A Note on the Design of CLAS Electron Scattering Targets

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This note summarizes the current status of the design for the CLAS electron scattering targets. Since the design of the electron scattering targets depends heavily on the physics requirements, the space limitation and its impact on the minitoroids, detectors and other beam line instruments, full input from the collaboration is crucial to have a "best design" of the targets. This note outlines the options for the target cells and the support structure in order to solicit input from the collaboration. Comments, suggestions and especially the clear physics requirements from the collaboration will be appreciated.

1. Requirements and Design Goals

For the electron scattering experiments using CLAS, we need at least one solid target and two gas targets. For most of the experiments, the beam current will be in the range of 10 to 100 nA with luminosity of up to 10^{34} $\mathrm{cm}^{-2}\mathrm{s}^{-1}$. The CLAS scattering angular acceptance ranges from 7° to 135°. We would like to minimize the target interference with the spectrometer acceptance. Angular resolution of $\sim$ 1 mr (for a 500 MeV/c scattered proton) is needed. Minimum background from the scattering of the electrons off the target windows is also required to reduce the burden on the CLAS data aquisition. Therefore the gas target cell must have a thin wall and very thin windows. Remote interchange of the targets is desirable. Also the whole target assembly should fit within the space limitation imposed by the minitoroid shield.

2. Gas Target Cell

Because of the space limitation and the simplicity consideration, we ruled out the option of a cryogenic target. Gas targets (e.g. ^{1}H and ^{2}H, or ^{3}He and ^{4}He) at room temperature and high pressure (10 to 20 atmospheres) will provide the desired luminosity. Currently, we have three designs of the gas cell. Each has its advantages, and may be suitable for certain experiments.

a) Option 1: 10 cm long Havar cylinder with two endcaps.

The first gas cell design is a 10 cm long, 1 cm diameter, cylinder with two end caps (see Figure 1). The end caps are made of 2 mm thick stainless steel with 2 mm diameter windows soldered on. The windows are made of 2 μm thick Havar. Havar is a composite metal containing Cobalt, Chromium, iron, Nickel and trace amounts of some other elements, and has a very high tensile strength (see Table 1). The wall will be made of 15 μm Havar. There are two gas ports at both ends for filling and purging gas. The two 2 mm outer diameter stainless steel tubes soldered onto the gas ports will also be connected with a steel spine as the support for the target cell. The gas tubes and the supporting spine will stay in shadow of the minitoroid, and therefore will have little or no interference with the CLAS acceptance.

The window-to-target material ratio is about 1:10 for 20 atmosphere ^{4}He gas, and about 1:5 for 20 atmosphere ^{1}H. The 15 μm Havar wall and the 2 μm Havar (2 mm diameter) window can hold pressure up to about 70 atmosphere. We have a safety factor of 3.5. However, the limit may be the joints of the Havar windows and the cylinder wall to the endcaps. We plan to try both glueing and soldering. Theoretically, the joints can be as strong as the windows (or the wall), but only after testing with prototype cells, can we be completely certain about how high pressure the cell can hold. The multiple scattering for a 500 MeV/c proton passing through the wall is about 1.3 mr, and is within the acceptable tolerance. Table 2 lists multiple scattering for several different materials. We have compared Havar material with several other materials: Aluminum, Steel (Iron), Mylar, Kapton and Diamond (see Table 3). Havar has the highest special tensile strength (tensile strength divided by density). The only other material which has a higher special tensile strength is diamond. However, diamond is much more expensive, and a very thin film of diamond is extremely hard to make (to make much thinner than 5 μm may not be possible).

Because of the end caps, part of the target will not be seen by the spectrometer for scattering at very small angles (near 7°) and very large angles (near 145°), This problem is not serious for the large angles because almost a 45° angular range was not accepted by CLAS. It is an important issue for the small angles where only a 7° angular range was not accepted by CLAS, and also since the cross sections are forward-angle peaked in most cases. Therefore, improvements based on eliminating the forward endcap interference with the spectrometer acceptance have been pursued. Two variations of the design are presented here for further consideration.

a) Option 2: 15 cm long Havar cylinder with two endcaps.

