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MECHANICAL DESIGN OF THE
350 GEV/C DICHROMATIC TRAIN

Herman Stredde

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Introduction

This report is intended to present some insight into the mechanical design of the 350 GeV/c Dichromatic Train. The physics, beam absorbers and radiation damage to magnet coils have previously been reported.[1,2,3] A schematic diagram of this train is shown in Figure 1. The design is somewhat typical to that of previous neutrino trains. However, there are two important exceptions. Beam dumping is done within some magnets, and we also have long "strings" of series magnets which require parallel cooling. These exceptions are described in detail.

Fully realizing that beam dumping within magnets will raise the radiation level of this train above that of previous units, remote handling and repair became prime design considerations. The magnet adjustment systems, power buss connections and utility trees were designed accordingly.

Most all of the necessary engineering calculations are of a routine nature and therefore, are not deemed essential to this report.

General Characteristics

This train consists of a target, 16 magnets: 5 dipoles, and 7 quads, all of the main ring type, 2 EPB dipoles, and 2 verniers. There are 8 SWIC's, one fixed beam dump, a momentum slit and a helium system.

The target is a water cooled aluminum block containing Beryllium oxide pellets. These pellets 1" O.D. x 1.5" Lg. Seven pellets are used for a 10.5" total length. The target has 6" of steel shielding around both sides, top, bottom, and the upstream end to reduce back scattering of thermal neturon radiation into Neuhall. An additional low sodium concrete shield 2 feet long is mounted on Bed plate 1 to further reduce the radiation[4].

Immediately upstream of the target are 4 EPB dipoles which direct the proton beam to the target. These magnets all have 1½ x 3 vacuum chambers and are connected to an independent vacuum system. Water for cooling these magnets is taken from the hall system.

A beam absorber is mounted between QV5 and QH1. This absorber is west of the beam line and its function is to allow positive high energy tunes and to protect the coils in QH-1. The absorber is mounted on a standard Neutrino target drive and is water cooled. It can be moved to the east, thus acting like collimator, if the need arises.

The momentum slit is mounted on Bed plate 8, upstream of D-4. This momentum slit is simply a modified variable jaw collimator which is used extensively in the experimental areas. This unit was altered to increase the maximum opening to 5", normally it is 4".

Downstream of D-5 on Bed plate 10 are two 4-5-30 vertical vernier steering magnets used for final directional correction of the Dichromatic beam.

From QH-1 thru D-5, the secondary beam is transported in a helium atmosphere. The helium supply is in the N-1 service building and the return is vented to the atmosphere through the air vent in Neuhall. The flow rate is set at 0.5 liters/hr. Each piece of equipment in this system is in parallel to the main helium supply line. Titanium windows of .002 thickness are used at each end of the magnets. The total number of windows is 10. The reason for this paralleling is due to the abundance of diagnostic equipment and unequal loading of the bed plates. This unequal loading would greatly exceed reasonable bellows deflections.

Six of the SWIC's are typical to the experimental areas, 2 mm wire spacing. Two special SWIC's were constructed to be used between magnets with very small beam apertures and close end to end distances[5]. These SWIC's are 1 mm spacing and are positioned with light duty vertical drive mechanisms. The remaining SWIC's are mounted on standard Neutrino instrumentation drives. These drives move the SWIC by rotation through 90^{0} in the horizontal plane. All drives are 2 position, in or out only, and their total travel is controlled by limit switches.

All cabling for instrumentation, thermocouples and other power requirements is carried in cable trays mounted on the west side of the train.

Bed Plates

The train is 10½ bed plates in total length. The bed plates are of standard Neutrino design, a steel inverted U section. Each bed plate is 19 feet long, spaced on 20 foot centers and has a checker-board hole pattern on 10 inch centers. A total of 88, ½-13 threaded holes are pre-machined in the bed plates. This predetermined hole pattern reduces final assembly time, since all equipment is designed to fit this pattern. Furthermore, any additions or modifications to the train can be designed to this hole pattern and thus requires no machining of the bed plates prior to assembly.

