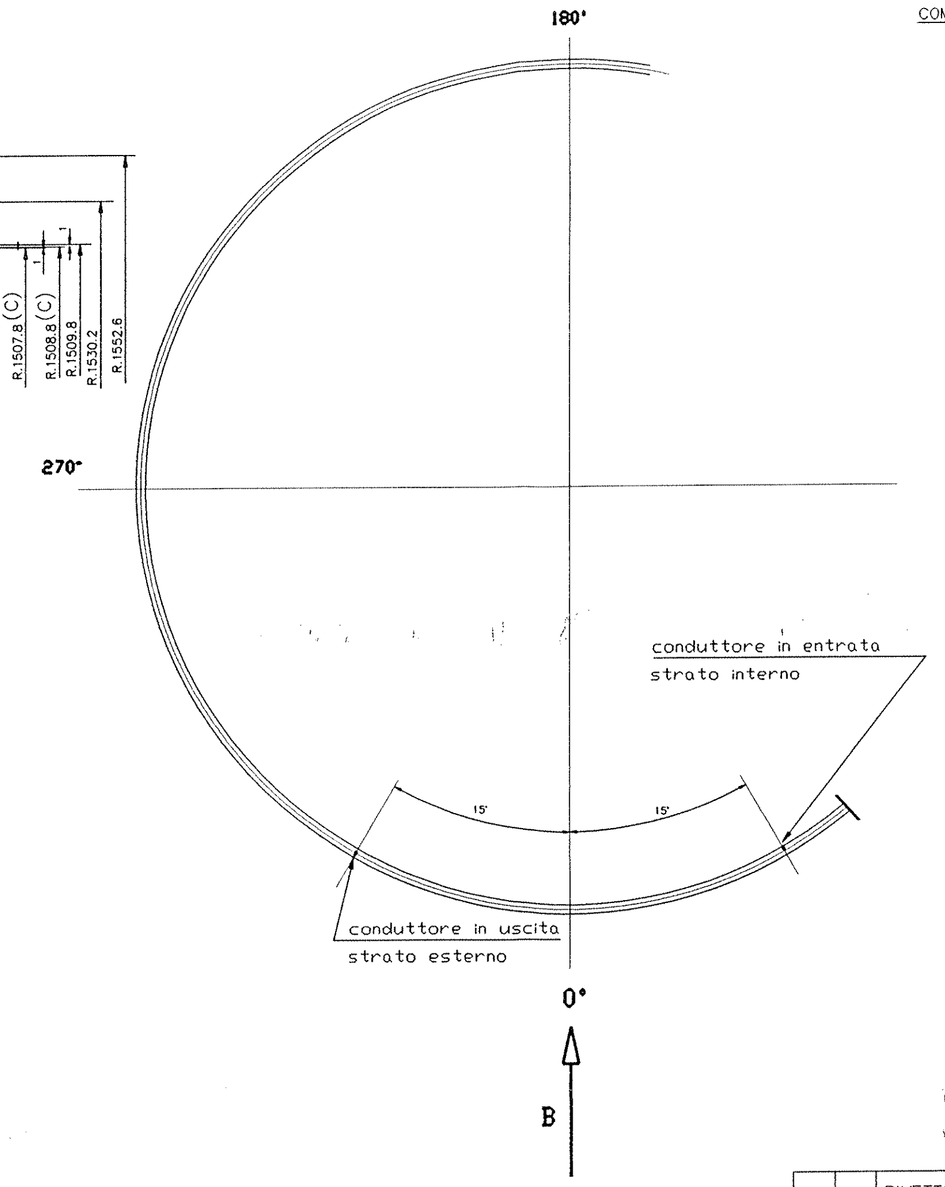
HTP
Foglio / Sheet 1 Di / Of 1

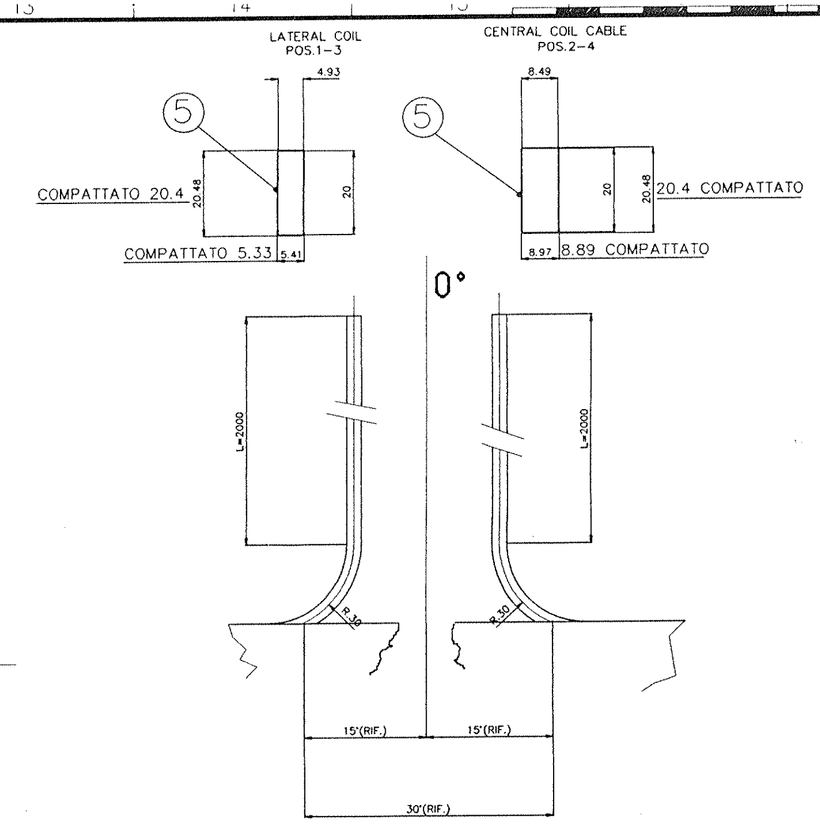
SCHIZZO Sketch	PCF/FCP N°& ITEM	TRATTAMENTO TERMICO Heat Treatment	~~FALLONI DI FABBRICAZIO~~ Coupons Under Going San
	- T.T. di distensione del composto saldato - Mat. AISI 5083.		* Cilindro supporto magnete Dis. 620 RM07009

Rev	Data: Date:	Preparato da: Prepared by:	Controllato: Checked:	Motivo Revisione: Revision Reason:	Approvazione / Approval: CQOP	Cliente / Customer	Ente Ispettivo / Autority
0	30/09/96	Tanan Di.		1° Emissione			