The first variation is to lengthen the cell to 15 cm long with the upstream 10 cm being the effective target length. This solves the problem of interference with the CLAS acceptance at forward angles (see Figure 2). However, in this case the target length has to be defined by software vertex reconstruction. The precision is limited by the resolution of the vertex reconstruction. At a scattering angle of 90°, the vertex reconstruction resolution is reasonable ($\sim$ 1 mm), while in the worst case, at angles close to 7°, the resolution is quite poor ($\sim$ 8 mm).

a) Option 3: 10 cm long tapered Nickel cell with one endcap.

The second variation is to have a test-tube shaped cell without a forward end-cap. Havar material can not be processed to be test-tube shaped. We therefore looked into different materials and also different ways of manufacture. An electro-formed Nickel cell can be made into the shape of our specification. Since Nickel does not have as good special tensile strength as Havar, much thought has been put into trying to reduce the amount of window material. The current design is a tapered shape (see Figure 3). The 10 cm long tube has 5 mm diameter at the backward end and gradually narrows down to 2 mm diameter at the forward end. It has a very thin (5 μm) forward window and the wall will be 20 μm thick. At the upstream side, the wall will be soldered onto a steel end cap with a Havar window (same as the Havar target cell design). The wall and the window will be able to hold pressure up to $\sim$ 70 atmospheres. The window-to-target material ratio is about 1:6 for 20 atmosphere ^{4}He, and 1:3 for 20 atmosphere ^{1}H.

The design looks quite reasonable, although manufacturing would not be easy. We have one manufacturing company (SERVOMETER) who claim that they may be able to meet our specifications. The other difficulty is the joining of the Nickel wall to the endcap. That joint could be the weakest place with respect to holding pressure, although theoretically the joint can be as strong as the wall.

The next step is to make prototypes of the above cells to test the designs.

3. Target Assembly

Decision on the design of the target assembly is difficult, because many options are available while none of them perfectly satisfy all the requirements. I will list the options currently under consideration.

a) Option 1: Three in a ladder.

This is our (MIT group) original design. Two gas targets, with one solid target in between, will be on a ladder. The ladder goes through two pulleys above and two below, and then is connected to a stepping motor to move the target in and out of the beam line. The original idea was to attach the pulleys to the minitoroid. However, as Bernhard Mecking pointed out, the minitoroid is not supposed to be a position-accurate device and it often needs to be moved in and out. Therefore, the minitoroid is not a good choice to serve as the pulley support. The other option we have considered is to attach the pulleys on a steel supporting structure, which in turn is attached to the beam pipes on both up- and down-stream sides. The problem with this arrangement is, because the supporting structure is under the shadow of the minitoroid, the minitoroid has to be rotated every time it is moved in and out in order that it will not interfere with the supporting structure. Rotating the minitoroid could cause interference with the Region One drift chambers. The way to get around this problem is to have a rotating supporting structure. Figure 4 shows the design of the rotating support structure.

The advantages of this option are as follows. With three targets available simultaneously, targets are interchangeable remotely. With only one wall for gas targets, multiple scattering of the scattered particles is minimized compared to other options.

One disadvantage is the extra two windows in the beam line. Aside from the gas cell windows, there are two windows connected with the up- and down-stream beam pipes. Because the beam pipes are under vacuum, the windows need only sustain one atmosphere of pressure. The extra windows add about 10% more window material in the beam line.

b) Option 2: Inside beam pipe.

This option, as was suggested first by Richard Sealock and Bernhard Mecking, will have one gas target and one solid target inside the beam pipe (see Figure 5). A supporting rod is connected to the beam pipe and a rotating wheel is connected to the supporting rod. A gas cell and a solid target are connected to the rotating wheel, and can be rotated in and out of beam line.

