ATLAS Muon Spectrometer

Thin Gap Chambers

Construction Manual

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Revision record

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1 Introduction

The present manual describes the various steps needed to construct, test and install the ATLAS Thin Gap Chambers. It includes the suppliers of the materials, the procedure for each operation, the quality checks to be performed at each point and the consequences of such checks.

Each construction step is given a step name, e.g. mchn_strip, which is used to identify the step in the construction data base, process flow charts and other documentation.

1.1 Definitions

The TGC system is divided into two regions: The *Forward* region with $|\eta|>\sim 1.9$ and the *End-cap* region with $\sim 1.0<|\eta|<\sim 1.9$. Chambers are located at various positions along the z-axis called *stations*. The middle *station*, ‘M’ consists of M1, a layer of triplets, and M2 and M3, each a layer of doublets. The inner station, ‘I’, consists of a layer of doublets. Chambers are grouped together in various entities, defined below:

chamber, counter a single layer of active detector elements. For TGCs, this is a wire plane and its strips.

unit a doublet or triplet of *chambers*. This is the object which is shipped to CERN.

module a group of End-cap *units* covering the range of radii of the End-cap, at the same *z* and ϕ. A module is not a mechanical entity, but a logical entity used by the trigger logic. For the Forward region a *module* is one *unit*.

set a group of 3 (End-cap inner station) or 2 (End-cap middle station) *modules* assembled in a frame and mounted on the TGC support wheel. For the Forward region, a *set* is one *module*, thus one *unit*.

octant depending on the context, either all the *sets* in one *station* of an octant or all the *sets* in all the *station*s of an octant

2 Pre-construction

2.1 Check of board thickness

Step name: chk_thick

Supplier: most likely DITRON (Italy), see included data sheet.

Procedure:

The thickness of the $2300\times1280\,mm^2$ FR4 boards are checked using a micrometer at 8 different points (3 on each long side and 1 on each short side). If deviations of more than ±0.1 mm are observed on the required thickness (Class 3 1.4 mm for boards to be used for frames, Class 2 1.8 mm for boards used as outer skin and 1.6 mm for read-out boards) The areas are marked. If the deviations are in a region where the board can still be used for a given detector size, they are kept, otherwise the board is returned to the manufacturer, as being outside tolerances. Boards that are within the tolerances are put on a flat table, covered with silicone rubber sheet and vacuum applied. A flat ruler is put on top of the silicone rubber sheet at 6 different positions (4 on the width and 2 on the length). Deviations from flatness are checked by sliding a piece of paper (one piece = 0.1 mm, two = 0.2 mm) under the ruler. If deviations of 0.2 mm or more are found in the required regions of the board, the board is rejected.

Duration: 15 minutes / board, 2 people.

Quality control: as described above.

2.2 Machining of cathode boards

Step name: mchn_cath

Supplier: most likely Maresco (Israel).

Procedure:
Boards are supplied by the Weizmann Institute after a quality check. The 1.8 mm or 1.6 mm boards without patterns are fixed by vacuum on a large CNC milling machine and cut to size. There will be a total of 3600 1.8 mm boards and 432 1.6 mm boards, both with 35 micron copper cladding. During the cutting holes for location pins will be drilled and the board type number will be marked in the copper.

There will be four batches of boards, not counting spares:

1. 768 boards at middle of 1998
2. 1152 boards at middle of 1999
3. 1344 boards at middle of 2000
4. 768 boards at middle of 2001

Data base procedure: a sticker that contains the type of detector and serial number of the board (in bar-code) is attached.

2.3 Machining of strip boards

Step name: mchn_strip

Supplier: most likely Maresco (Israel).

Procedure:

The strip patterns on 3200 boards, 1.6 mm, 35 microns copper cladding one side, are made by machining in a large CNC milling machine. Boards are supplied by the Weizmann Institute after the quality check. There will be two types of boards ($1280\times1800\,mm^2$, where the bad parts have been eliminated and $1250\times2300\,mm^2$).

There will be four batches, not counting spares:

5. 576 boards at middle of 1998
6. 960 boards at September of 1999
7. 864 boards at September of 2000
8. 768 boards at September of 2001

The strip patterns are supplied by the Weizmann Institute on a computer diskette. The patterns consists of strips, with the widths varying between 48 mm to 15 mm. There are 11 different patterns. The gap between strips is 2.2 mm and it should not be to less than 1 mm for any length. Gaps of 1.5 mm can be tolerated for lengths not exceeding 20 mm. There must not be any shorts between strips; there must not be any electrical break along any strip. While the boards are mounted on the milling machine, they are machined to the correct size and holes for pins are drilled as in Section 2.2, "Machining of cathode boards". Also the board type number is marked in the copper.

Quality control: Visual inspection and check for shorts and cuts. The control is performed using an ohmmeter. Any shorts are cut with a surgical knife. Any discontinuities are corrected by soldering.

Duration of the quality control: 5' / board.

Data base procedure: a sticker that contains the type of detector and serial number of the board (in bar-code) is attached.

2.4 Etching of wire soldering pads

Step name: etch_wpad

Supplier: most likely Slikha (Israel).

Procedure:

Etching of 112 boards, 1.4 ± 0.1 mm, 35 microns copper cladding on one side. Boards supplied by the Weizmann Institute after the quality check. The boards could have width varying between 300 mm to 600 mm depending on the demands of the supplier, with a length of 2300 mm. The pattern (see Figure 2-1) consists of a chain of soldering pads, 4 mm width and varying length (9 mm to 45 mm). The space between pads being 0.5 ± 0.1. The tolerance on the full length

(2300 mm) is ±0.2 mm. Every 600 mm, the pattern contains a marking for a pin, which will be used for cutting and alignment of the frame. The etching should be made by direct contact. No holes larger than 0.5 mm can be accepted in the print. The print for the etching pattern will also contain a type code (a number or possibly bar-code) for the individual pattern.

There will be two batches of 50 and of 62 boards (one in 1998 and one at the end of 1999). The patterns will be supplied by the Weizmann Institute on a diskette.

Quality control: to be done by the firm, as part of the specifications.

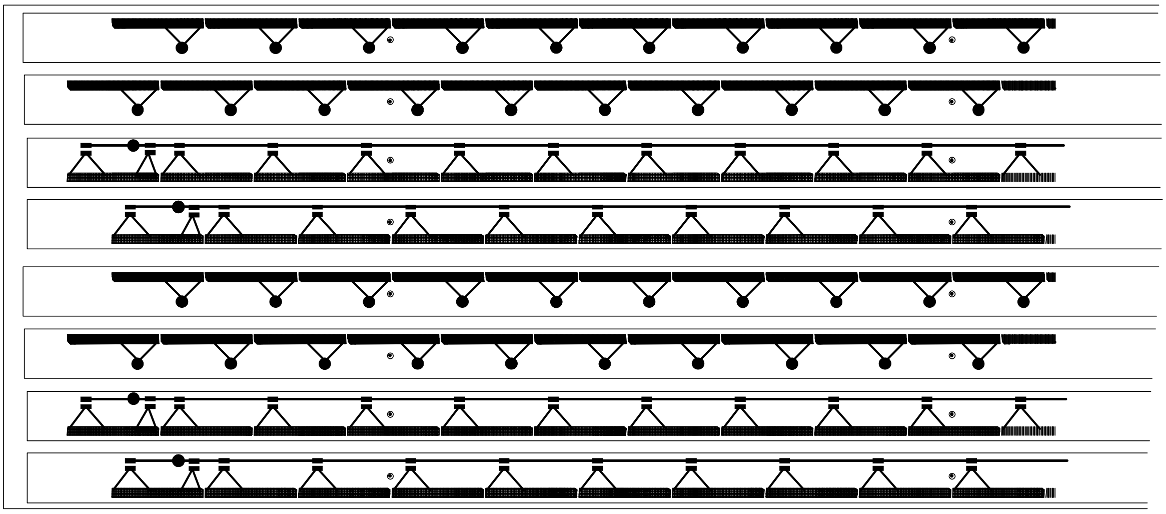

Figure 2-1 End of one of the long thin boards showing eight wire-pad frames with their wire soldering pads, four frames with pads for resistors and four with pads for capacitors.

2.5 Machining of wire-pad frames and covering frames

Step name: mchn_wpad, mchn_wcov

Supplier: Weizmann Institute mechanical workshop

Procedure:

The boards for the wire-pad frames have the locations for alignment holes etched on them. Holes are drilled at these points. For the covering frames, which have no etched pattern, the holes are drilled every 60 cm using an aluminium jig plate with 20 frames stacked together. Pins are then inserted at the holes and 20 frames are machined together on one side (the side on the inner edge of the detector, at a fixed distance from the pins). Single profiles are then individually machined by passing through a multi-head profile maker which uses the machined edge as the guide. The shape of the final profile is shown in Figure 2-2. After machining, the machined edge is painted with an epoxy layer.

Duration of the process: 1'/hole drilling; 10'/stack of frames to insert pins; 20'/side for machining stack of 20; 5'/frame to machine the profile.

Quality control: Visual inspection of the frames, under a magnifying glass, while painting the edges with an epoxy layer.

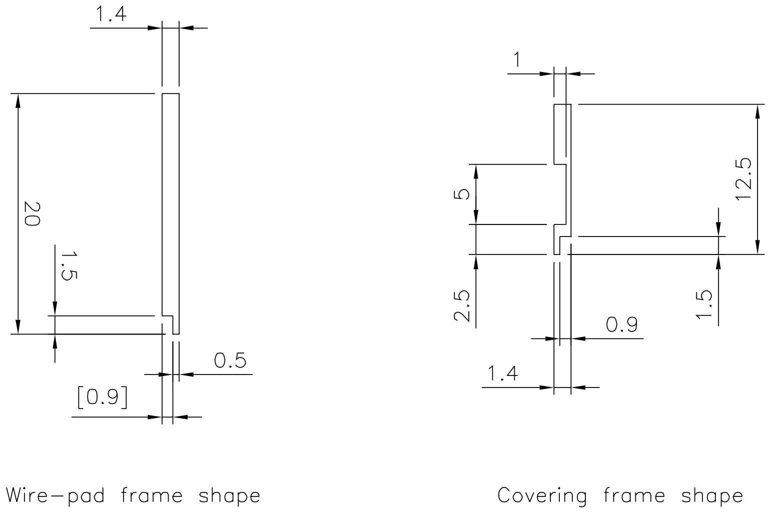

Figure 2-2 Shape of the final profiles of the wire-pad frame and covering frame.

2.6 Machining of wire supports and end frames

Step name: mchn_sup, mchn_end

Supplier: Weizmann Institute mechanical workshop.

Procedure:

The FR4 boards are cut to their approximate size (+5mm) with a guillotine. The profiles are then machined to size by passing through a multi-head profile maker. The shape of the final profile for the wire support is shown in Figure 2-3. The profiles for end-frames are stuck to a plate with double-sided sticky tape and then the grooves for the gas and ground connections and an alignment hole are machined. The machined edges are painted with epoxy.

Duration of the process: 5'/support; 3'/frame, 5' to stick 20 end-frames 10' for machining the grooves on a set of 20. 2’ for the epoxy painting.

Quality control: Visual inspection of the wire supports, under a magnifying glass, while painting the edges with an epoxy layer.

2.7 Cutting of honey-comb frames

Step name: cut_hcframe

Supplier: Pas-Gon (Israel) (see data sheet); work to be performed by Weizmann Institute mechanical workshop.

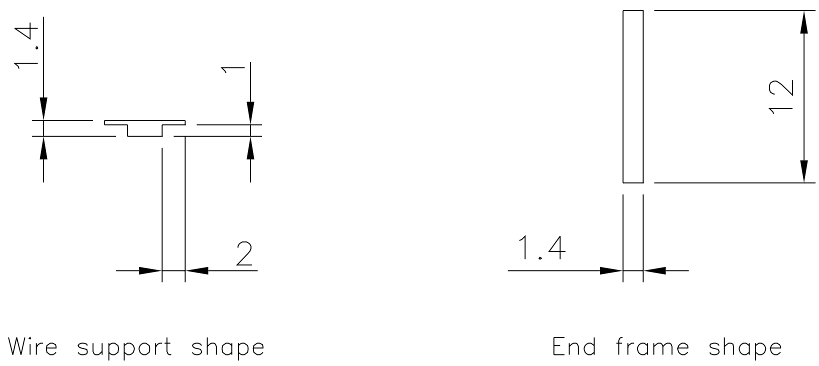

Figure 2-3 The shape of the final profile of the wire support and end frames.

Procedure:

Hollow epoxy-fibre glass profiles are cut to approximate length (+10mm) and then 5 pieces are put on a jig to do the final cutting (at the appropriate angle). Holes for the frame assembly are drilled, either by aligning various frames or by using a special jig for the edges. Every joint of the frames contains one hole for a pin.

Duration of the process: 1' for approximate cutting of bar; 5' for exact cutting of 5 bars; 10'/bar for holes; 15' for assembly of frames.

Quality control: The flatness of the frame is checked by laying it on a flat table. Deviations of less than 0.2mm will be solved during the honey-comb gluing. Larger deviations are solved at this step by re-adjusting the connection pins.

2.8 Preparation of small button supports

Step name: mold_button

Supplier: Weizmann Institute mechanical workshop.

Procedure:

Small round button supports will be produced by moulding. A large number are made at once in a mold made of three layers of teflon. Heated Araldite mixed with glass-fibres is poured into the moulds and covered. They are taken out after a curing of 12hours.

Quality control: Performed when the supports are at mounted for gluing, described later in Section 3.5, "Gluing of frames and wire supports".

3 Construction

3.1 Masking for graphite spraying

Step name: mask_graph

Supplier: Procedure performed at Weizmann Institute and KEK.

Procedure:

Special masking tape is used to cover the cathode plates in the areas where frames and wire supports are to be glued. The FR-4 boards are put on a flat table; dummy frames are attached to the boards using pins. A jig containing the position of the wire supports is then inserted and the lines where the support frames are going to be glued is covered with masking tape (3.2 mm width). One by one, each of the dummy frames are removed and are covered with masking tape.

Duration of the process: 15' / board.

Data base procedure: The bar-code sticker on the jig and the one on the board are read by a bar-code reader. In the case of a wrong combination, an error message appears on a terminal screen with an audible alarm, otherwise, the type of cathode is attributed to that particular board in the data base.

3.2 Graphite spraying

Step name: spray_graph

Supplier: Graphite supplier: Kontakt Chemie (Germany), see data sheet; operation performed at KEK and Weizmann Institute.

Procedure:

Boards are hung from hangers that role on rails into the spraying area. Before any spraying operation (to be performed from once a week to once a month), the two component graphite mixture is prepared in a tank connected to the spraying tool. The quality of the mixture's resistivity and viscosity) are checked by spraying a sample board with the same thickness. After changing the mixture to achieve the right qualities (the quality is checked by fast drying of the spayed board and performing a surface resistivity measurement), the boards are slid, one-by-one, into the spraying area and sprayed (20 to 80 boards each time). The spraying is done with a manual spray gun at Weizmann and with an automatic sprayer (see Figure 3-1) at KEK.

Duration of the process: 5' / board; 60" for preparatory work. Boards are left to dry for more than 10 hours.

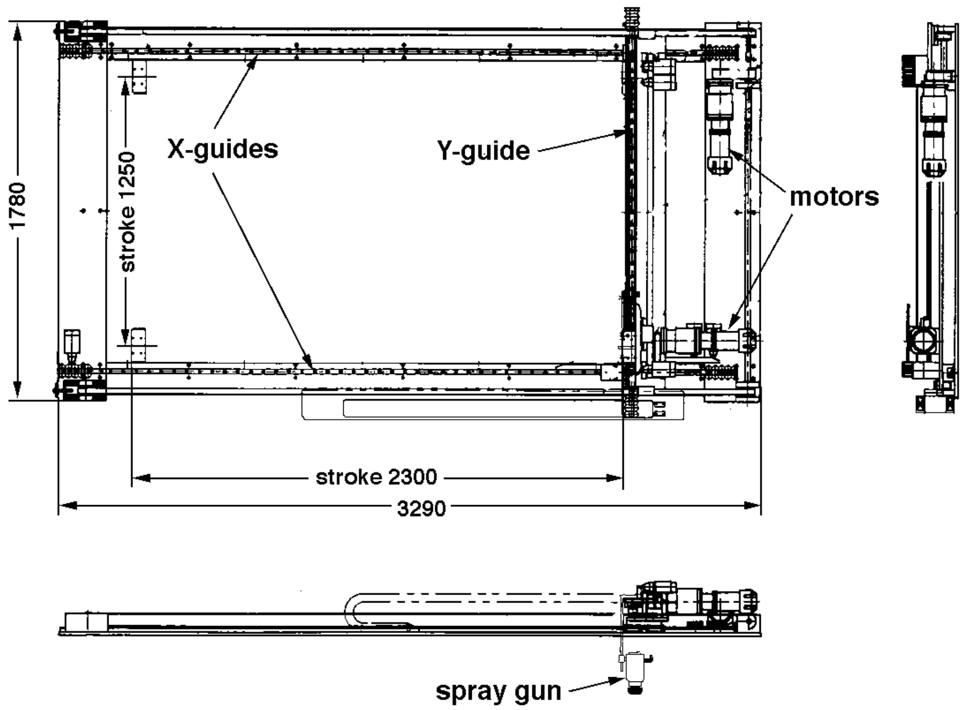

Figure 3-1 The automatic graphite sprayer at KEK.

3.3 Graphite polishing

Step name: polish_graph

Supplier: Weizmann Institute and KEK

Procedure:

The bar-code of the board is read and the board is put on a flat table, where the masking tape is removed. The graphite is then polished using anti-static paper. After polishing, a first measurement of the resistivity is performed at six points (two on each side and two in the central part). If all the measurements are in the range of 0.5 to $2.0 M\Omega/\text{square}$, then the final resistivity measurement is performed. If the resistivity exceeds the above values, the board is polished with a grinding machine, until the needed resistivity is achieved. If the resistivity is below the above values, the board is set aside for removing all the graphite and repeating the procedures of Sections 3.1-3.3 and the information on the board type is erased in the data base. The resistivity measurement is then performed at five points between each line of wire supports and the measured values are entered into the data base. Contacts are then glued at each ground output using silver paint, covered with graphite paint. After drying, the resistivity values between adjacent ground contacts are entered into the data base. The ground contacts (copper strips) are then stuck to the back of the board. The boards are then stored until needed.

Duration of the process: removing masking tape: 2'/board, testing: 2'/board, polishing: 10'/board, resistivity measurement: 5'/board (two people); contacts and measuring: 10'/board.

Data base procedure: the data on the given board are updated according to the procedure described above.

3.4 Gluing of honey-comb ½-panels

Step name: glue_hcpanel

Supplier: Boards and frames as described above. Honey-comb paper from Halat D'vash (Israel); glue from Kibbutz Gvulot (Israel). Procedure to be performed at Weizmann Institute and KEK.