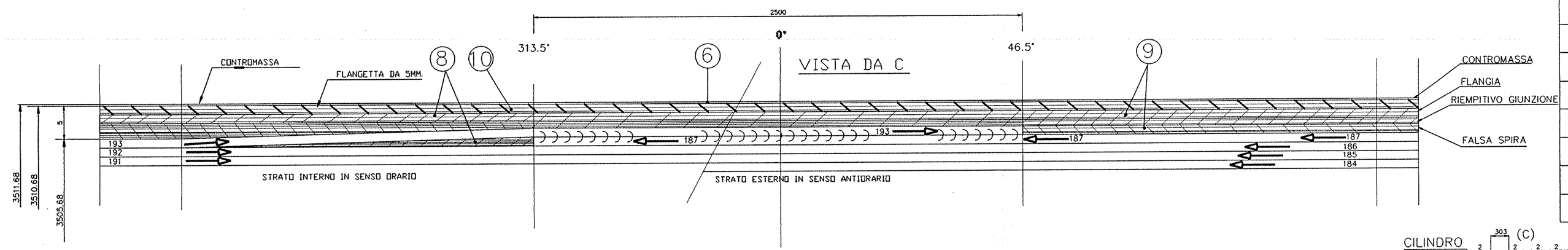
Visto da B

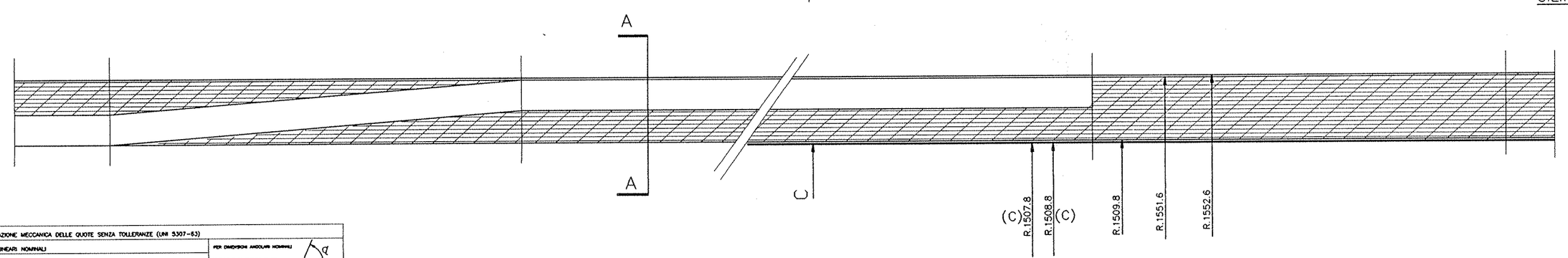
NOTE

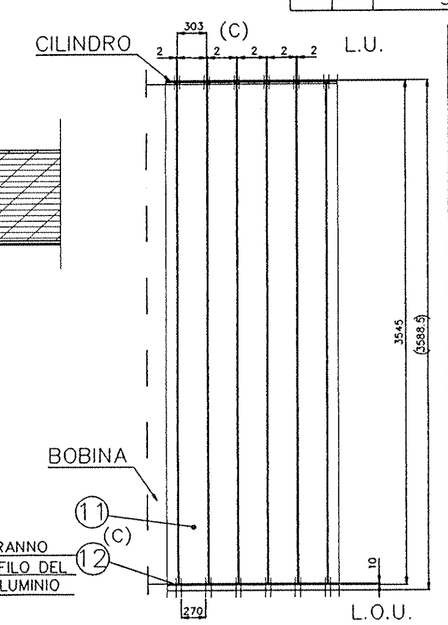
1) L'ISOLAMENTO DI SPIRA SARA' ESEGUITO CON N.°1 NASTRATURA 1/2 SOVRAPPOSTA.–
2) LO STRATO INTERNO SARA' AVVOLTO IN SENSO ORARIO.
3) LO STRATO ESTERNO SARA' AVVOLTO IN SENSO ANTIORARIO.
4) DURANTE L'AVVOLGIMENTO DOVRANNO ESSERE ESEGUITE OPERAZIONI DI COMPATTAMENTO DELLE SPIRE TRAMITE APPOSITI ANELLI.(VED.METODO).–
5) IL CONDUTTORE LATERALE ESTERNO ,POS.1, SARA'FORNITO IN N° 2 SPEZZONI DI SEZ.4.93mm.x20mm.E LUNGHEZZA m.1813 e m.1817 RISPETTIVAMENTE.
6) IL CONDUTTORE CENTRALE ESTERNO ,POS.2, SARA'FORNITO IN N° 1 SPEZZONE DI SEZ.8.49mm.x20mm.E LUNGHEZZA m.1608.–
7) IL CONDUTTORE LATERALE INTERNO ,POS.3, SARA' FORNITO IN N° 2 SPEZZONI DI SEZ.4.93mm.x20mm.E LUNGHEZZA m.1845 e m.1849 RISPETTIVAMENTE.
8) IL CONDUTTORE CENTRALE ESTERNO ,POS.4, SARA'FORNITO IN N° 1 SPEZZONE DI SEZ.8.49mm.x20mm.E LUNGHEZZA m.1518.–
9) L'ISOLAMENTO DI CONTROMASSA SARA' ESEGUITO CON NASTRO DI VETRO DA 200X0.28MM. ,POS.6. (PER L'APPLICAZIONE VED. METODO).–
10) LA GIUNZIONE TRA I DUE STRATI DEVE ESSERE ISOLATA CON N.°2 NASTRATURE 1/2 SOVRAPPOSTE CON NASTRO DA 0.15X25.–
11) PER LA SALDATURA DEGLI SPEZZONI VED. PARTIC. SU FOGLI 2,3.–
12) COMPESARE DURANTE L'AVVOLGIMENTO DELLO STRATO INTERNO I 2mm. IN MENO RISPETTO ALLO STRATO ESTERNO IN MODO DA ARRIVARE ALLA GIUNZIONE CON LE SPIRE DEI DUE STRATI ALLA STESSA ALTEZZA.–

TOT. KG. 3700

N°.						KG.
130	RIVETTO TESTA SVASATA 1.9x3	12	130	UNI7347–74	INOX	
32	FASCIA DI ALLUMINIO 303x1 l.=3545	11	32	V.DIS.	NASTRO DI ALLUM. Sp.1	
1	FLANGIA LATO GIUNZIONE	10	1	620RM07256 POS.4		15
1	SALTO DI SPIRA,STRATO ESTERNO, E RIEMPITIVI	9	1	620RM07256 POS.3		15
1	SALTO DI SPIRA,STRATO INTERNO, E RIEMPITIVI	8	1	620RM07256 POS.2		10
1	FLANGIA LATO USCITE	7	1	620RM07256 POS.1		10
1	ISOLAMENTO DI CONTROMASSA Sp.0.28X500	6	1		R. UM00740	
1	ISOLAMENTO DI SPIRA Sp.0.12X25	5	1		R. UM00740	
m. 1518	CONDUTTORE CENTRALE INTERNO SEZ.8.49x20	4	m. 1518	1 Spezzone= m. 1518	R.	750
m. 3694	CONDUTTORE LATERALE INTERNO SEZ.4.93x20	3	m. 3694	1 Spezzone= m. 1845 1 Spezzone= m. 1849	R.	1060
m. 1608	CONDUTTORE CENTRALE ESTERNO SEZ.8.49x20	2	m. 1608	1 Spezzone= m. 1608	R.	790
m. 3630	CONDUTTORE LATERALE ESTERNO SEZ.4.93x20	1	m. 3630	1 Spezzone= m. 1813 1 Spezzone= m.1817	R.	1040







Rev rev.	St. st.	Sc. sc.	Descrizione kind of revision	Preparato prepared	Controllato checked	Verificato checked	Verificato checked	Verificato checked	Approvato approved	Data date
C			AGGIUNTO CONTROMASSA DIA INTERNO E POS.11–12.–							09.10.96
B			AGGIORNATO DIS.–							07.06.96
A			AGGIORNATO DIS.–							18.04.96
0										02.04.96

Progetto/project: BABAR

Cliente/client:

Commessa job no.	Emittente issued by	Tipo doc. doc. type	Form. size	Scala scale	Derivato da derived from	Rev. rev.
I30004EM	PMA/CRSP		A1			

ANSALDO

Ansaldo Energia s.p.a.

Titolo title: AVVOLGIMENTO MAGNETE

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Identificazione file file identification: CED

Codice struttura product breakdown structure: Identificativo/document no. 620RM07142

Rev./rev.: 0 A B C | Foglio sheet 1 | Segue fg. fol. sheet | Di of 3

A/Ed. 0000 ⓐ

TOLLERANZE GENERALI DI LAVORAZIONE MECCANICA DELLE QUOTE SENZA TOLLERANZE (UNI 5307-63)

GRADO DI PRECISIONE	PER DIMENSIONI LINEARI NOMINALI — GRUPPO DI DIMENSIONI IN MM. fino a 6	da 6 a 30	da 30 a 120	da 120 a 315	da 315 a 1000	da 1000 a 2000	da 2000 a 4000	oltre 4000	PER DIMENSIONI ANGOLARI NOMINALI — GRUPPO DI DIMENSIONI IN MM. (lati più corti) da 3 a 6	da 6 a 30	da 30 a 120	oltre 120
GROSSOLANO	±0.2	±0.5	±0.8	±1.2	±2	±3	±4	±5	±1°	±30'	±20'	±10'
MEDIO	±0.1	±0.2	±0.3	±0.5	±0.8	±1.2	±2	±3				
PRECISO	±0.05	±0.1	±0.15	±0.2	±0.3	±0.5	/	/				

SALVO INDICAZIONE CONTRARIA TUTTI GLI SPIGOLI VANNO ARROTONDATI

Simboli di rugosita' secondo ISO 1302 — symbols for roughness according to ISO 1302

Tolleranze di forma e di posizione sec. ISO 2768/2 — shape and position tolerances according to ISO 2768/2

Quote di lavorazione senza indicazione di tolleranza secondo ISO 2768/1 — tolerances for non-limited dimensions for machining according to ISO 2768/1

Classi di tolleranza deviations grade: mK ☐ cK ☐

EXTERNAL LAYER

R.1541.4

313.5°

46.5°

2500

171°

5.33

1

5

3509.9

1003.75

5.33+(5.33x187)+1/3 DI SPIRA

m.1817

VEDI PARTIC.SALDATURA

5.13

8.69

1484.63

8.89+(8.89x166)

m.1608

78°

1001.84

5.13+(5.33x187)

m.1813

10.77

5.44

9.7

4.37

4.11

13.66

8.33

13.43

8.1

12.1

6.76

~2421

270°

~2500

~400

0°

90°

180°

~252°

345°

~9685

STRATO ESTERNO

particolare per saldatura spezzoni

300 | 200 | 1500 | 200 | 300

Sn/pb — Saldatura da eseguire al TIG — Sn/pb

Rev rev.	St. st.	Sc. sc.	Descrizione kind of revision	Preparato prepared	Controllato checked	Verificato checked	Verificato checked	Verificato checked	Approvato approved	Data date
C			V.FGL.1.–							09.10.96
B			V.FGL.1.–							05.06.96
A			V.FGL.1.–							18.04.96
0										02.04.96

Progetto/project: BABAR

Cliente/client:

Commessa job no.: 130004EM

Emittente issued by: PMA/CRSP

Tipo doc. doc. type:

Form. size: A1

Scala scale:

Derivato da derived from:

Rev. rev.:

Identificazione file: file identification:

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Titolo title: AVVOLGIMENTO MAGNETE

