MUON CRYOSYSTEM DESIGN NOTE 30

Subsystem: ( ) CCM (X) CVM ( ) Plant

Title: CVM Vacuum Vessel

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Vacuum Vessel Engineering Note
(per Mandatory Standard SD-41)

Prepared By R. W. Fast Date 6/16/86 Div/Sect RD/Cryo

Reviewed By J. Hess Date 7/31/86 Div/Sect Safety Section

Div/Dept Head K. C. Stanfield Date 8/1/86 Div/Sect RD

I. **Identification and Verification of Compliance**

Fill in the Fermilab Engineering Conformance Label information below:

This vessel conforms to Engineering Standard SD-41

Vessel Title CERN Vertex Magnet Vacuum Vessel

Vessel Number 1143

Vessel Drawing Number CERN 30-33-76

Working Temperature Range -20 °F 100 °F

Designer/Manufacturer CERN/Ansaldo (Italy)

Date of Manufacture c. 1977

Acceptance Date N/A

Director's signature (or designee) if vessel is for manned area and requires an exception to the provisions of this standard.

____

Amendment No.:	Reviewed By:	Date:

II. Description of Vessel and Relief System

Laboratory location code NEU NMS

Laboratory property number N/A

Purpose of vessel Insulating vacuum vessel for superconducting magnet

List all pertinent drawings (append copies)

	Drawing No.:	Location of Original:
Cern	30-33-09	Original at Cern; copy at WH-11E, RD/Cryo
	30-33-10	"
	30-33-60	"
	30-33-61 30-33-69	" "
	30-33-70 30-33-76	" "
	32-49-40 32-49-41	" "

Is an operating procedure necessary for the safe operation of this vessel? No

If yes, supply the written procedure with this Engineering Note.

List all reliefs and settings. Provide a schematic of the relief system components, and appropriate calculations or test results to prove that overpressurization beyond the maximum allowable internal pressure will not occur. See Appendixes A, B and C.

Manufacturer	Relief	Setting	Flow Rate	Size	ASME Stamped Device Yes/No
Cern-parallel plate	SV-057-V SV-058-V	few inches of water	200 g/s	4"	No

Welding Information

Has the vessel been fabricated in a Fermilab shop? Yes ____ No X

If "Yes", append a copy of the welding shop statement of welder qualification.

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Appendix A: Analysis of Vacuum Vessel

OBJECTIVE

To demonstrate that the vacuum vessel of the CERN Vertex Magnet complies with Fermilab Engineering Standard SD-41, "Vacuum Vessels".

DESCRIPTION OF VESSEL

The magnet vacuum vessel has upper and lower assemblies. Each assembly consists of a toroidal coil vessel of rectangular cross section and a rectangular connection box (Fig. A1). The two connection boxes are of different sizes. The assemblies were fabricated by Ansaldo, an Italian firm, to CERN specifications. The assemblies are joined by a vacuum pipe containing interconnecting cryofluid lines. The material is 304 stainless steel. A bolted, aluminum cover plate closes each connection box.

APPLICABLE VESSEL STANDARDS

The Fermilab engineering standard, SD-41 "Vacuum Vessels" is applicable to vacuum vessels of greater than 50 cubic feet, which this vessel is. The standard requires that the vessel be designed for 30 psid collapse or in accordance with the ASME Pressure Vessel Code, Section VIII, Division 1 for 7.5 psid. The Code requirement will be used for this vessel.

ANALYSIS OF COIL VESSELS

Outer Cylindrical Shell (Item A, Fig. A1)

I will analyze this as a cylindrical shell with external pressure, using Division 1, Paragraph UG-28(c) of the Code and the following dimensions: D_o = 3560 mm, L = 495 mm, t = 15 mm. Since D_o/t = 237, L/D_o = 0.139, A = 0.0033, B = 12500 and the allowable pressure is

$$P_a = \frac{4B}{3(D_o/t)} = 70.3 \text{ psi},$$

which is in excess of the 7.5-psi requirement.