Between bed plates 7 and 8, a 10 foot spacer (½ bed plate) is required to provide the necessary distance between D-3 & D-4 in accordance with the beam optics. This spacer is simply an extension of a transporter coupler.

An analysis of the bed plates deflection was made and this method has been reported[6].

Magnets

All magnets located downstream of the target are of Main Ring type. There are 3, B-1 dipoles 10-feet long (D-1, D-2, D-5), 2 B-1 dipoles 20-feet long (D3 & D4), 5 3Q84 Quads (QV1, QV2, QV3, QV5, QH1, QH2) and 1 3Q52 (QV4). All quadrupole magnets, except QH-1 and QH-2 were constructed without vacuum chambers.

Two modifications were made to these magnets. First the power leads were terminated at the center of the magnet and on the east side. (The power buss for the train was designed to be on the east side.) This change solved two space problems. It eliminated the congestion at the end of the magnet due to the very close end to end locations of the magnets. Further, it provided adequate space at the center for the buss and water connections.

The second modification was to add brackets which enable easy installation and removal of the magnets. The weight, center of gravity centerline, and nomenclature of magnet was stenciled on top.

Equipment Stands

The basic philosophy for the stand design was to be structurally strong, to provide a reasonable amount of adjustment for equipment location, and finally to be able to make these adjustments remotely. i.e. with the manipulators in the Target Service Building.

The majority of magnets on this train have the bottom surface parallel to the bed plate. The basic stand is of I Beam construction with feet welded at the bottom and matching the bed plate hole pattern. Two bolts in slotted holes on the feet are used to fasten the stand to the bed plates. For installation and/or removal the bolts need only be loosened, not removed. Two plates are mounted on top of the I Beam. The upper most plate acts as a cradle for the magnet. This plate has 2, 1" diameter screws threaded through it and anchored to the lower plate. These screws provide elevation and rotational adjustments. The bottom plate is a slider plate able to move normal to beam axis. It is moved by a screw jack mounted on the I-beam. The jack is positioned so that the drive shaft is in the vertical position. Thus, for any required adjustment, the screws and jack are easily visible and accessible from the top of the train. All adjusting units are fitted with the same size hex nut, thus enabling adjustments to be made to all units with one tool.

The stands for D1, D2 & D3 are somewhat different in design. The magnets are rotated at fixed angles with respect to the bed plate. Because of space limitations (41" wide bed plate). These stands have only one vertical adjustment control. This vertical adjustment is accomplished by means of a parallel linkage system driven by a screw jack and a sliding saddle plate also driven by a screw jack controls horizontal motion.

The angle that the stand produces for the magnet position is preset. There is no adjustable provision for rotational misalignment. Shims between the slider plate and the magnet resolve this problem.

The D2 magnet provides another unique problem in that for different train tunes it must be moved remotely to a new position. This total movement is 1.5 cm parallel to the fixed angle of rotation. The basic stand is similar to D1 & D3 except that for D2, the lateral movement is controlled by a stepping motor and gear train. Both stands are connected through gear trains for synchronous movement. These gear trains are easily disconnnected from the total system to permit independent adjustment of each end. They are then connected to the system for simultaneous motion. A microswitch and rotoswitch (position indicator) assembly provides positional control of this magnet.

All stands have a device to restrain the equipment from axial movement. Most are screw actuated and a few are spring loaded self-locking pivots.

