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VIRGO Vacuum Cabling

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CHANGE RECORD

Issue/Rev	*Date*	*Section affected*	*Reason/ remarks*

Authors:	**Date**	**Signature**
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Approved by:		

Table of contents

Introduction

In this note the cabling function and requirements, the technical and cost aspects, needed quantities, the status of the selection process for the various components are described.

This is not a conclusive report since some parts are still under study, while for other parts a temporary solution exists and this will be frozen if no less expensive alternative is found within the scheduled time.

I. Cabling function

The cabling is used for the electrical connection between the equipment inside the towers and the one outside. The most part of the equipment in the tower vacuum environment is mounted on the SuperAttenuator elements or on the optical benches. Cables start their path from the front-end electronics in racks placed sideways each tower, enter in the vacuum environment through a set of electrical feedthroughs mounted on few tower flanges, reach the top stage, all mechanical filters and the payload.

II. Cabling design requirements

The vacuum cabling of VIRGO is subjected to several constraints which must be taken into account on the selection of the components, on the assembling tools and on clamping. The main design requirements can be summarised as follows:

- *Vacuum compatibility*. All the materials used for cabling have to be clean and with a low outgassing rate, to match the VIRGO vacuum specifications [1]. Also if the temperature in vacuum will be around the ambient one, in some conductors there will be a temperature rise due to the current across them: hence some cabling components have to be vacuum compatible also at a temperature above the nominal one. Besides the components installed in the lower part of the tall towers have to be compatible with the 150° C bake-out 100 hours long. This process will be performed in order to speed up the degassing of water from the chamber surface; components at the level of filter 7 have to be compatible with intermediate temperatures, during bake-out.

- *Seismic isolation compatibility*. The cabling has not to reduce the attenuation performances of the SuperAttenuators (SA). Particularly, for the cables attached to the SA is required a high mechanical flexibility and a clamping performed at suitable points, in order to prevent vibration transmission or generation of new resonances.

- *Electrical compatibility*. Depending on the type of application, some ratings have to be made. They are current, crosstalk, electrical disturbances and impedance. Current ratings are based on the conductor sizes, on the amount of current that will produce certain rises in the temperature of conductors and contacts, on the thermal capacity and heat transfer capability (in vacuum) of the electrical insulation. Impedance ratings come from the considerable length of the cables (up to 25 m): in fact, in this case, the cable impedance may become comparable with the load impedance, thus reducing the driving capability. Crosstalk is the electrical pickup caused in a conductor by near conductors, while electrical disturbances come from external electromagnetic field or from ground loops. Cables connected to the mirror coils and to the accelerometers are particularly sensitive to these effects (in particular to inductive coupling): hence they should be suitably shielded and driven.

Finally, cabling should not introduce additional noise, such as microphonics and triboelectric effects in cables or contact noise in connectors.

III. Cables

III.a Cables description

Cables can be classified on the basis of their function[1] (see also Fig.1 for the leads of the devices hosted in vacuum):

- *Readout cables*. These cables bring back the signals from:
  - LVDT secondary coils
  - Thermal probes
  - LVDT secondary coils of accelerometers
  - End stroke of motors
  - Photodiodes

[1] Cables connecting the devices on the detection bench are not classified here, since these cables will be provided by the detection bench group (Annecy). The Pisa cabling group will provide the required electrical feedthroughs only.

- *Control cables*. These cables have to power:
  Coils
  Stepping motors
  Accelerometer coils
  Piezoelectrics
  Picomotors
- *Driving cables*. These cables provide the driving signal for:
  LVDT primary coils
  LVDT primary coils of accelerometers

Due to the large number of conductors needed for each tower (about 350 conductors), it is necessary to use multi-pole cables. For our applications flat cables are preferred to round cables. The latter exhibit a lower mechanical flexibility and a higher air entrapment inside the insulation.

The immunity to electrical disturbances is critical for cables connected to the accelerometers, to some LVDTs, to the mirror actuators (i.e. coil-magnet systems), to the optical bench devices. This has been achieved by means of the following methods:

– for the connection of the accelerometers (except the motor inside them) and the top stage LVDTs: usage of cables composed of twisted and shielded pairs. For the working frequency of these sensor this kind of cable is the best solution [2].

– for the connection of reference mass coils: usage of cables composed of twisted and shielded pairs for the link feedthrough-conductance pipe, usage of twisted pair cables (due to practical reasons) in the link conductance pipe-coils, but driven by means of low noise current generators with a high output impedance R_G (larger than 100KΩ). In this way any voltage ΔV induced in the conductor path, or any contact resistance variation ΔR_C produce negligible current variations ΔI ($\frac{\Delta V}{R_G}$ and $I_0 \frac{\Delta R_C}{R_G}$, respectively, where I_0 is the nominal current). This means that the induced mirror displacements are well below the VRGO specifications ($10^{-18}\ \mathrm{m}/\sqrt{\mathrm{Hz}}$ at 10 Hz), also thanks to the very low actuation factor α ($\alpha = \frac{\text{displacement}}{\text{current}} \approx 10^{-6}$ m/A).

– for the connection to the optical table: usage of flat cables with parallel conductors, but with approximately one half of conductors used for ground connection and with every signal conductor placed between two ground conductors. The effectiveness of such a method has been verified by the Detection Bench Group and it was satisfactory for this kind of application.

For other cables no particular shielding is necessary, so it would be enough to use flat cables with parallel conductors.

III.b Electrical layout and cables clamping

Inside each tall tower there are 22 cables with length ranging from 10 m to 25 m (Table 2). Inside each short tower there are 20 cables with length ranging from 3 m to 13 m (Table 3). Inside the short towers there are additional cables, depending on the tower functionality: four 25 pole flat cables for the optical table of the Detection Tower, one 25 pole flat cable and three coaxial cables for the optical bench of the Injection Tower, three coaxial cables for the mirror of the Mode Cleaner Tower.

The majority of cables from the electrical feedthroughs go up along the safety structure, reach the SA top stage, go down along the filters, end to the devices (Fig. 2). The remaining cables connect devices placed on the safety structure, hence for this group of cables no particular flexibility is required.

In order to minimise cable mechanical effects on filter performances, the links of cables between two adjacent filters have to be very slack, large bend shaped and with at minimum a 90° cable rotation in each link (Fig. 3). A clamp at suitable points is also fundamental to avoid any possible friction. Mechanical tests on a chain of two filters cabled with eight flat cables have shown [3] that the effects of cabling are slight and acceptable, provided that the above recommendations on their arrangement are taken into account. The results of these tests come from measuring systems having a limited sensitivity. The measured cable mechanical characteristics will be introduced in SIESTA to simulate the effects of cables on mechanical suspensions.

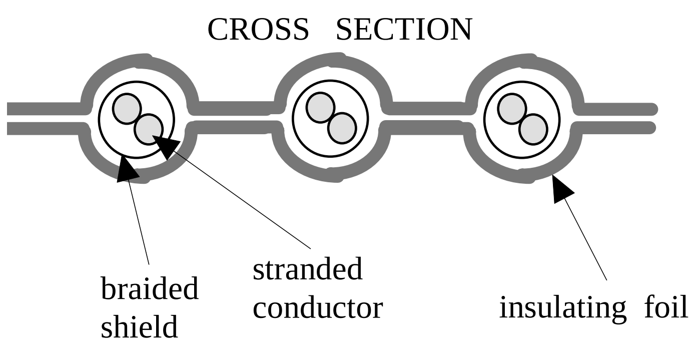
Another improvement in cable flexibility is achieved by using stranded conductors[2] and braided shields, except in the last SA stages, where solid conductors are preferred in order to avoid mechanical friction among the wires of the stranded conductors.

III.c Cables selection process

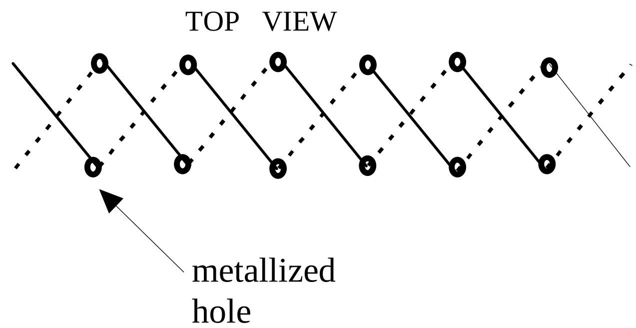
[2] A stranded conductor is composed of single solid wires twisted together, either singly or in groups.