Codice struttura product breakdown structure:

Identificativo/document no.: 620RM07142

Rev./rev.: A B C

Foglio sheet: 2

Segue fg. foll. sheet:

Di of: 3

AD 00027/240

INTERNAL LAYER

R.1520

313.5°

46.5°

2500

m.1849

1035.8

5.33+(5.33x193)+1/3 DI SPIRA

VEDI PARTIC.SALDATURA

5.13

8.69

1422.4

8.89+(8.89x159)

m.1518

3511.68

1033.82

5.13+(5.33x193)

m.1845

10.77

5.44

6.76

12.1

8.1

13.43

8.33

13.66

4.11

9.7

4.37

2387.5

400

~2500

186.5°

270°

~280.7°

0°

15°

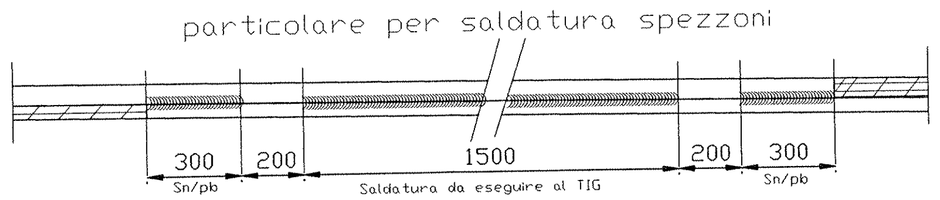
90°

108°

180°

9550

STRATO INTERNO



Rev. rev.	St. st.	Sc. sc.	Descrizione kind of revision	Preparato prepared	Controllato checked	Verificato checked	Verificato checked	Verificato checked	Approvato approved	Data date
C			V.FGL.1.–							09.10.96
B			V.FGL.1.–							05.06.96
A			V.FGL.1.–							18.04.96
0			Prima emissione.–							02.04.96

Progetto/project: BABAR

Cliente/client:

Commessa job no.: 130004EM

Emittente issued by: PMA/CRSP

Tipo doc. doc. type:

Form. size: A1

Scala scale:

Derivato da derived from:

Rev. rev.:

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Titolo title: AVVOLGIMENTO MAGNETE

Identificazione file file identification:

Codice struttura product breakdown structure:

Identificativo/document no.: 620RM07142

Rev./rev.: A B C

Foglio sheet: 3

Segue fg. foll. sheet:

Di of: 3

MD 00017/50

CED

List of Reviewers:

Dr. Steve St. Lorant
P.O Box 4349, M/S 20
Stanford Linear Accelerator Center
Stanford, CA 94309
(415) 926-2671

Dr. Stewart Shen
Lawrence Livermore Nat. Lab
P.O. Box 808, L-287
Livermore, CA 94550
(510) 423-4826
(510) 422-6747 (fax)

shen@maverick.llnl.gov

Dr. Jon Zbasnik
Lawrence Livermore Nat. Lab
P.O. Box 808, L-643
Livermore, CA 94550
(510) 423-5634
(510) 422-2477 (fax)

Quench Protection Review

Thursday October 17, 1996
Orange Room
Agenda

9:00 - 9:30	Introduction	T. O'Connor (LLNL)
9:30 - 10:00	BABAR Solenoid	P. Fabbricatore (INFN)
10:00 - 11:00	Quench Analysis	P. Valente (Ansaldo)
11:00 - 12:00	Quench Protection	P. Valente (Ansaldo)
12:00 - 1:00	Working Lunch - Orange Room	
1:00 - 2:00	Quench Protection (Cont. if necessary)	P. Valente (Ansaldo)
2:00 - 3:00	Discussion	All

Technical Review Report
of
Quench Protection of BABAR Magnet System

1. Introduction

On October 17, 1996, a technical review meeting on the Quench Protection of BABAR Magnet System was conducted at SLAC. The review group consisted of:

Jon Zbasnik of LLNL
Steve St. Lorant of SLAC
Stewart Shen of LLNL

with Stewart Shen identified as the lead reviewer. In addition to the BABAR-SLAC personnel, the group met with Ansaldo and INFN staff who gave the technical presentation and answered the questions by the review group. The group was charged specifically with addressing the following questions:

1. Is the quench analysis complete?
2. Is the Babar solenoid adequately protected during a quench?
3. Is there anything that could be done to improve the protection?
4. Is adequate testing being planned?
5. Is there enough redundancy in the quench protection system?
6. Have we overlooked anything?

In the end of this review, the group requested additional information on several technical issues for further review.

On 1/14, 1997, a second review meeting was convened at LLNL. This meeting was emphasized on the examination of new information recently provided by Ansaldo and INFN staff, and the preparation of the report.

This report briefly describes the discussions and comments in both review meetings, and summarized the conclusion and recommendation.

2. Review of October 17

The Review Committee has discovered no obvious omissions in the Quench analysis or design of the BaBar magnet system.

REFERECES:

1. BABAR Superconducting Solenoid Review @ Ansaldo, Nov. 7-8, 1996

Review Committee

Stewart Shen (LLNL) _____ Date: _____

Steve St. Lorant (SLAC) _____ Date: _____

Jon Zbasnik (LLNL) _____ Date: _____

In general, the group is much satisfied with the response and feels that the Quench Protection System for BABAR Magnet is well designed with complete analysis. The conclusion and recommendation for each charged question are:

1. Is the quench analysis complete?

Yes. The group specially appreciated the results of calibration run of the Code "PROTECT"against the ZEUS magnet.

2. Is the Babar solenoid adequately protected during a quench?

It is well demonstrated that the magnet is conservatively designed with sufficient operating margins. The analysis has also clearly shown that the BABAR Magnet System is Self-Protected, since the hot spot temperature for the case of quench without fast discharge results in peak temperatures that will not cause a catastrophic magnet failure.

3. Is there anything that could be done to improve the protection?

The group feels that the "action time" of 5 ms designed for the quench detector may be too short. To avoid inadvertent discharge of the magnet system, this"action time" should be increased.

4. Is adequate testing being planned?

Yes, however, the group strongly recommends the proposed "Tests Without Quench Protection" tests to be deleted.

5. Is there enough redundancy in the quench protection system?

The group feels that there are other design options available for the power supply system which may offer more redundancy for circuit breakers and ground fault protection. The group recommends the project to reevaluate the design.

6. Have we overlooked anything?

Temp rise of dump resistor.
Voltage taps on all splices.
Probility repime.

This review of the Quench Protection System went very well. The review group deeply appreciated the effort made by the Ansaldo/INFN/SLAC staff in the technical presentation. The reviewers generally felt that BABAR Magnet system has a good quench protection system. However, the group requested additional technical information for further review before they could prepare the review report. Technical information requested include:

1) Detailed field plots of the maximum field in the conductor.
2) MPZ analysis.
3) Calibration or bench marking of the code-"PROTECT".

4) A document contains all material properties that are used in the magnet analysis.
5) Description of the heat treatment of the 5083 Aluminum winding cylinder.
6) Effect of lower RRR in the AL stabilizer on the case without the protection.
7) Transient structural analysis (ANSYS) that includes the beginning of the discharge.
Rerun the stress analysis of the for time = 30 sec. What is the effect of high
temperature gradient at approximate 75% current. Use the quench results from Run15 (no dump resistor and quench from one end).
8) Detailed design of the joints.
9) Sensitivity and threshold of the QD. Could the joint between the two layers (J4) be eliminated. This joint is in the high field region where quench is likely to start from. What happens if the quench propagates equally on both layers.
The voltage taps looking at the change in voltage between the two layers may not detect a quench of this kind for some time.

3. Review of January 14

After receiving the response to above issues1, the group conducted the second review meeting to further review these issues and draft this review report. Participants included all review group members and Tom O'Connor representing the BABAR project team.

LAWRENCE LIVERMORE NATIONAL LABORATORY

7000 East Ave., P.O. Box 808, L-287, Livermore, CA 94550
Email: toconnor@llnl.gov Phone: (510) 423-8781
Fax: (510) 422-6747 (verify, 510-423-7533)

October 11, 1996

Dr. Steve St. Lorant
P.O Box 4349, M/S 20
Stanford Linear Accelerator Center
Stanford, CA 94309

Dear Dr. St. Lorant:

Thank you for agreeing to participate in the Quench Protection Review of the superconducting solenoid for the BABAR Detector scheduled for October 17, 1996 at Stanford Linear Accelerator Center. This review is part of our normal preparation before procuring the solenoid.

The charge to the review group is:

1. Is the quench analysis complete?
2. Is the BABAR solenoid adequately protected during a quench?
3. Is there anything that could be done to improve the protection?
4. Is adequate testing being planned?
5. Is there enough redundancy in the quench protection system?
6. Have we overlooked anything?

Stewart Shen has agreed to be the lead reviewer, and the full membership is attached.

The review agenda and maps of the area are enclosed. If documentation is available before the review I will send you a copy of it.