Procedure:

The operation is performed on a granite table, flat to within 0.03 mm over its full surface ($1300\times2400\,mm^2$). There are two types of ½-panels: one containing the chamber cathodes, that will be described here, and the other for over-pressure protection (5 mm thick), which is a simplified version of the present description. The board is put on the flat table and vacuum is applied inside the lower part of the frame shown in Figure 3-2. The bar-code sticker is removed

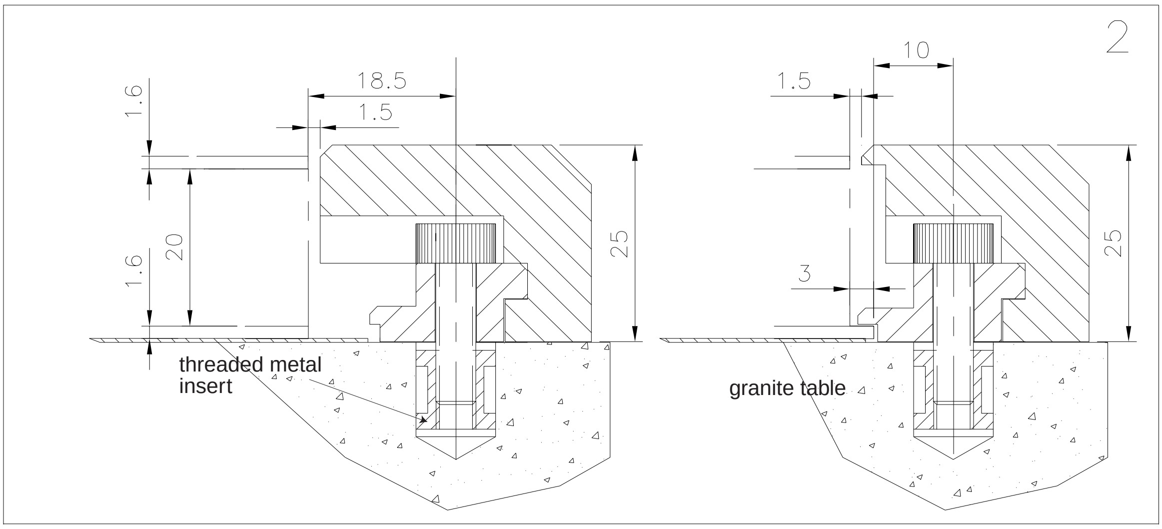

Figure 3-2 Aluminum profiles around the cathode-honeycomb assembly for gluing the honeycomb to the cathode board (the profile perpendicular to the wires, left, and parallel, right).

and the ground contacts for the graphite are covered with tape. The gluing surface is cleaned with a paper impregnated in isopropyl-alcohol and the area then dried with paper. Pins are inserted in the holes on the long and short sides of the trapezoid and the holes for fixing the chamber frames are covered with Scotch tape (0.05 mm thickness). The glue, pre-mixed with isopropyl-alcohol (to achieved the needed viscosity) is applied with a roller. Glue is also applied to the frame on the sides that will be in contact with the board and with the honey-comb, before bringing it into contact with the board. This contact is achieved using the two pins as a guide. Hammering (with a plastic hammer) on the two pins, ensures good contact between frame and board. The pre-cut (to achieve a trapezoidal shape) and pre-stressed honey-comb paper is also impregnated with glue, using a roller on the surface to be glued. The honey-comb is then inserted into the frame and attached to the long and short bases of the trapezoid using Scotch tape, to ensure good contact between the two. The assembly is covered with a teflon plate of the same size. Four aluminium profiles, as shown in Figure 3-2, are put around the edges (to ensure that the vacuum will not press on the side of the frames) and then, the full assembly is covered with a silicone rubber sheet, and vacuum is applied on the edges from under the table. The vacuum is checked with a gauge, ensuring that the internal pressure does not go below 660mm Hg (otherwise an alarm is activated). A straight ruler is then laid on the assembly at four points (the two base frames and two places close to the middle) to check the planarity of the set-up. If deviations of more than 0.2 mm are observed (two pieces of papers inserted between ruler and silicone rubber sheet), the assembly is re-opened and the reason for the problem corrected. A sample of the glue used for the process is left on top of the table for further checks before releasing the vacuum.

Duration of the process: 45' / stack, two people.

Quality control: After checking the curing on the sample of glue, the vacuum is released and the silicone rubber sheet is lifted. A ruler is posed on the stack to check that the planarity is better than 0.2 mm.

Data base procedure: The bar-code sticker is applied to the back of the honey-comb (no bar-code is put on the over-pressure ½-panel). The bar-code is read and the data base is updated with the information that the stack is completed.

3.5 Gluing of frames and wire supports

Step name: glue_frame

Supplier: Araldite 2011 from Ciba-Geigy (see data sheet). Work performed at Weizmann Institute and KEK

Procedure:

The operation is performed on a flat table, flat to within 0.2 mm over its full surface ($1300 \times 2400\,mm^2$). There are two types of cathodes: one incorporating a ½-honey-comb panel (for which the frame shown in Figure 3-3a is used) while the other is a 1.8 mm thick FR4 cathode (for which the frame shown in Figure 3-3b is used). The bar-code number of the cathode is read in. The cathode is placed on the flat table and the graphite surface is cleaned with anti-static paper. The two wire frames are attached to the cathode using two pins and their bar-codes are read (in the case of honey-comb backed cathode, no bar-code is attached to the wirecover. The gluing jig is then inserted between the frames and its bar-code is read. The data base gives the OK if it is a correct combination. Glue is then applied to the back of the wire supports, which are then attached through the slits of the jig, while pressing on them, to ensure good contact. The wire frames are then removed one-by-one and glue is applied to them and they are attached to the cathode. Two teflon pins are inserted in the holes at the extreme ends of the frames. The two frames for the long and short bases are then glued using the pins as a guide. Using a special flat grinding tool and the holes in the jig as a guide, the graphite underneath each hole is cleaned and then compressed air is used to clean any remaining graphite dust. The small wire supports are then picked up with a vacuum pencil on the wide side. The quality of foot is then inspected and covered with glue and then inserted into the hole. After releasing the vacuum in the pencil, the support is pressed into its position. The aluminium profiles (Figure 3-3) around the edges ensure that the vacuum will not press on the side of the frames. The full assembly is covered with a silicone rubber sheet, and vacuum is applied on the edges from under the table. The vacuum is monitored by a gauge, ensuring that the internal pressure does not drop below 660 mm Hg (otherwise an alarm is activated). A sample of the epoxy glue used for the process (slow setting Araldite with bubbles eliminated by applying a vacuum) is left on top of the table for further checks before releasing the vacuum.

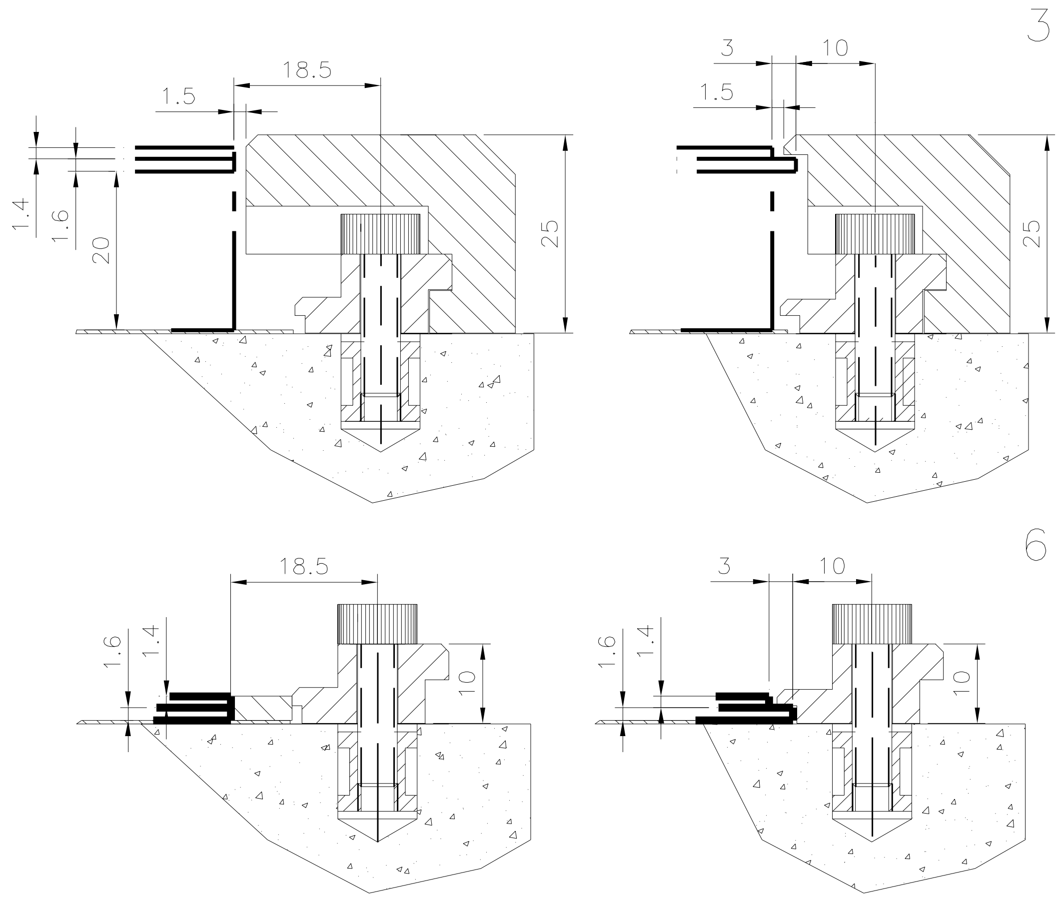

Figure 3-3 Profiles for gluing (above) the frame for a cathode incorporating a ½-honey-comb panel, (below) the frame for a cathode consisting of 1.8mm FR4. (The profile perpendicular to the wires, is on the left, and parallel, the right).

Duration of the process: 30'/stack, two people; curing time: 12hours.

Quality control: After checking the curing on the sample of glue left on top of the table, the vacuum is released and the silicone rubber sheet is lifted. A visual inspection is then made, to ensure that the various parts that have been glued are in good contact (one can see if bubbles are present).

Data base procedure: At the beginning of the procedure, the various bar-codes (boards, gluing jig) are read and the wire frame types are entered; these uniquely define the board type.

3.6 Anode wire plane winding of two detectors

Step name: wind

Supplier : 50micron gold-plated tungsten wire from Osram (USA), see data sheet. Work performed at Weizmann Institute and KEK

Procedure:

Two cathode planes with their corresponding frames are mounted on a rotating winding machine (see Figure 3-4) and the anode plane is wound around the two with a fixed tension of 350 g. The procedure is started by winding 10 wire lines with a special mounted elevator that keeps the wires 5 mm above the wire plane. With the winding table in an horizontal position, a cathode board is inserted and aligned on one side with the third wire. Vacuum is then applied on that corner. The board is then rotated until the other side is aligned with the same wire and full vacuum is then applied underneath the board. The board is then fixed to the table with side supports. The valve is then opened to the central vacuum system of the table, and, provided that the vacuum gauge shows less than xx mb, the auxiliary vacuum is disconnected and the table turned by 180°. The same procedure is repeated with the second board, using the auxiliary vacuum system on the upper side. Once the vacuum gauge on the auxiliary system shows the proper value, the valves connecting to the central vacuum system are opened. The auxiliary vacuum system is then disconnected; the winding machine is then rotated backwards 10 turns and the elevator pieces are removed. The winding machine is then operated normally until the winding is completed.

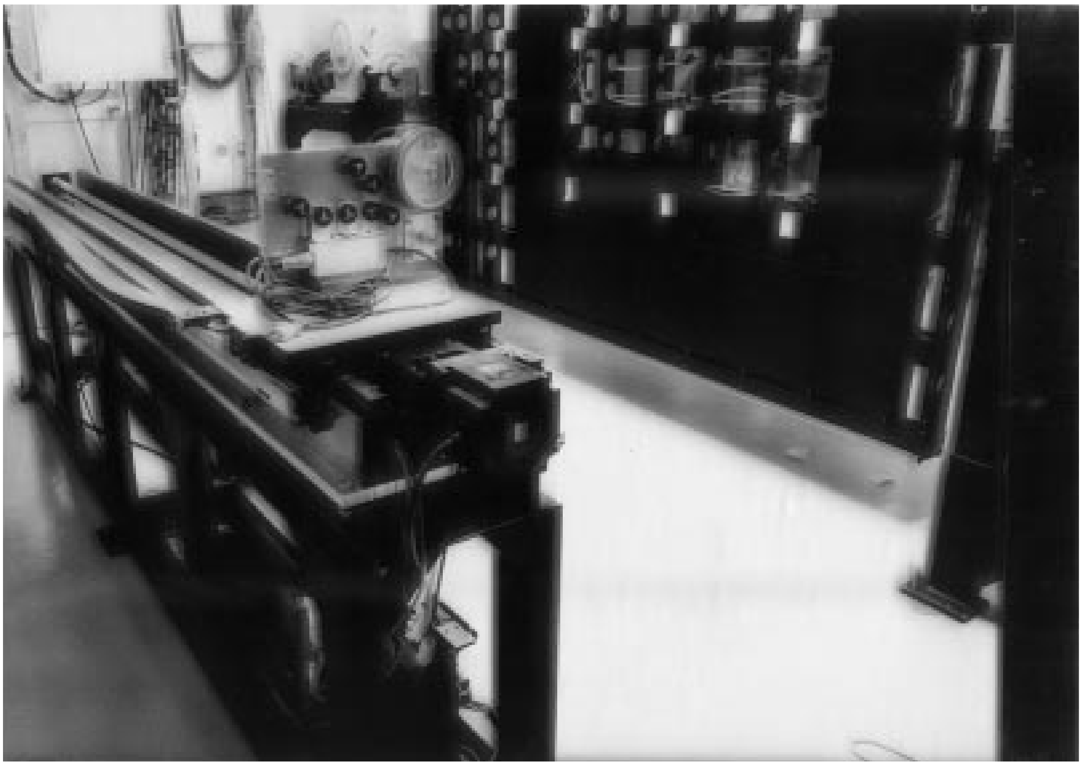

Figure 3-4 Winding machine at KEK showing the attachment vacuum system.

Duration of the process: 20', 2 people to attached the boards. Winding time: 2 hours.

Quality control: See Section 3.8, "Soldering of resistors and wire tension check".

Possible problems:

- *Power cut during winding*: Both the winding machine and the vacuum pump are supplied by a UPS. In the event of a power failure, the winding machine will be brought to a vertical position and the vacuum pump will continue working for ½-hour. When power is restored, the vacuum pump and machine are restarted. The wire is unwound five turns (where tension is still OK) and then continued winding forward.

- *Wire break*: Occurs very seldom. In this case the winding machine stops immediately (due to lack of wire tension. Solder the last ten rows of wires to a piece of copper coated FR4. Rewind the machine 5 turns, solder the new wire end, together with the last ten rows; start rewinding and check that the wire overlaps with the previous wire for at least two rows. Cut the last five rows of the first wire and continue winding.

3.7 Soldering and washing

Step name: solder_wires

Supplier: Soldering tin and flux made by Universal Soldering (South Africa), see data sheet from chemical analysis. Operation performed at Weizmann Institute and KEK.

Procedure:

The winding table is fixed in the horizontal position with the blocking mechanism. The flux is applied with a brush. Pre-made strips of tin are placed above the wires and touched with the soldering iron at 350°C. The tin melts over a total distance of 10 mm and one touches at each wire with the soldering iron. The operation is repeated over the full detector length. The winding table is then turned by 180° and the soldering operation is repeated for the second plane. At this point, the auxiliary vacuum systems are connected to the two planes and the wires are cut with a surgical knife. The excess of wires are removed and the winding table is placed in a vertical position. Demineralized water, with the help of a brush, is then used to wash away the water soluble flux from the lower part of both detectors. The detectors are dried with dry air. The winding table is then turned by 180° and the operation is repeated on the other edge.

Duration of the process: soldering 15'/side; washing 10'/side.

Quality control: See Section 3.8, "Soldering of resistors and wire tension check".

3.8 Soldering of resistors and wire tension check

Step name: solder_resistors, chk_tension

Supplier: Soldering tin Supersold (Israel); 10 MΩ, ¼ W SMD resistors xx (xx). Operation performed at Weizmann Institute and KEK.

Procedure:

The winding table is fixed on the horizontal position with the blocking mechanism. The resistors are soldered with fast evaporating flux and then the soldering area is cleaned with a brush wetted with isopropyl alcohol and dried with dry air. The resistivity is measured between the HV distribution line and the output of the wire groups with an ohm-meter. The resistivity should be 10 MΩ; if larger, the resistor is changed, if smaller, the soldering around resistor is cleaned. If the problem still remains, the resistivity is then measured between the two adjacent wire groups on the side opposite to the HV resistors; if smaller than 20MΩ, a surgical knife is used to separate the groups, if larger, the resistor with a bad contact is located and repaired.

The vacuum valve to the upper plane is closed. The side supports on the side opposite to the HV resistors are removed. The board then curves, due to the wire tension, and a visual inspection readily detects any wire with lower tension than its neighbours. If such a a wire is detected (which is seldom the case), its corresponding group of wires and their corresponding resistors are removed. The cathode board is then re-attached to the table for rewinding that particular group. In the case of uniform tension, an aluminium transport frame is attached to the side opposite to the HV resistors and connected with springs to the winding table. The table is then rotated by 80° and the transport frame is attached to the crane; the side supports on the HV resistors side are then removed, as well as the springs, and the cathode is transported with the crane to the clean room. The winding table is then set in the horizontal position and the operation is repeated for the other cathode plane.

Duration of the process: checking of the tension: 15'; soldering of the resistors: 15'; 2' for checking; transport to clean room: 10'.

Quality control: The measurements of the resistivity between high voltage line and capacitor soldering pads (10MΩ each) and between adjacent ground groups (20MΩ) are checked.

3.9 Mounting on the detector closing table

Step name: mount_toclose

Supplier: Operation performed at Weizmann Institute and KEK.

Procedure:

The bar-code sticker on the back of the board is removed and set aside. The board with the anode plane is attached to a fixed support on the right hand side (looking towards the smaller base) of the trapezoid, on top of the granite table. It is then slid towards the small base of the trapezoid until it is fixed under the fixed support. The vacuum is then opened under the cathode and the left side is then pushed towards the table and fixed by supports of 400mm length with screws to the table. The procedure is completed by fixing the supports on the long base of the trapezoid. See Figure 3-5.

Duration of the process: 15'; 2 people.

3.10 High voltage tests before closure

Step name: chk_HVclose

Supplier: Operation performed at Weizmann Institute and KEK.