Inner Cylindrical Shell (Item B, Fig. A1)

This shell is under internal pressure; Paragraph UG-27(c)(1) was used. The allowable pressure is

$$P_a = \frac{S\ E\ t}{R + 0.6\ t}$$

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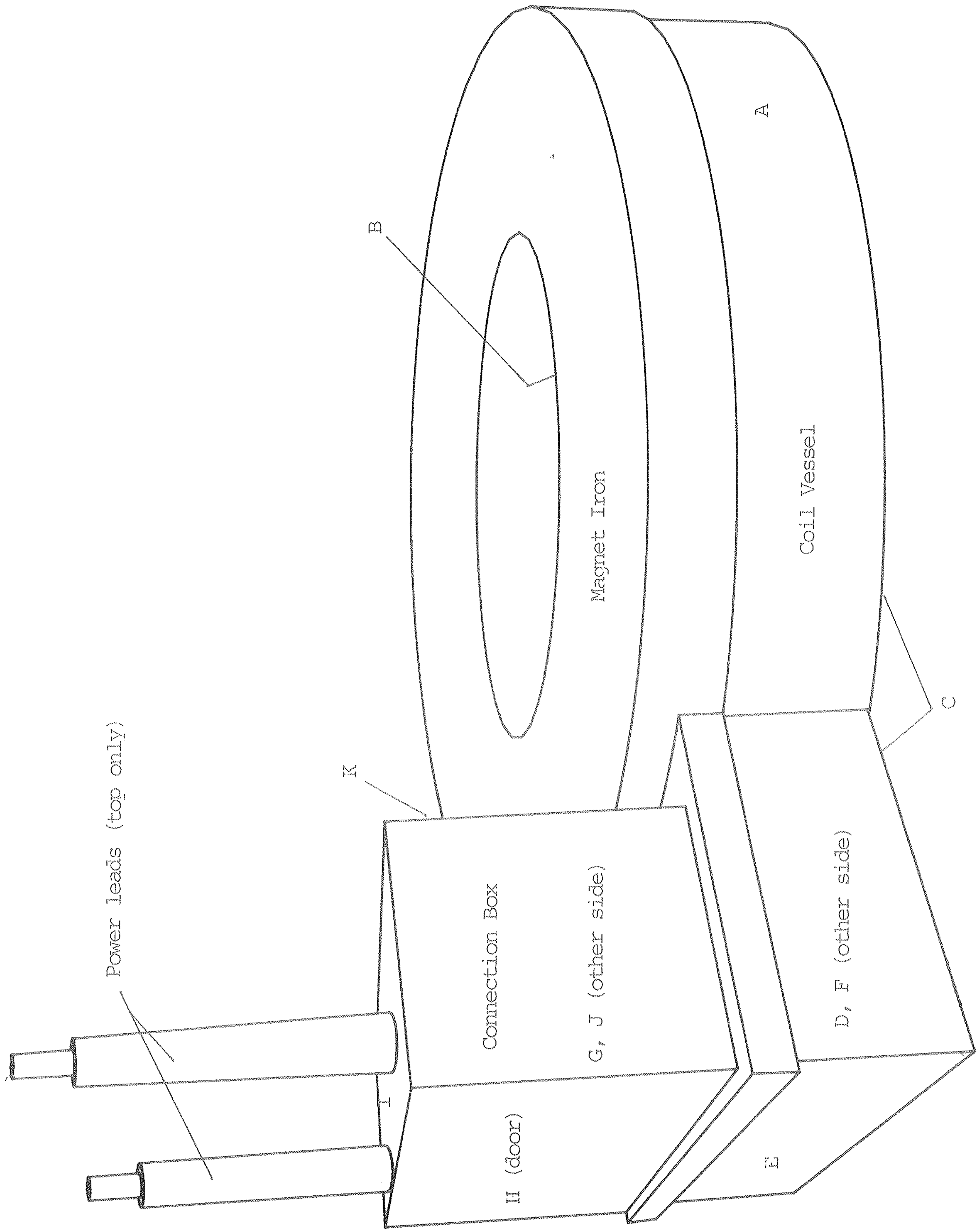

Fig. A1. CVM vacuum vessel

where S = allowable stress for SS304, with Fermilab 0.8 factor

= 15040 psi

E = weld efficiency for single-side, full penetration weld without radiography (all the vessel welds are full penetration).

= 0.6.