The problem with this option is that, within the limited space inside the beam pipe (inner diameter of about 6 cm), it is very hard to make a high precision supporting and rotating structure. In addition, the unused target will be in the way of the scattered particles.

The advantage of the option is that the material in the beam line is minimized. The disadvantage is the extra beam pipe wall which increases multiple scattering of the scattered particles. If we use 300 μm Beryllium, the additional multiple scattering for a 500 MeV/c proton is about 1.2 mr.

c) Option 3: Gas cell directly connected to beam pipe.

This option was suggested by Volker Burkert. It puts one gas cell directly connected to the beam pipe. The solid target will have to be a separate target. Target change is not easy. Target gas changes would be accomplished by purging many times.

The advantages are obvious: simple supporting structure, minimum material in the beam line and minimum material for multiple scattering.

d) Option 4: Three on rotating wheels.

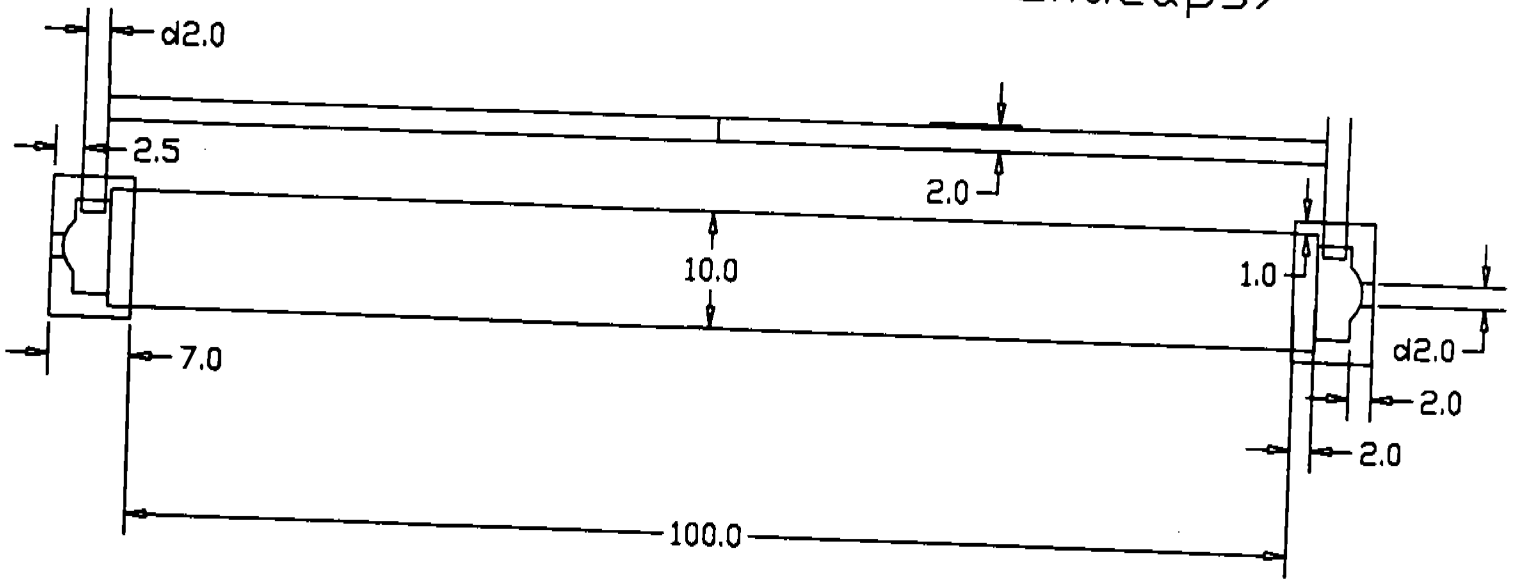
This option was first suggested by Larry Weinstein. This design uses a frame on the upstream beam pipe with three targets (two gas cells and one solid target) mounted on it (see Figure 6). Each of the targets can be moved horizontally along the beam direction and also can be rotated in and out of the beam line. The details of this design still need to be worked out, but the basic idea is sound.