Cabling requirements (listed in § II.) and cost considerations yield to some difficulties in finding the cables on the market or in purposely producing them. In fact, from vacuum tests resulted approved only cables insulated with Kapton without FEP layer or glues (outgassing rate:$1.1\cdot10^{-10}$ mbar·l·s^{-1}·cm^{-2})[4], Pyre-ML ($8.4\cdot10^{-11}$ mbar·l·s^{-1}·cm^{-2})[5], Gore-tex ($2\cdot10^{-12}$ mbar·l·s^{-1}·cm^{-2})[6], alumina ($4.7\cdot10^{-11}$ mbar·l·s^{-1}·cm^{-2})[7]. In addition silver or nickel plated copper conductors have to be used instead of the common tinned conductors. Some considerations on these insulators are the following (see also Tables 1.a÷1.c):

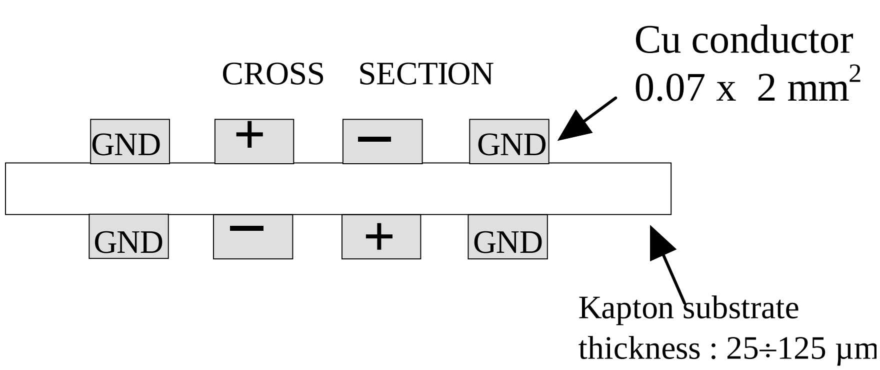
- *Gore-tex* is an expanded PTFE. Among the vacuum compatible tested materials, only Gore-tex can be used for the insulation of twisted & shielded pair (STP) flat cables, due to processing reasons. The realisation is achieved by means of a “sandwich” like mounting: a set of single STP round cables inside two insulating foils. In addition, the Gore-tex is more porous (hence no air trapping) and flexible than the normal PTFE. Due to the considerable price (about 100 DM/meter for a cable of 8 STP) we are trying to found on the market an equivalent cable but less expensive than the Gore-tex one.



- *Kapton* is a polymide, thermally stable up to 150°C. In principle STP flat cables could be made of kapton too. In fact, by means of photolithographic technology it is possible to define a twisted pair geometry on a double side Cu covered kapton substrate.



Problems come from the poor reliability of the hole metalization and high costs (~20$/meter/conductor, by FlexLink-USA). We investigated a more feasible kind of kapton cable (as sketched below), with the aim that this, suitably driven, would have exhibited a STP cable like behaviour, at least in the frequency range of interest. This cable consists in the definition of double parallel pair geometry on a double sided Cu covered kapton substrate by means of photolithographic technology. Unfortunately, electric tests showed that these cables can be used only for motors and for vertical LVDTs. Kapton flat cables with a single metallization need a less difficult processing than the ones described above. Some contacted firms (FlexLink, Cicorel-CH) have the capability in purposely producing this kind of cables, starting from kapton reels. A French firm (Axon) has these parallel conductor kapton cables in its catalogue. They exhibit excellent flexibility and, if the ultimate vacuum tests on them (to verify the vacuum compatibility of the glue used for their assembly) will be positive, it is possible their use along the SA chain.



- *Pyre-ML* is an aromatic polymide among the most thermally stable organic material yet characterised by DuPont. Thanks to its excellent vacuum properties, it is recommended also for the insulation of cables used in the lower part of the long towers. With this insulator it is possible only the manufacturing of single solid conductor cables (CaliforniaFineWire - USA). The reasonable price (few $/meter/conductor) and the availability, make Pyre-ML cable a strong candidate for the use in the lower part of towers.

- *Alumina* is a ceramic deposited onto the conductors by a new technology (Ceramecky) which involves electrodeposition. Ceramecky technology achieves greater flexibility and adhesion of the insulation film than the one of other inorganic coating technologies. As a consequence, the Japanese company (Dipsol Chemicals) which has developed this technique, has the capability in producing ceramic insulated wires and coaxial cables. Even if this cable has a very low outgassing rate and therefore ideally suited for the lower part of the towers, some factors might discourage their use: some difficulty in contacting the company, long delivery times, quite high prices, sharp bending or strong twisting which could cause peeling of the coating film.

STP flat cables are not present on the market, whether for vacuum applications or not, but are custom cables. The reason comes from technological difficulties in realising them. Several companies (Amphenol-USA, AlphaWire-USA, Axon-F, Belden-USA, BICC-UK, Calmont-USA, Cavicel-I, Cicorel-CH, Dipsol-JP, DuPont-USA, CFW-USA, Filotex-F, FlexLink-USA, Framatone-F, Minco-USA, Pirelli-I, Raychem-USA, Raidex-UK, Reynolds-F, SEEA-F, Thomas&Betts-USA, Tactus-UK, Rogers-USA, 3M-USA, etc.) have been contacted with the aim to obtain custom-made cables according to the requirements, but a more competitive price than the Gore one. It seems there is some possibility in obtaining this by Amphenol and Calmont. However further investigations are needed.

III.d Conclusions on cables

The electrical layout and the mechanical arrangement of cables have been designed, the AWG[3] and length of cables and the types of shielding has been defined. At the present time the main candidate cables, listed in tables I.a÷I.c, are: STP flat cables in Gore-tex (connection of low level signal devices), parallel conductor flat cables in Kapton (connections of the remaining devices), single conductor cables in Pyre-ML (for the passage through the conductance pipe and the cabling of the devices hosted in the lower part of the tall towers). Gore-tex cable are quite

[3] Abbreviation of American Wire Gauge, the most widely used system to classify the electrical wires on the basis of their section.

expensive and will be purchased if no equivalent and economical cables are found before the scheduled cabling of the towers.

IV. Flanges and feedthroughs

The path of each vacuum cable ends on an electrical feedthrough welded on a flange (DN 250 CF, 304 mm outer diameter). On the "technical virole" (i.e. the 600 mm height bottom ring of the cylindrical vacuum chamber[4])). are mounted three flanges and displaced in the horizontal plane with a 120° symmetry. The centres of the flanges are in the median plane of the virole.

Due to the considerable number of pins needed through each tower (~400), the selection process for the electrical feedthroughs was based on available space, easy handling of conductor connections, costs and quality (see Table 1.d).

Traditional multipin circular feedthroughs are quite expensive and require a crimp on each pin (single ended) or circular plugs (double ended): the first possibility is difficult in the case of the thousands of pins in VIRGO, while for both types the pin density is not enough.
The choice was 25 pin D-type subminiature feedthroughs (at the moment the possibility of 50 pin D-type subminiature feedthroughs is under investigation): they are quite cheap, from few years they are catalogue products of some important companies (Ceramaseal, Caburn), they are compatible with industry standard D-connector, good pin density, they incorporate a totally new glass-ceramic technique, which provides higher temperature strength (rated for 350°C) and increased UHV capabilities.

The arrangement of the feedthroughs on the flange has been changed several time. The present arrangement, for which six assemblies has been ordered, is schematised in Fig.4. It is the same for all the 18 VIRGO flanges containing feedthroughs. For every tower, only two flanges are supplied with the feedthroughs, while the third one is left blind for future developments.

V. Connectors

Cables are terminate by using two types of connectors (see Fig.5 and Tables 1.e÷1.f):

[4] Each of the four rings of the cylindrical vacuum chamber is named "virole".

- 25 pin type-D subminiature connectors to mate with the electrical feedthroughs (possibility of 50 pin D-connectors)
- multipin LEMO connectors to mate with the devices

The type-D connectors (Fig. 5.a) are wholly in PEEK with gold plated copper alloy contacts, UHV temperature rated to 200°C. The same connector may be shared between two cables.

The LEMO connectors belong to a multipin series having push-pull and bias features, have a PEEK insulation and a nickel plated brass shell (stainless steel shell for the lower part of the tall towers), with gold plated brass contacts. At the device side, each cable is ended with several LEMO connectors, whose quantity and number of pins depends on the type of connected devices (Fig. 5.b).

Type-D and LEMO connectors include crimp contacts. In our applications, the crimping has been preferred to the soldering because it is more cleaner, reproducible and practical.

VI. Cabling through the conductance pipe

The connection between the filter 7 and the marionette is performed by an 1.85 mm diameter suspension wire with a length of about 1130 mm. In the case of tall towers, where the separating roof is present, the only possible passage for electrical wires is through the conductance pipe.

The arrangement of these wires and the suspension wire has been done taking into account some constraints:

1. to minimise the effective section of the conductance pipe;
2. to leave the possibility of a relative motion of ±5 mm in the horizontal plane between separating roof and wires;
3. to avoid any movement or friction among components of the assembly in order not to deteriorate the quality factor;
4. to avoid an excessive lowering of the violin mode of the suspension wire;
5. UHV compatible with a bakeout at 150°C;
6. possibility to be easily connected and disconnected in the SA.

The basic idea is to put all the wires in a small metal tube and then completely fill it with some UHV compatible material. Then to terminate the wires with round connectors small enough to go through the conductance pipe (Fig.6).

The tube is made of INOX 304, has an inner diameter of 6.2 mm (slightly larger than the 6 mm diameter of the nail heads), a length of 500 mm (longer than the conductance pipe), a thickness of 0.1 mm (to minimise the weight). Taking into account the outer diameter of this metal tube and the required value of the conductance, has been defined for the conductance pipe a diameter of 20 mm and a length of 400 mm. From these sizes results a conductance value of about 1.6 litres/s.