For R = inner radius = 1020 mm = 40.16"

t = 15 mm = 0.591"

$$P_a = \frac{(15040)(0.6)(0.591)}{40.16 + (0.6)(0.591)} = 131.6 \text{ psi},$$

which is in excess of the requirement.

Flat Keyhole Plate (Item C, Fig. A1)

Since this component is not covered specifically by the Code, the provisions of U-2(g), which require that the design be "as safe as those provided by the rules of this Division", will be followed. This was done by calculating the stresses in the keyhole plate using ANSYS.

The CVM vacuum heads were modeled as shown in Figs. A2 and A3. The boundary conditions at the edges of the plates were assumed to be those of a fixed edge; i.e., no edge displacements or rotations. This assumption will produce the largest radial bending stresses in the plate. A uniform pressure of 15 psi was applied.

The stress results are given in Table A1. Stresses are categorized according to the ASME Boiler and Pressure Vessel Code, Section VIII, Division 2, Appendix 4. A maximum allowable stress intensity of 15040 psi for primary membrane stress was used.

In an effort to judge the adequacy of the mesh refinement a calculation of radial bending stress using the formulas from Formulas for Stress and Strain by R. Roark and W. Young was made for comparison. From Case 2h, Table 24:

a = 70.87, b = 39.37, b/a = 0.55, t = 0.787, K_{mrb} = -0.0205, K_{mra} = -0.0158, M_{rm} = $(K_{mrb})\ q\ a^2$ = 1544 in·lbs/in, M_{ra} = $(K_{mra})\ q\ a^2$ = 1190 in·lbs/in. Then, $\sigma_b = 6\ M_{rb}/t^2$ = 15000 psi and $\sigma_a = 6\ M_{ra}/t^2$ = 11500 psi.

The region of the head at which the rectangular projection meets the outer circumference shows a stress concentration. Peak stresses at stress concentration are of no consequence in evaluating a ductile material under static loading. The stresses in this region are evaluated close to but not at the "notch" and as can be seen, are well within the limits imposed by the Div. 2 criteria.

In conclusion, it is clear that the vacuum heads meet the criteria of Div. 2 for primary and secondary stress limits.