Power Buss

There are four electrical circuits for the magnets on this train. Circuit one has D1, through D4 in series. Circuit two has QV1 through QV5 in series. Circuit three has QH1 & QH2 in series and circuit four is D5. For 350 GeV/c operation, circuit one runs at 5 KA, circuit two at 4.5 KA, circuit three at 4.5 KA and circuit four at 2.4 KA. Principally, due to space limitations, copper tube 1 5/8 O.D. x 3/16 wall was used in place of the usual 2" O.D. x ¼ wall aluminum! The use of copper also reduced the amount of dissimilar metals in the cooling system. All joints and buss flag connections were silver brazed and water tested at 250 psi. Connections from the power buss to the magnets were made with Burndy flexible braided straps. In some instances, extra long straps (24") were used to provide the necessary flexibility as the train traveled through the various curves to the target area track system. The buss changes in axial length ~ 4" as the train negotiates a 9^{o} curve. The straps are bolted both to the magnet flag and the power flag. Four straps are used at each junction - two on top and two on the bottom. Also four bolts are used per flag. The bottom set of straps have threaded nut plates fixed to them. Further, the bottom strap set is bolted to the power buss flag. The top straps are individually mounted. For magnet replacement, the 8 bolts and the top straps are removed at both junctions. This frees the magnet from the power buss. Since nut plates are used on the straps and also because the bottom set is fixed to the power buss flag, the only "loose" parts to contend with are the top straps and 8 bolts. The manner in which the nut plate is used allows a one tool operation for the power buss connection.

In addition to the cooled buss for the magnets, one insulated water supply and return line is on the train. This arrangement enables the magnets to be parallel cooled. Those magnets which run in series electrically must be cooled individually. For example, water is supplied to the power buss of D-1. This water circulates through the coils of D-1 and through the power buss jumper to, but not through D-2. At this point, the water is directed to the insulated return line and back to the reservoir. The water to cool the D-2 coils comes from the insulated supply line. Main ring type ceramic insulators provide electrical discontinuity. This description is typical for any intermediate magnet in a series line.

The power buss is supported in utility stands which are located approximately 10 feet apart (2 per bed plate). These stands are on the east side of the train. They are constructed of an aluminum outer frame work and G-10, G-30 are used as electrical insulators. The stand is of an egg crate design with the insulators easily removable. The reason for both G-10 and G-30 is the radiation resistance vs. cost syndrome. G-30, being better for radiation and about 5 times the cost of G-10, is used only where the highest radiation levels are expected.

Ceramic and machineable glass materials were investigated as possible insulators, but were ruled out either because of cost or size.

Beam Absorbers

The first seven magnets (D-1, QV1, QV2, D-2, QV3, QV4 & QV5) have beam absorbers.[2,7] These absorbers are made of aluminum, water cooled and completely fill the normal beam aperture of the magnets. There is a precisely machined beam hole in each unit. The absorbers are used as dumps (QV2, D-2 & QV4) and as collimators (D-1 & QV1 for secondary beams). Figures 2, 3 and 4 depict the absorbers in cross-section and are shown as viewed from upstream. A complete treatise on the absorber design and thermal analysis has been reported[2].

Due to the beam lossed in the absorbers, the magnet steel will heat up. Aluminum cooling panels were added to the outside of these magnets to control the core temperature. These panels are fastened to the magnet with steel bonding straps.

Thermocouples are mounted on the absorbers and also in counterbored holes in the cores to monitor the change in temperature.

System Cooling

This train is supplied with cooling water from the N1 closed loop water system. This system supplies 200 gpm of water at 200 psi nominally.

Flow rates were based on published data[9], for standard magnets and prorated for modified units with corresponding pressure drops. The water lines on the train were balanced by using different diameter lines and also by placing orifices in the magnet supply line to restrict the flow to the desired amount[8]. See Figure 5 for flow rates of each piece of equipment requiring cooling water.

Common throughout all cooling lines are stainless steel, corrugated, braided flexible hoses along with compression type fittings for all joints. These hoses provide not only flexibility, but also eliminate corrosive action where aluminum and copper lines are to be joined.

REFERENCES

1. D.Edwards, S.Mori, and S.Pruss, 350 GeV/c Dichromatic Neutrino Target Train, TM-661, May 1976. The diagram shown in Figure 1 is the final design and is slightly modified from the design shown in Figure 5 of the reference.