Procedure:

The HV distribution line is soldered to an external HV source, as well as the contacts of the graphite to ground. The ½-detector is then cleaned with dry air and HV is applied to the ½-detector. At 2500V, the current should not exceed 20μA. If no sparks are observed the HV is

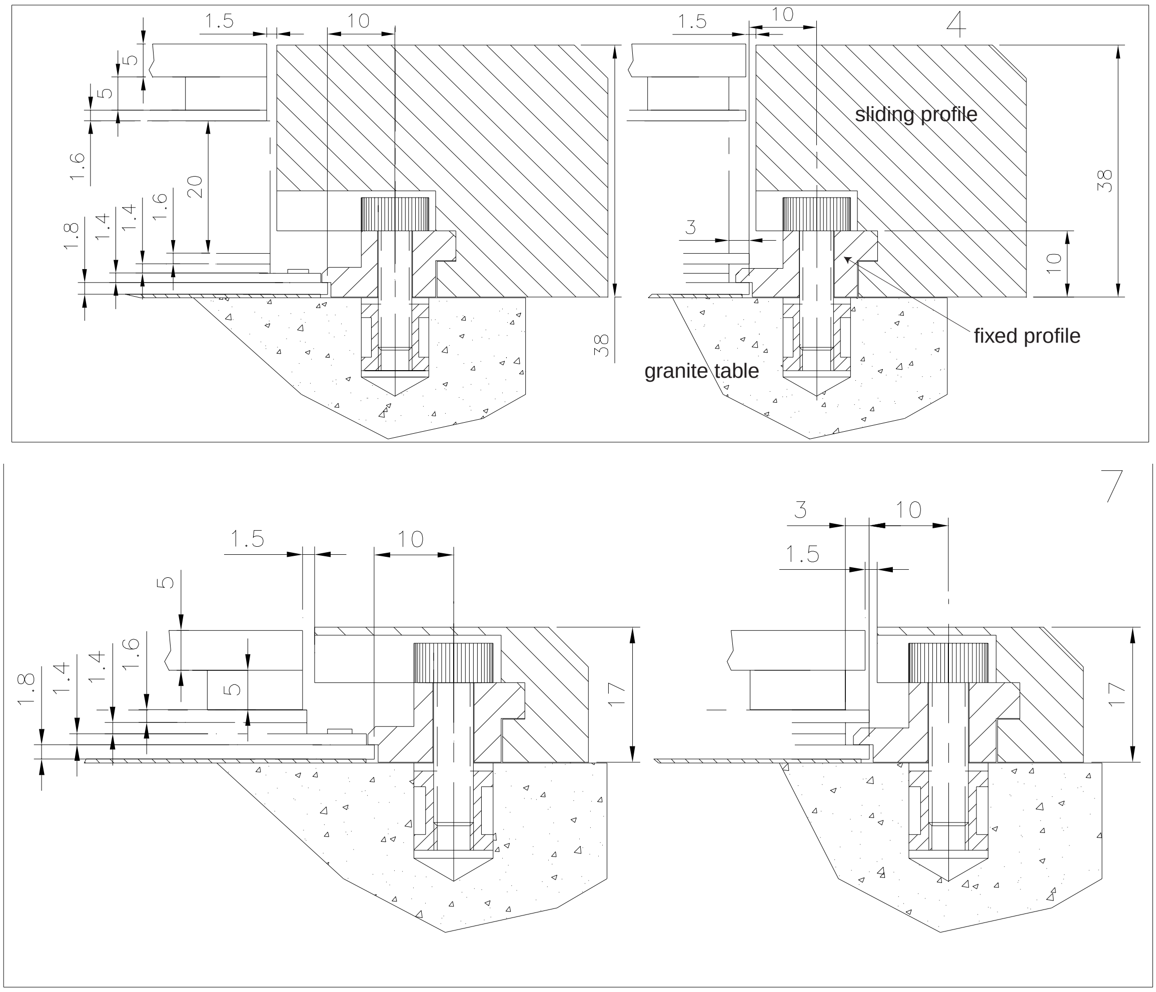

Figure 3-5 Profiles for closing the detector for a cathode incorporating a ½-honey-comb panel (above), and a cathode consisting of 1.8 mm FR4 (below). (The profile perpendicular to the wires, is on the left, and parallel, on the right).

switched off. The alignment pins are then inserted and the second cathode is lowered with the crane, using the pins as a guide and the graphite contacts are connected to ground. An aluminium plate that has rubber inserts located opposite each wire support is then lowered to close the detector. Before performing this operation, the data base procedure is performed. Gas lines are connected to the chamber inputs and aluminium profiles (see Figure 3-5) are put around the closed detector. The full assembly is then covered with a silicone rubber sheet and a vacuum of 720 mm Hg is applied. The vacuum is then stopped and CO_2 is flowed until the silicone rubber sheet is inflated. The vacuum / CO_2 procedure is applied a second time, and while CO_2 is flowing through the detector, a voltage of 2800 V is applied. The current should stay under 20 μA. The above procedure is repeated again, but this time a mixture of CO_2-*n*-pentane is used, and the detector is operated at 3200 V, with a current not exceeding 50 μA. The detector is kept operating for two minutes. Vacuum is then applied to remove the CO_2-*n*-pentane mixture. The silicone rubber sheet and the aluminium cover plate are then removed. Finally, the cover cathode plate is disconnected from ground and lifted with the crane. If there have been sparks during the above procedure, one searches for their signs in the graphite and removes the cause (usually dirt).

Duration of the process: 20'; 2 people.

Data base procedure: The bar-code is removed also from the cover cathode The bar-code of the cathodes are read-out as well as the bar-code of the aluminium pressure plate. If the matching is correct, an OK appears on the screen and a new bar-code sticker is printed and attached to the cover cathode. This new bar-code is an identifier for the chamber.

3.11 Closing of the detector

Step name: close

Supplier: Slow setting Araldite treated by vacuum to eliminate bubbles. Procedure to be performed at Weizmann Institute and KEK.

Procedure:

Glue is applied to the frames and supports of the cover cathode, as well as to the frame of the side with the anode plane. Two guiding pins are inserted again (only on one of the sides perpendicular to the wires), but this time with glue. Then the cover cathode is lower again with the crane and connected to ground. The aluminium pressure plate is then lowered and the aluminium profiles around are inserted. Finally, the silicone rubber sheet is lowered and a vacuum of 720 mm Hg is applied. A voltage of 300 V is applied to the detector in order to check that there are no broken wires. Finally, a sample of the glue is put on top of the stack for checking the curing.

Duration of the process: 20', two people. Curing time: 12 hours.

3.12 Mounting of HV capacitors

Step name: mount_caps, test_caps

Supplier: Capacitors: Murata (Japan). Anti-corona paint: Isola (Switzerland). Procedure to be performed at Weizmann and KEK.

Procedure:

The vacuum is released from the upper part of the detector and the silicone rubber sheet and aluminium pressure plate are removed. While the detector is still with vacuum from underneath, the planarity is checked again as above. The aluminium profiles are removed from around the detector and the tested capacitors (two in series) are soldered. The capacitors and soldering points are painted with anti-corona paint. Connection wires are also soldered to the cathode strips. The vacuum is released and 6 mb over-pressure is introduced from underneath, to allow lifting of the detector with a crane. The detector is mounted on a special carriage (see Figure 3-6), where the detector can be gas sealed.

Duration of the process: 30', two people.

Quality control: HV capacitors are tested for 2 days at 4 KV in a capacitor testing bank.

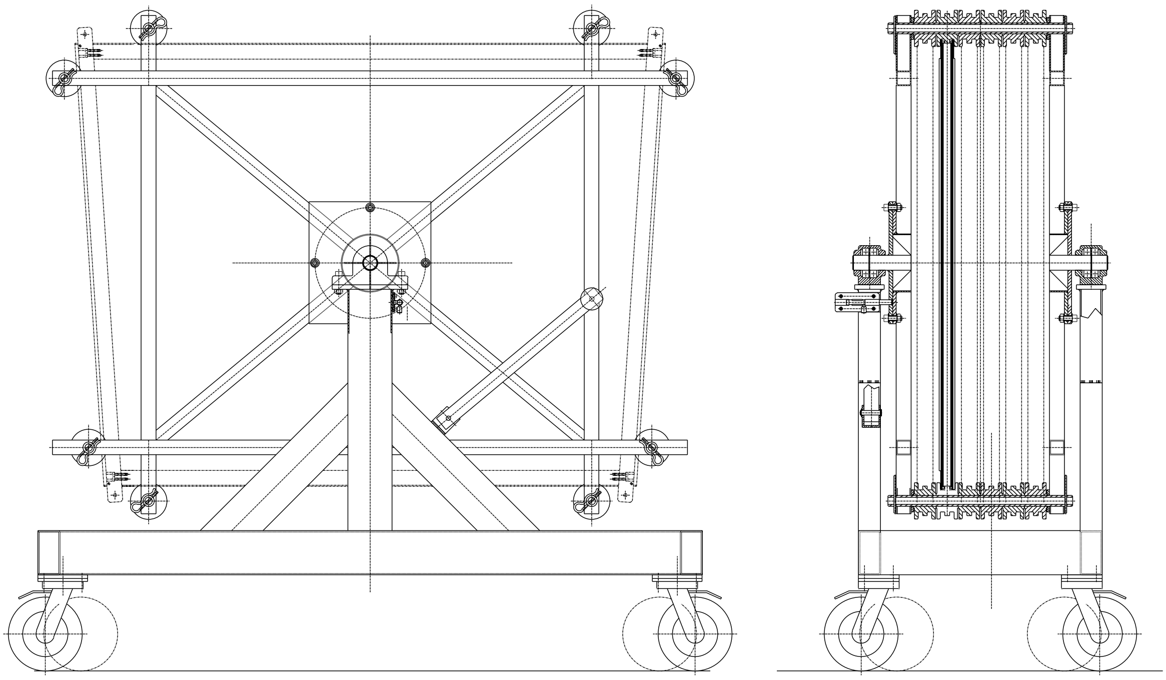

Figure 3-6 The special carriage for detector sealing.

3.13 Gas sealing of detector plane

Step name: seal_edges

Supplier: heated epoxy glue from Kibbutz Gvulot (Israel). Procedure to be performed at Weizmann and KEK.

Procedure:

The missing pins are introduced with glue. Heated epoxy is applied using a syringe to the capacitor edge of the detector. If the plane has a backing honey-comb, the capacitors are then pushed towards the honeycomb frame. After 5 hours curing time, the carriage is rotated by 90° and the same procedure is repeated. On the side where the HV resistors are located, they are also potted with the epoxy. On the side where input and output gas holes are located, the gas connectors (made of machined FR4) are also glued in the same operation. The relative order in which the edges are sealed, is not important and up to 10 detector planes can be mounted on the carriage and sealed simultaneously.

Duration of the process: 10' / edge.

Quality control: Once the detector is sealed, CO_2 is flowed through with a 1 mb over-pressure. If no proper flow is achieved within 5 minutes, the leak is found using a leak detector and fixed with fast setting Araldite.

3.14 Gluing together of doublets and triplets

Step name: glue_units

Supplier: Epoxy glue from Kibbutz Gvulot (Israel) mixed with isopropyl alcohol to achieve the needed viscosity. Procedure to be performed at Weizmann and KEK.

Procedure:

The operation is performed on a granite table, flat to within 0.03 mm over its full surface (1300×2400 mm^2). The bar-code stickers are removed from the detectors that will be joined together and read into the data base. An OK will appear on the screen if the combination is correct. A new bar-code sticker is printed for the final unit. The basic counter (without backing honey-comb) is put on the flat table within a plastic frame (see Figure 3-7) and vacuum is ap-

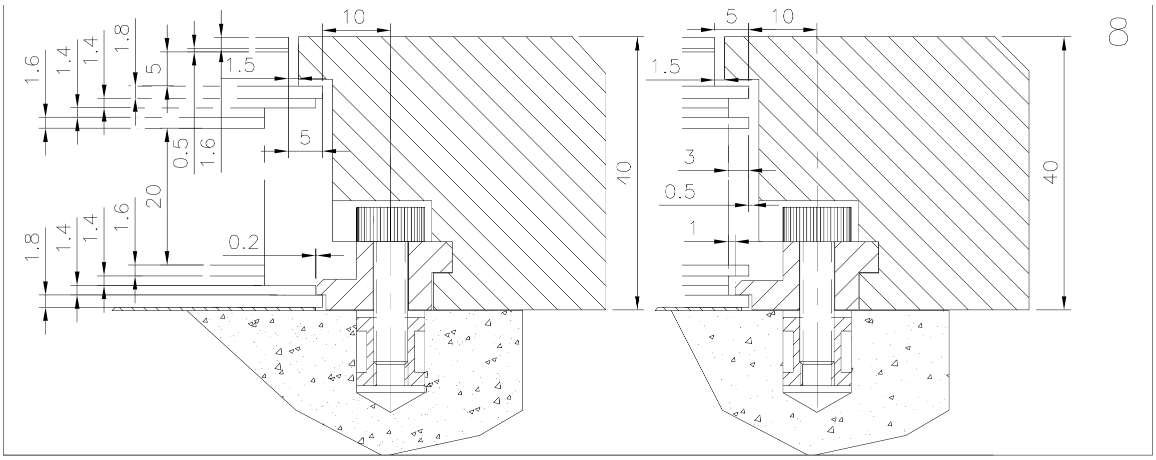

Figure 3-7 Profiles for gluing two chambers and an over-pressure protection layer together.

plied from underneath. A ruler is put on top to check the flatness (should be within 0.2 mm), and then the counter is pressurize with 6 mb over-pressure, using CO_2. The flatness should stay within the above limits. The ruler is removed and the glue is applied using a roller. Two pins are then inserted in the short and long bases to guide the frame of the next chamber in the stack. Glue is also applied to the backing honey-comb of the next counter in the stack, as well as to its honey-comb frame. The detector is lowered with the crane, using the pins as a guide. A ruler is put on top to check the planarity (again to within 0.2 mm) and then the over-pressure of 6 mb is applied. The same operation is repeated with either the detector (for a triplet) or for the over-pressure protection (for the doublet) and the planarity is checked again. Aluminium profiles are put around the stack (see Figure 3-7), the silicone rubber sheet is lowered and a vacuum of 720 mm Hg is applied, while regulating the CO_2 pressure to keep the 6 mb over-pressure. A ruler is put on top of the stack, to check the flatness and a sample of glue is left on top, to check the curing. After 12 hours curing time, the vacuum is released, the flatness is checked again and the stack is turned around to glue the second over-pressure protection honey-comb layer. This is done using the same procedure, i.e. 6 mb over-pressure in each counter, however without any vacuum underneath the stack (see Figure 3-8). Again here, the glue is applied using a roller and the final stack is left to cure for 12 hours.

Duration of the process: 20' / gluing layer, two people. Curing time: 12 hours.

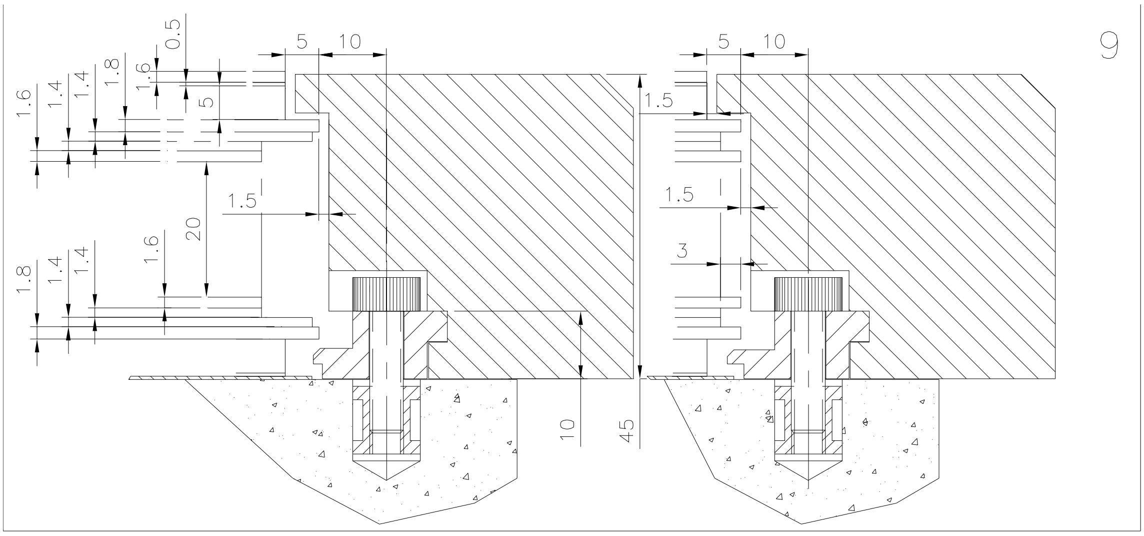

Figure 3-8 Profiles for gluing the second over-pressure protection layer.

Quality control: Described in the procedure.

Data base procedure: the sticker containing the bar-code, as well as the serial number and type of unit in a print form is attached to the unit on its front face.

3.15 Over-pressure test

Step name: test_over

Supplier: Procedure to be performed at Weizmann Institute and KEK.

Procedure:

The unit is released from the gluing table and put on the transport carriage. At this point, CO_2 is flowed through the gas volume of the unit, the output is closed and the over-pressure protection is set at 6mb. The input is then closed and the detector is kept at over-pressure. If the over-pressure drops to 5mb in less than 5 minutes, the gas input is then opened to search for the leak using a leak detector. Once the leak is fixed, the procedure is repeated until the above condition is satisfied. CO_2 is then flowed through the detector at atmospheric pressure.

Duration of the process: 20'/unit, if no leak. 60' if there is a leak.

Quality control: Described in the procedure.

Data base procedure: The sticker containing the bar-code is read and the time taken for the pressure to drop from 6 to 5mb is entered (leak rate).

3.16 Installation of adapter board and HV cables

Step name: mount_adapt

Procedure:
The transport carriage is rotated so the HV capacitors are pointing upwards. The adapter board (which includes the lines that bring the output signals to the amplifier connector) is then attached and the output wires from either the capacitors or the strips are soldered with tin containing a fast evaporating flux. The soldering points are then cleaned with a brush that has been immersed in acetone and evaporated with dry air. The HV tested cables are then soldered to the HV distribution lines and the ground to the ground decoupling resistor.

Duration of the process: 20' / side, for a doublet or 30' for a triplet. 10' for the HV cables.

Quality control: The output connectors are connected to a DAQ system. Pulses of 200V, 10µs long are sent through the HV line and their output read out and histogramed. If one channel does not give the right output, the connection, and the capacitor are checked, and the fault is corrected.

Data base procedure: The bar-code is read and the name of the file where the average and RMS pulse height for each channel is entered into the data base.

3.17 Potting of adapter boards and installation of cover plates

Step name: pot_adapt

Supplier: Procedure to be performed at Weizmann Institute and KEK.

Procedure:
After two days of CO_2 flow at 40 ml / min, a voltage of 2900V is applied to the detector. The current should not exceed 100µA. This is done to check possible leakage current due to insufficient cleaning of the flux on the adapter board. If a problem is found, one uses dry air to find the location by scanning with dry air while watching the current and then cleaning the spot. The plastic screws that support the amplifier cards are then inserted into the honey-comb frame (see Figure 3-9) and the adapter boards are put in a vertical position. Heated glue is then applied with a syringe to pot the capacitors and to ensure a gas-sealed volume between the chamber and the adapter boards. The gas cover plates (see Figure 3-9) are then glued to the adapter boards. After 6 hours of curing, the procedure is repeated on the strip read out side (without potting of capacitors) and then on the following two sides. When the gluing procedure is completed, the volume around the detector is subjected to an over-pressure of CO_2. An over-pressure of 3 mbar that falls to 2 mbar in less than 5 minutes indicates a leak that must be repaired. Following this, copper U-profiles, 0.2 mm thick, which have soldering holes every 150 mm are then put around the unit and soldered to the chamber’s outside ground through the holes. Finally, temporary attachment rings are attached at the places where the kinematic mountings will be installed (see Figure 3-10), in order to transport with the crane.