Yours in appreciation,

Thomas G. O'Connor
Magnet Co-System Manager

cc: B. Bell (SLAC)
D. Hitlin (SLAC)
L. Keller (SLAC)
V. Luth (SLAC)

Date: Mon, 28 Oct 1996 10:55:52 -0800 (PST)
From: Stewart Shen <shen@maverick.llnl.gov>
Subject: BABAR Protection Review
To: saint@SLAC.Stanford.EDU, zbasnik@maverick.llnl.gov
MIME-version: 1.0

Hi Steve and Jon,

Following is a status report of the Review. As soon as I receive the requested materials, I'll forward them to you. Then we'll schedule a review video conference at LLNL.

Stewart

Solenoid Group,
The review of the Quench Protection System held on Oct 17, 1996 went very well. The reviews felt the we have a good quench protection system and that there is enough redundancy in the system to adequately protect the superconducting solenoid. Before the reviewers write up their report they have requested that we send them the information listed below. After they have had time to review this new information we will have a conference call to discuss it some time during the week of November 11, 1996.

The list includes the person or group responsible for obtaining the information, a brief description of the requested information, and the date when this information is needed.

Please let me know if you have any questions

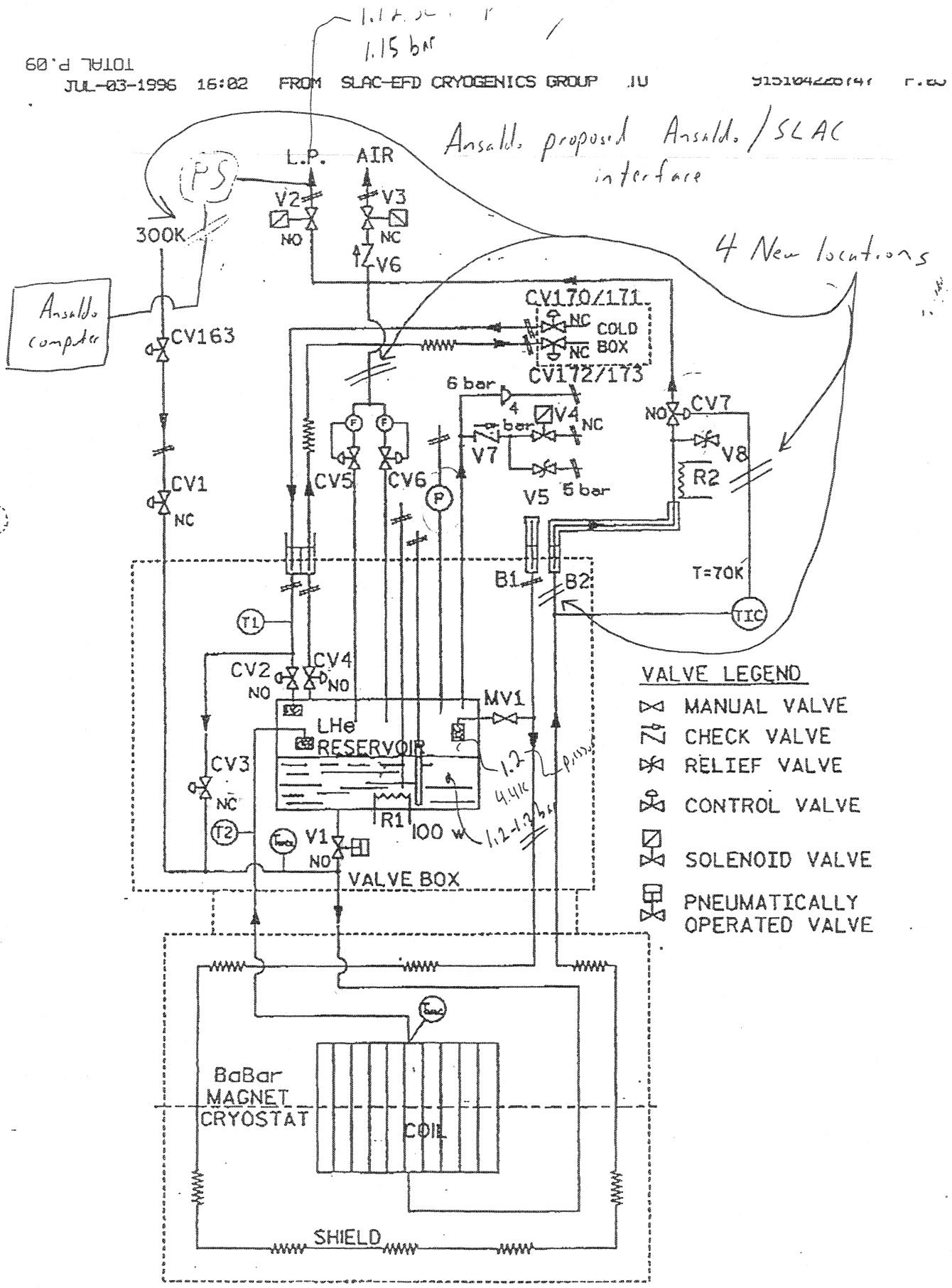
Regards,
Tom

1) INFN - Detailed field plots of the maximum field in the conductor
Send to T. O'Connor by Friday Oct 25, 1996
2) INFN - MPZ analysis - analysis already complete, P. Fabbricatore will write a summary of the results.
Send to T. O'Connor by Friday Oct 25, 1996
3) Ansaldo - Has your quench protection code been calibrated? If not the reviewers would like it to be bench marked against some know quench problem
4) Ansaldo - The values of all mechanical, thermal and electrical properties used in your quench and stress analysis.
Send to T. O'Connor by Friday Oct 25, 1996
5) Ansaldo - what is the heat treatment of the 5083 Aluminum winding cylinder. For example "T6"
Send to T. O'Connor by Friday Oct 25, 1996
6) Ansaldo - Re run quench with an RRR of 500, what is the effect of the lower RRR.
Present results at the Nov 7-8 review at Ansaldo
7) Ansaldo - Re run the stress analysis of the for time = 30 sec.
What is the effect of high temperature gradient at approx 75% current. Use the quench results from Run15 (no dump resistor

and quench from one end)
Present results at the Nov 7-8 review at Ansaldo

8) O'Connor - The review committee wanted to see the detailed design of the joints.
T. O'Connor already has this drawing describing the joints.

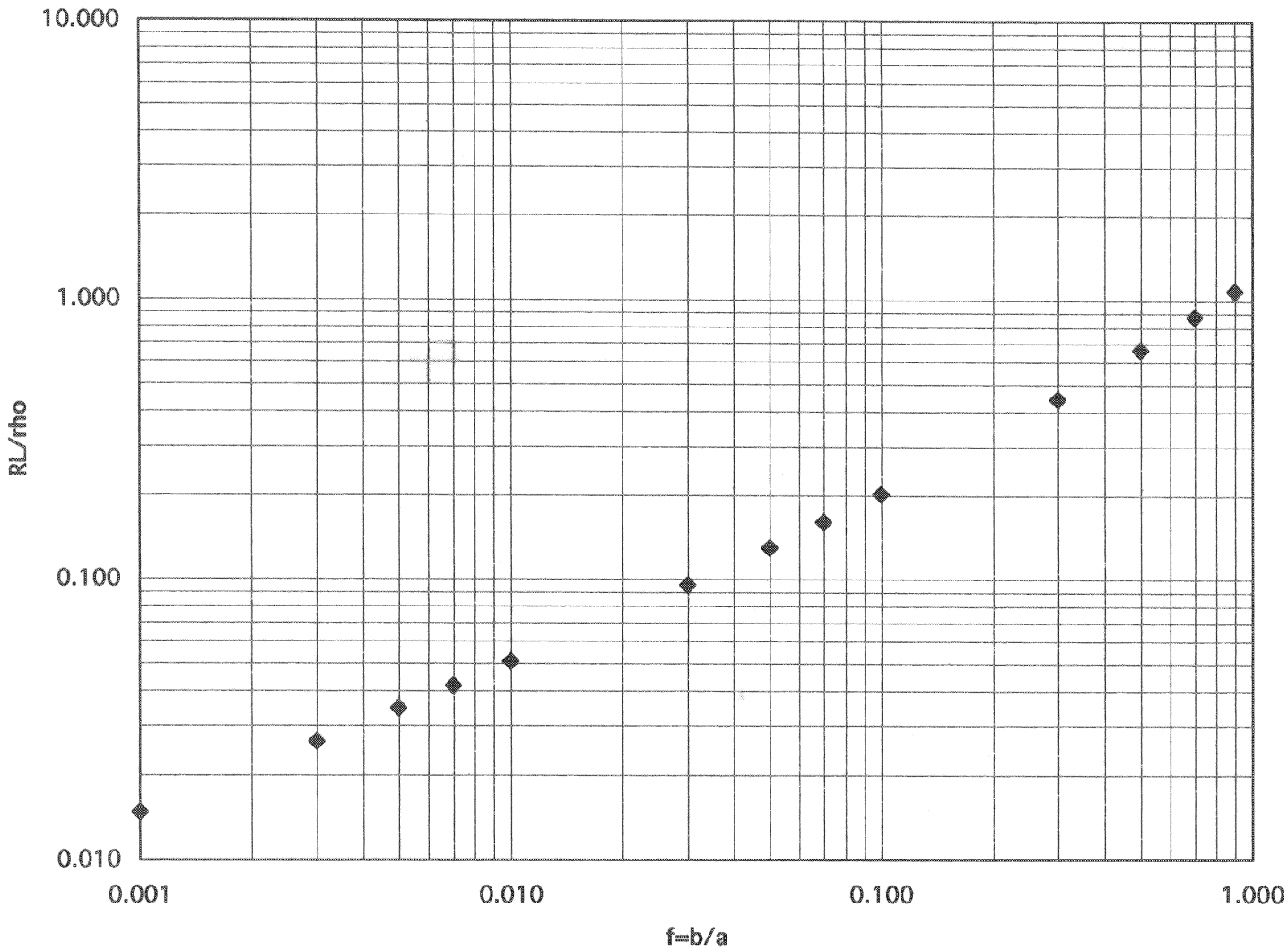
9) Ansaldo - Could the joint between the two layers (J4) be eliminated. This joint is in the high field region where quench is likely to start from. What happens if the quench propagates equally on both layers. The voltage taps looking at the change in voltage between the two layers may not detect a quench of this kind for some time.
Discuss this issue at the Nov 7-8 review at Ansaldo