2. S.Mori and H. Stredde, Magnet Beam Absorbers of the 350 GeV/c Dichromatic Train, TM-761, January 1978.

3. S.Mori, Radiation Damages on Magnet Coils of the 350 GeV/c Dichromatic Train, TM-764, February 1978.

4. F.Gardner, Private Communication.

5. The special SWIC's were unusable, possibly due to large fringe magnetic fields.

6. H.Stredde, Neutrino Bed Plate Deflections, TM-738, May 1977.

7. D.Edwards, Private Communication.

8. J.Grimson, Private Communication.

9. T.Toohig, Fermilab Magnets, Power Supplies and Auxiliary Devices: Technical Data, TM-632, December 1975.

Figure Captions

1. Schematic diagram of the 350 GeV/c Dichromatic Train (N-30)
2. D-1 (top), QV-1 (center) and QV-2 (bottom), beam absorbers shown as viewed from target.
3. D-2 (top), QV-3 (center) and QV-4 (bottom), beam absorbers shown as viewed from target.
4. QV-5 beam absorber shown as viewed from target.
5. Tabulated chart for total water requirements of the 350 GeV/c Dichromatic Train.

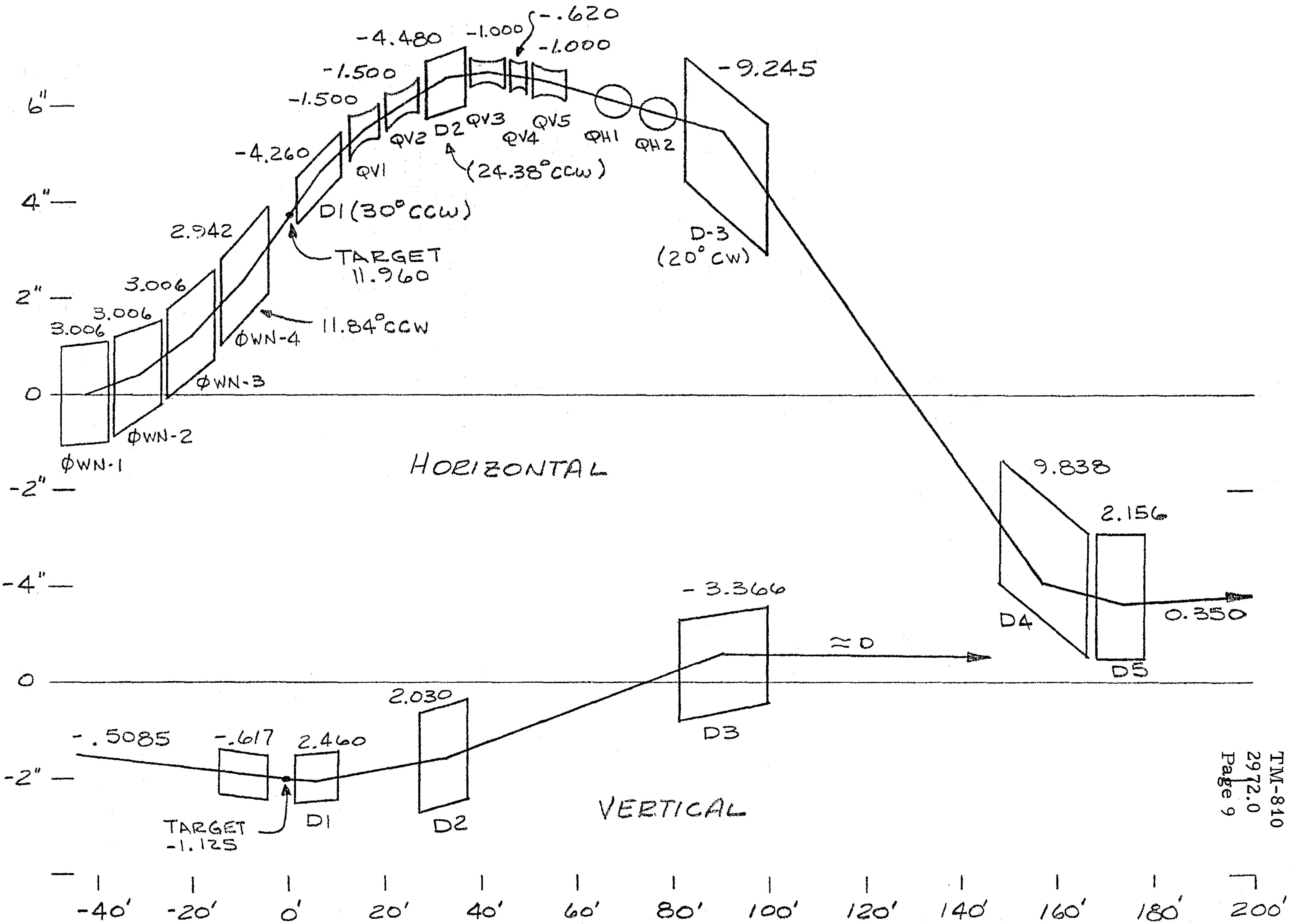
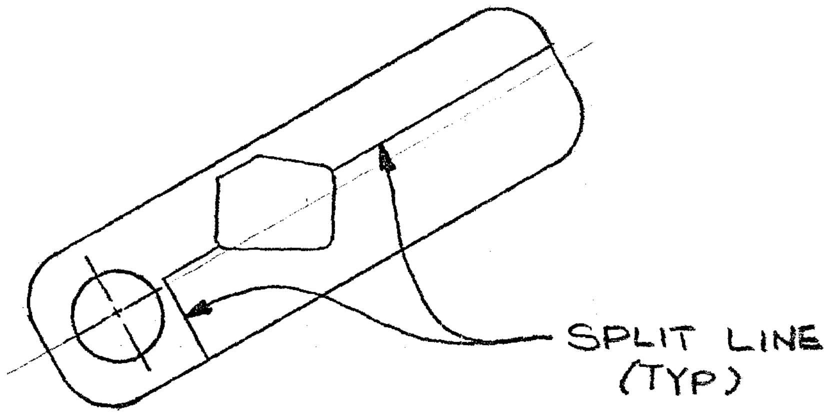
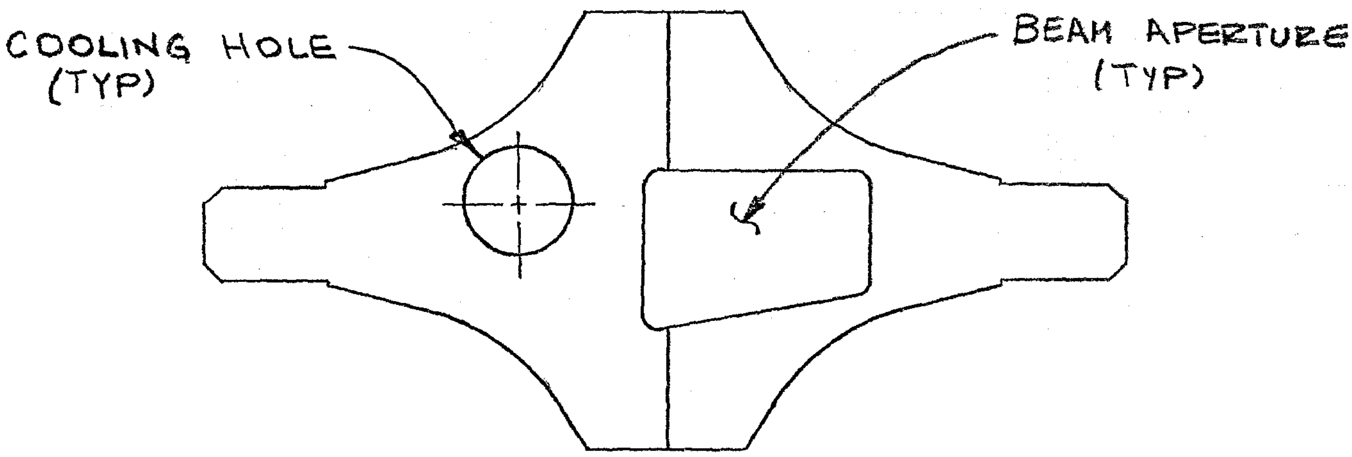