Duration of the process: 10' for the HV test. 20' / side for the potting and 10' / side for the covering sides. 30' to apply the copper U-profiles and solder them.

Quality control: After the procedure, and while CO_2 is still flowing through the unit, 2800V is applied. The total current should not exceed 100µA. A set of 10 units are then taken by the transport carriage to the testing area.

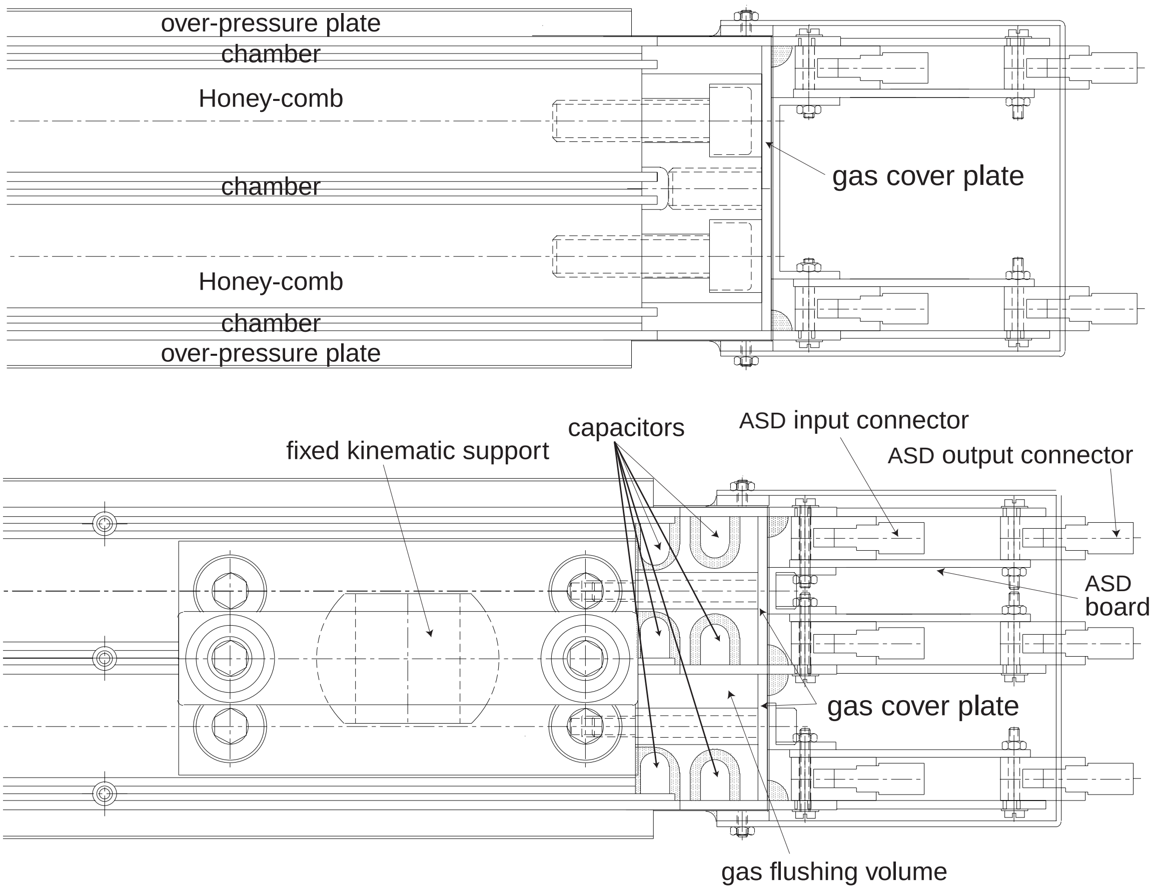

Figure 3-9 The plastic screws that support the amplifier cards are then inserted into the honey-comb frame, and the gas cover plate glued for the wire side (above) and the strip side (below).

3.18 General testing of the chambers

Step name: test_source

Supplier: Procedure to be performed at Weizmann Institute and KEK.

Procedure:

After completion, the chamber unit (doublet or triplet) is kept at 2900V for a day, while flowing CO_2 at 40 ml / min. If no current trips are observed, they will be flushed with the operating gas (CO_2-*n*-pentane) for two days, then run for one day at the nominal operating voltage and for two days at 200V above the nominal operating voltage. Also at 200V above the nominal operating voltage, the chambers are scanned with a 5 mCi ^{90}Sr source, to be able to detect any hot spots. Finally, each of the output channels is checked for the presence of signals, while irradiating with the source. The unit is then flushed with CO_2 and sealed. This procedure has been used previously in the OPAL TGC detectors, where detectors constructed in 1987 and stored as explained above have been operated in 1996 after two days of gas flushing.

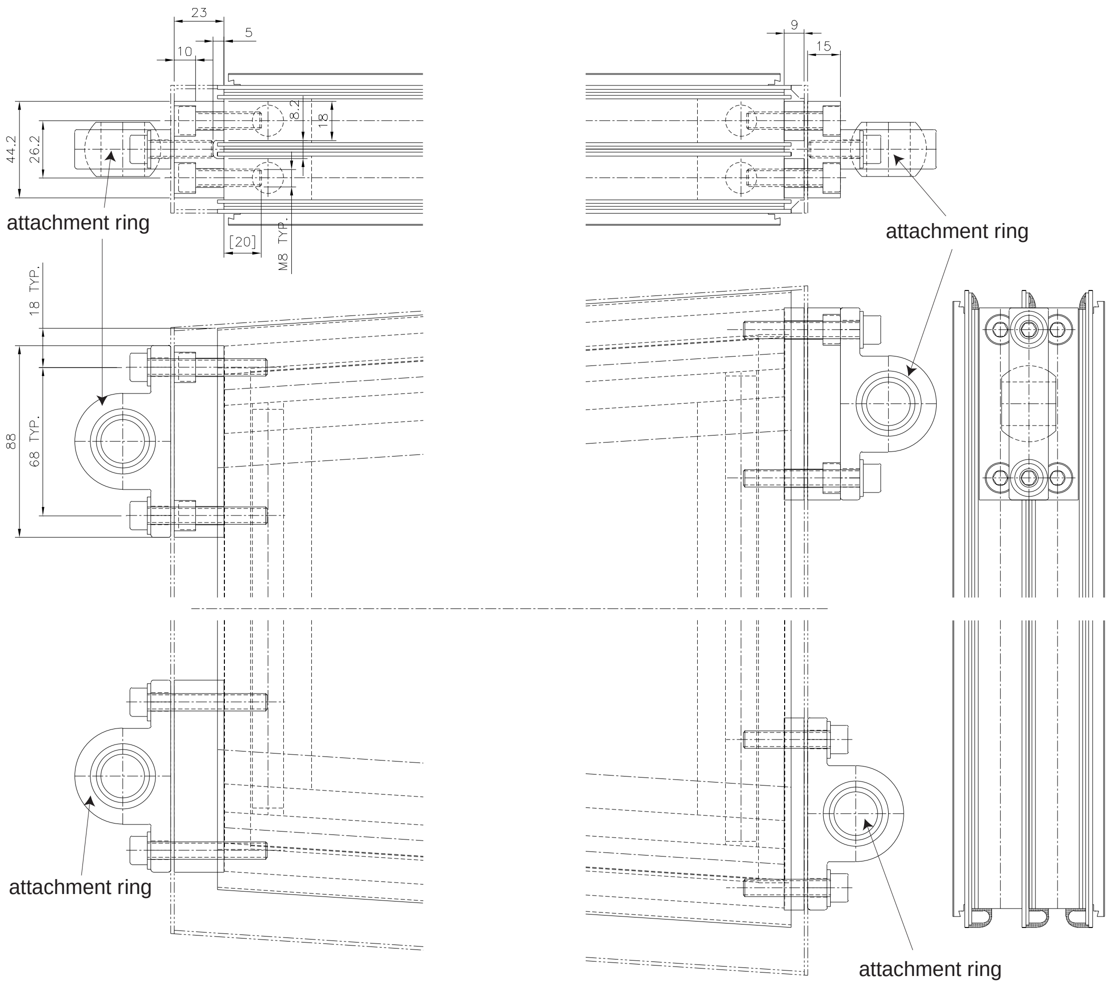

Figure 3-10 Triplet unit with temporary attachment frames installed

4 Acceptance tests

4.1 Test of TGC units in a cosmic ray telescope

Step name: test_cosmic

Supplier: Procedure to be performed at Technion, Tel Aviv University, Kobe University.

Procedure:

At the test site the TGC units pass three steps of processing, shown in the flow diagram in Figure 4-1:

- Preliminary checks
- Efficiency test
- Validation (Acceptance / Rejection)

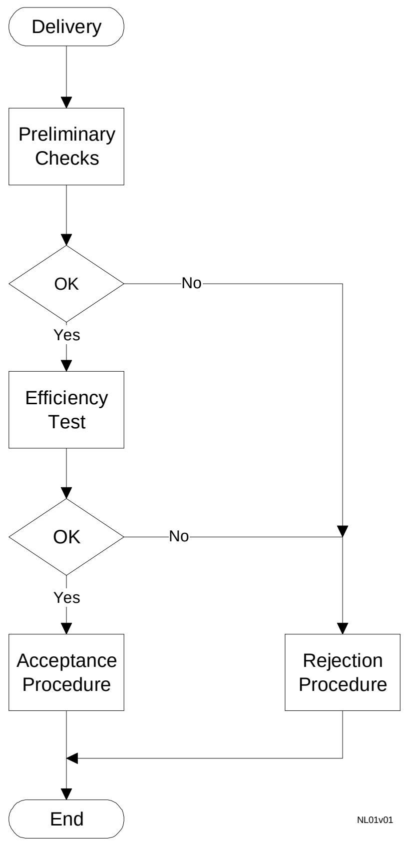

Figure 4-1 Process flow of the TGC cosmic ray test.

4.1.1 Preliminary Checks

This set of checks is performed at the TGC test site in order to screen out defects or damage during transportation from the production site. Incoming TGC units are identified by their code number and are registered in the data base.

Mechanical integrity inspection A visual inspection of the incoming TGC units is performed to check that no damage was done to them during transport.

Electrical integrity check A signal generator injects pulses at the TGS HV connection. Resulting signals are recorded by a multi-channeled Data Acquisition System based on a PC. The purpose of this procedure is to identify bad TGC wires and strips channels and automatically record the status in the data base.

Gas integrity of chambers A gas over-pressure test, as described in Section 3.15, "Over-pressure test" and Section 3.17, "Potting of adapter boards and installation of cover plates", is performed.

High Voltage check After flowing gas mixture for 48 hours, the module is tested under HV of Nominal +200V = 3300V. The current of each counter should be < 15μA. No sparking should be encountered. The current and number of sparks (if any) should be recorded in the data base.

4.1.2 Efficiency Test

Only the units that pass all the four preliminary tests are transferred to the TGC Cosmic Ray Test Bench for the efficiency test. The scope of this test is to measure the time response of the TGC counters. This is done with a cosmic rays telescope, schematically shown in Figure 4-2. Two precision chambers on top and bottom provide accurate tracking of cosmic rays. Accumulating events for a period of two weeks will permit a full mapping of the efficiency of each detector in the stack. Three such telescopes will be constructed to complete the scanning of the TGCs during a three year period.

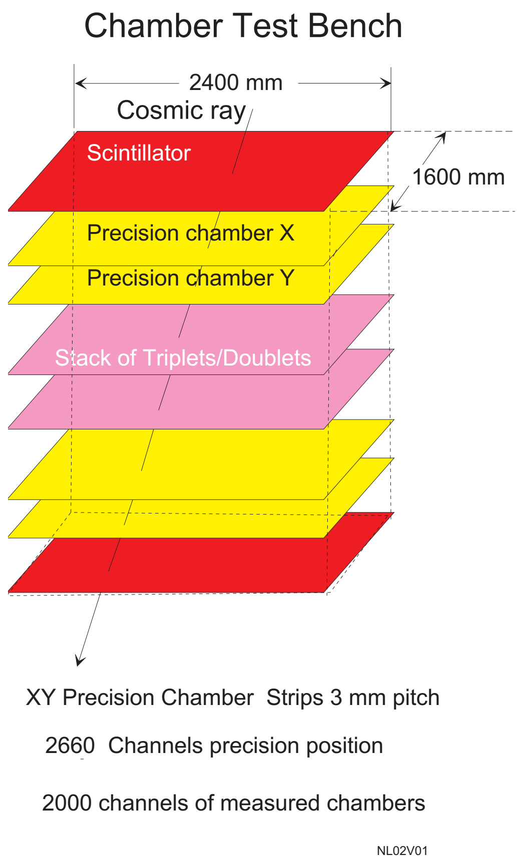

Figure 4-2 Schematic diagram of cosmic ray telescope

Procedure:

Groups of 5 to 6 TGC units (12 to 15 wire planes) equipped with front-end electronics (ASD) are mounted on the cosmic-ray telescope and the output from each of the discriminator channels is read for cosmic events. At the end of approximately one week of data acquisition a provisional evaluation of the performance of each counter is done.

The pass criteria is 98% efficiency with a 25 nsec gate for 95% of the total pixels on wires and strips.

1. If the preliminary efficiency test is passed, the test is continue for another week to accumulate enough statistics for the final efficiency evaluation.
2. If not, the signal detection threshold is lowered by 10%, and the efficiency test is continued for another week for new evaluation.
3. If the test is not passed, the unit is removed from the test bench for off-line local repairs if possible.

After successfully passing this test, detectors are flushed with CO_2, sealed and prepared for the transportation to CERN in shipping containers, with a container reaching CERN every few months from the end of 2002.

4.1.3 Validation procedure

For each TGC unit (doublet or triplet) its bar-code is read and the efficiency test results and other information for that unit is fetched from the data base. If all the criteria are passed, an acceptance status is recorded in the data base for future reference. If not, a rejection status is recorded in the data base for future reference.

Data base procedure: Efficiency test results and other information is read from the data base and the cosmic test pass / fail result is recorded.

4.2 Preparation for storage and shipping to CERN

Step name: prep_store, ship

Supplier: Procedure to be performed at Weizmann Institute and Kobe University.

Procedure:

After successfully passing the validation process the chamber are flushed with CO_2, sealed and stored. When the front-end electronics becomes available, it will mounted on the chambers and the chamber ground will be connected around it, to make a Faraday cage. The mounted front-end electronics will be tested again by connecting to a trigger card that will inject pulses to the front-end channels and test the response. The transport to CERN will be performed in shipping containers, with a container reaching CERN every few months from 2002.

Data base procedure: The bar-code is read-in and the shipping details recorded.

4.3 Test on arrival at CERN

Step name: test_arrival

Procedure:

On arrival at CERN a test of each unit is performed following the same procedures described in Section 4.1.1, "Preliminary Checks".

Data base procedure: The bar-code is read-in and the test results are recorded.

4.4 Radioactive source scan at CERN

Step name: scan_source

Supplier: Procedure to be performed by a joint team from Israel and Japan.

Procedure:

At CERN, the chamber is stored until final mounting and testing. Experience in OPAL shows that storing the chambers for a few years, until final mounting in the experiment should not be a problem. The OPAL TGC's, some of which were constructed in 1987, were stored for nine years and then operated again without problem, after two days of gas flushing, for testing purposes.

Groups of chambers will be attached to the test trigger electronics and a read out system.This group will then be flushed with gas for two days, chambers and electronics will then be powered for a period of a few weeks, and scanned for two days with a ^{60}Co source. This source permits scanning simultaneously all the layers of a doublet or triplet. Assuming that the source moves at a uniform speed, one will be able, from the integrated rates of each channel, to monitor the performance of the detector and front-end electronics. Following this test, the chambers will be flushed with CO_2, and stored until final mounting on the support structures.

Data base procedure: The bar-code is read-in and the test results are recorded.

5 Installation

The TGC support will connect to the TGC wheel structures. A simplified scheme using only standard aluminium profiles and right-angle brackets is proposed. The aluminium profiles will add considerable stiffness to the wheel support structure and should be taken into consideration for the final wheel design.

The frames will connect two 'ladders¹ of chambers and serve to stiffen the whole structure. The assembly of these structure will be done at CERN in the horizontal position. When the full frame structure of 1 sector (out of 24) is completed, electronics, cables, and gas lines can be mounted before the chambers are connected to the frame. Then only a small number of connections has to be made.

To move the completed frame into the vertical position, a stiffening and transport frame will be used. The chambers will be added to the frame when it is in the vertical position. For the installation of the TGCs on the detector a number (about 20) of these transport frames will be built.

5.1 Assembly of the support frame

Step name: assemble_support

See Figure 5-1a-c. *To be completed.*

5.2 Cabling of support frame and gas leak test of gas tubing

Step name: cable_frame, leaktest_tubing

To be completed.

5.3 Mounting units on the support frame

Step name: mount_units, connect_infra, mount_elect, leaktest_tubing2

- Mounting of units on the support frame.
- Connection to infrastructure.
- Mounting electronics
- Gas leak test.

To be completed.