CROSS REF: PROPOSED SOLENOID CRYO CONTROLS
REV. 2 (ORIGINAL FLOW SCHEME) JULY 3, 1996

DETVBSCM8.EFK

Splice Resistance



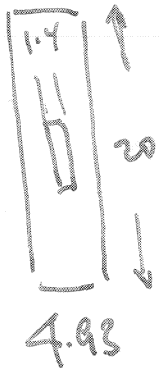
$f = 1.26$

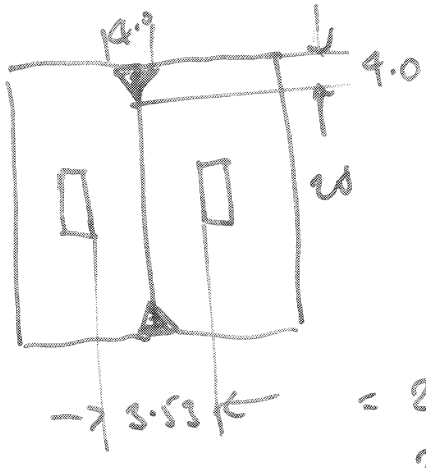
$\frac{RL}{\rho} = 1.445$

mm

$$\begin{array}{r} 4.93 \\ 1.40 \\ \hline 3.53 \end{array}$$

$\Delta = 1.765$





$= 2b$

$2a = 2.8$

$f = b/a = \frac{3.53}{2.8} = 1.26$

$R = \rho \frac{L}{A}$ $\quad \frac{\rho}{L R_j} = \frac{1}{A}$ $\quad \frac{R_j L}{\rho} = A = 1.445\ mm^2$

$\Delta = 4\ mm^2 = \frac{R_j L}{\rho}$

univ. joint length = 1500 mm

$\rho_{(2T)} = 8.10^{-5}\ \mu\Omega m$

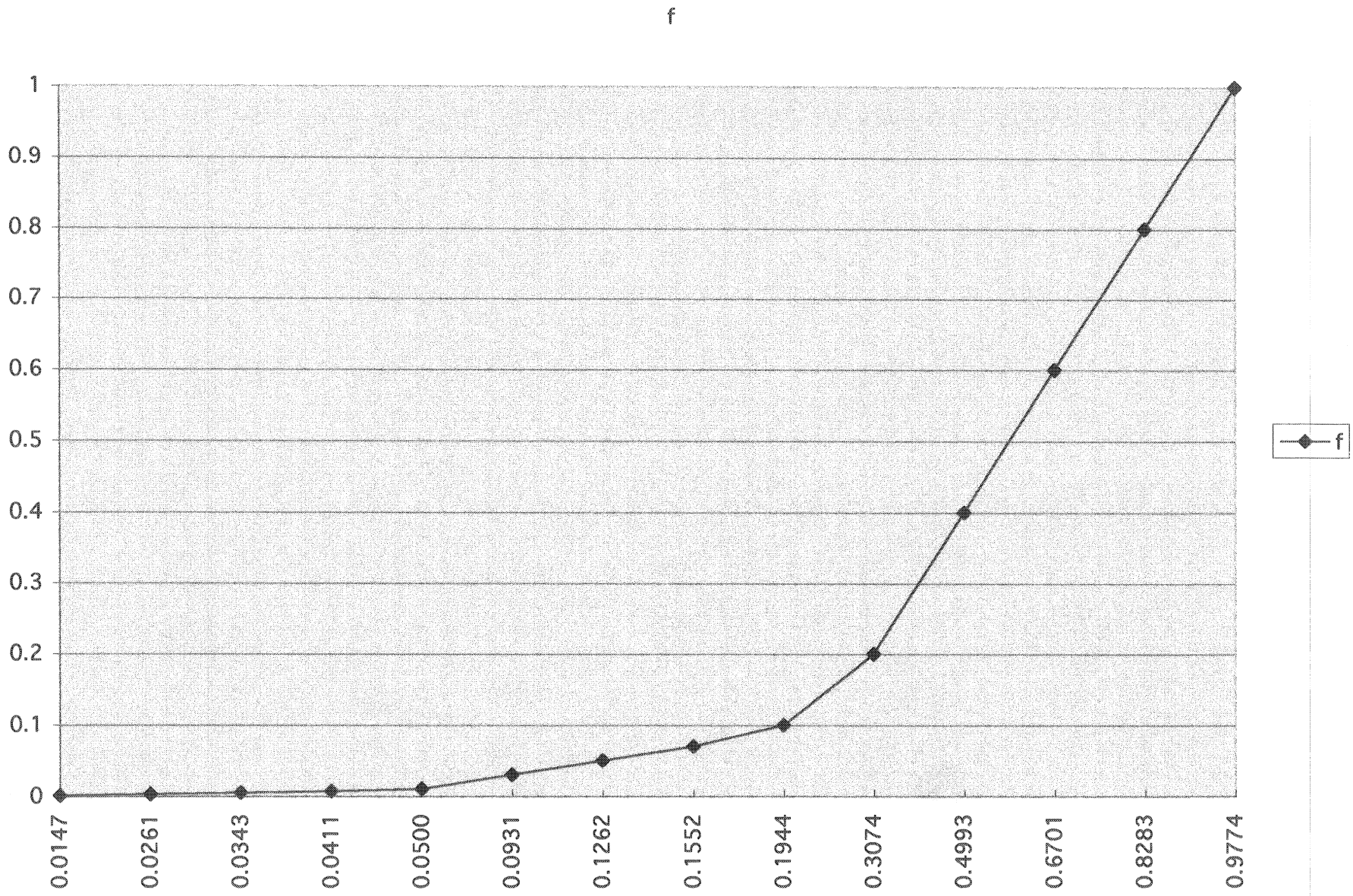
$R_j^{(1)} = \frac{1.445 \cdot 8.10^{-5} \cdot 10^{3} \cdot 10^{-6}}{1.500 \cdot 10^{3}} = \frac{8 \cdot 1.445}{1.5} \cdot 10^{-11} = 7.7 \cdot 10^{-11}$

$R_j^{(2)} = \frac{4 \cdot 8.10^{-5} \cdot 10^{3} \cdot 10^{-6}}{1.5 \cdot 10^{3}} = 3.2 \cdot 10^{-10}\ \Omega \rightarrow$

Check: $f = 0.1$, $L = 0.1$, $\rho = 3.10^{-8}\ \Omega m$

$\frac{RL}{\rho} = .12$; $R = \frac{.12 \cdot 3.10^{-8}}{0.1} = 3.6.10^{-9}\ \Omega$

I = 4811


f
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.0147
0.0261
0.0343
0.0411
0.0500
0.0931
0.1262
0.1552
0.1944
0.3074
0.4993
0.6701
0.8283
0.9774
f

Lawrence Livermore National Laboratory

Fax Cover Sheet

Date: 3/7-97

Time: 11:00 AM

Please Deliver the Following Pages ...

To:

Name: Steve St. Lorant

Company: SLAC

City:

Fax #: 415-926-~~4999~~ 4126

Voice #:

From:

Stewart Sheen

Accelerator Technologies Engineering Group

Lawrence Livermore National Laboratory

Fax #: (510) ~~422-6747~~ 424-3532

Voice #:

Info:

You should be receiving 12 pages including this cover sheet. If you do not receive all pages or there is an error during transmission, please call.

Notes:

INFN-GE

JOINT RESISTANCE MEASUREMENT REPORT

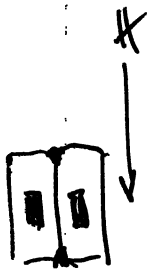
P.Fabbricatore, R.Musenich and C. Priano

Genova, 8 February, 1997

- A sample of the BABAR thin cable length #1 coextruded at Cortaillod on 30th October 1996 was jointed by Ansaldo on 31st January 1997. The sample provided to INFN-GE on 6th February 1997.