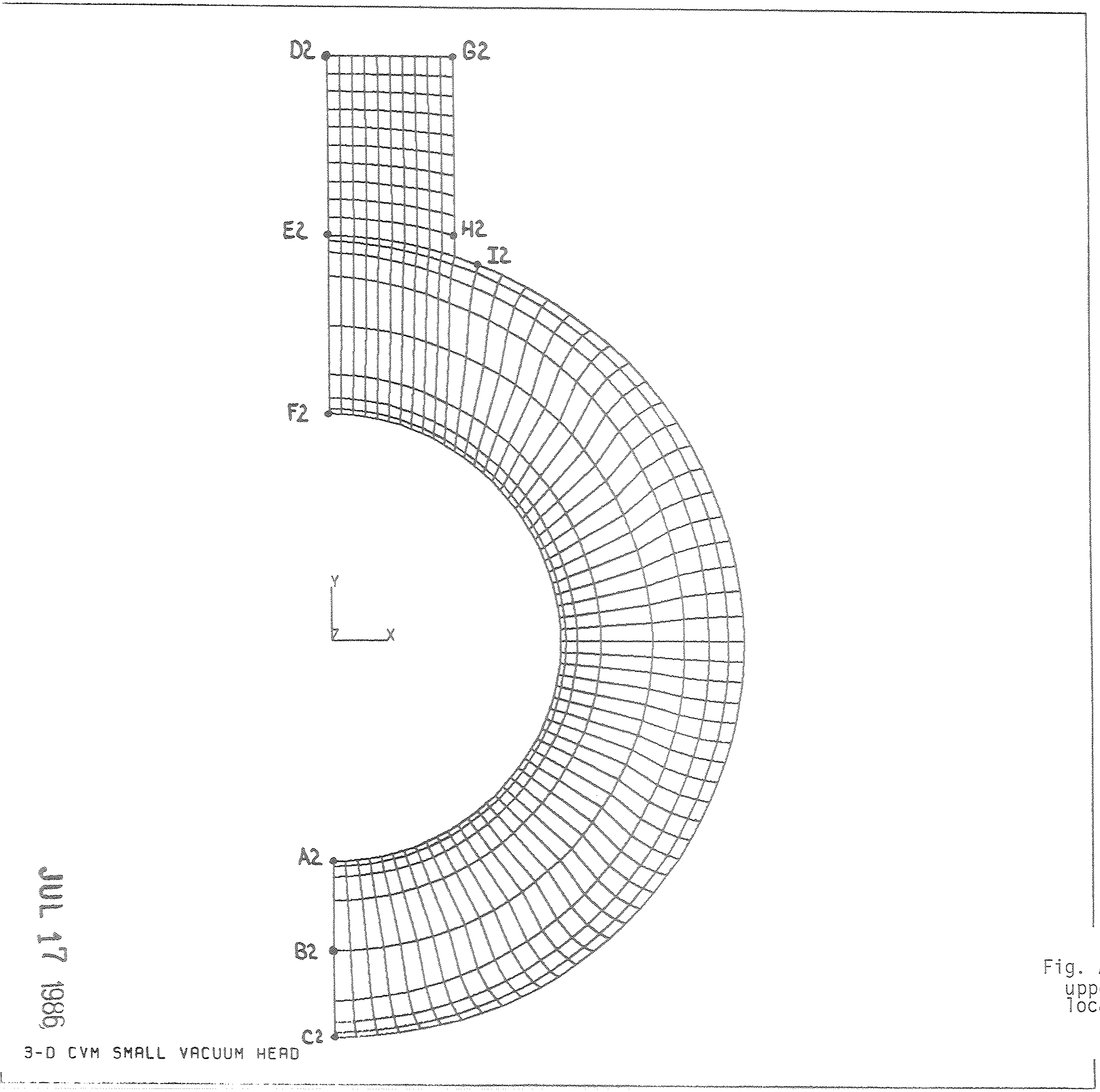

Fig. A2. Finite element model of upper keyhole plate, showing locations of stress output.