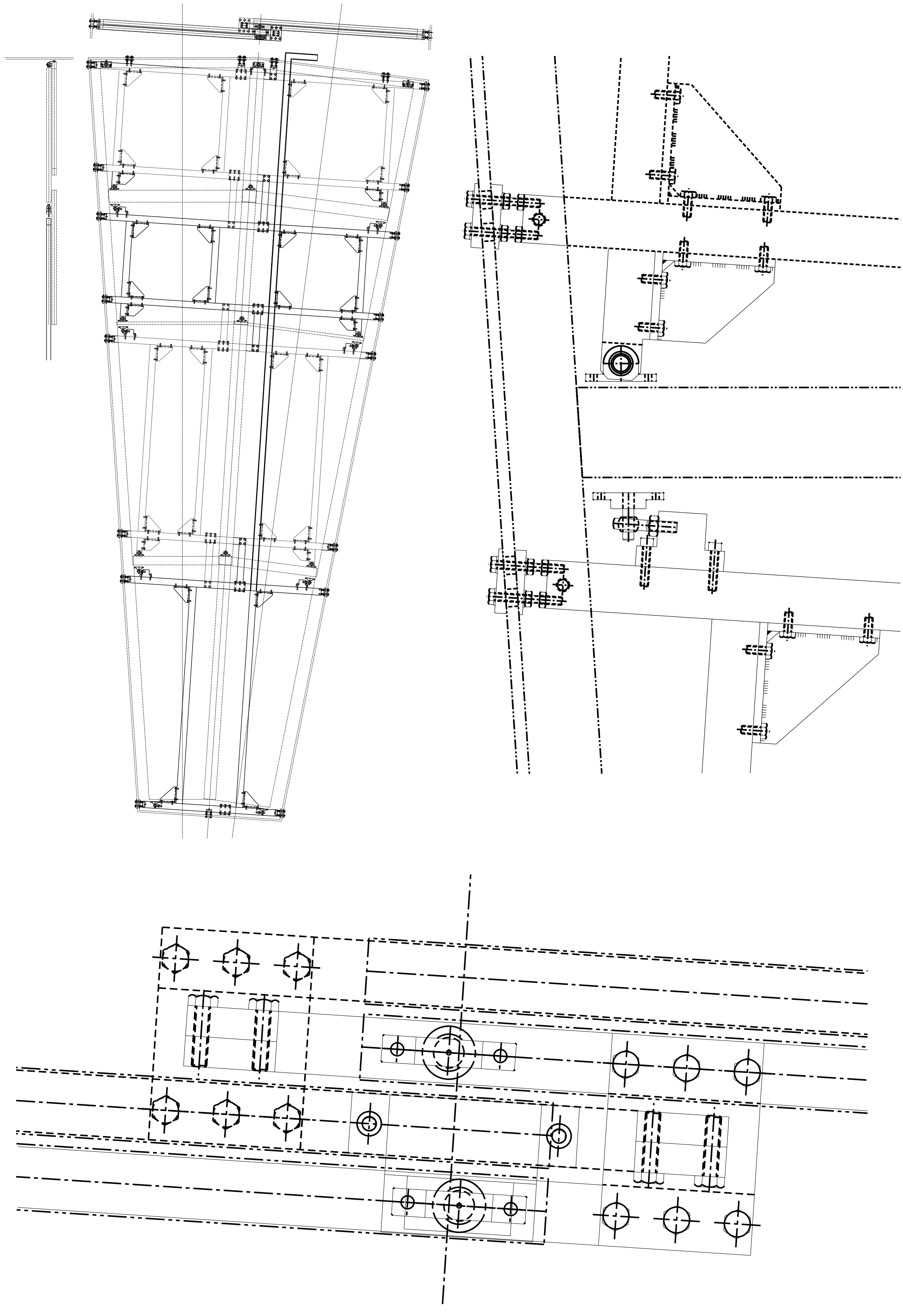

Figure 5-1 Support frame: overview (left), mounting details(bottom), and kinematic supports attachment (right).

5.4 Mounting on the final structure and release of the transport frame

Step name:

To be completed.

5.5 Over-pressure test of CO_2-*n*-pentane and CO_2 circuits

Step name:

To be completed.

5.6 Testing the electronics

Step name:

To be completed.

5.7 Testing the detectors with the operating gas

Step name:

To be completed.

6 Appendix

6.1 Summary of Quality Control procedures

Table 6-1 Summary of Quality Control procedures

Item	Procedure	Section
FR-4 boards	Control of thickness using micrometer and straight ruler with board under vacuum. (deviations of ±0.1 mm)	2.2
Strip boards	Check for shorts with ohmmeter.	2.3
Wire supports & frames	Visual inspection while painting with Araldite (no hairs).	2.5, 2.6
Honey-comb frame flatness	Checked on flat table (deviations of 0.2 mm)	2.7
Graphite resist	Surface resistivity measured with ohmmeter at 25 points (0.5-2.0MΩ) and between adjacent ground contacts (10-20 MΩ)	3.3
Planarity of honey-comb ½-panel	Checked with straight ruler and slide paper pieces (<0.2 mm)	3.4
Gluing of supports and frames	Visual inspection, looking for large bubbles (>3 mm diameter)	3.5
Resistors and contacts	Checked with ohmmeter between input HV and capacitor pad (10 ±1 MΩ)	3.8
Wire tension	Release detector from winding table (±10%)	3.8
Closing of chamber	Full operation of chamber at 3200 V after evacuating and filling twice with CO_2 and twice with CO_2-*n*-pentane (current <50 μA)	3.10
Check for broken wires	Apply 300V after closing for gluing (current <0.1 μA)	3.11
Capacitor tests	2 days at 4000V (no shorts)	3.12
Leak test I	Flow achieved in 5' at 1mb	3.13
Gluing chambers	Check planarity using a ruler (<0.2 mm)	3.14
Leak test II	Test of triplet (doublet) with 6 mb over-pressure (6 to 5 mb in >5')	3.15
Electrical test I	Inject 200V, 10 μsec pulses through HV line and read all outputs (PH to within 10%)	3.16
CO_2-HV test	2900V with flushing CO_2 (current <0.1 mA)	3.17
Leak test III	Check CO_2 dilution circuit around module by measuring leak rate from 3 to 2 mb (>5')	3.17
General testing of module	2 Days operation at 3300 V (no more than 3 current trips at 100 μA). Scan with source to find hot spots	3.18
Acceptance test	Cosmic ray testing of modules	4.1
Arrival tests at CERN	Leak test II and III and general testing of module	4.3
Radioactive scan at CERN	Scan chamber with ^{60}Co source and check rate uniformity	4.4

6.2 Summary of data base procedures

Table 6-2 Summary of Data base procedures

Item	Procedure	Section
Cathode board ID	While machining the boards, the board type is machined in the copper.	2.2, 2.3
Cathode board bar-code	Upon reception, a sticker with a bar-code and a serial number is attached.	2.2, 2.3
Wire soldering pads ID	For each detector type, there are 10 different wire pads types, which are etched in numbers and in bar-code.	2.4
Masking for wire supports	The bar-code of the board and of the jig are read. This defines the position of the boards along the 7 layers. Each layer has the supports at a different place.	3.1
Resistivity measurement	The bar-code of the board is read-in and the measured resistivities are entered in the data base (for that board).	3.3
Honey-comb gluing	The bar-code of the board is read-in and the information that contains a backing honey-comb is added in the data-base.	3.4
Gluing of frames	The bar-code of the board and of the identifier of the wire frame is either read or typed. This defines uniquely the position of the cathode (front-end electronics on the left or on the right). It also checks if the combination board-jig-frame is legal.	3.5
Closing of detector	The bar-code of the two cathodes are read-in and a new bar-code is produced with a detector identification, which in the data base points to the information of the two cathodes. Reading the bar-code of both cathodes as well as the pressure plate permits a check of the correctness of the matching.	3.10
Gluing together of doublets and triplets	The bar-codes of all the detectors to be glued is read in. This checks the legality of the matching and allows for the new identifier (unit bar-code) to point to its individual parts in the data-base.	3.14
Over-pressure tests	The bar-code sticker of the unit is read-in and the leak rate is typed for each test.	3.15, 3.17, 4.1.1, 4.3
Test-pulsing of detector	The bar-code of the unit is read-in and a pointer to the results of the pulse test file is given in the data-base.	3.16
Efficiency check	The bar-code of the unit is read-in and a pointer to the file containing the efficiency measurement is given.	4.1.3
Scan at CERN	The bar-code of the unit is read-in and a pointer to the file containing the rate per channel information is given.	4.4

6.3 Bar-codes of the TGC components

The bar codes ensure that every unit will be built with the proper components assembled with the proper jigs. One can distinguish 4 types of items, which will be marked using an alphanumeric code (bar-code '39-extended' is a candidate):

- Large items identified by both a type code and a serial number
- Items identified by a type code only
- Items wearing no bar-code, but stored in batches with bar-code
- Jigs with a type code and no serial number

Only the minimum essential information needed to actually define the item is encoded as a bar-code. Item's are not assigned to specific chambers. The following notations are used in the definitions below:

[0001..0nnn]	Serial number
[01..11]	Chamber major type number, defined by the outer dimensions
[A,C]	Side of ATLAS on which the item will be mounted
[1..4]	Station number: 1 to 3 for M1 to M3, 4 for I
[1..9]	Layer (within doublet or triplet) in which the item will be mounted: M1 spans from 1 to 3, M2, M3 and I from 4 to 5, 6 to 7, and 8 to 9, respectively.
[L,R]	Left and Right module inside a set
[P,N]	pivot plane, not pivot plane (for strip board)
[F,E1..E5]	Forward, EndCap innermost..EndCap outermost (E4 for triplet, E5 for doublets)

Table 6-3 Bar-code definitions

Large items	
Cathode board (no strips, 1.8 mm)	C [01..11] [0001..3600]
Inner board for triplet (no strips, 1.6 mm)	I [01..11] [001..432]
Strip board (1.6 mm)	S [01..11] [A, C] [P, N] [0001..3168]
Detector (chamber)	D [01..11] [A, C] [1..9] [L, R] [0001..3600]
Unit	U [1..4] [A,C] [F, E1..E5] [L,R] [0001..1600]
Items with type code only	
Wire soldering pad, resistor side	PR [01..11] [L, R] [1..9]
Wire soldering pad, capacitor side	PC [01..11] [L, R] [1..9]
Adapter board for wires	AW [01..11] [L, R] [1..9]
Adapter board for strips	AS [01..11]
Items with a bar-code for a batch	
Wire cover	WC [01..11] [L, R]
Gas cover	GC [01..11] [1..9] *(see note)*
End cover	EC [01..11] [1..9] *(see note)*
Wire support	WS [01..11]
Jigs	
Spraying jig	SJ [01..11] [1..9] *(see note)*
Gluing jig	GJ [01..11] [1..9] *(see note)*
Pressure plate	PP [01..11] [1..9] *(see note)*

Note: This enumeration requires that the wire supports are arranged in such a way that:

- the 1st and last layers in a triplet are mirror images of each other
- the central layer of a triplet is its own mirror image
- the layers of a doublet are mirror images of each other

Example:

The complete bar-code for one of the 24 (3 per octant) outer-most left Endcap triplet units for the A side of ATLAS shipped to CERN is:

U1AE4L0079

U1AE4L0079

Note that the serial number runs from 0 to 1600, the total number of units, and so is independent of the particular unit type.

6.4 Supplier's data sheets

FR4 (Ditron)

Honey-comb frames (Pas-Gon)

Tungsten wire (Osram)

Araldite epoxy (Ciba-Geigy)

Graphite (Kontakt Chemie)

Soldering materials (Universal Soldering)

Kinematic mounting pieces (Igus)

7 TGC Product Breakdown Structure (PBS)

7.1 PBS

- *7. Muon Spectrometer*
  - *7.1. MDT Chambers*
  - *7.2. CSC Chambers*
  - *7.3. RPC Chambers*
  - 7.4. TGC System
    - 7.4.1. **M1 station**
      - 7.4.1.1. Supports
        - 7.4.1.1.1. Frames
        - 7.4.1.1.2. Frame interconnection
        - 7.4.1.1.3. Kinematic mountings
        - 7.4.1.1.4. Service trays
      - 7.4.1.2. Units
        - 7.4.1.2.1. Forward units
          - 7.4.1.2.1.1. Left unit Side A
            - 7.4.1.2.1.1.1. Gas Connections
            - 7.4.1.2.1.1.2. Front End electronics
            - 7.4.1.2.1.1.3. Faraday cage
            - 7.4.1.2.1.1.4. CO_2 flushing system
            - 7.4.1.2.1.1.5. Hanging points
            - 7.4.1.2.1.1.6. Chambers
              - 7.4.1.2.1.1.6.1. First layer of triplet
                - 7.4.1.2.1.1.6.1.1. Cathode board
                - 7.4.1.2.1.1.6.1.2. Strip board
                - 7.4.1.2.1.1.6.1.3. Wire soldering frame (Res)
                - 7.4.1.2.1.1.6.1.4. Wire soldering frame (Cap)
                - 7.4.1.2.1.1.6.1.5. Wire cover frame
                - 7.4.1.2.1.1.6.1.6. Ending frame
                - 7.4.1.2.1.1.6.1.7. Gas frame
                - 7.4.1.2.1.1.6.1.8. Long supports
                - 7.4.1.2.1.1.6.1.9. Small supports
                - 7.4.1.2.1.1.6.1.10. Adapter boards
              - 7.4.1.2.1.1.6.2. Second layer of triplet
              - 7.4.1.2.1.1.6.3. Third layer of triplet
            - 7.4.1.2.1.1.7. Joining honey-comb panel
            - 7.4.1.2.1.1.8. Over-pressure protection panel
          - 7.4.1.2.1.2. Right unit Side A, as for left unit side A, 7.4.1.2.1.1
          - 7.4.1.2.1.3. Left unit Side C, as for left unit side A, 7.4.1.2.1.1
          - 7.4.1.2.1.4. Right unit Side C, as for left unit side A, 7.4.1.2.1.1
        - 7.4.1.2.2. EndCap E1 units, as for Forward units, 7.4.1.2.1
        - 7.4.1.2.3. EndCap E2 units, as for Forward units, 7.4.1.2.1
        - 7.4.1.2.4. EndCap E3 units, as for Forward units, 7.4.1.2.1
        - 7.4.1.2.5. EndCap E4 units, as for Forward units, 7.4.1.2.1
      - 7.4.1.3. General Services
      - 7.4.1.4. Assembly Tools
    - 7.4.2. **M2 station**
      - 7.4.2.1. Supports
      - 7.4.2.2. Units
        - 7.4.2.2.1. Forward units, as for M1 Forward units, 7.4.1.2.1

7.4.2.2.2. EndCapE1 units, as for M1 Forward units, 7.4.1.2.1
7.4.2.2.3. EndCap E2 units, as for M1 Forward units, 7.4.1.2.1
7.4.2.2.4. EndCap E3 units, as for M1 Forward units, 7.4.1.2.1
7.4.2.2.5. EndCap E4 units, as for M1 Forward units, 7.4.1.2.1
7.4.2.2.6. EndCap E5 units, as for M1 Forward units, 7.4.1.2.1
7.4.2.3. General Services
7.4.2.4. Assembly Tools

7.4.3. **M3 station**

7.4.3.1. Supports
7.4.3.2. Units
7.4.3.2.1. Forward units, as for M1 Forward units, 7.4.1.2.1
7.4.3.2.2. EndCap E1 units, as for M1 Forward units, 7.4.1.2.1
7.4.3.2.3. EndCap E2 units, as for M1 Forward units, 7.4.1.2.1
7.4.3.2.4. EndCap E3 units, as for M1 Forward units, 7.4.1.2.1
7.4.3.2.5. EndCap E4 units, as for M1 Forward units, 7.4.1.2.1
7.4.3.2.6. EndCap E5 units, as for M1 Forward units, 7.4.1.2.1
7.4.3.3. General Services
7.4.3.4. Assembly Tools

7.4.4. **I station**

7.4.4.1. Supports
7.4.4.2. Units
7.4.4.2.1. Forward units, as for M1 Forward units, 7.4.1.2.1
7.4.4.2.2. EndCap units, as for M1 Forward units, 7.4.1.2.1
7.4.4.3. General Services
7.4.4.4. Assembly Tools

7.2 PBS drawings

The following drawings are annotated by their PBS number. The drawings are for the M1 station and for the M1 station EndCap E4 units.