HORIZONTAL
6"
4"
2"
0
-2"
-4"
-4"
0
-2"
ΦWN-1
ΦWN-2
ΦWN-3
ΦWN-4
3.006
3.006
3.006
2.942
11.84°CCW
TARGET
11.960
D1 (30°CCW)
-4.260
-1.500
-1.500
-4.480
-1.000
-.620
-1.000
QV1
QV2
D2
QV3
QV4
QV5
QH1
QH2
(24.38°CCW)
-9.245
D-3
(20° CW)
9.838
2.156
D4
D5
0.350
VERTICAL
-.5085
-.617
2.460
TARGET
-1.125
D1
2.030
D2
-3.366
D3
≈0
-40'
-20'
0'
20'
40'
60'
80'
100'
120'
140'
160'
180'
200'

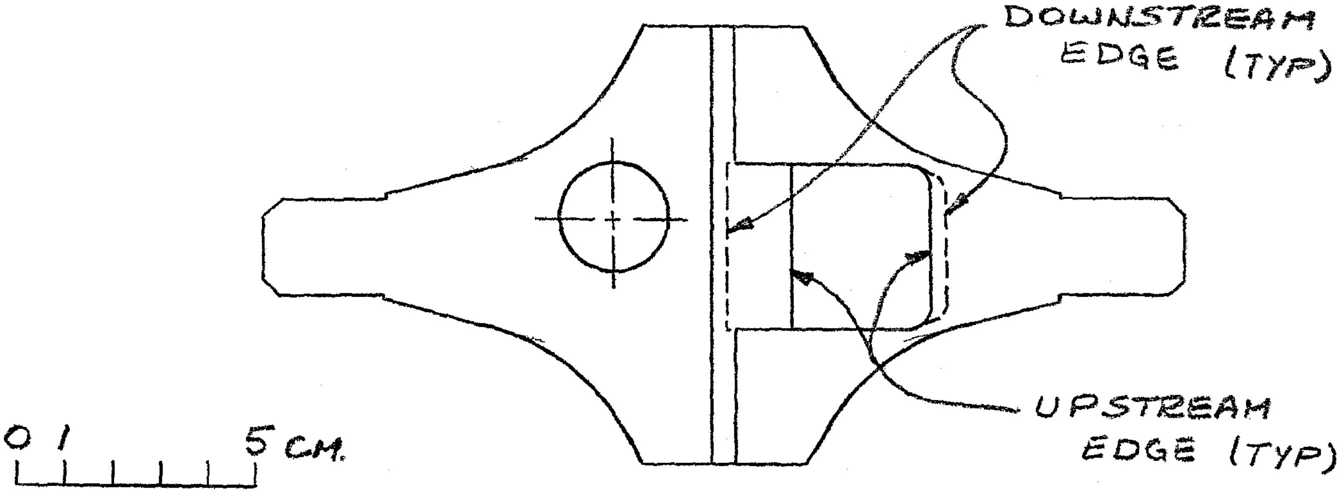
FIGURE 1.