Inside the 6.2 mm tube are hosted 7 wires for the balancing motor in the marionette (terminated with a 7 pin connector), 4 twisted pairs for the 4 coils on the reference mass plus 2 spare twisted pairs (terminated with a 12 pin connector), the suspension wire. The excess length of the wire leads is 300 mm in the lower part and TBD for the wire leads in the upper part. Particular care is needed during the filling in order to avoid air entrapment in the metal tube, that would produce virtual leaks. We chose a special UHV glue as filling material: a kind of Araldite with a working time of about one hour and with very low viscosity when heated. The filling is performed by plunging one end of the metal tube in the glue and by means of a vacuum pump connected to the other end which aspire the glue; during the filling the tube and the glue are heated to about 100°C. Some prototypes have been realised and some improvements are under study.

VII. Estimated quantities and costs

The estimates, reported in Table 4, concern the vacuum cabling for three short towers (by end of 1998), six tall towers (by end of 1999 for Power Recycling, Beam Splitter, North Injection, West Injection).

The costs evaluation is made in a conservative approach, often taking into account a 25% of spare components. Gore cables have been taken into account for the evaluation.

Due to economic reasons, instead of a complete product we purchase the cable reels and the connectors separately and then we perform the assembly cable-connector. In the case that this assembly will be performed by some external technician, its cost has to be added. Costs for the air-side cabling from the electrical feedthroughs to the racks have been also excluded.

Due to the non homogeneous data available (or even to their lack) it is difficult to give figures of the outgassing flow of the alternative cabling components listed in Table 1. Anyway, concerning the cabling components we decided to use in VIRGO (i.e. mainly Gore cables and Lemo connectors), the orders of magnitude of the outgassing flows have been estimated. These values are reported in Table 5. For a comparison, are also listed in the table the outgassing flows relative to other components hosted in the towers. As it can be noted, for the chosen cabling components the outgassing is well within the VIRGO specifications.

VIII. Product breakdown structure of cabling

1 - Cables
2 - Connectors
- 2.a - Pins
- 2.b - Sockets
- 2.c - Cases
- 2.d - Insulators

3 - Feed-throughs
4 - Flanges
5 - Mechanical interfaces & clamps
6 - Accessories
- 6.a - Gaskets
- 6.b - Soldering tin
- 6.c - Labels
- 6.d - Heat-shrinkable tubes

7 - Tools
- 7.a - Crimping tool
- 7.b - Soldering tools
- 7.c - Stripping tool
- 7.d - Typewriter (for metal labels)

8 - Cabling along the conductance pipe
- 8.a - Cables
- 8.b - Connectors
- 8.c - Thin metal tubes
- 8.d - Special potting

References

[1] VIRGO Final Design, § 30.2 and § 30.4 (May, 1997)

[2] H.W.Ott: "Noise reduction techniques in electronic systems", second edition, J.Wiley & Sons Inc., New York (1988)

[3] V.Dattilo: "Effects of cables on a two filters chain", in progress

[4] M.Bernardini et al.: "Outgassing measurements of Kapton insulated cables", VACPISA-036-P (January,1996)

[5] M.Bernardini et al.: "Outgassing test of cabling with Pyre-ML insulation", VIR-TRE-PIS-3400-115 (April, 1997)

[6] M.Bernardini et al.: "Outgassing test of a Gore-tex ribbon", VIR-TRE-PIS-3400-116 (April, 1997)

[7] M.Bernardini et al.: "Outgassing measurements of alumina insulated cables", VACPISA-037-P (January,1996)

[8] R.Poggiani: "Updated estimation of the suspension contamination budget", VIR-TRE-PIS-3400-135 (September, 1998)

Figure captions

[Fig.1] Leads description of the devices connected in vacuum.

[Fig.2] Electrical cables layout for tall towers (a) and short towers (b).

[Fig.3] Examples of the arrangement and clamping of the cables. The actual supports for cables are slight different from the ones drawn in the figures.

[Fig.4] Design of the flange with the electrical feedthroughs.

[Fig.5] Connectors for feedthroughs (a) and for devices (b).

[Fig.6] Assembly of the cables through the conductance pipe

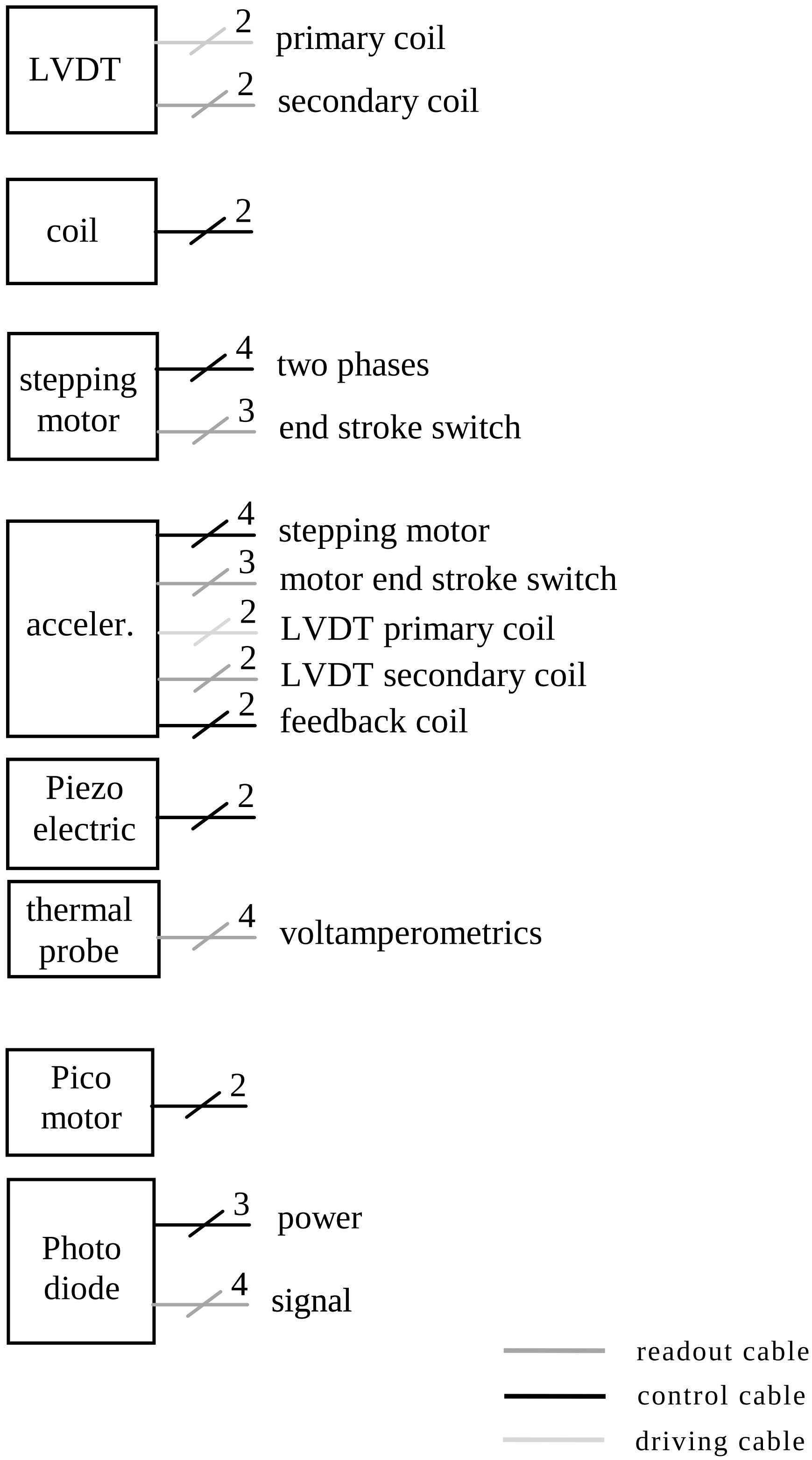

LVDT
2
primary coil
2
secondary coil
coil
2
stepping motor
4
two phases
3
end stroke switch
acceler.
4
stepping motor
3
motor end stroke switch
2
LVDT primary coil
2
LVDT secondary coil
2
feedback coil
Piezo electric
2
thermal probe
4
voltamperometrics
Pico motor
2
Photo diode
3
power
4
signal
readout cable
control cable
driving cable