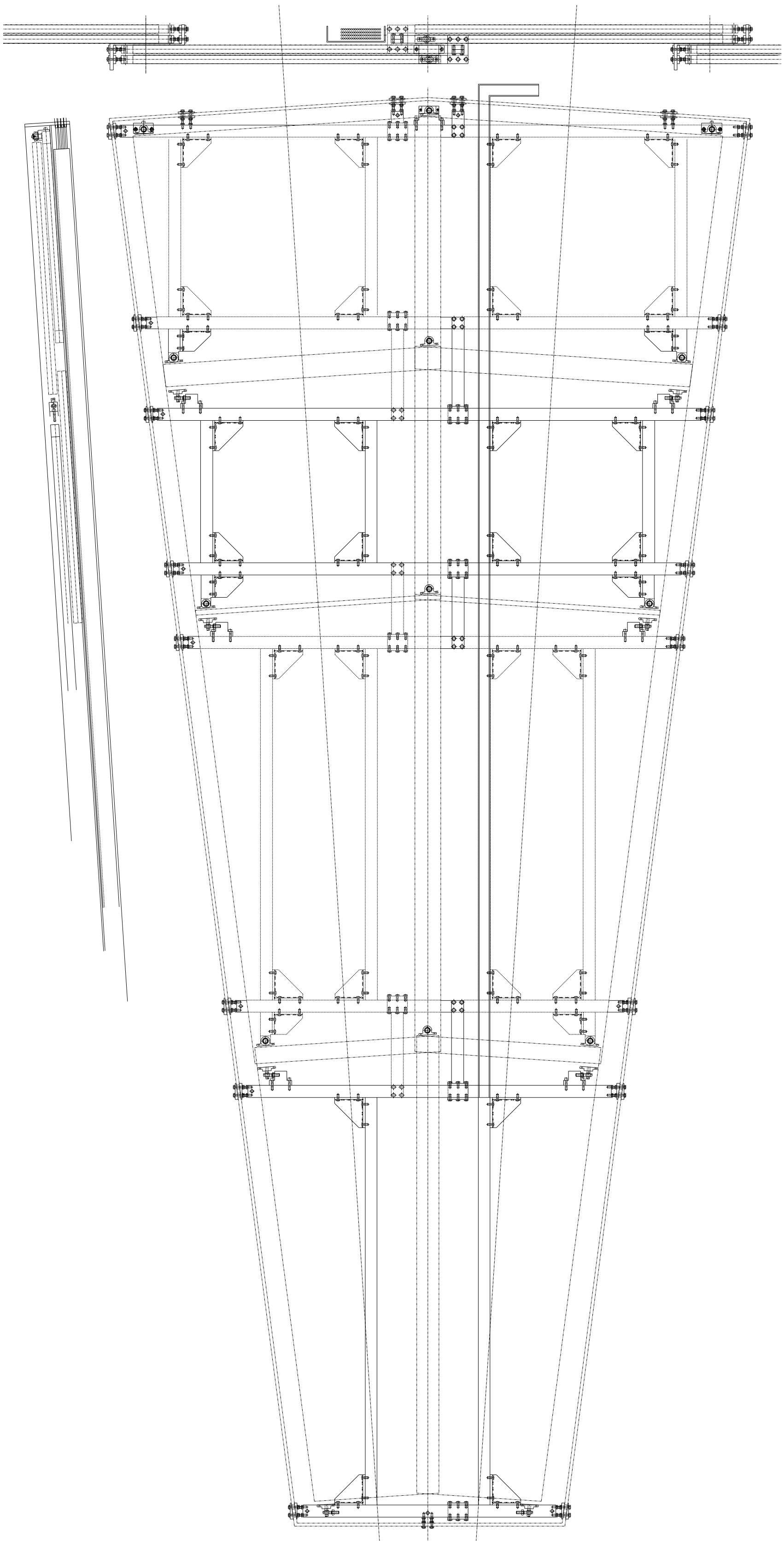

Figure 7-1 7.4.1.1. Supports

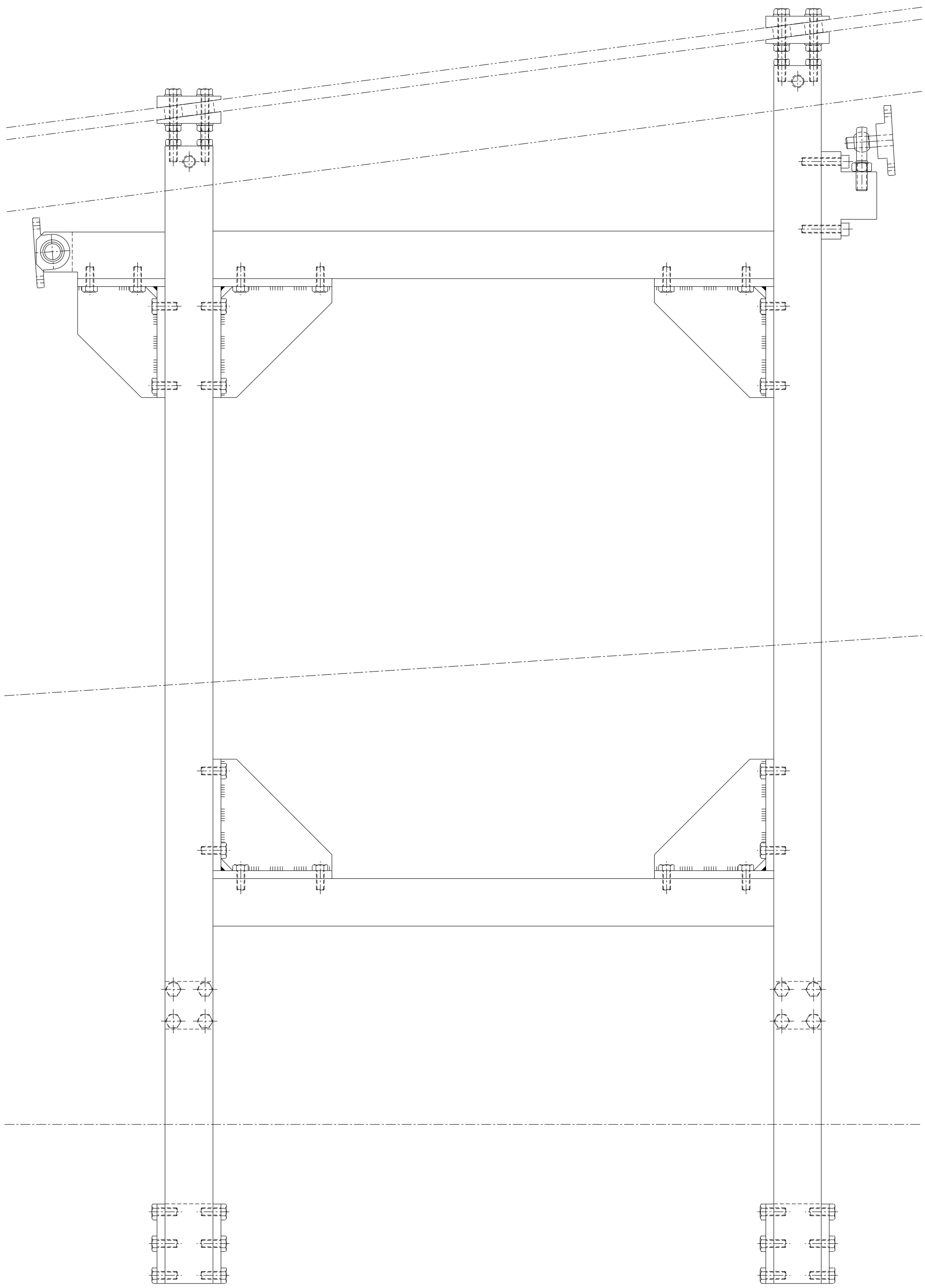

Figure 7-2 7.4.1.1.1. Frames

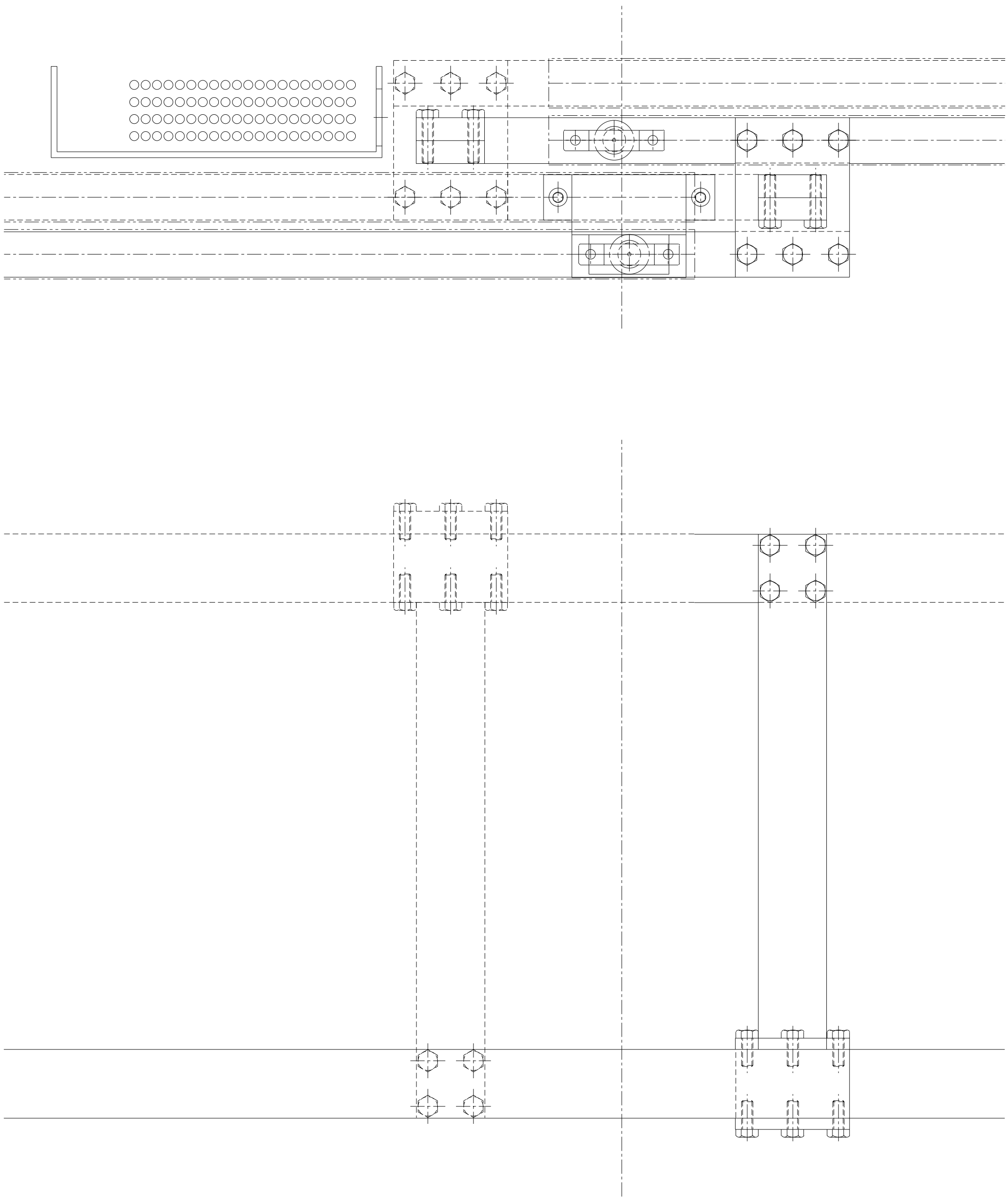

Figure 7-3 7.4.1.1.2. Frame interconnection

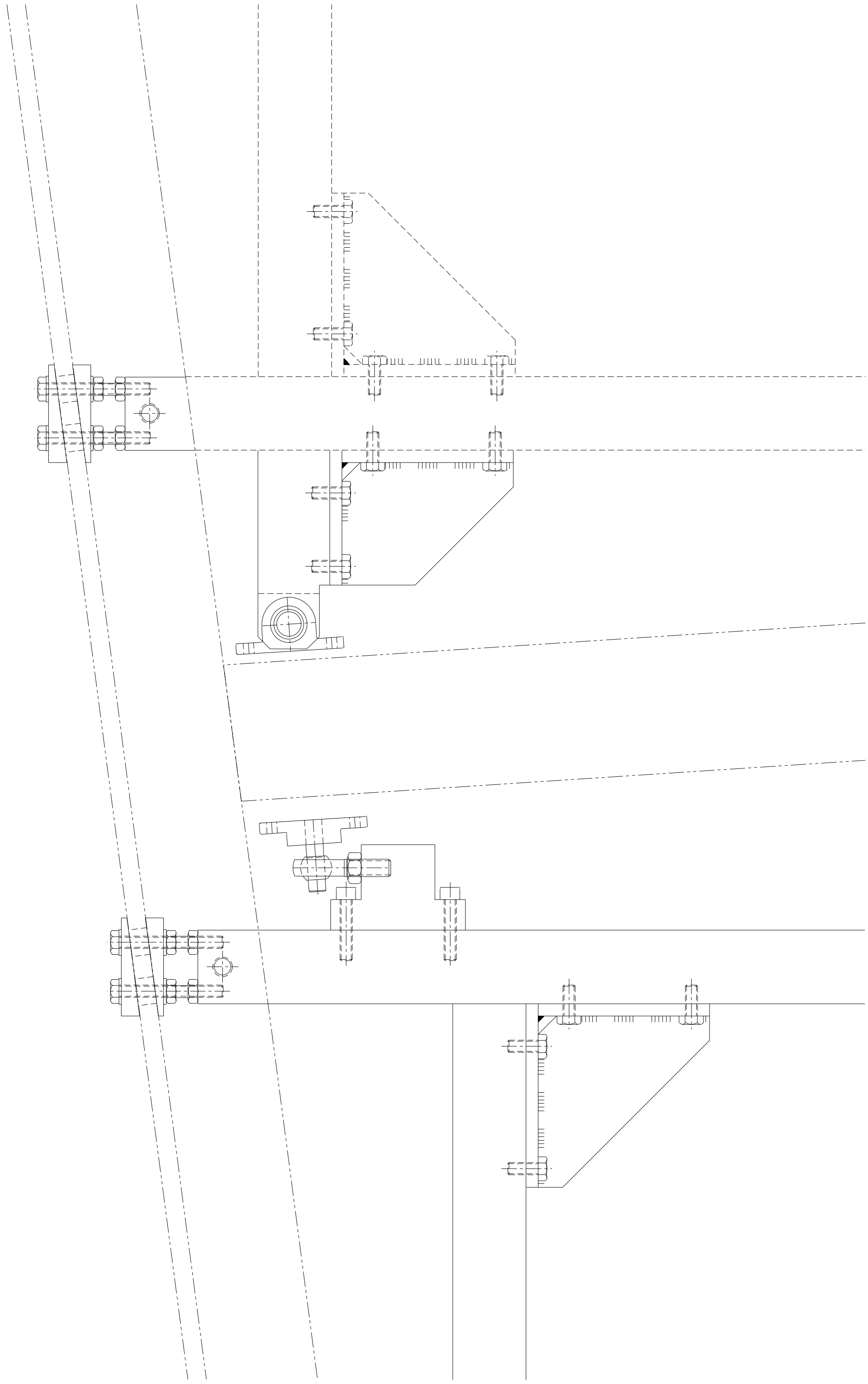

Figure 7-4 7.4.1.1.3. Kinematic mountings

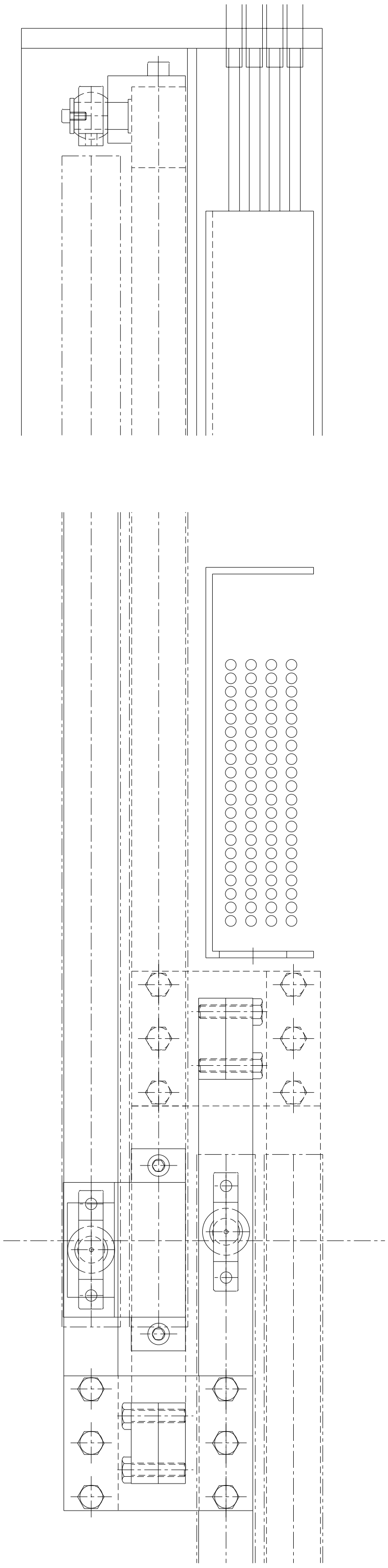

Figure 7-5 7.4.1.1.4. Service trays

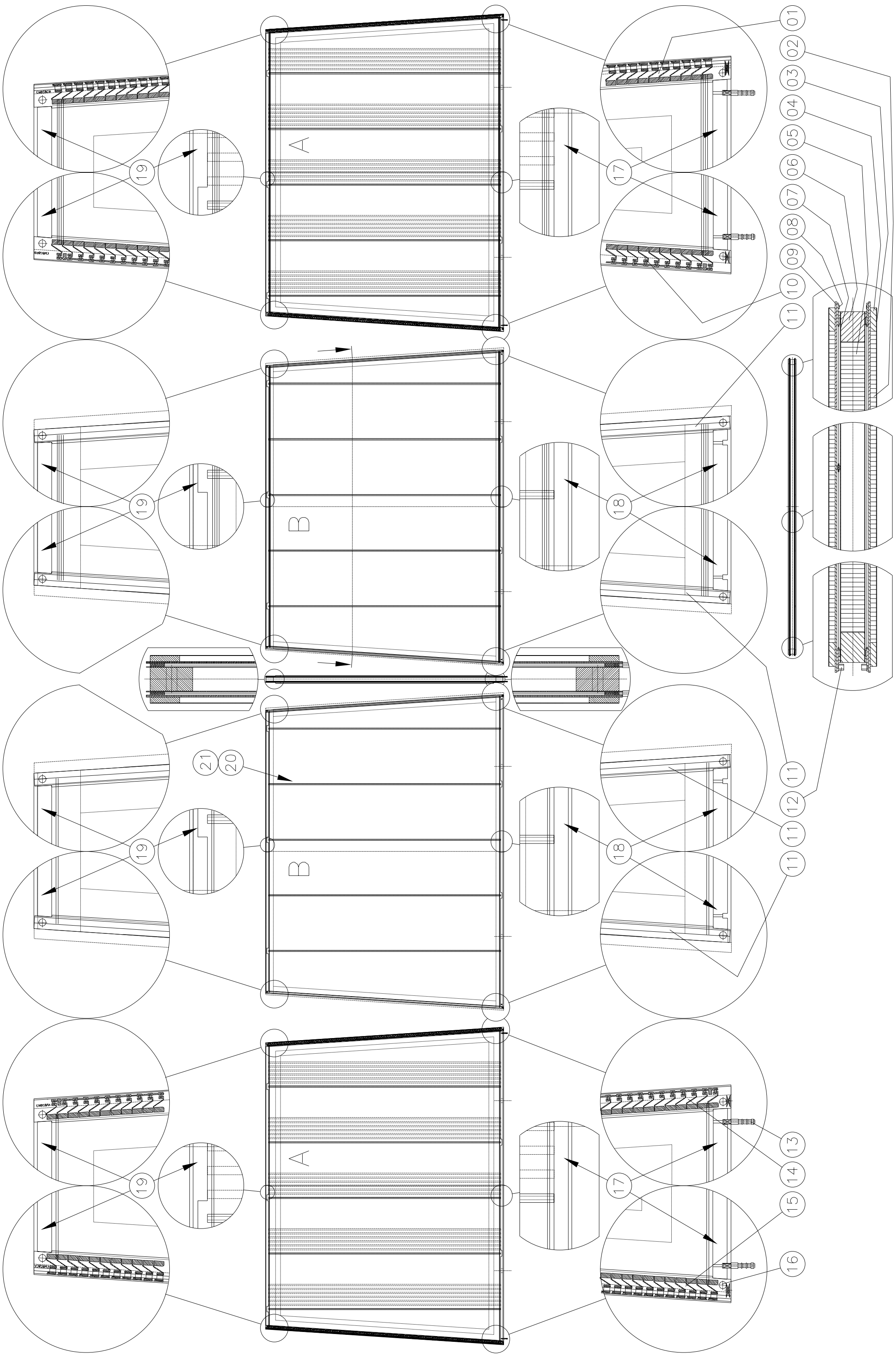

Figure 7-6 7.4.1.2.5. EndCap E4 units

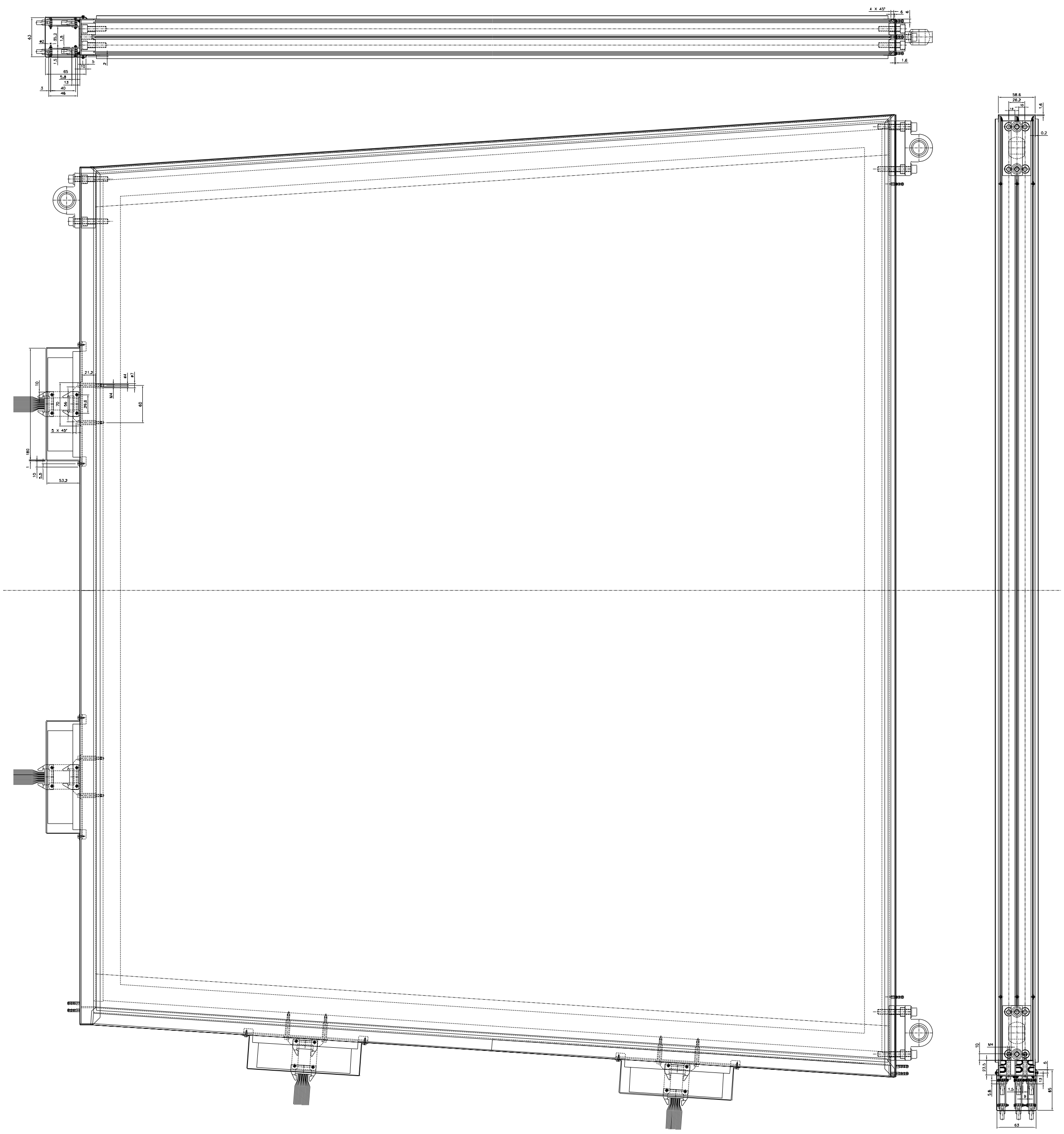