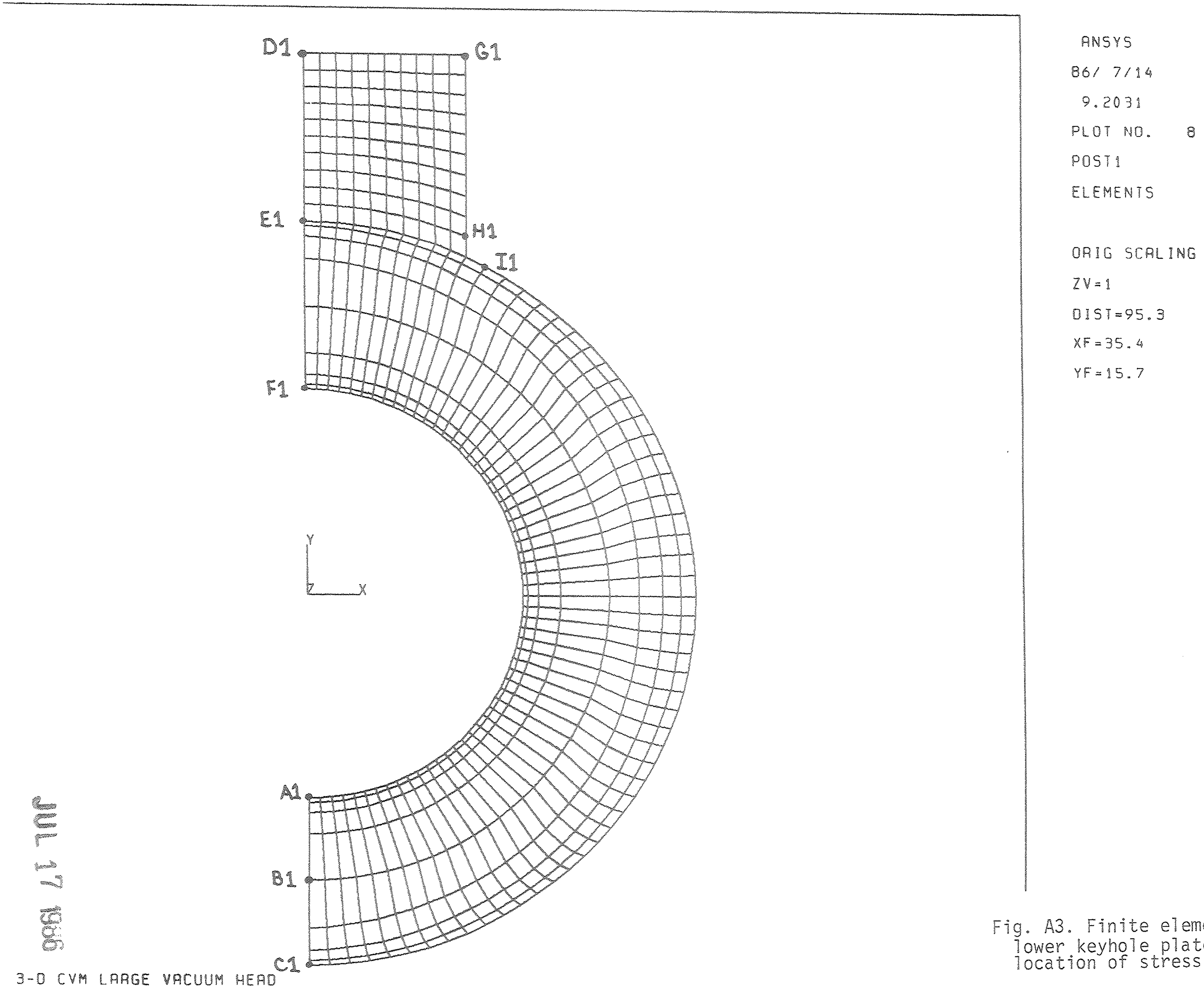

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Fig. A3. Finite element model of lower keyhole plate, showing location of stress output

Table A1. Stress in Keyhole Plates of CVM Vacuum Vessel at 15 psid External Pressure

Location (See Figs. A2 & A3)	Stress Category (1)	Maximum allowable Stress Intensity (2) (psi)	ANSYS Stress Intensity (psi)
A1	$P_L + Q$	45120	13800
A2	$P_L + Q$	45120	13800
B1	$P_m + P_b$	22560	4300
B2	$P_m + P_b$	22560	4300
C1	$P_L + Q$	45120	11400
C2	$P_L + Q$	45120	11400
D1	$P_L + Q$	45120	16700
D2	$P_L + Q$	45120	8300
E1	$P_m + P_b$	22560	13200
E2	$P_m + P_b$	22560	10400
F1	$P_L + Q$	45120	34300
F2	$P_L + Q$	45120	22800
G1	$P_L + Q$	45120	1600
G2	$P_L + Q$	45120	1300
H1	$P_L + Q$	45120	27500
H2	$P_L + Q$	45120	21900
I1	$P_l + Q$	45120	10900
I2	$P_L + Q$	45120	10600

(1) Stress intensities are defined in the ASME Code, Section VIII, Division 2, Appendix 4-120(b): P_L = local primary membrane, P_m = general primary membrane, Q = secondary bending.

(2) Allowable stress is 80% of that permitted by Division 1, Table UHA-23 (18800 psi) for primary membrane stress.

Flat Rectangular Plates

The flat rectangular plates of the coil vessels were analyzed using TM-1052A, "Design Charts for Vacuum Plates," by J.E. O'Meara. The results are given in Table A2; the stresses are all less than the allowable.

Table A2. Plate Analysis - Coil Vessels

Part (Fig. A1)	Material	Dimensions mm (in)	Thick mm (in)	Stress-supported (psi)	Stress-fixed (psi)
D,F-upper	SS	515 x 850	20(0.78)	8000	5000
		(20.3 x 33.5)	20(0.78)	[5500]	
E-upper	SS	515 x 1600		8000	5000
		(20.3 x 63.0)		[7500]	
D,F-lower	SS	515 x 850	20(0.78)	8000	5000
		(20.3 x 33.5)	20(0.78)	[5000]	
E-lower	SS	515 x 1200		8000	5000
		(20.3 x 47.2		[7200]	

Note: Stresses in [] include a correction factor depending on the ratio of width to length.