- The conductor joint resistance was determined via measurements of the current decay time on 6th February 1997. Using the direct transformer method a current higher then 5000 A is induced in the sample and, using a hall probe, we detect the exponential decay of the current. The joint resistance is obtained using $\tau = \frac{L_{sample}}{R_j}$

- The sample was arranged in a loop of external radius 203.3 mm and inductance L_{sample}=1.2 10^{-6} H.



- The sample was bent on lower inertia so that the solenoid external field is applied parallel to the wide face.

- The sample was TIG welded on both side on a length of 150 mm.

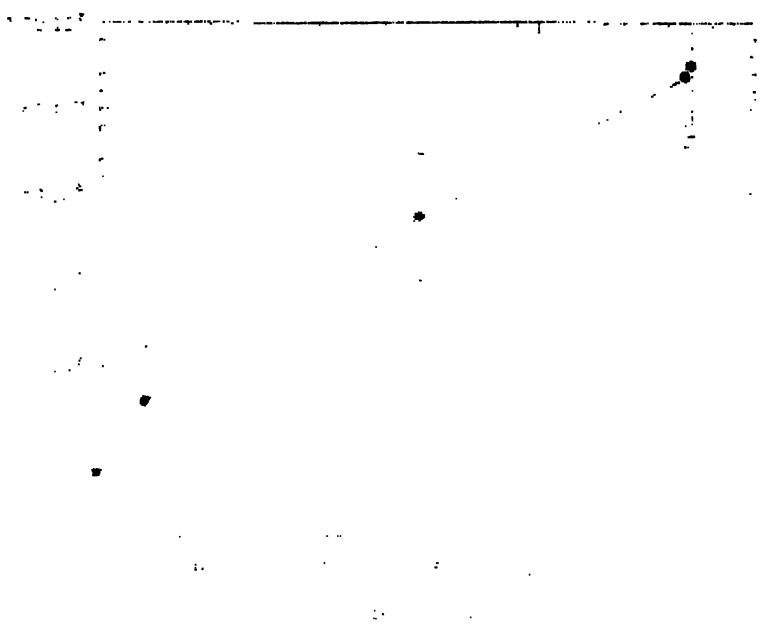
- 5 measurements were carried out in the field range 0-2.7 T (applied external field).

The performed measurements are summarized in the following table

External Field (T)	Joint Resistance (Ω)	Joint Resistance per meter (Ω)
0.0	1.175 10^{-3}	[illegible]
0.215	1.260 10^{-3}	[illegible]
1.46	1.474 10^{-3}	2.21 10^{-3}
2.68	1.636 10^{-3}	2.45 10^{-3}
2.71	1.648 10^{-3}	2.47 10^{-3}

The results are also shown on R-B graph in the following page

BABAR-LMI. Lenght #1
TIG welded Joint resistance



INFN-GE

CRITICAL CURRENT MEAS[illegible]RT

[illegible] OF MEASUREMENT [illegible] CONDUCTOR (LENGTH #5) COEXTRUDED [illegible]

P.Fab[illegible] R.Musenich and [illegible]

[illegible] 14 February, [illegible]

[illegible] cable sample was [illegible] conductor coextruded at [illegible]

[illegible] was measured [illegible] sample was arranged in a loop [illegible]

[illegible] larger [illegible] so that [illegible]

- 3 measurements were carried out in the field range 2.0-2.7 T (applied external field)

BABAR-LMI (No self-field correction)