Each option has its advantages and disadvantages. The decision to choose a specific option depends on the experimental requirements and technical feasibility. I would like to know how important it is to be able to remotely interchange targets, and also how critical the multiple scattering and the target-to-window material ratio are. Any suggestions on technical issues will also be very helpful.

4. Summary

The electron scattering targets for CLAS are under design. The gas target cell preliminary designs are presented. Options for support structure are discussed. Input from the collaboration will be helpful.

Fig. 1 Target Cell (2 Endcaps)



End-cap Cross-section

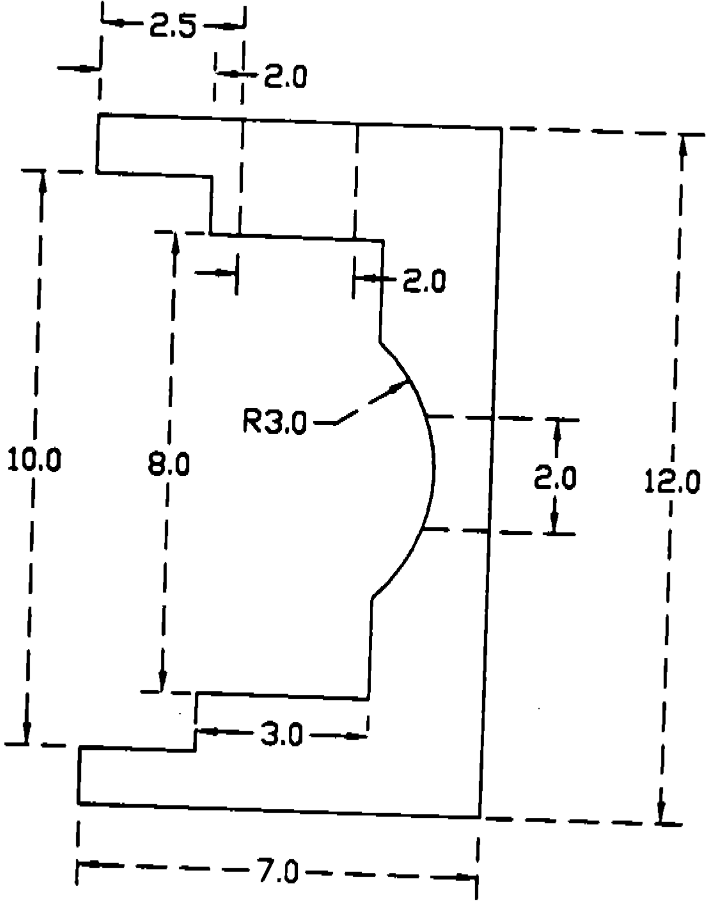


Fig. 2

End-caps and CLAS acceptance

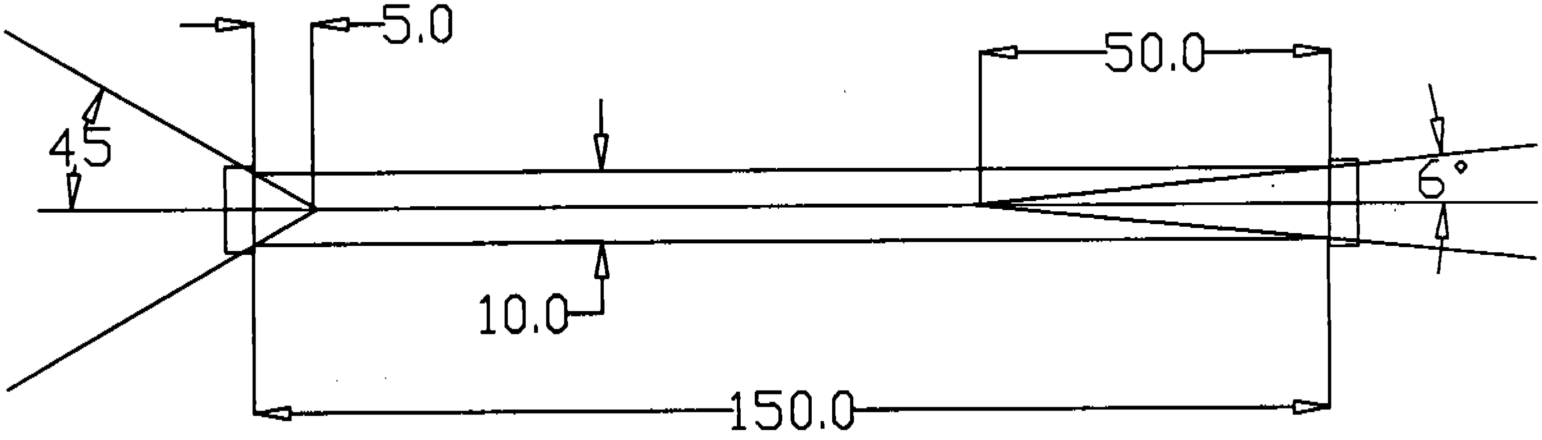


Fig. 3 Electo-formed Nickel Cell

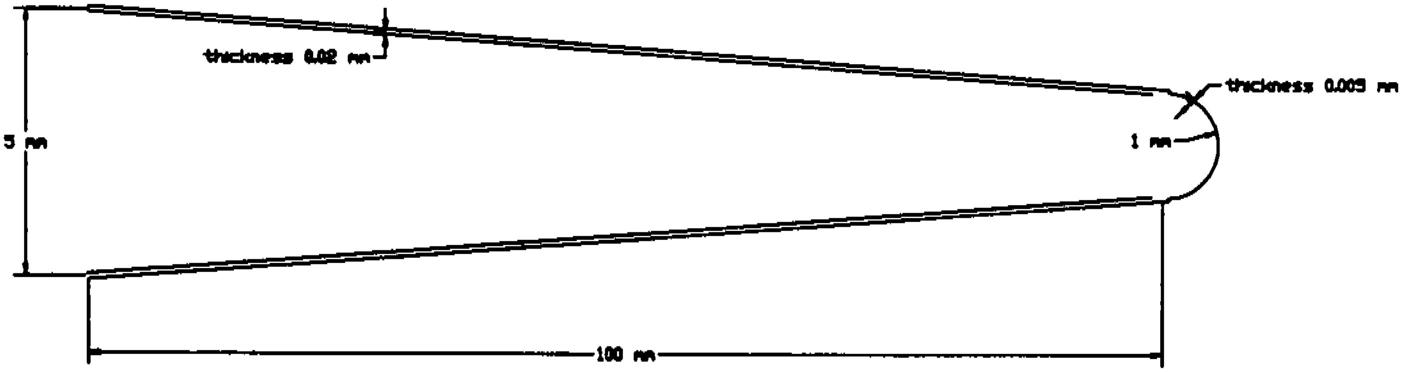
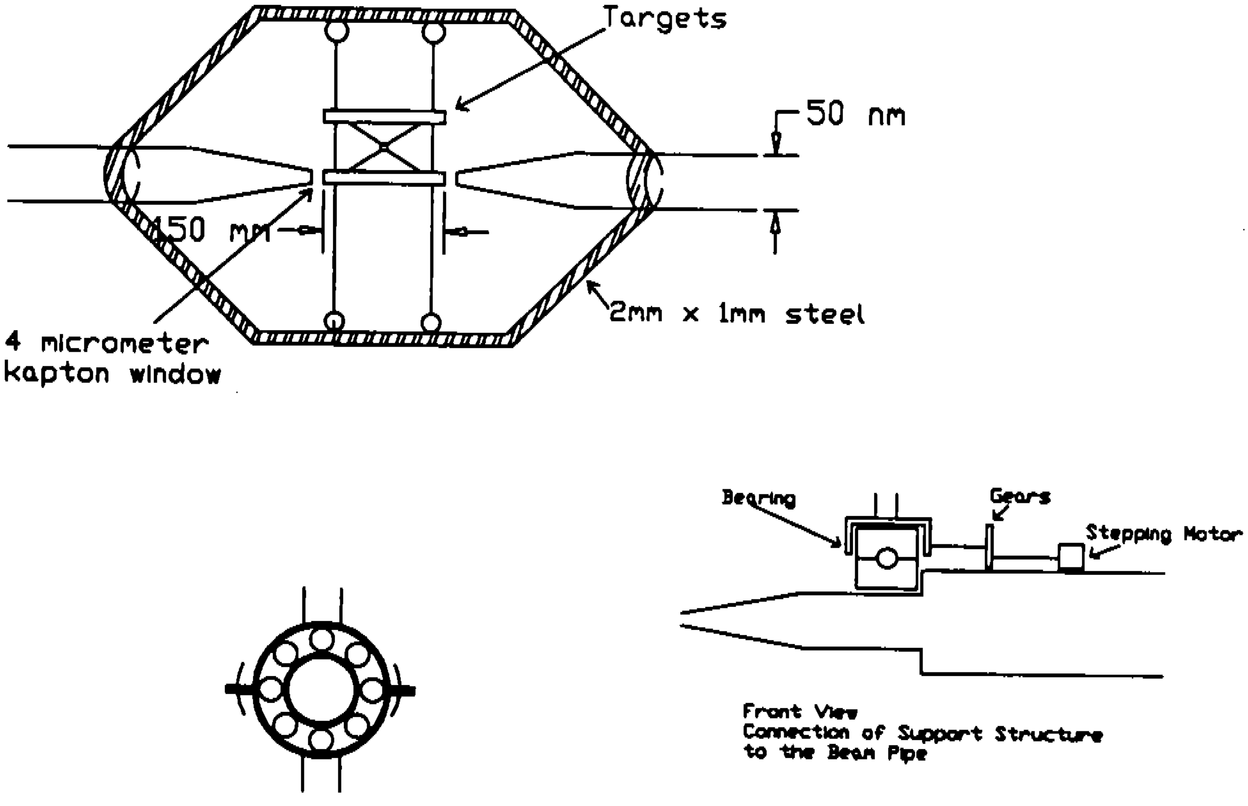


Fig. 4

Supporting structure (I)