ANALYSIS OF UPPER CONNECTION BOX

The upper connection box was analyzed using TM-1052-A, "Design Charts for Vacuum Plates," by J.E. O'Meara. The plate dimensions were taken from CERN drawing 30-33-69B. The results are given in Table A3; the stresses are all less than the allowable.

ANALYSIS OF LOWER CONNECTION BOX

The lower connection box was similarly analyzed and the results given in Table A4; the stresses are all less than the allowable.

Table A3. Plate Analysis - Upper Connection Box

Part (Fig. A1)	Material	Dimensions mm (in)	Thick mm (in)	Stress-supported (psi)	Stress-fixed (psi)
I	SS	1600 x 750 (63 x 29.5)	28 (1.10)	10000 [8700]	7000
H	Alum	1480 x 725 (58.3 x 28.5)	30 (1.2)	7000 [5600]	<5000
G,J	SS	775 x 655 (30.5 x 25.8)	20 (0.78)	13000 [6500]	8000
K	SS	1500 x 775 (59 x 30.5)	20 (0.78)	17000 [14000]	11000

NOTE: The stress values in brackets are the result of applying a correction factor dependent on the slenderness ratio.

Table A3. Plate Analysis - Lower Connection Box

Part (Fig. A1)	Material	Dimensions mm (in)	Thick mm (in)	Stress-supported (psi)	Stress-fixed (psi)
I	SS	1200 x 750 (47.2 x 29.5)	28 (1.1)	10000 [7000]	7000
H	Alum	1080 x 725 (42.5 x 28.5)	30 (1.2)	7000 [4600]	<5000
G,J	SS	775 x 655 (30.5 x 25.8)	20 (0.78)	13000 [6500]	8000
K	SS	1100 x 775 (43.3 x 30.5)	20 (0.78)	17000 [11000]	11000

Note: Stresses in brackets include corection factor.

SUMMARY

The CVM magnet vessels satisfy the provisions of the Code and therefore are in accordance with SD-41.

Appendix B: Safety Relief Devices

OBJECTIVE

To demonstrate that the vacuum vessel of the CERN Vertex Magnet is adequately relieved in the event of a failure in the magnet cooling circuit.

DESCRIPTION OF FAILURE MODE

The superconducting composite conductor used for the CVM coil is hollow; the coil is refrigerated by pumping liquid helium from the pump dewar through the conductor. The inventory of liquid in the two coils and associated piping is about 400 L. The helium circuit has 14 parallel paths. Electrically insulating "isolaters" are used to separate the electrical and cooling circuits. A rupture in the helium circuit will result in a flow of liquid helium from the pump dewar to the magnet vacuum space at a rate equal to the combined maximum capacity of the LHe pumps (200 g/s). Relief device on the vacuum vessel must be adequate for this flow rate. Figure B1 is the relief schematic.

CAPACITY OF RELIEF DEVICES

The original CERN parallel-plate relief devices, which used a spring to determine the set pressure, were modified by removing the springs. This allowed me to make a simple calculation to determine the pressure in the vessel when venting at the rate of 200 g/s.

The open relief was considered as a square-edge orifice, which is treated in the Crane booklet (1). The pressure in the vessel when venting through a square-edge orifice to atmosphere is derived from Crane Equation 2-24,

$$q = YCA \left[\frac{2\ g\ (144)\ P}{\rho} \right]^{0.5},$$

as

$$P = \frac{\rho\ q^2}{288\ g\ (YCA)^2} \qquad \text{(Eq. B1)}$$

where

$\rho =$ fluid density (lb/ft^3)

$q =$ flow rate at flowing conditions (ft^3/sec)

$g =$ acceleration of gravity $= 32.2$ ft/sec^2

$Y =$ expansion factor for orifice, determined by the ratio of diameters

$C =$ flow coefficient in the Reynolds number range where C is a constant for the given diameter ratio

$A =$ area of the orifice (ft^2)