D-1



QV-1



QV-2

VIEWS TAKEN
LOOKING DOWNSTREAM

FIGURE 2

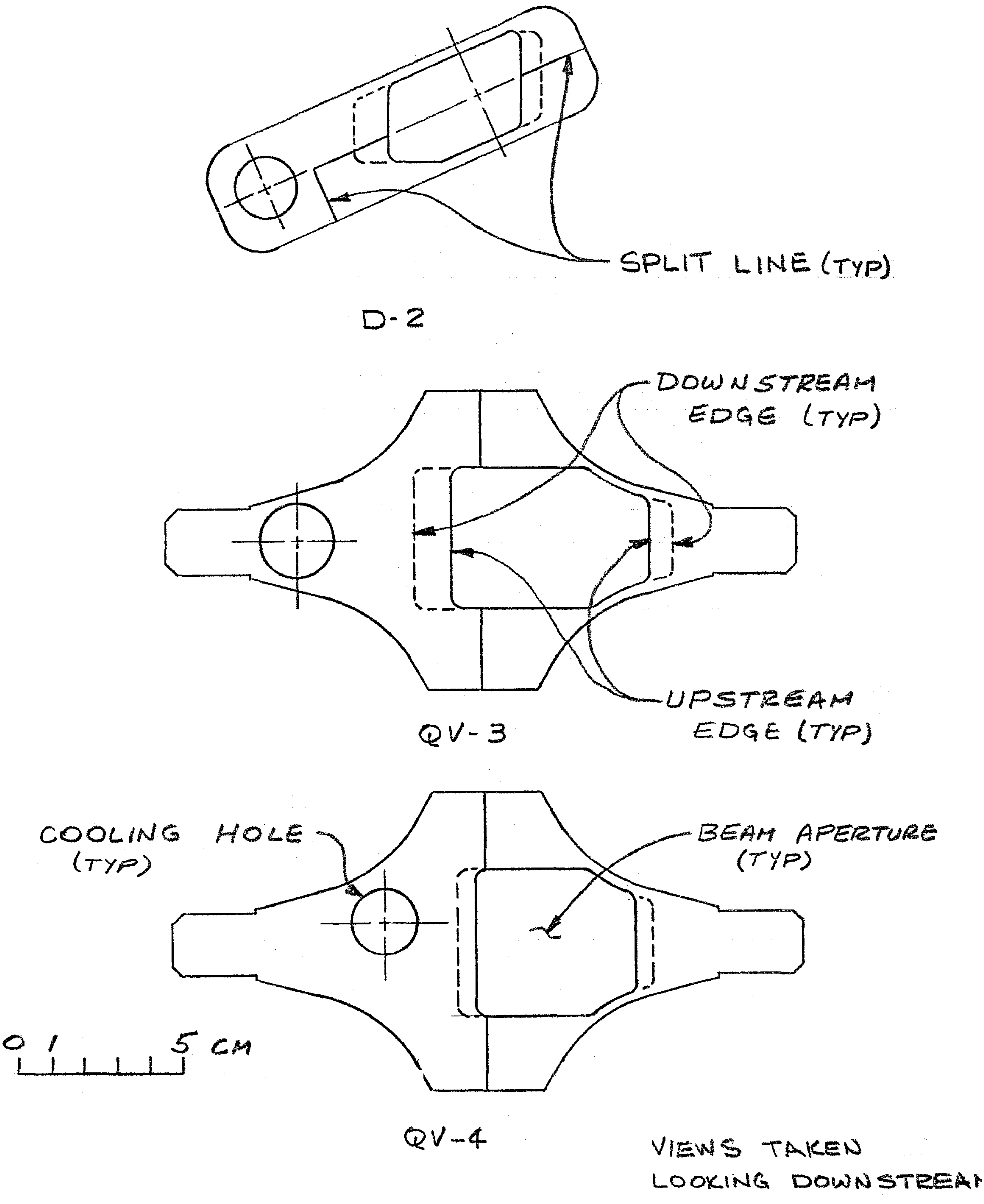

SPLIT LINE (TYP)
D-2
DOWNSTREAM EDGE (TYP)
UPSTREAM EDGE (TYP)
QV-3
COOLING HOLE (TYP)
BEAM APERTURE (TYP)
0 1 5 CM
QV-4
VIEWS TAKEN LOOKING DOWNSTREAM