Bearing Side View

Front View
Connection of Support Structure
to the Beam Pipe

Fig. 5 Supporting Structure
Inside Beampipe

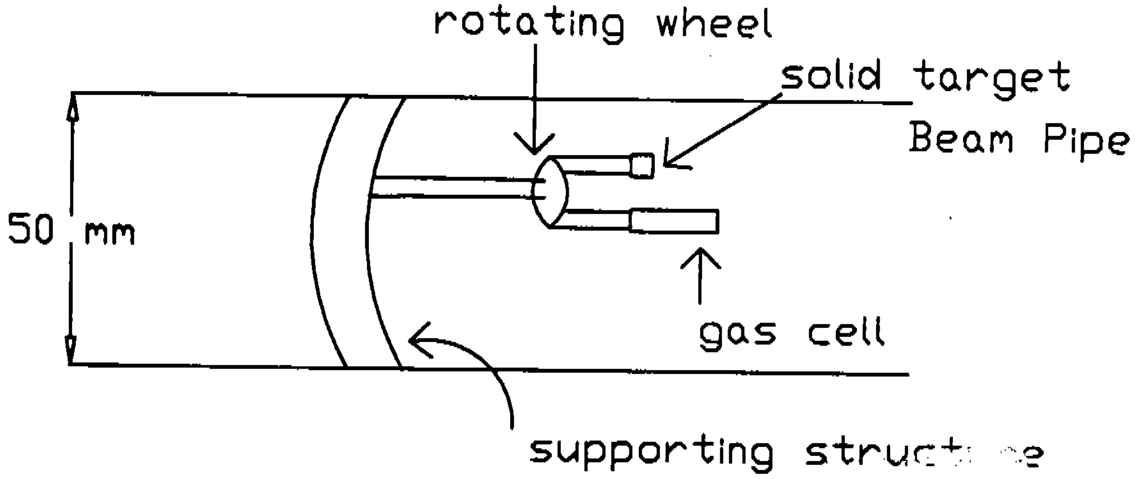
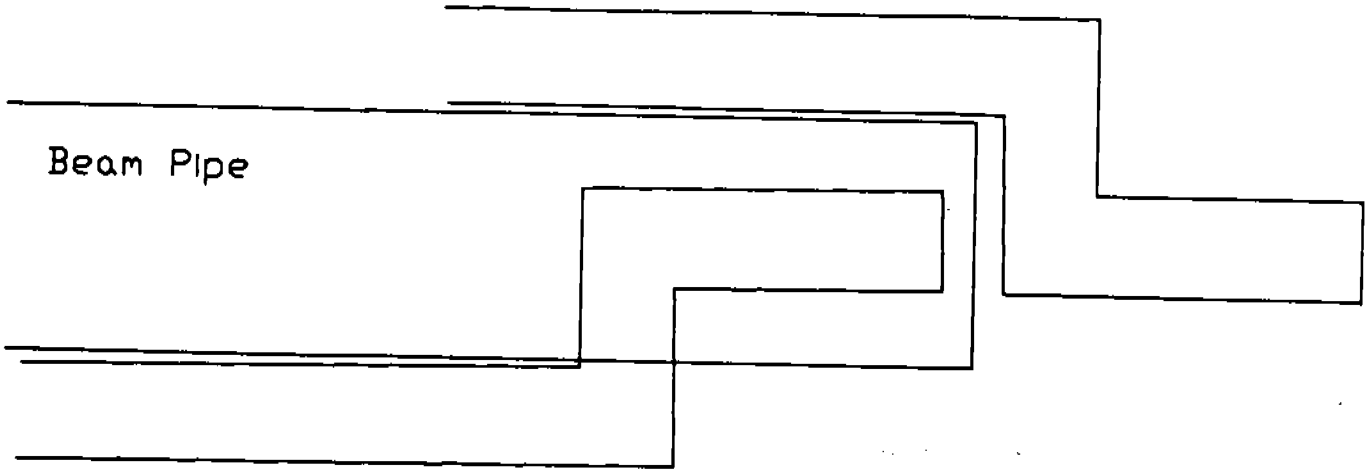