Fig. 1

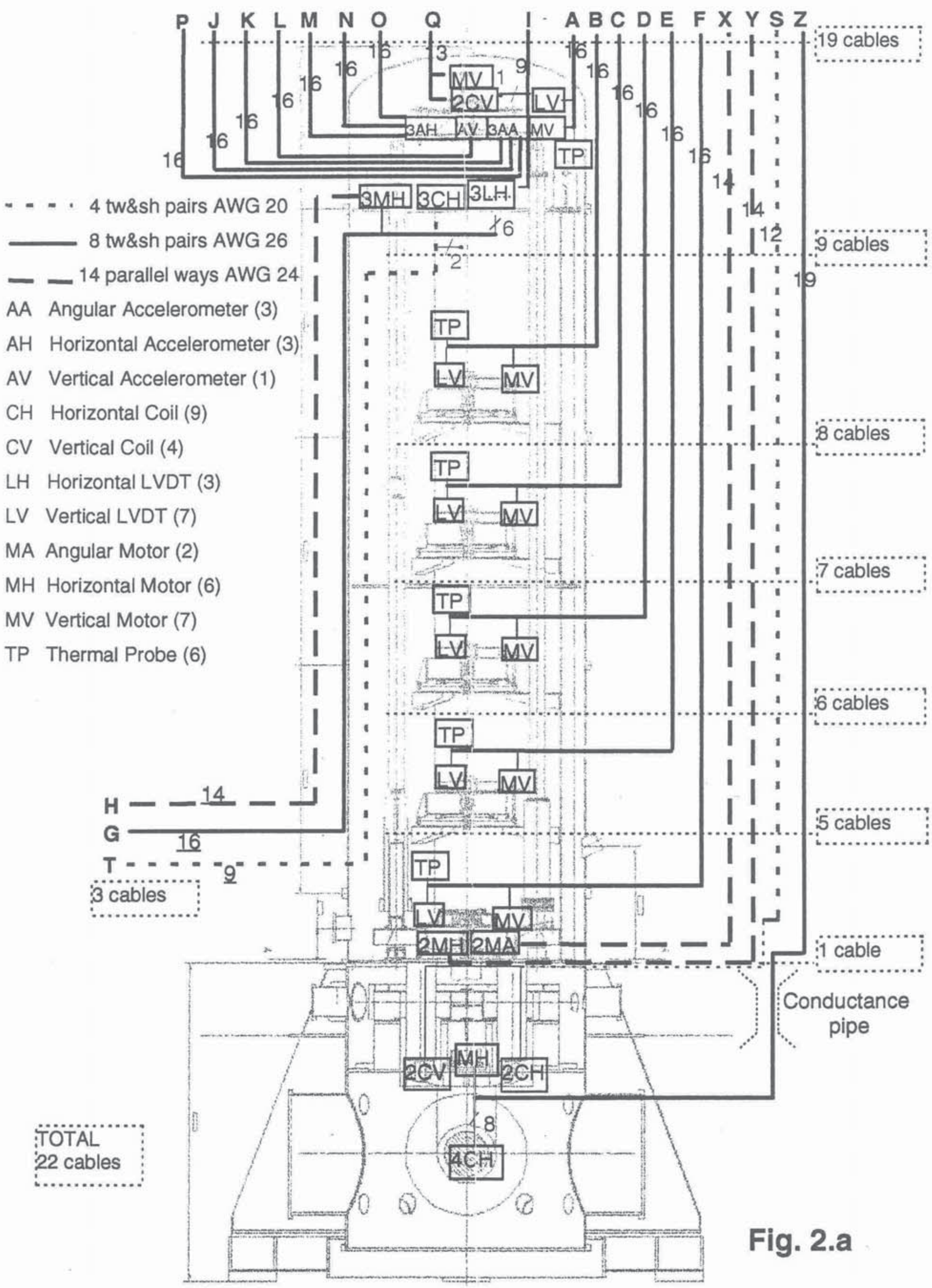
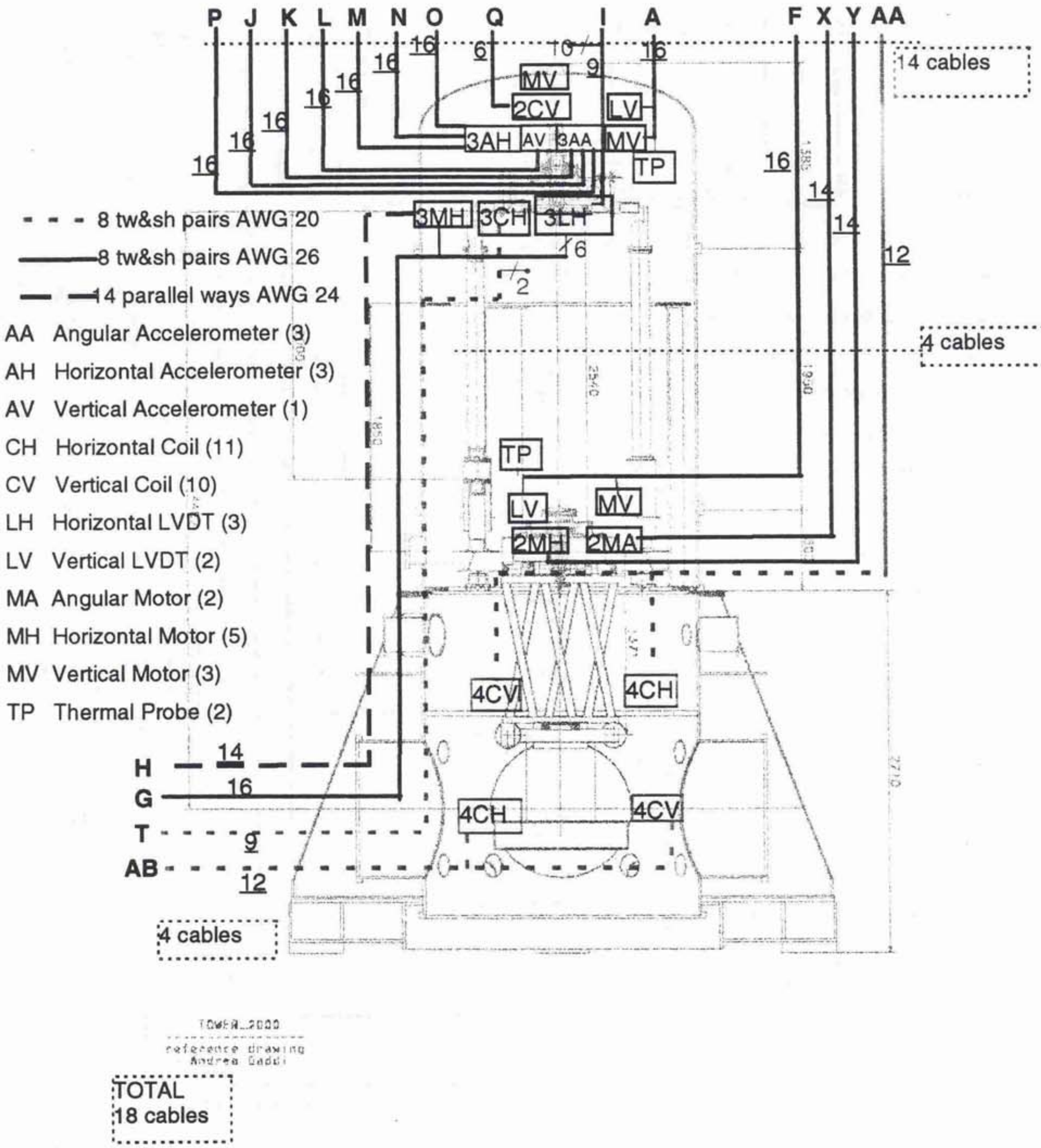
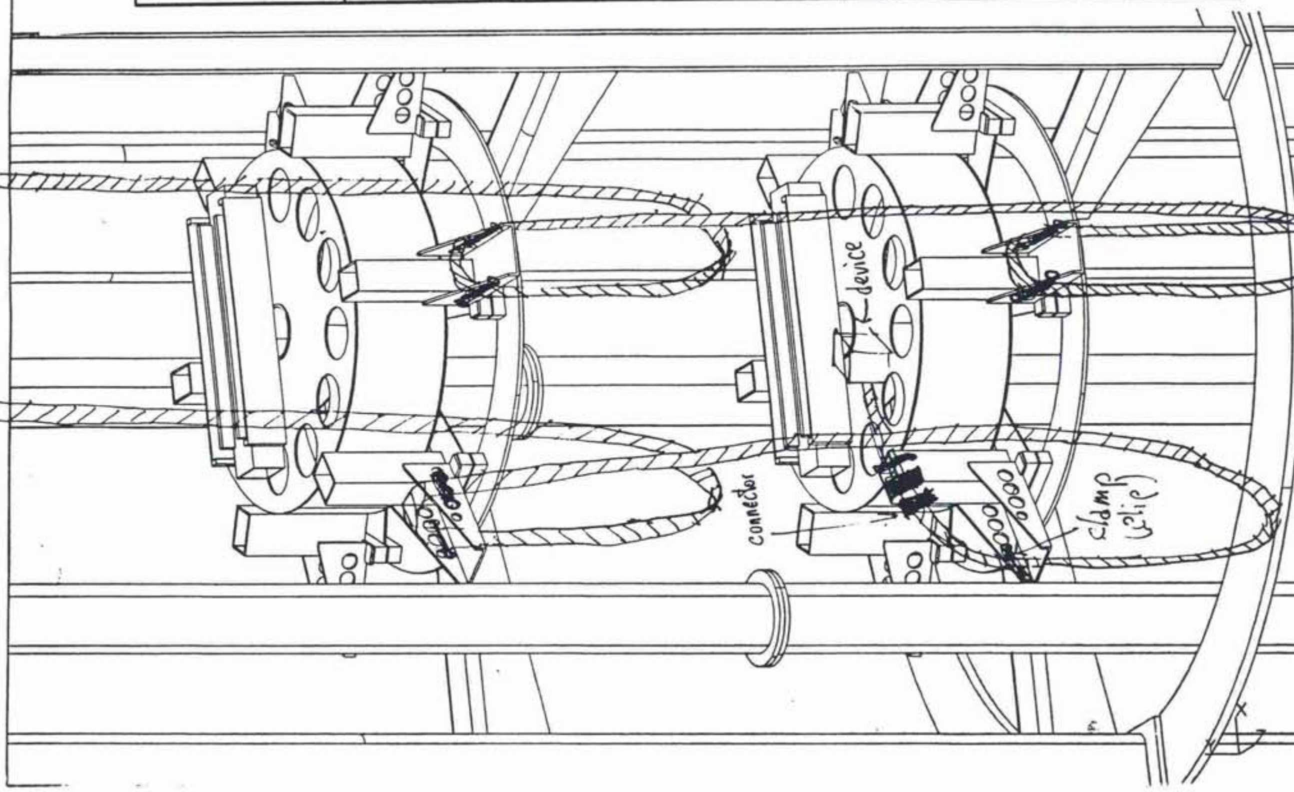