Figure 7-7 7.4.1.2.5.1. Left unit Side A

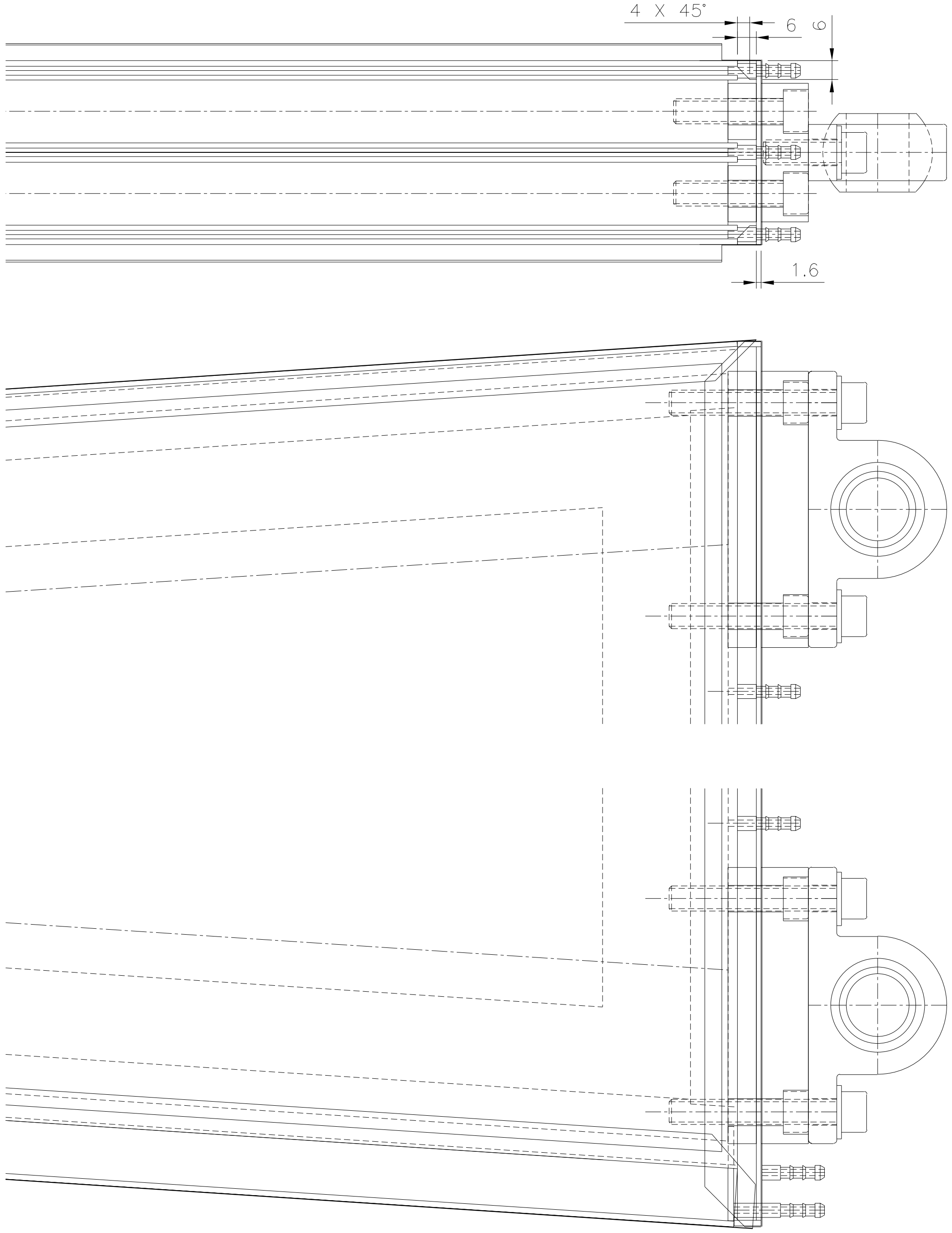

Figure 7-8 7.4.1.2.5.1.1. Gas Connections

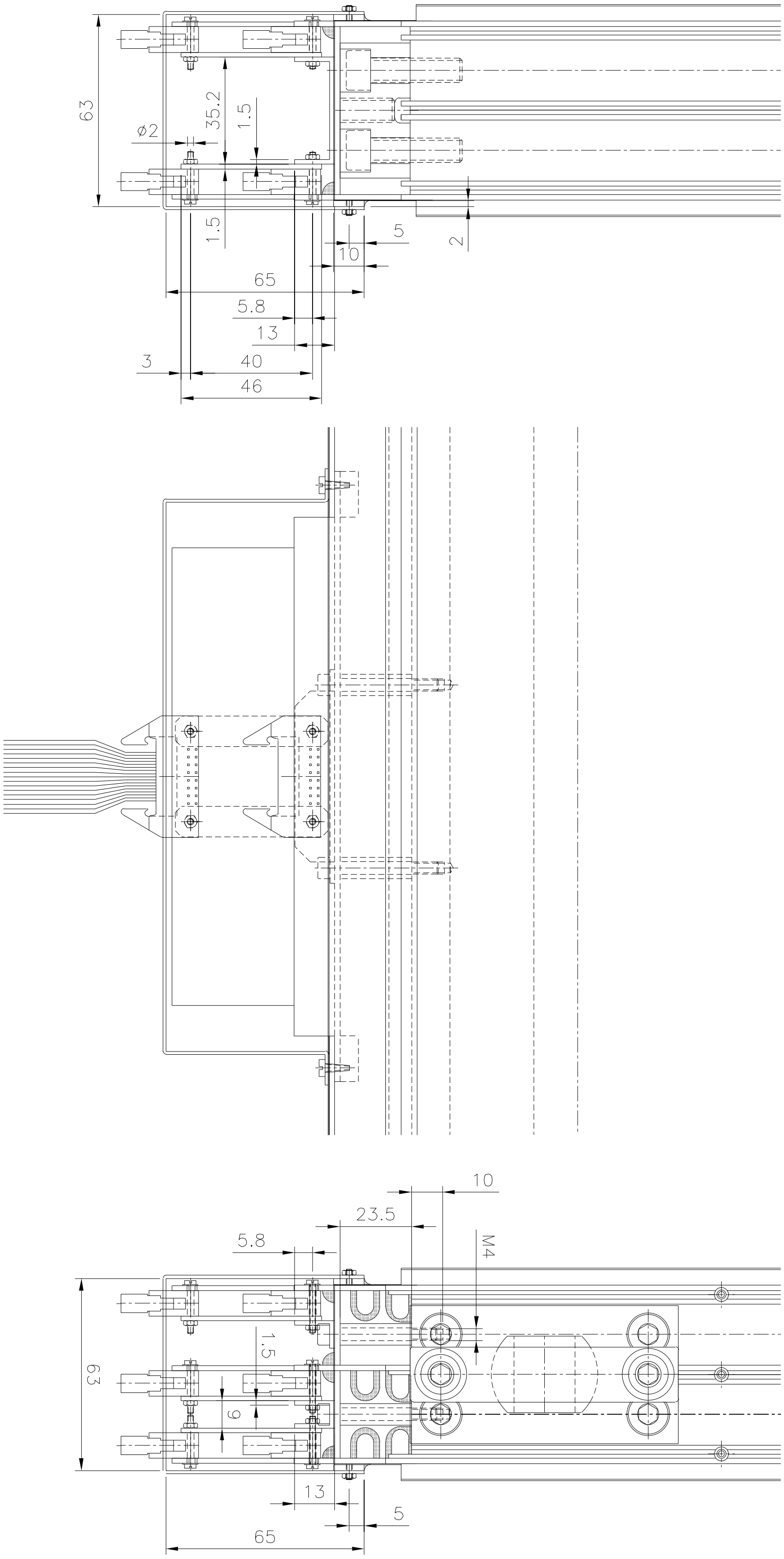

Figure 7-9 7.4.1.2.5.1.2. Front End electronics

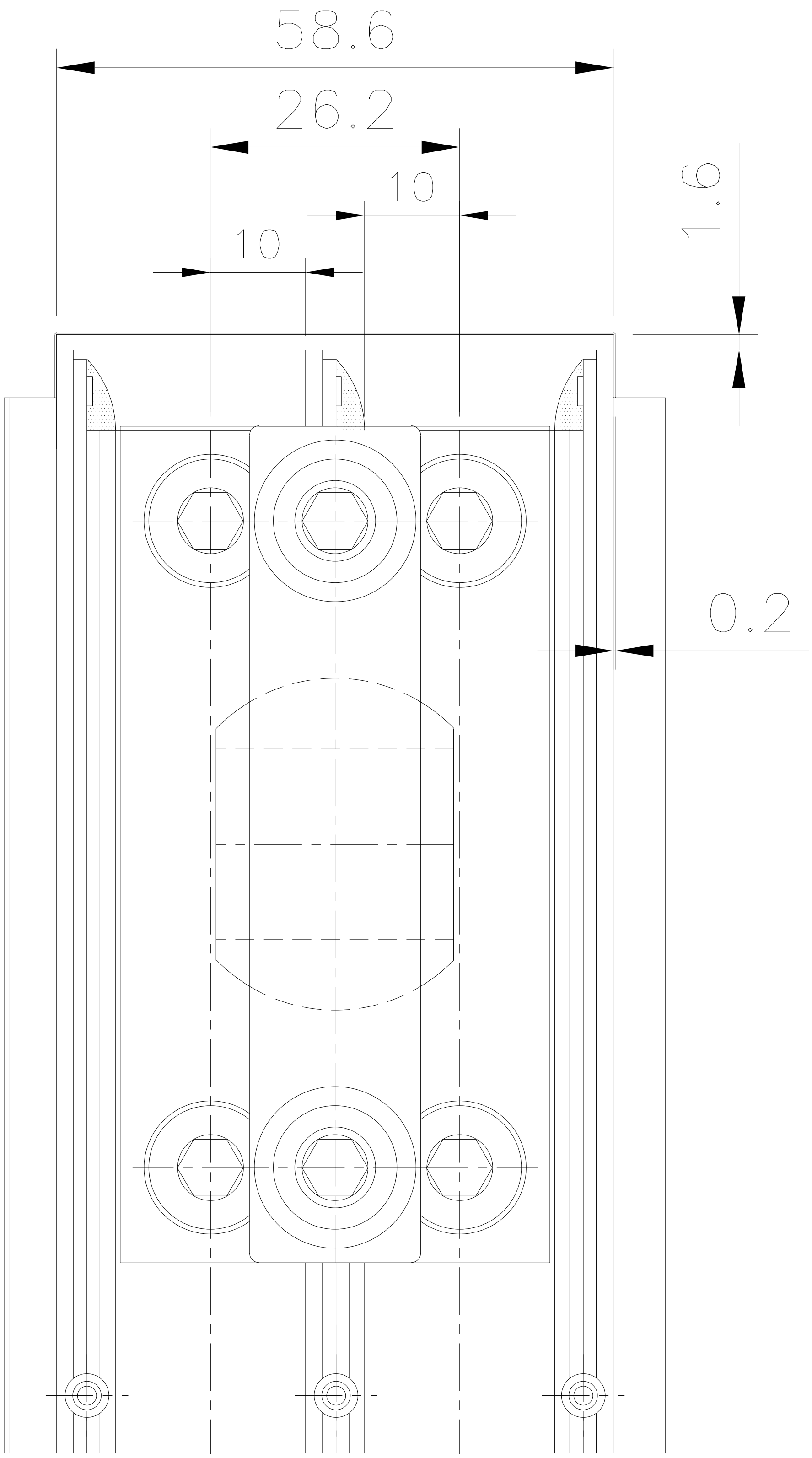

Figure 7-10 7.4.1.2.5.1.3. Faraday cage

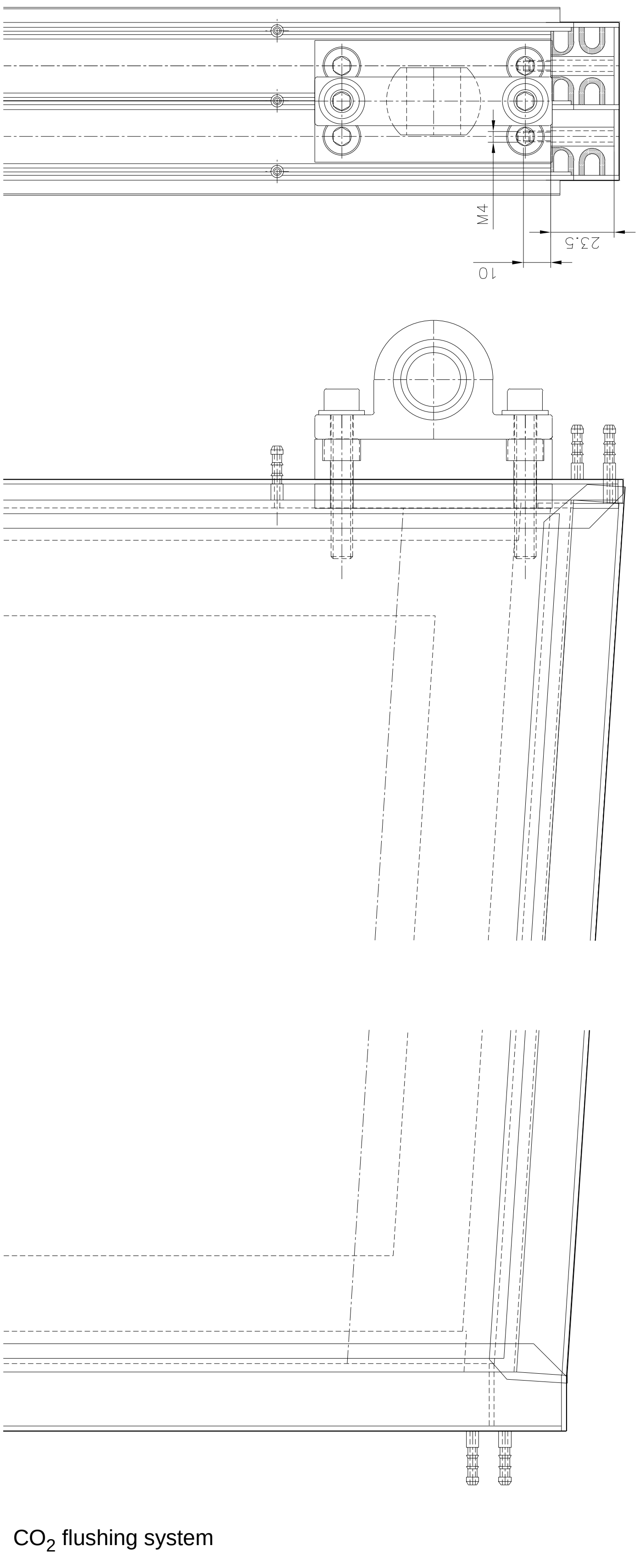

Figure 7-11 7.4.1.2.5.1.4. CO_2 flushing system

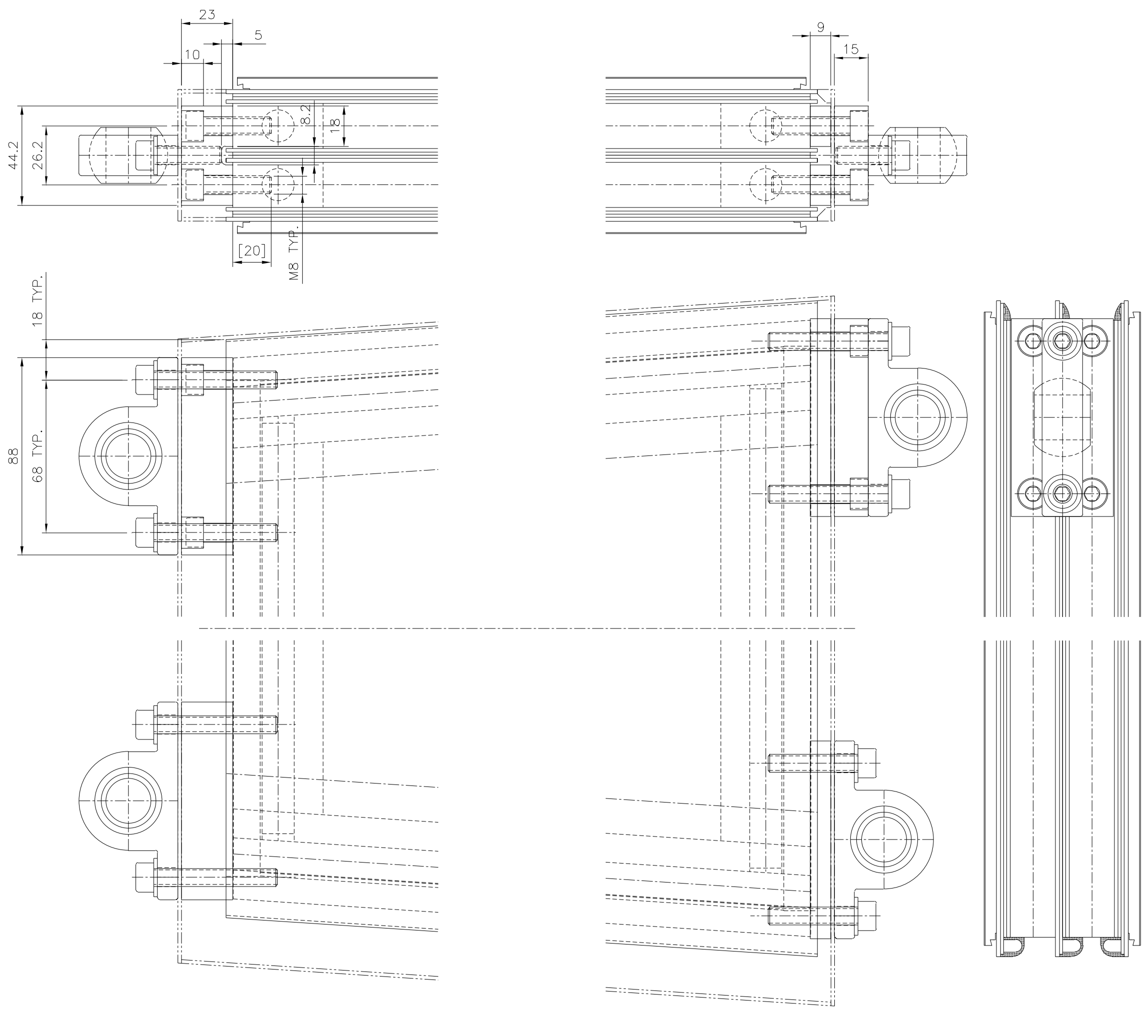

Figure 7-12 7.4.1.2.5.1.5. Hanging points

Figure 7-13 7.4.1.2.5.1.6.1.1. Cathode board