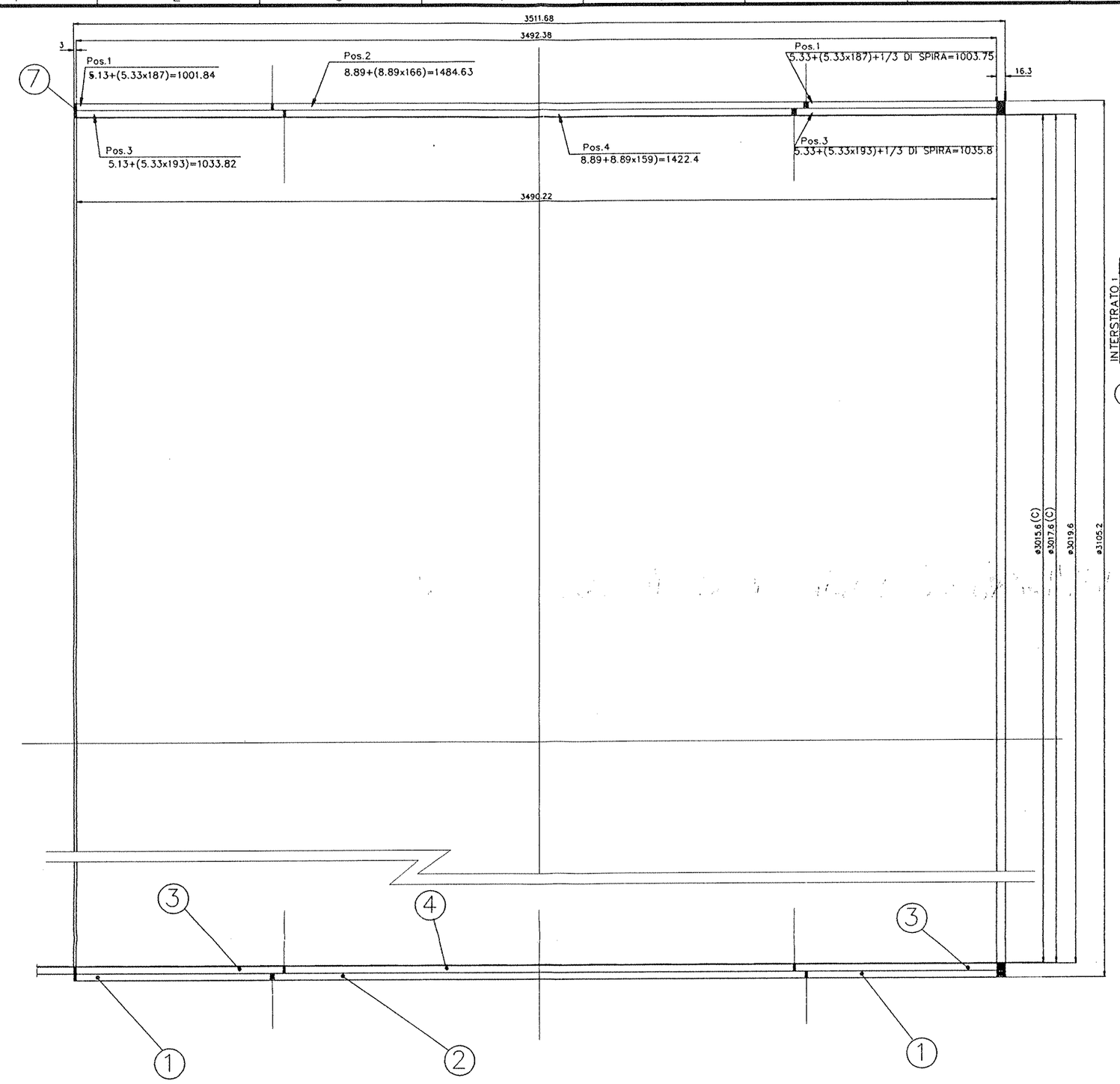
$I_c(B_{ex}=5\ T;\ T=4.2\ K) = 9530\ A$

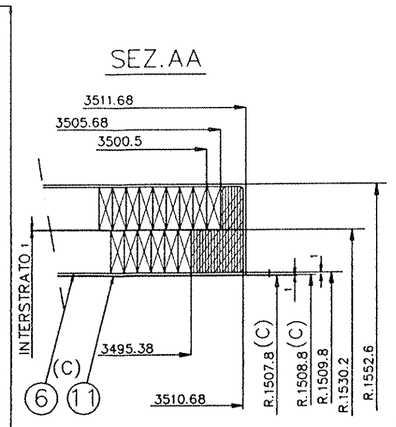
INFN-GF

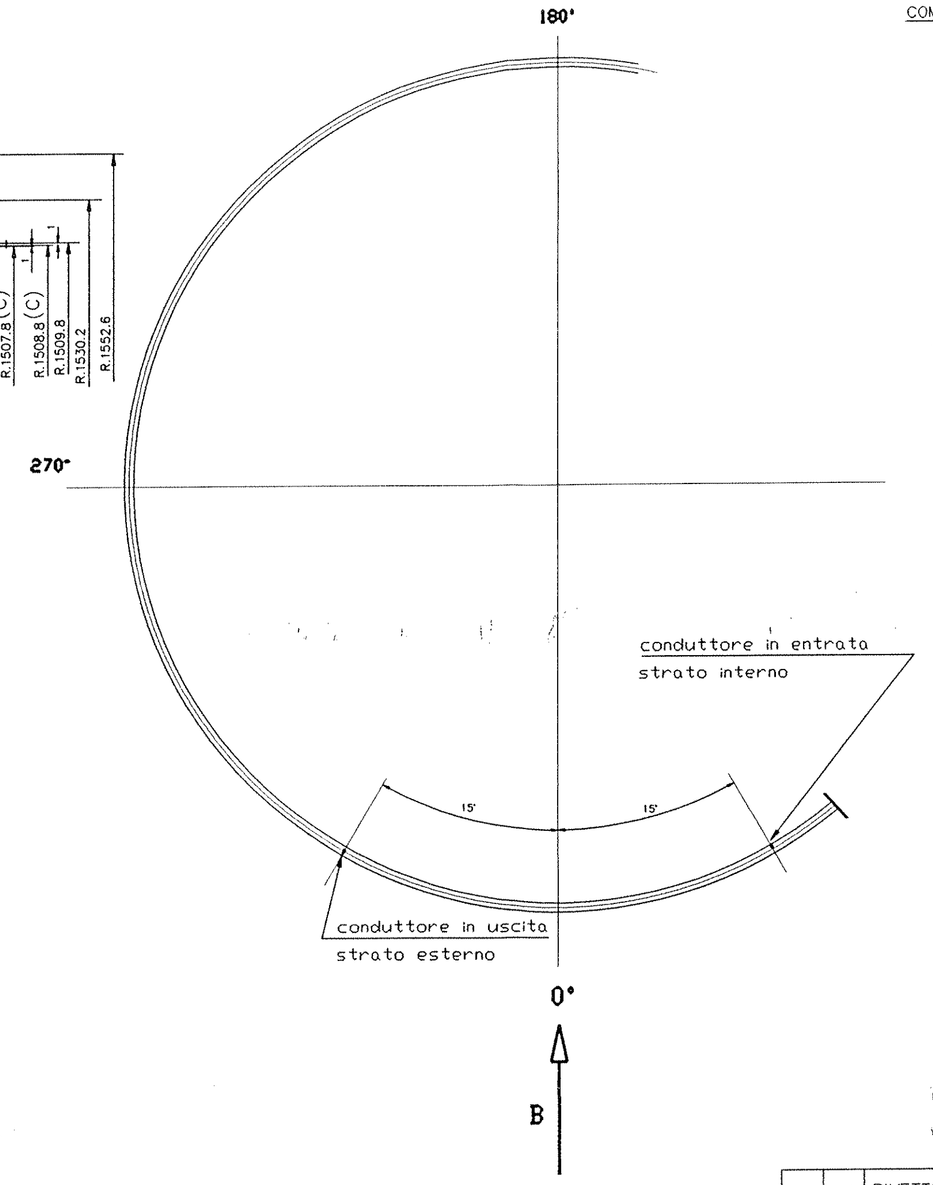
obs

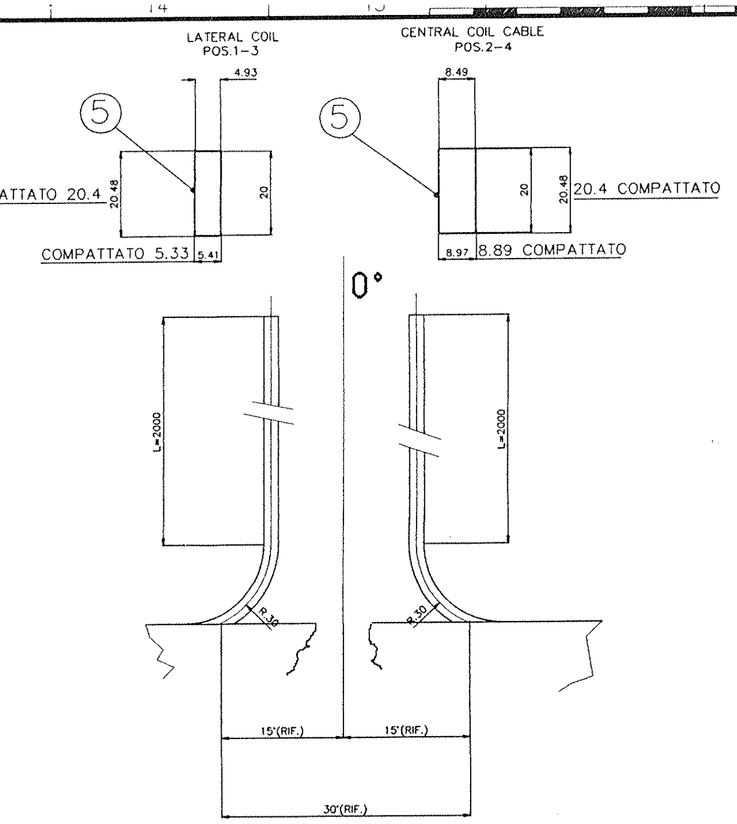
BABAR-LMI

B = 5 t, T=4.2 K









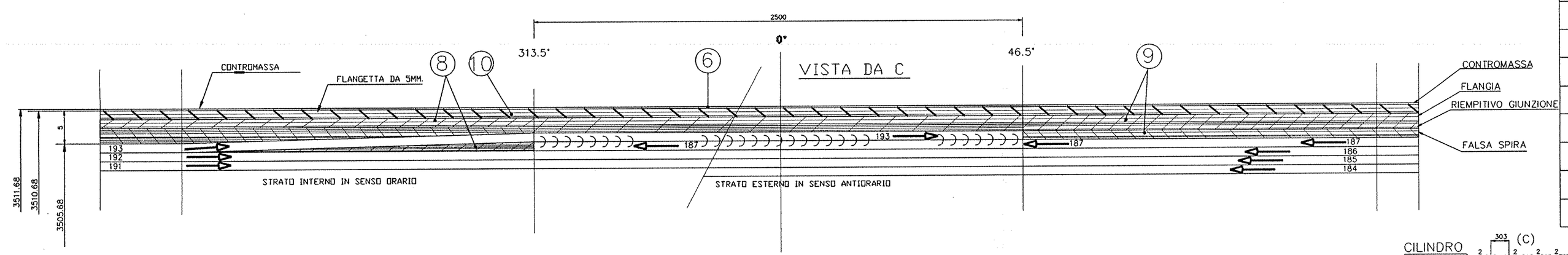
Visto da B

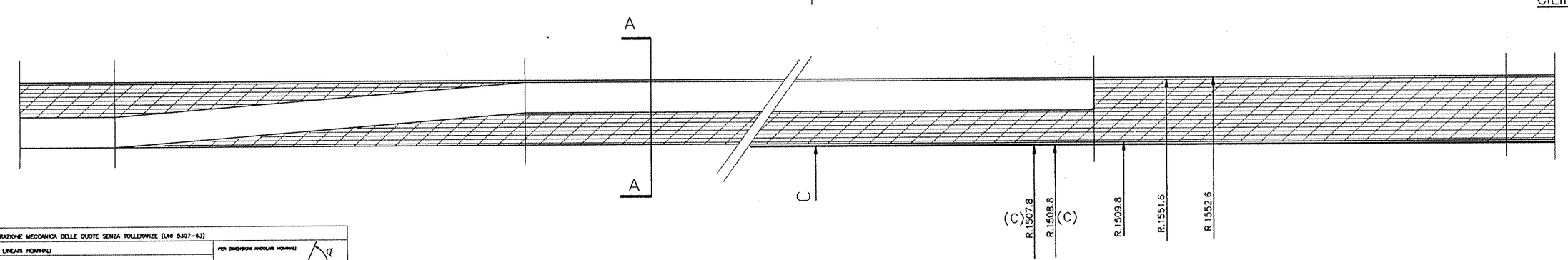
NOTE

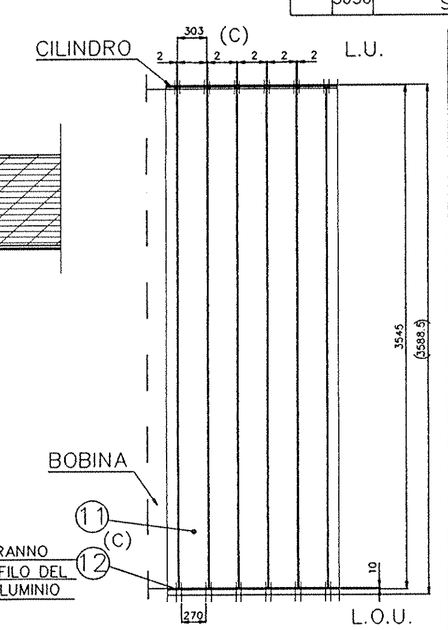
1) L'ISOLAMENTO DI SPIRA SARA' ESEGUITO CON N.°1 NASTRATURA 1/2 SOVRAPPOSTA.–
2) LO STRATO INTERNO SARA' AVVOLTO IN SENSO ORARIO.
3) LO STRATO ESTERNO SARA' AVVOLTO IN SENSO ANTIORARIO.
4) DURANTE L'AVVOLGIMENTO DOVRANNO ESSERE ESEGUITE OPERAZIONI DI COMPATTAMENTO DELLE SPIRE TRAMITE APPOSITI ANELLI.(VED.METODO).–
5) IL CONDUTTORE LATERALE ESTERNO ,POS.1, SARA'FORNITO IN N° 2 SPEZZONI DI SEZ.4.93mm.x20mm.E LUNGHEZZA m.1813 e m.1817 RISPETTIVAMENTE.
6) IL CONDUTTORE CENTRALE ESTERNO ,POS.2, SARA'FORNITO IN N° 1 SPEZZONE DI SEZ.8.49mm.x20mm.E LUNGHEZZA m.1608.–
7) IL CONDUTTORE LATERALE INTERNO ,POS.3, SARA' FORNITO IN N° 2 SPEZZONI DI SEZ.4.93mm.x20mm.E LUNGHEZZA m.1845 e m.1849 RISPETTIVAMENTE.
8) IL CONDUTTORE CENTRALE ESTERNO ,POS.4, SARA'FORNITO IN N° 1 SPEZZONE DI SEZ.8.49mm.x20mm.E LUNGHEZZA m.1518.–
9) L'ISOLAMENTO DI CONTROMASSA SARA' ESEGUITO CON NASTRO DI VETRO DA 200X0.28MM. ,POS.6. (PER L'APPLICAZIONE VED. METODO).–
10) LA GIUNZIONE TRA I DUE STRATI DEVE ESSERE ISOLATA CON N.°2 NASTRATURE 1/2 SOVRAPPOSTE CON NASTRO DA 0.15X25.–
11) PER LA SALDATURA DEGLI SPEZZONI VED. PARTIC. SU FOGLI 2,3.–
12) COMPESARE DURANTE L'AVVOLGIMENTO DELLO STRATO INTERNO I 2mm. IN MENO RISPETTO ALLO STRATO ESTERNO IN MODO DA ARRIVARE ALLA GIUNZIONE CON LE SPIRE DEI DUE STRATI ALLA STESSA ALTEZZA.–