P J K L M N O Q I A B C D E F X Y S Z
19 cables
9 cables
8 cables
7 cables
6 cables
5 cables
1 cable
3 cables
Conductance pipe
4 tw&sh pairs AWG 20
8 tw&sh pairs AWG 26
14 parallel ways AWG 24
AA Angular Accelerometer (3)
AH Horizontal Accelerometer (3)
AV Vertical Accelerometer (1)
CH Horizontal Coil (9)
CV Vertical Coil (4)
LH Horizontal LVDT (3)
LV Vertical LVDT (7)
MA Angular Motor (2)
MH Horizontal Motor (6)
MV Vertical Motor (7)
TP Thermal Probe (6)
H
G
T
TOTAL 22 cables

Fig. 2.a



P J K L M N O Q I A F X Y AA
14 cables
4 cables
MV
2CV
LV
3AH
AV
3AA
MV
TP
3MH
3CH
3LH
TP
LV
MV
2MH
2MA
4CV
4CH
4CH
4CV
- - - 8 tw&sh pairs AWG 20
—— 8 tw&sh pairs AWG 26
— — 14 parallel ways AWG 24
AA Angular Accelerometer (3)
AH Horizontal Accelerometer (3)
AV Vertical Accelerometer (1)
CH Horizontal Coil (11)
CV Vertical Coil (10)
LH Horizontal LVDT (3)
LV Vertical LVDT (2)
MA Angular Motor (2)
MH Horizontal Motor (5)
MV Vertical Motor (3)
TP Thermal Probe (2)
H 14
G 16
T 9
AB 12
4 cables
TOWER_2000
reference drawing
Andrea Gaddi
TOTAL
18 cables

Fig. 2.b



I-DEAS Master Series 5: Design

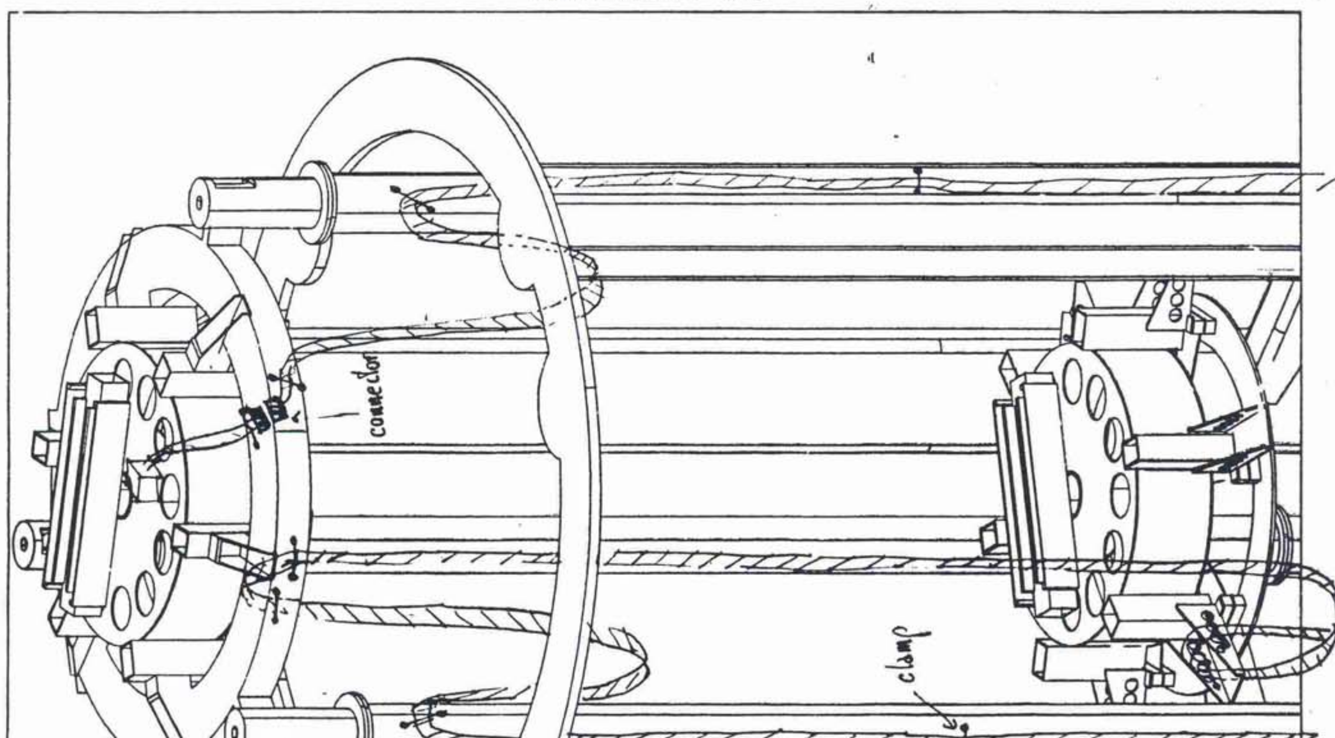


Fig. 3

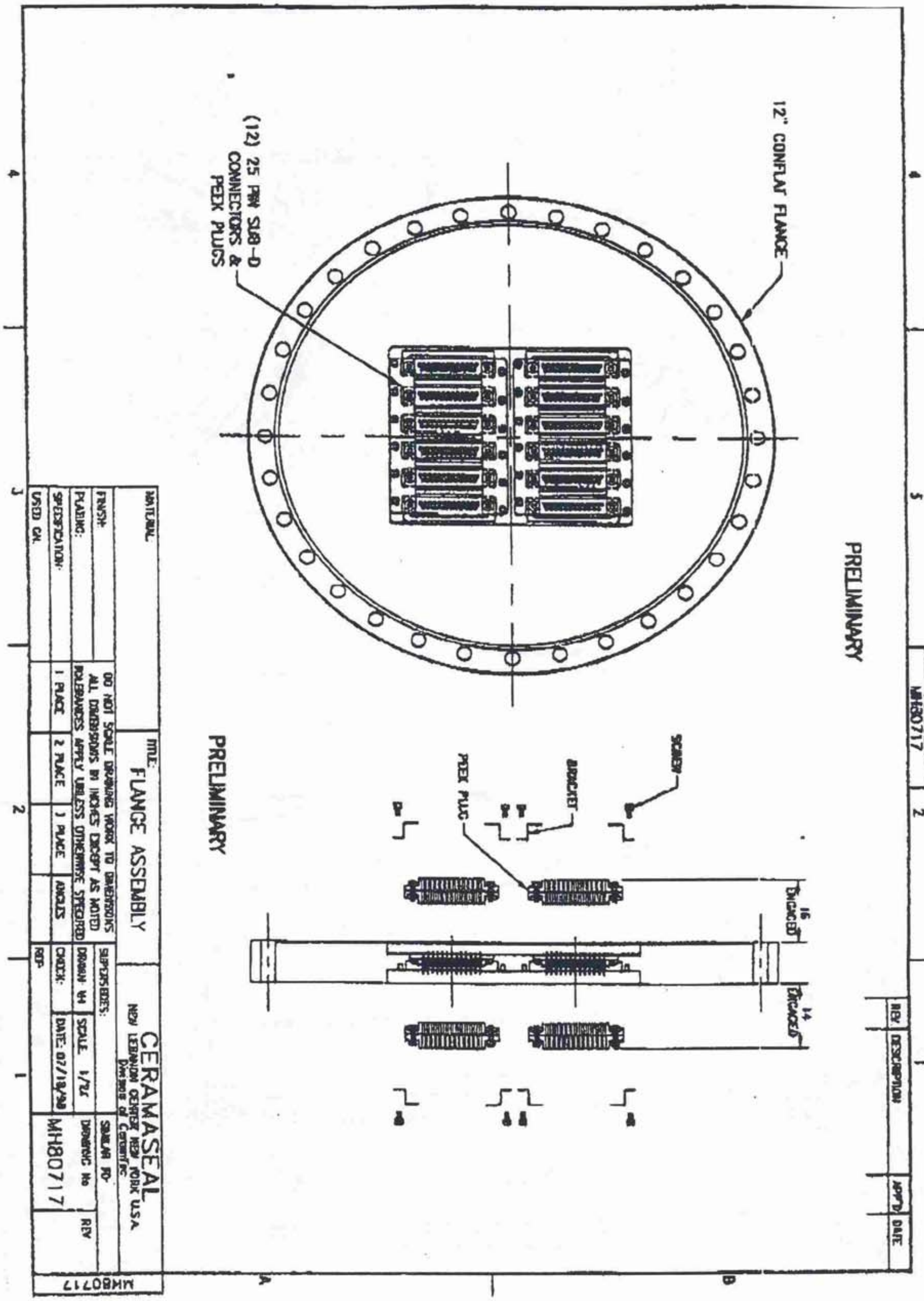

12" CONFLAT FLANGE
(12) 25 PIN SUB-D CONNECTORS & PEEK PLUGS
PRELIMINARY
SCREW
BRACKET
PEEK PLUG
PRELIMINARY
MATERIAL:
FINISH:
PLATING:
SPECIFICATION:
USED ON:
TITLE: FLANGE ASSEMBLY
DO NOT SCALE DRAWING WORK TO DIMENSIONS
ALL DIMENSIONS IN INCHES EXCEPT AS NOTED
TOLERANCES APPLY UNLESS OTHERWISE SPECIFIED
1 PLACE
2 PLACE
3 PLACE
ANGLES
CERAMASEAL
NEW LEBANON CENTER NEW YORK U.S.A.
SUPERSEDES:
SIMILAR TO:
DRAWN
SCALE
CHECK:
DATE: 07/13/98
REF:
DRAWING No
REV
MH80717
REV
DESCRIPTION
APP'D
DATE