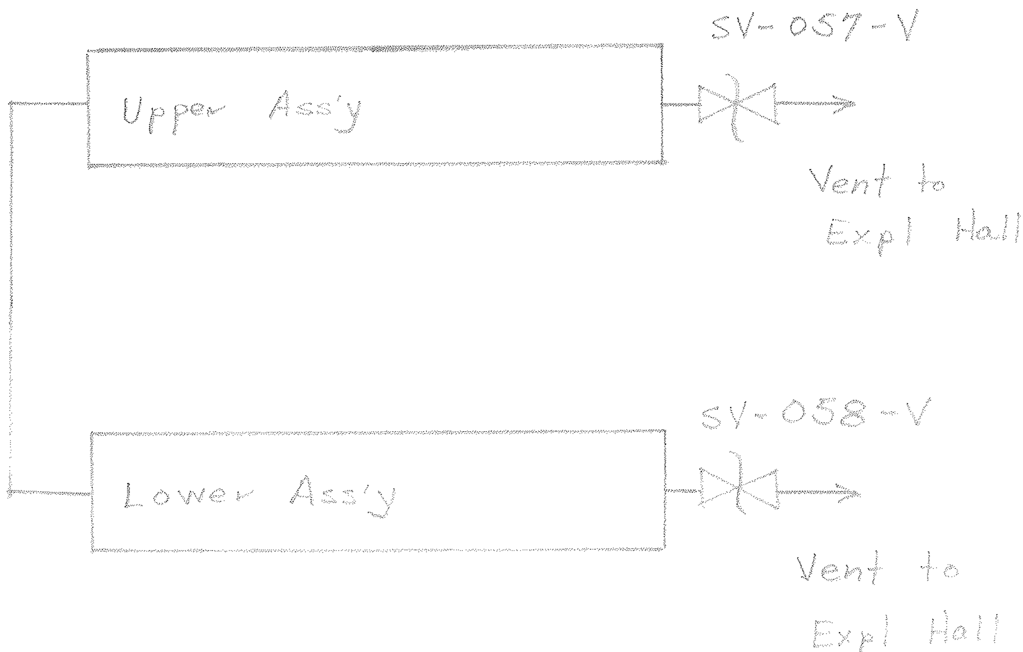

Fig B1. Relief schematic

For the CERN device

d_1 = orifice diameter = 4"

d_2 = inlet pipe diameter = 12.5"

A = 0.087 ft^2

The helium gas was assumed to exit the orifice at 1 ata and 10 K and so

$\rho = 0.005021 \text{ g/cm}^3 = 0.313 \text{ lb/ft}^3$

and

$$q = (200 \text{ g/s})(199.1 \text{ cm}^3/\text{g})$$
$$= 39820 \text{ cm}^2/\text{s} = 1.406 \text{ ft}^3/\text{sec.}$$

The factor Y and C are taken from curves on page A-20 of the Crane manual. The smallest typical value of each was taken in order to calculate the worst-case pressure: C = 0.6 and Y = 0.8.

The pressure in the vessel is then calculated:

$$P = \frac{(0.313)(1.406)^2}{(288)(32.2)[(0.8)(0.6)(0.0873)]^2}$$

$$= 0.038 \text{ psig} = 1.05 \text{ inches of water.}$$

It is clear therefore that the modified CERN relief devices on the CVM vacuum vessel are adequate for the postulated worst-case failure mode.

REFERENCE

(1) "Flow of Fluids through Valves, Fittings, and Pipe," Technical Paper No. 410, Crane Co., N.Y. (1981).

Appendix C: Operating History of CVM

Three spectrometer magnets using the same conductor and style of cooling were built in the 1977-1979 period by various vendors for CERN. All have been used on experiments at CERN and in several cases have been moved from one experimental area to another. It is not possible to trace the specific history of the magnet now at Fermilab, but it is correct that it operated at CERN for several years (3 or 4) prior to its disassembly in January, 1984 and shipment to Fermilab.

As far as we know, there has never been a failure - rupture of conductor or piping - of the helium circuit inside the magnet vacuum vessel.

A deformed lifting lug on the upper vessel, the only visible damage sustained in the move from CERN to Fermilab, was found, by a radiographic inspection, not to be of concern.

The conclusion to be drawn is that the magnet vacuum vessel is at least as reliable as it was at CERN, and perhaps more so because of improvements made at Fermilab to improve the pumping and venting characteristics.