TOT. KG. 3700

N°.						KG.
130	RIVETTO TESTA SVASATA 1.9x3	12	130	UNI7347–74	INOX	
32	FASCIA DI ALLUMINIO 303x1 l.=3545	11	32	V.DIS.	NASTRO DI ALLUM. Sp.1	
1	FLANGIA LATO GIUNZIONE	10	1	620RM07256 POS.4		15
1	SALTO DI SPIRA,STRATO ESTERNO, E RIEMPITIVI	9	1	620RM07256 POS.3		15
1	SALTO DI SPIRA,STRATO INTERNO, E RIEMPITIVI	8	1	620RM07256 POS.2		10
1	FLANGIA LATO USCITE	7	1	620RM07256 POS.1		10
1	ISOLAMENTO DI CONTROMASSA Sp.0.28X500	6	1		R. UM00740	
1	ISOLAMENTO DI SPIRA Sp.0.12X25	5	1		R. UM00740	
m. 1518	CONDUTTORE CENTRALE INTERNO SEZ.8.49x20	4	m. 1518	1 Spezzone= m. 1518	R.	750
m. 3694	CONDUTTORE LATERALE INTERNO SEZ.4.93x20	3	m. 3694	1 Spezzone= m. 1845 1 Spezzone= m. 1849	R.	1060
m. 1608	CONDUTTORE CENTRALE ESTERNO SEZ.8.49x20	2	m. 1608	1 Spezzone= m. 1608	R.	790
m. 3630	CONDUTTORE LATERALE ESTERNO SEZ.4.93x20	1	m. 3630	1 Spezzone= m.1813 1 Spezzone= m.1817	R.	1040







Rev rev.	St. st.	Sc. sc.	Descrizione kind of revision	Preparato prepared	Controllato checked	Verificato checked	Verificato checked	Verificato checked	Approvato approved	Data date
C			AGGIUNTO CONTROMASSA DIA INTERNO E POS.11–12.–							09.10.96
B			AGGIORNATO DIS.–							07.06.96
A			AGGIORNATO DIS.–							18.04.96
0										02.04.96

Progetto/project: BABAR

Cliente/client

Commessa job no.	Emittente issued by	Tipo doc. doc. type	Form. size	Scala scale	Derivato da derived from	Rev. rev.
I30004EM	PMA/CRSP		A1			

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Titolo title: AVVOLGIMENTO MAGNETE

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Identificazione file file identification

Codice struttura product breakdown structure	Identificativo/document no.	Rev./rev.	Foglio sheet	Segue fg. fol. sheet	Di of
	620RM07142	0 A B C	1		3

A/69/0000 ⓐ

TOLLERANZE GENERALI DI LAVORAZIONE MECCANICA DELLE QUOTE SENZA TOLLERANZE (UNI 5307-63)

GRADO DI PRECISIONE	PER DIMENSIONI LINEARI NOMINALI — GRUPPO DI DIMENSIONI IN MM.								PER DIMENSIONI ANGOLARI NOMINALI — GRUPPO DI DIMENSIONI IN MM. (ad una sola per serie)			
	da 0 a 6	da 6 a 30	da 30 a 120	da 120 a 315	da 315 a 1000	da 1000 a 2000	da 2000 a 4000	oltre 4000	da 3 a 6	da 6 a 30	da 30 a 120	oltre 120
GROSSOLANO	±0.2	±0.5	±0.8	±1.2	±2	±3	±4	±5	±1°	±30'	±20'	±10'
MEDIO	±0.1	±0.2	±0.3	±0.5	±0.8	±1.2	±2	±3				
PRECISO	±0.05	±0.1	±0.15	±0.2	±0.3	±0.5	/	/				

SALVO INDICAZIONE CONTRARIA TUTTI GLI SPIGOLI VANNO ARROTONDATI

Simboli di rugosita' secondo ISO 1302 — symbols for roughness according to ISO 1302

Tolleranze di forma e di posizione sec. ISO 2768/2 — shape and position tolerances according to ISO 2768/2

Quote di lavorazione senza indicazione di tolleranza secondo ISO 2768/1 — tolerances for non-limited dimensions for machining according to ISO 2768/1

Classi di tolleranza deviations grade: mK ☐ cK ☐

EXTERNAL LAYER

R.1541.4

313.5°

46.5°

2500

171°

5.33

1

5

1003.75

5.33+(5.33x187)+1/3 DI SPIRA

m.1817

VEDI PARTIC.SALDATURA

5.13

8.69

1484.63

8.89+(8.89x166)

m.1608

3509.9

78°

5.33

1001.84

5.13+(5.33x187)

m.1813

VEDI PARTIC.SALDATURA

8.69

10.77

10.77

5.44

1

9.7

4.37

4.11

13.66

8.33

13.43

8.1

12.1

6.76

5.44

~2421

~2421

~2421

~2421

180°

270°

~2500

~400

0°

78°

90°

180°

~252°

345°

~9685

STRATO ESTERNO

particolare per saldatura spezzoni

300 | 200 | 1500 | 200 | 300

Sn/pb — Saldatura da eseguire al TIG — Sn/pb

Rev rev.	St. st.	Sc. sc.	Descrizione kind of revision	Preparato prepared	Controllato checked	Verificato checked	Verificato checked	Verificato checked	Approvato approved	Data date
C			V.FGL.1.–							09.10.96
B			V.FGL.1.–							05.06.96
A			V.FGL.1.–							18.04.96
0										02.04.96

Progetto/project: BABAR

Cliente/client:

Commessa job no.: 130004EM

Emittente issued by: PMA/CRSP

Tipo doc. doc. type:

Form. size: A1

Scala scale:

Derivato da derived from:

Rev. rev.:

Identificazione file file identification:

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Codice struttura product breakdown structure:

Identificativo/document no.: 620RM07142

Rev./rev.: A B C

Foglio sheet: 2

Segue fg. foll. sheet:

Di of: 3

GED

MD 00027/240

INTERNAL LAYER

R.1520

313.5°

46.5°

2500

m.1849

1035.8

5.33+(5.33x193)+1/3 DI SPIRA

VEDI PARTIC.SALDATURA

5.13

8.69

3511.68

1422.4

8.89+(8.89x159)

m.1518

8.69

VEDI PARTIC.SALDATURA

1033.82

5.33+(5.33x193)

m.1845

VEDI PARTIC.SALDATURA

10.77

5.44

1

6.76

12.1

8.1

13.43

2

8.33

13.66

4.11

9.7

4.37

10.77

5.44

2387.5

2387.5

2387.5

2387.5

186.5°

270°

~280.7°

0°

400

~2500

90°

108°

180°

180°

15°

9550

STRATO INTERNO

particolare per saldatura spezzoni

300 | 200 | 1500 | 200 | 300

Sn/pb — Saldatura da eseguire al TIG — Sn/pb

Rev. rev.	St. st.	Sc. sc.	Descrizione kind of revision	Preparato prepared	Controllato checked	Verificato checked	Verificato checked	Verificato checked	Approvato approved	Data date
C			V.FGL.1.–							09.10.96
B			V.FGL.1.–							05.06.96
A			V.FGL.1.–							18.04.96
0			Prima emissione.–							02.04.96

Progetto/project: BABAR

Cliente/client:

Commessa job no.: 130004EM

Emittente issued by: PMA/CRSP

Tipo doc. doc. type:

Form. size: A1

Scala scale:

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Rev. rev.:

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Codice struttura product breakdown structure

Identificativo/document no.: 620RM07142

Rev./rev.: A B C

Foglio sheet: 3

Segue fg. foll. sheet:

Di of: 3

CED

MD 00027/CAD