Fig. 4

IN-VACUUM CONNECTOR

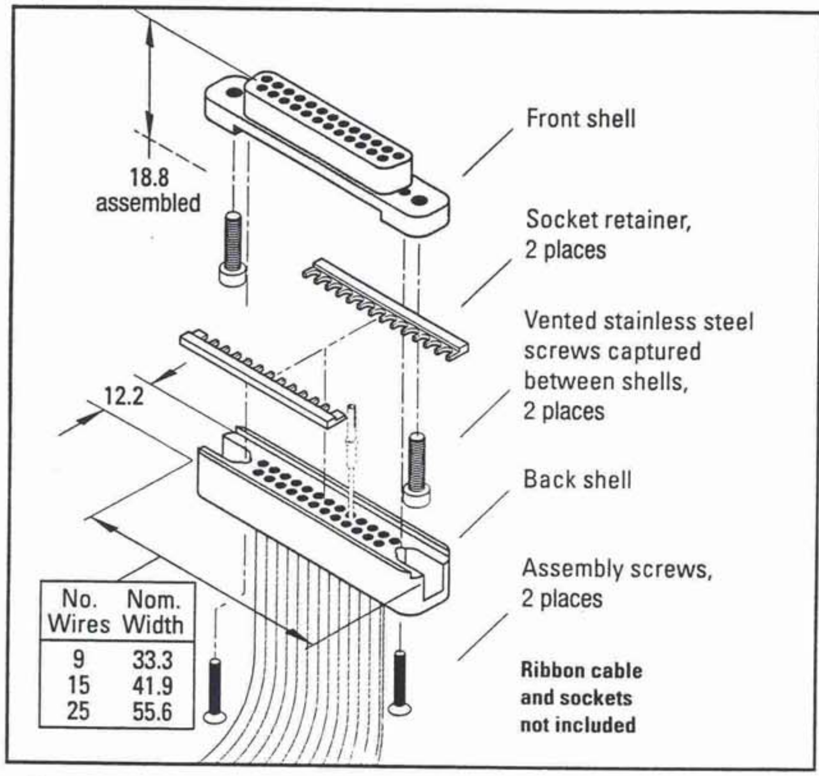


Fig. 5.a

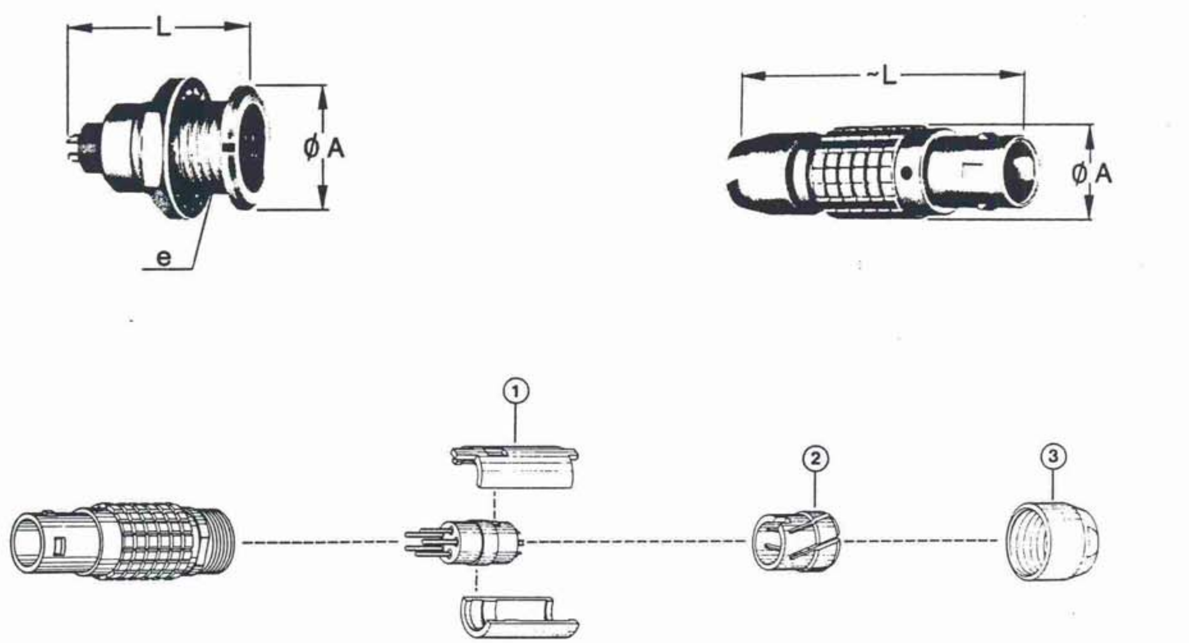
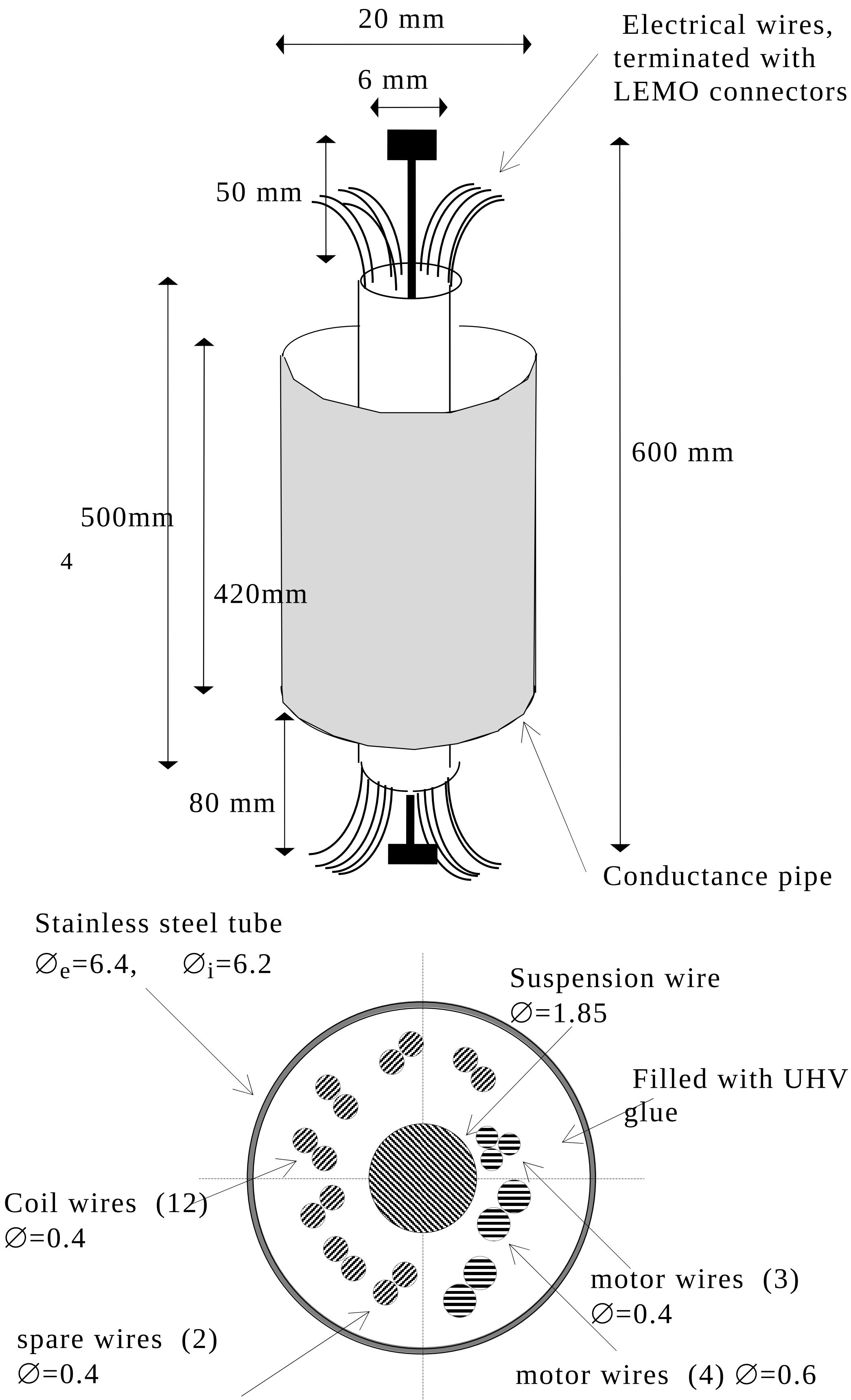