Fig. 6 Rotating Wheel Suuporting Structure

Front View



Right Side View

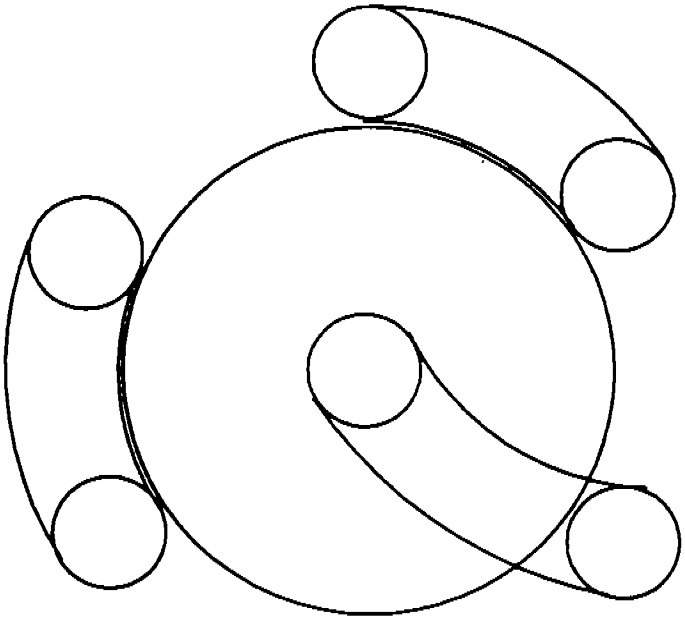


Table 1.

Hamilton Precision Metals

1780 ROHRERSTOWN ROAD, P.O. BOX 3014, LANCASTER, PA 17604-3014
PHONE (717) 569-7061 FAX (717) 569-7642

PRODUCT DESIGNATION: HAVAR®

DESCRIPTION:

HAVAR is a non-magnetic, corrosion resistant, cobalt-base alloy which exhibits high strength and a high fatigue endurance limit.

NOMINAL COMPOSITION:

Cobalt	42.5%	Beryllium	.04%
Nickel	13.0%	Manganese	1.60%
Chromium	20.0%	Tungsten	2.80%
Molybdenum	2.0%	Iron	Bal.
Carbon	.20%		

TYPICAL MECHANICAL PROPERTIES: (for strip cold reduced 75%)

	As Rolled	Age Hardened
Ultimate Tensile Strength	260,000 – 290,000 psi	320,000 – 350,000 psi
Yield Strength (at .2% offset)	235,000 – 265,000 psi	300,000 – 330,000 psi
Hardness (Rockwell C)	44 – 50	56 – 60

See Figures 1 and 2 for mechanical properties as a function of cold reduction.

PHYSICAL CONSTANTS:

Density	8.3 gm./cc.	.300 lb./cu. in.
Linear Coefficient of Thermal Expansion		12.5×10^{6} in/in/°C (0–50°C)
Electrical Resistivity		91.4 microhm cm.
Modulus of Elasticity (Tension)		$29.5 - 30.2 \times 10^{6}$ psi

$\Rightarrow 6.9 \cdot 10^{-6}$ /°F

PRODUCT CHARACTERISTICS:

The outstanding mechanical properties of HAVAR are developed through a combination of cold working and heat treatment. HAVAR work hardens readily, and for many applications the as-rolled properties are adequate. A simple heat treatment will bring about a substantial increase in the strength and hardness of the as-rolled material, however, solution annealed HAVAR will not respond to the age hardening treatment. HAVAR can be utilized at elevated temperatures, especially in spring applications, with highly satisfactory results. A maximum service temperature of 750°F is recommended. Although maximum strengthening is achieved by heat treating for 3 hours at 950°F to 1000°F, the time can be varied from 3 to 5 hours, depending upon the required properties. In all cases, the treatment should be carried out in vacuum or a dry hydrogen atmosphere.

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Table 2) Multiple Scattering (500 MeV/c proton)			
Material	Thickness	Radiation Length L/L_R	$\Delta\theta$ (mr)
Havar	15 μm	0.0009	1.3
^{4}He (15 atm)	0.5 cm	0.000014	0.12
Air	15 cm	0.00049	0.9
^{4}He (1 atm)	15 cm	0.000028	0.17
Beryllium	300 μm	0.00085	1.2

TABLE 3. Comparison of Different Materials

Material	**Havar**	**Diamond**	**Kapton**	**Mylar**	**Nickel**
Density	**8.3(g/cm^3)**	**3.34**	**1.42**	**1.25**	**8.9**
Tensile strength	**350(Kpsi)**	**250**	**25**	**20**	**125**
Cost	**cheap**	**expensive**	**cheap**	**cheap**	**cheap**