FIGURE 3

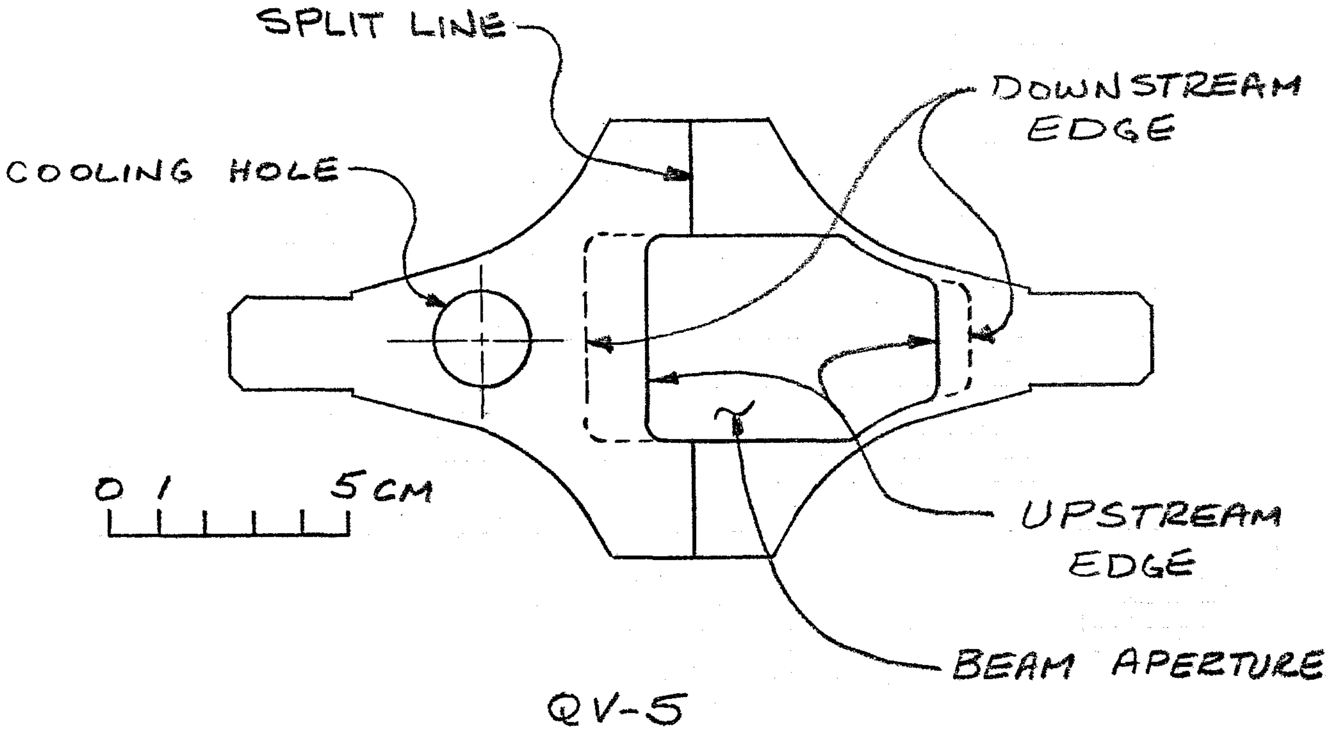

SPLIT LINE
COOLING HOLE
DOWNSTREAM EDGE
UPSTREAM EDGE
BEAM APERTURE
0 1 5CM
QV-5

FIGURE 4

DICHROMATIC COOLING REQUIREMENTS

Flow in g.p.m.

Component	Coil	Absorber	Panels	General	Supply Line Designation
Target	-	-	-	2	Target
D-1	8	8	6	-	D-1
QV-1	6	3	2	-	QV-1
QV-2	6	3	6	-	Insulated Supply
D-2	8	20	2	-	Insulated Supply
QV-3	6	3	2	-	Insulated Supply
QV-4	6	3	6	-	"
QV-5	6	3	2	-	"
Fixed Absorber	-	-	-	8	Absorber
QH-1	6	-	-	-	QH-1
QH-2	6	-	-	-	Insulated Supply
D-3	10	-	-	-	"
D-4	10	-	-	-	"
D-5	8	-	-	-	D-5
Vernier	4	-	-	-	Insulated Supply
Vernier	4	-	-	-	"
Total	94	43	26	10	

Train Total = 173 gpm

Figure 5