Fig. 5.b



20 mm
6 mm
Electrical wires, terminated with LEMO connectors
50 mm
500mm
4
420mm
600 mm
80 mm
Conductance pipe
Stainless steel tube
∅e=6.4, ∅i=6.2
Suspension wire
∅=1.85
Filled with UHV glue
Coil wires (12)
∅=0.4
motor wires (3)
∅=0.4
spare wires (2)
∅=0.4
motor wires (4) ∅=0.6

Fig. 6

candidate	notes	quantity /tower	unit price	price /tower	outgassing data[5]	total area	outgassing /tower
flat cables with 8 STP, in Gore-tex (Gore)	good flexibility and cleaned for vacuum	130 m	125 DM/m (123KL/m)	18.000 KL	$2\cdot10^{-12}$ [$mbar\cdot l\cdot s^{-1}\cdot cm^{-2}$] [6]	10^5 [cm^2]	$2\cdot10^{-7}$ [$mbar\cdot l\cdot s^{-1}$]
flat cables with 8 STP, in FEP, held together by a woven in VALOX (Calmont)	possible friction noise	130 m	20 GBP/m (58 KL/m)	7.000 KL	FEP: TML[6]<0.02 CVCM[7]<0.01 WVR[8]<0.01 VALOX: TML=0.24 CVCM=0.07 WVR=0.06		
flat cables with 8 STP in halogen-free polyolefin (Amphenol)	easy air trapping and poor flexibility	130 m	21 KL	2.700 KL	not yet available	10^5 [cm^2]	
flat cables with 24 parallel conductors in Kapton (Axon)	excellent flexibility, but for the lack of shielding they could not be used for the total amount of the connections (it is preferred the usage of a unique kind of cable). Possible problems for the connector-cable assembly	130 m	170 FF/m (50 KL)	6.500 KL	$8\cdot10^{-12}$ [$mbar\cdot l\cdot s^{-1}\cdot cm^{-2}$] (preliminary data)	10^5 [cm^2]	$8\cdot10^{-7}$ [$mbar\cdot l\cdot s^{-1}$]

Table I.a
Cables for short towers

[5] The outgassing rate values (expressed in $mbar\cdot l\cdot s^{-1}\cdot cm^{-2}$) were measured at Calambrone. The values of TML, CVCM, WPR were measured by NASA
(see tables at: http://epims.gsfc.nasa.gov/og-cgi/sectionc/sectionc_html.sh)

[6] TML (Total Mass Loss). The mass loss of the sample, determined from the weights before and after the 398 K exposure for 24 hours, expressed as a percentage of the starting mass.

[7] CVCM (Collected Volatile Condensable Material). The difference between the weight of a clean collector and of the collector having condensed materials will provide the mass of condensables. Expressed as a percentage of the starting mass.

[8] WVR (Water Vapor Regained). It is that amount of water reabsorbed in 24 hours while the sample is exposed to 25° C, and 50 % relative humidity (determination made after the vacuum test is completed and TML and CVCM have been determined) . Expressed as a percentage of the starting mass.

candidate	***notes***	***quantity /tower***	***unit price***	***price /tower***	***outgassing data***	***total area***	***outgassing /tower***
flat cables with 8 STP, in Gore-tex (Gore)	good flexibility and cleaned for vacuum	330 m	100 DM/m (98 KL/m)	32.000 KL	$2{\cdot}10^{-12}$ [$mbar{\cdot}l{\cdot}s^{-1}{\cdot}cm^{-2}$] [6]	$2.5{\cdot}10^{5}$ [cm^{2}]	$5{\cdot}10^{-7}$ [$mbar{\cdot}l{\cdot}s^{-1}$]
flat cables with 8 STP, in FEP, held together by a woven in VALOX (Calmont)	possible friction noise	330 m	15 GBP/m (44 KL/m)	14.500 KL	FEP: TML<0.02 CVCM<0.01 WVR<0.01 VALOX: TML=0.24 CVCM=0.07 WVR=0.06		
flat cables with 8 STP, in halogen-free polyolefin (Amphenol)	easy air trapping and poor flexibility	330 m	20 KL	6.600 KL	not yet available	$2.5{\cdot}10^{5}$ [cm^{2}]	
flat cables with 24 parallel conductors (Axon)	excellent flexibility, but for the lack of shielding they could not be used for the total amount of the connections (it is preferred the usage of a unique kind of cable). Possible problems for the connector mounting	330 m	150 FF/m (44 KL)	14.500 KL	$8{\cdot}10^{-12}$ [$mbar{\cdot}l{\cdot}s^{-1}{\cdot}cm^{-2}$] (preliminary data)	$2.5{\cdot}10^{5}$ [cm^{2}]	$2{\cdot}10^{-6}$ [$mbar{\cdot}l{\cdot}s^{-1}$]

Table I.b

Cables for tall towers (upper part)

candidate	notes	quantity /tower	unit price	price /tower	outgassing data	total area	outgassing /tower
simple wires coated with Pyre-ML. (California Fine Wire Company)	The pair twisting is performed by ourselves. Cleaned for vacuum.	20 m AWG 24 6 m AWG 22	2 KL/m 2.2 KL/m	55 KL	$1 \cdot 10^{-10}$ [$mbar \cdot l \cdot s^{-1} \cdot cm^{-2}$] no organic contamination [5]	350 [cm^2]	$3.5 \cdot 10^{-8}$ [$mbar \cdot l \cdot s^{-1}$]
simple wires coated with alumina by electro deposition (Dipsol Chemicals)	The pair twisting is performed by ourselves. Cleaned for vacuum. Possible peeling of the ceramic during the twisting. Some difficulty in contacting the company (Japan) and in the payment forms.	20 m AWG 24 6 m AWG 22	17 US$/m (30 KL/m) 20 US$/m (38 KL/m)	850 KL	$4.7 \cdot 10^{-10}$ [$mbar \cdot l \cdot s^{-1} \cdot cm^{-2}$] no organic contamination [7]	350 [cm^2]	$1.6 \cdot 10^{-7}$ [$mbar \cdot l \cdot s^{-1}$]
shielded and twisted pair cable coated with alumina by electro deposition (Dipsol Chemicals)	Poor flexibility. Some difficulty in contacting the company (Japan) and in the payment forms.	10 m AWG 24 3 m AWG 22	not quoted		$4.7 \cdot 10^{-10}$ [$mbar \cdot l \cdot s^{-1} \cdot cm^{-2}$] no organic contamination [7]	400 [cm^2]	$1.9 \cdot 10^{-7}$ [$mbar \cdot l \cdot s^{-1}$]

Table I.c
Cables for tall towers (lower part)

candidate	***notes***	***quantity /tower***	***unit price***	***price /tower***	***outgassing data***
CF 250 flange with 5 SUB-D 50 multipin feedthroughs (Caburn)	Easy connectivity with SUB-D connectors. Some feed-throughs are shared by hree cables.	2	2.620 US$ (4.700 KL)	9.400 KL	vacuum range[9]: $5 \cdot 10^{-11}$ [mbar]
CF 250 flange with 12 SUB-D 25 multipin feedthroughs (Ceramaseal)	Easy connectivity with SUB-D connectors. Some feed-throughs are shared by two cables. Each assembly is tested and certified.	2	2.590 US$ (4.650 KL)	9.300 KL	minimum leak rate[10] $1 \cdot 10^{-9}$ standard cc He/sec
CF 250 flange with 5 SUB-D 50 multipin feedthroughs (Ceramaseal)	Easy connectivity with SUB-D connectors. Some feed-throughs are shared by three cables. Each assembly is tested and certified.	2	2.410 US$ (4.300 KL)	8.600 KL	minimum leak rate[10]: $1 \cdot 10^{-9}$ standard cc He/sec
fully custom assembly with 200 pins plus custom air/vacuum side connectors. (VLT-Rome)	Not experimented product, unlike SUB-D feedthroughs.	2	> 15.000 KL	> 30.000 KL	

Table I.d
Electrical feedthrough assemblies (same quantity for all the towers)

[9] Specification by Caburn-MDC
[10] Specification by ceramaseal

candidate	notes	quantity /tower	unit price	price /tower	outgassing data
SUB-D 25 pin connector, in PEEK (Caburn)	Easy connectivity (push-on). Some connectors are shared by two cables. Crimp sockets.	24	320 KL	5.000 KL	vacuum range[11]: $5 \cdot 10^{-11}$ [mbar]
SUB-D 25 pin connector, in PEEK (Ceramaseal)	Easy connectivity (push-on). Some connectors are shared by two cables. Crimp sockets.	24	85 US$ (150 KL)	2.400 KL	data for PEEK[12] TML=0.30 CVCM=0.00 WVR=0.02
SUB-D 50 pin connector, in PEEK (Ceramaseal)	Easy connectivity (push-on). Some connectors are shared by three cables. Crimp sockets.	10	120 US$ (210 KL)	1.700 KL	data for PEEK TML=0.30 CVCM=0.00 WVR=0.02
SUB-D 25 pin connector, in high alumina ceramic (Ceramaseal)	Easy connectivity (push-on). Some connectors are shared by two cables. Crimp sockets. High mating force.	24	> 600 KL	> 10.000 KL	
SUB-D 50 pin connector, in high alumina ceramic (Ceramaseal)	Easy connectivity (push-on). Some connectors are shared by three cables. Crimp sockets. High mating force.	10	> 1.000 KL	> 8.000 KL	
crimp sockets only (gold plated copper alloy)	Connection requires long time. Possible mistakes or short circuits during the connection.	400	2 KL	800 KL	

Table I.e
Connectors for feedthroughs (vacuum side) (same quantity for all the towers)

[11] Specification by Caburn

[12] Specification by Ceramseal

candidate	***notes***	***quantity /tower***	***unit price***	***price /tower***	***outgassing data/piece***	***outgassing data/tower***
multipin connectors. Shell in nickel plated brass, insulation in PEEK (Lemo)	Biased and push-pull type, with several number of poles (14, 12, 8, 4, 2). Available for crimping or soldering	100 pieces (plugs for devices included)	14 poles: 60 KL 12 poles: 50 KL 8 poles: 38 KL 4 poles: 22 KL 2 poles: 18 KL	2.700 KL	$1 \cdot 10^{-9}$ [$mbar \cdot l \cdot s^{-1}$] (preliminary data)	$1 \cdot 10^{-7}$ [$mbar \cdot l \cdot s^{-1}$]
multipin connectors. Shell in AISI 316, insulation in PEEK (Lemo)	Based and push-pull type, with several number of poles (14, 12, 8, 4, 2). Available for crimping or soldering. Long delivery time (14 weeks)	100 pieces (plugs for devices included)	about a factor 4.3 higher the prices indicated in the upper cell	11.600 KL		
crimp sockets only (gold plated copper alloy)	Connection requires long time. Possible mistakes or short circuits during the connection.	800 pieces (plugs for devices included)	2 KL	1.600 KL		

Table I.f
Connectors for in-vacuum devices (roughly the same quantity for all the towers)

candidate	*notes*	*quantity/tower*	*unit price*	*price/tower*	*outgassing data*
thin ribbons of aluminium, dry marked		ribbon 10 meter long, 12 mm wide	3 KL/m	30 KL	

Table I.g

Markers for cables and/or connectors (roughly the same quantity for all the towers)

candidate	*notes*	*quantity/ tower*	*unit price*	*price/ tower*	*outgassing data*
thermofit KYNAR tubing (Raychem)	shrinkage: 50% Shrinks when heated over 175°C. Temperature range: -55°C to + 175 °C	10 meters	5 KL/m	50 KL	TML=0.36[13] CVCM=0.07
thermofit Polyolefin tubing (Raychem)	shrinkage: 50% Shrinks when heated over 100°C. Temperature range: -55°C to + 135 °C	10 meters	5 KL/m	50 KL	TML=0.8[9] CVCM=0.08

Table I.h

Heat-shrinkable tubes (roughly the same quantity for all the towers)

candidate	*notes*	*quantity/tower*	*unit price*	*price/tower*	*outgassing data*
solder wires (Multicore)	halide free version lower flux content clear residue	TBD			

Table I.i

Solder wires (roughly the same quantity for all the towers

[13] Specification by Raychem

TALL TOWERS

	cable ID	length [m] and type STP AWG 26	STP AWG 20	parallel AWG 24	source	connected devices	LEMO connectors
1	A	11			#0	LV,MV,TP	3
2	B	13			#1	LV,MV,TP	3
3	C	16			#2	LV,MV,TP	3
4	D	19			#3	LV,MV,TP	3
5	E	22			#4	LV,MV,TP	3
6	F	25			#7	LV,MV,TP	3
7	G			12	SF	3LH,MH	2
8	H			12	SF	2MH	2
9	I	11			#0	3LH	3
10	J	10			#0	AA	1
11	K	10			#0	AA	1
12	L	10			#0	AV	1
13	M	10			#0	AH	1
14	N	10			#0	AH	1
15	O	10			#0	AH	1
16	P	10			#0	AA	1
17	Q	10			#0	2CV, 1MV	3
18	S		26		#7	2CH,2CV	4
19	T		12		#0	3CH	3
20	X			25	#7	2MA	2
21	Y			25	#7	2MH	2
22	Z	25			LS	1MH,6CH	2

TOTAL (for each tall tower) :

17 Tw&sh cables AWG 26/19, with a total lenght of m	222
2 Tw&sh cables AWG 20/19, with a total lenght of m	38
4 parall. cond. cables AWG 24/19, with a total lenght of m	74
multipin LEMO connectors	96
PEEK connectors	22

LEGEND

CH	coil with horizontal axis	#0	filter number 0 and top-ring
CV	coil with vertical axis	#N	standard filter number N
LH	LVDT with horizontal axis	#7	steering filter
LV	LVDT with vertical axis	B	Bottom of the inverted pendulum
AH	horizontal accelerometer	SF	top ring of the safety frame
AV	vertical accelerometer	LS	ast stage
AA	angular accelerometer		
MH	horizontal motor		
MV	vertical motor		
MA	angular motor		

features common to all cables, when not differently noted:

AWG 26, 19/38 stranded (i.e. 0.5 mm diameter) STP pair cables, with 8 pairs
AWG 20, 19/32 stranded (i.e. 0.94 mm diameter) STP pair cables, with 8 pairs
AWG 24, 19/34 stranded (i.e. 0.61 mm diameter) parallel conductor cables, with 14 conductors

Table II

Cables and connectors inside each tall tower

SHORT TOWERS

	cable ID	length [m] and type			source	connected devices	LEMO connectors
		STP AWG 26	STP AWG 20	parallel AWG 24			
1	A	6			#0	LV,MV,TP	3
2	F	11			#7	LV,MV,TP	3
3	G		5		SF	3LH,MH	4
4	H			5	SF	2MH	2
5	I	6			#0	3LH	4
6	J	6			#0	AA	1
7	K	6			#0	AA	1
8	L	6			#0	AV	1
9	M	6			#0	AH	1
10	N	6			#0	AH	1
11	O	6			#0	AH	1
12	P	6			#0	AA	1
13	Q	6			#0	2CV,1MV	2
14	T		5		#0	3CH	3
15	X			10	#7	2MA	2
16	Y			10	#7	2MH	2
	AA+AB		12		#7	8C	8
	AC+AD		4		B	8C	8

TOTAL (for each short tower) :

12 Tw&sh cables AWG 26, with a total lenght of m	71
4 Tw&sh cables AWG 20, with a total lenght of m	26
3 parall. cond. cables AWG 24, with a total lenght of m	25
cables for optical benches	
multipin LEMO connectors	96
PEEK connectors	20 / 22

LEGEND

CH	coil with horizontal axis	#0	filter number 0 and top-ring
CV	coil with vertical axis	#N	standard filter number N
LH	LVDT with horizontal axis	#7	steering filter
LV	LVDT with vertical axis	B	Bottom of the inverted pendulum
AH	horizontal accelerometer	SF	top ring of the safety frame
AV	vertical accelerometer	LS	last stage
AA	angular accelerometer		
MH	horizontal motor		
MV	vertical motor		
MA	angular motor		

features common to all cables, when not differently noted:

AWG 26, 19/38 stranded (i.e. 0.5 mm diameter) STP pair cables, with 8 pairs
AWG 20, 19/32 stranded (i.e. 0.94 mm diameter) STP pair cables, with 8 pairs
AWG 24, 19/34 stranded (i.e. 0.61 mm diameter) parallel conductor cables, with 14 conductors

Table III

Cables and connectors inside each short tower
(cables connecting the optical table are non described here)

COSTS for 6 tall towers **(committment starting from january 99)**

component	quantity		unity price (KL)	price	spare %
STP AWG 26	1700	m	95	161500	25
STP AWG 20	300	m	120	36000	25
parall.AWG 24	600	m	85	51000	25
flanges	14	pcs	4650	65100	15
PEEK connectors	150	pcs	150	22500	10
LEMO connectors	720	pcs	60	43200	25
accessories				20000	
tools				5000	
conductance pipe assembly				20000	
mech.clamps				20000	
			TOTAL	**444300**	**KL**

COSTS for 3 small towers **(committment starting from june 98)**

component	quantity		unity price (KL)	price	spare %
STP AWG 26	270	m	115	31050	25
STP AWG 20	100	m	138	13800	25
parall.AWG 24	100	m	110	11000	25
flanges	7	pcs	4650	32550	15
PEEK connectors	85	pcs	150	12750	10
LEMO connectors	360	pcs	60	21600	25
accessories				10000	
tools				15000	
mech. clamps					
			TOTAL	**147750**	**KL**

Table IV

Estimated costs for the vacuum cabling
(air-side cabling and costs for external manpower are not included)

item	**total outgassing flow [mbar·l/s]**
cabling	$7 \cdot 10^{-7}$
blades	$6.4 \cdot 10^{-6}$ [8]
filters	$7 \cdot 10^{-6}$ [8]
allowable total value	10^{-3} [1]

Table V
Estimated outgassing flow of cabling, compared with the ones of other items (from ref. [8]) and with the allowable total value [1].