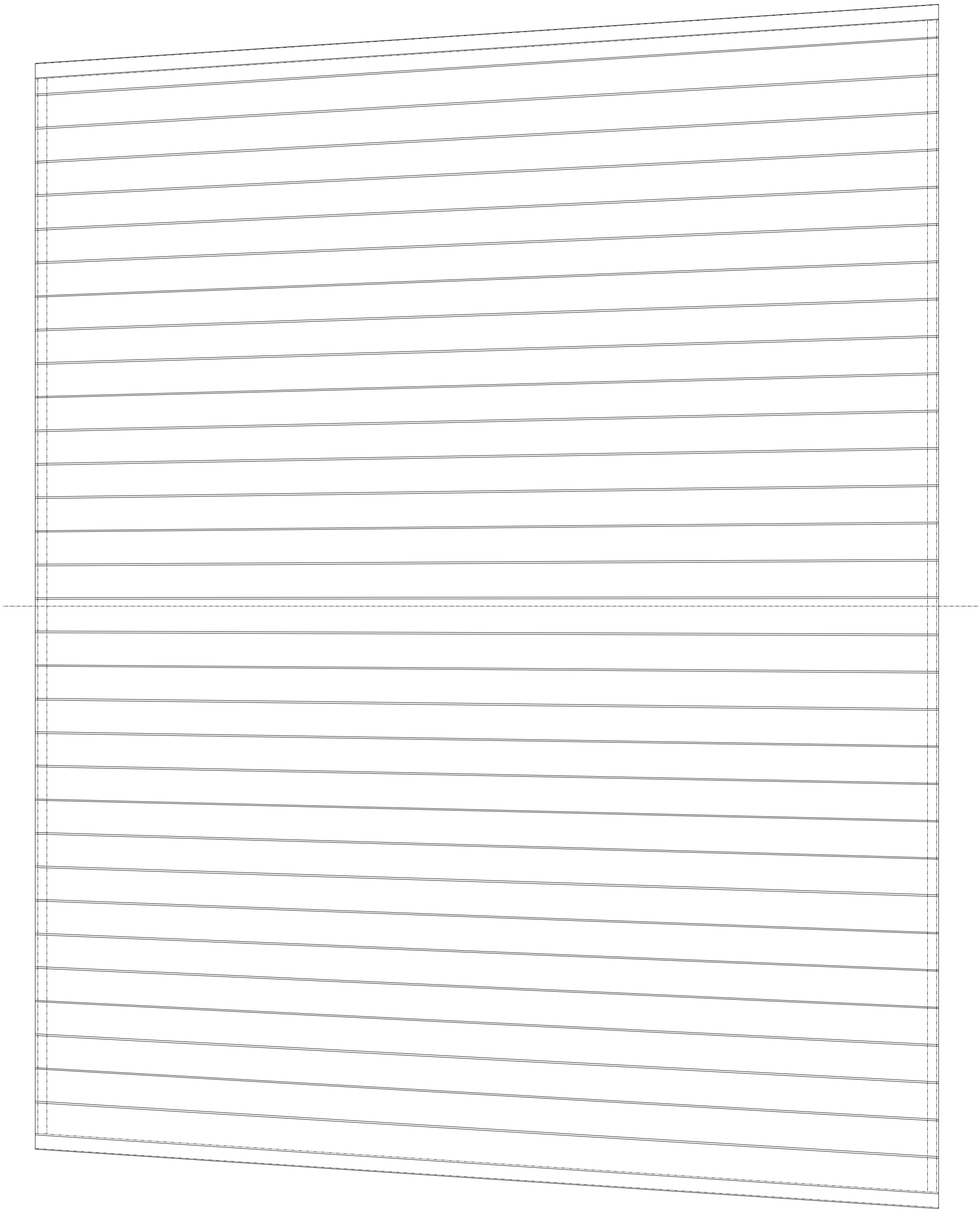

Figure 7-14 7.4.1.2.5.1.6.1.2. Strip board

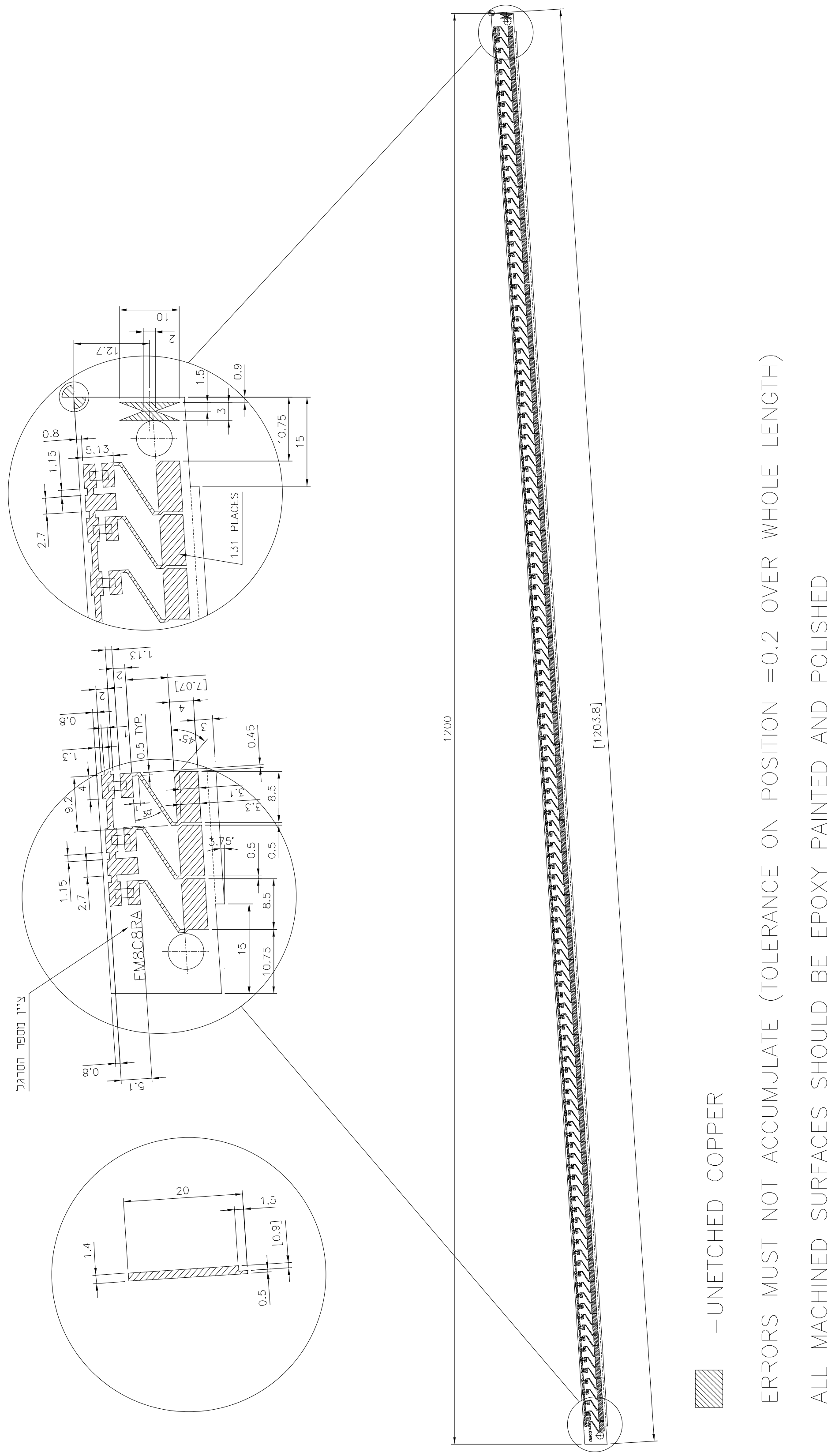

Figure 7-15 7.4.1.2.5.1.6.1.3. Wire soldering frame (Resistor side)

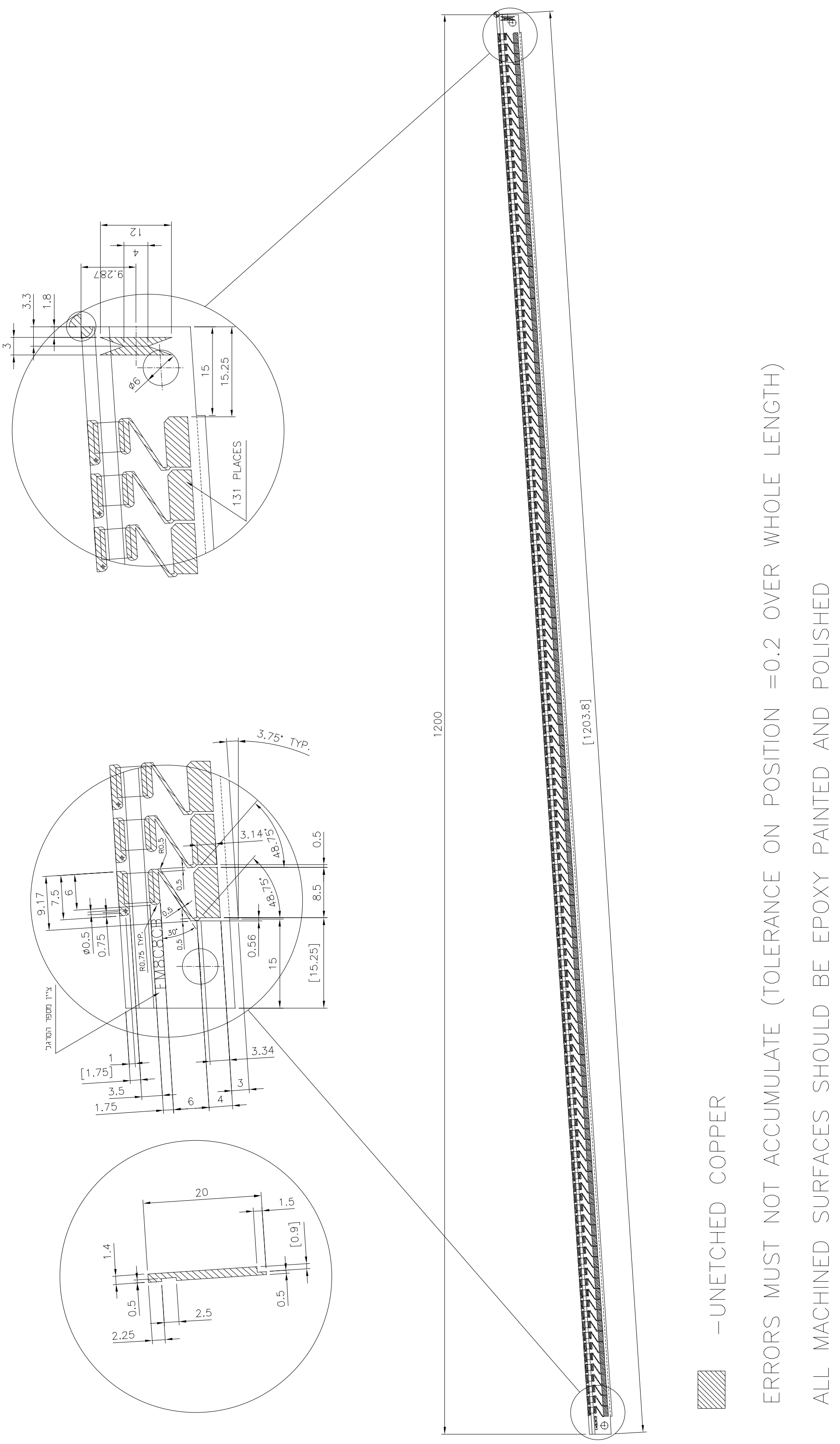

Figure 7-16 7.4.1.2.5.1.6.1.4. Wire soldering frame (Capacitor side)

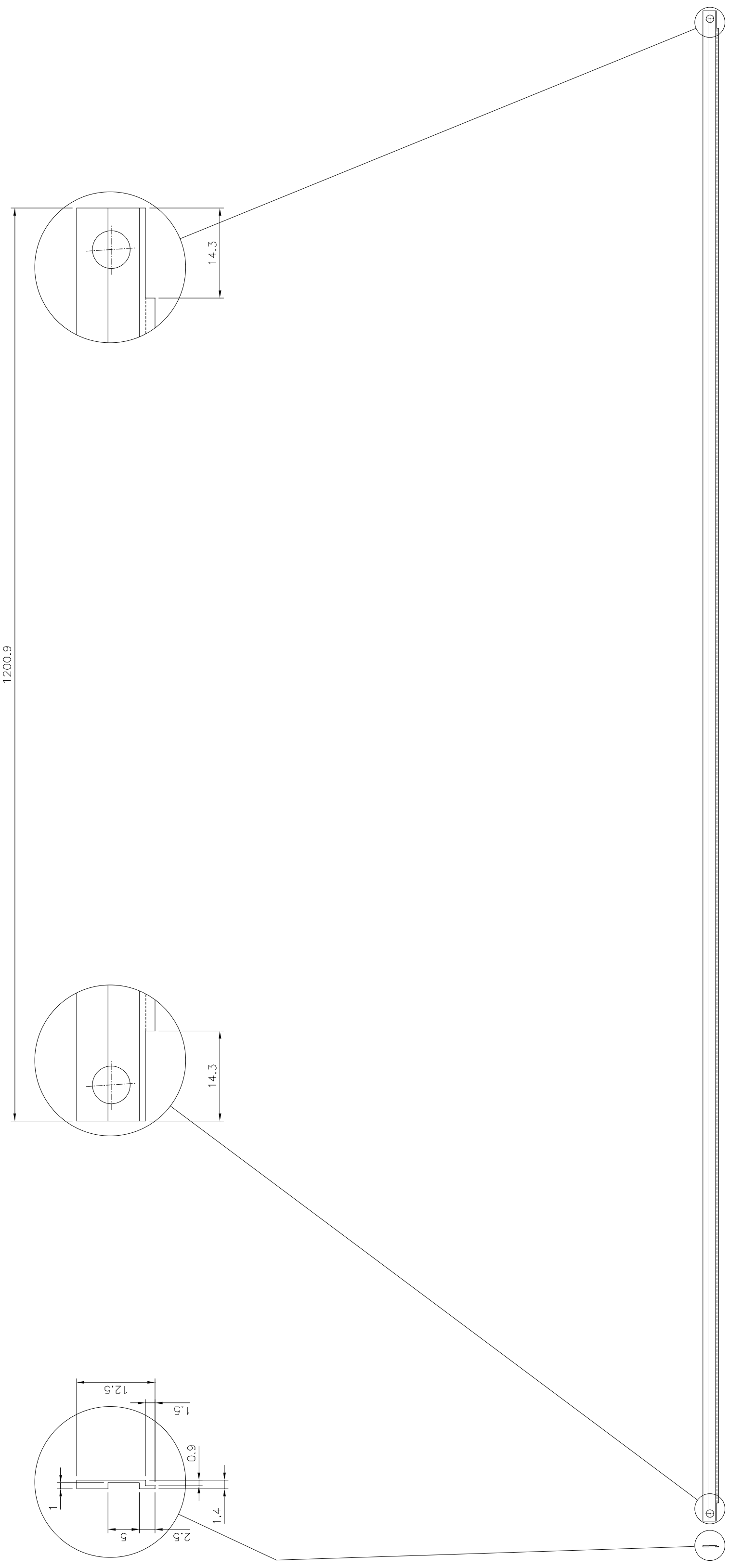

Figure 7-17 7.4.1.2.5.1.6.1.5. Wire cover frame

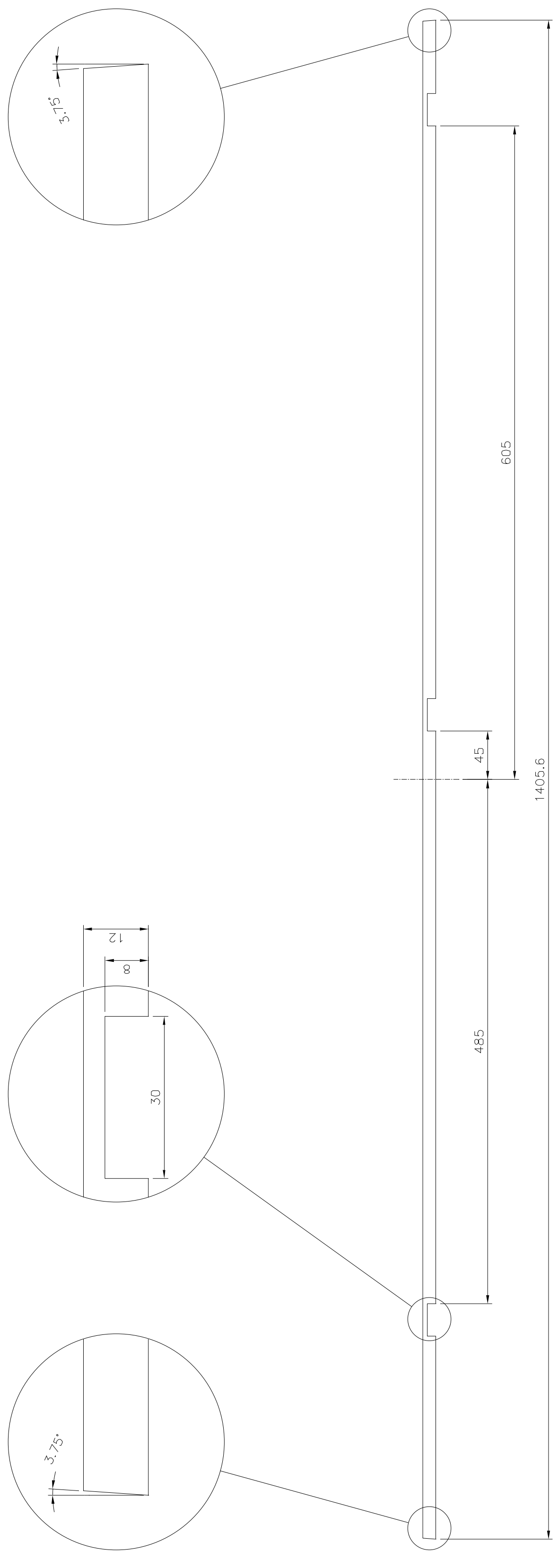

Figure 7-18 7.4.1.2.5.1.6.1.6. Ending frame

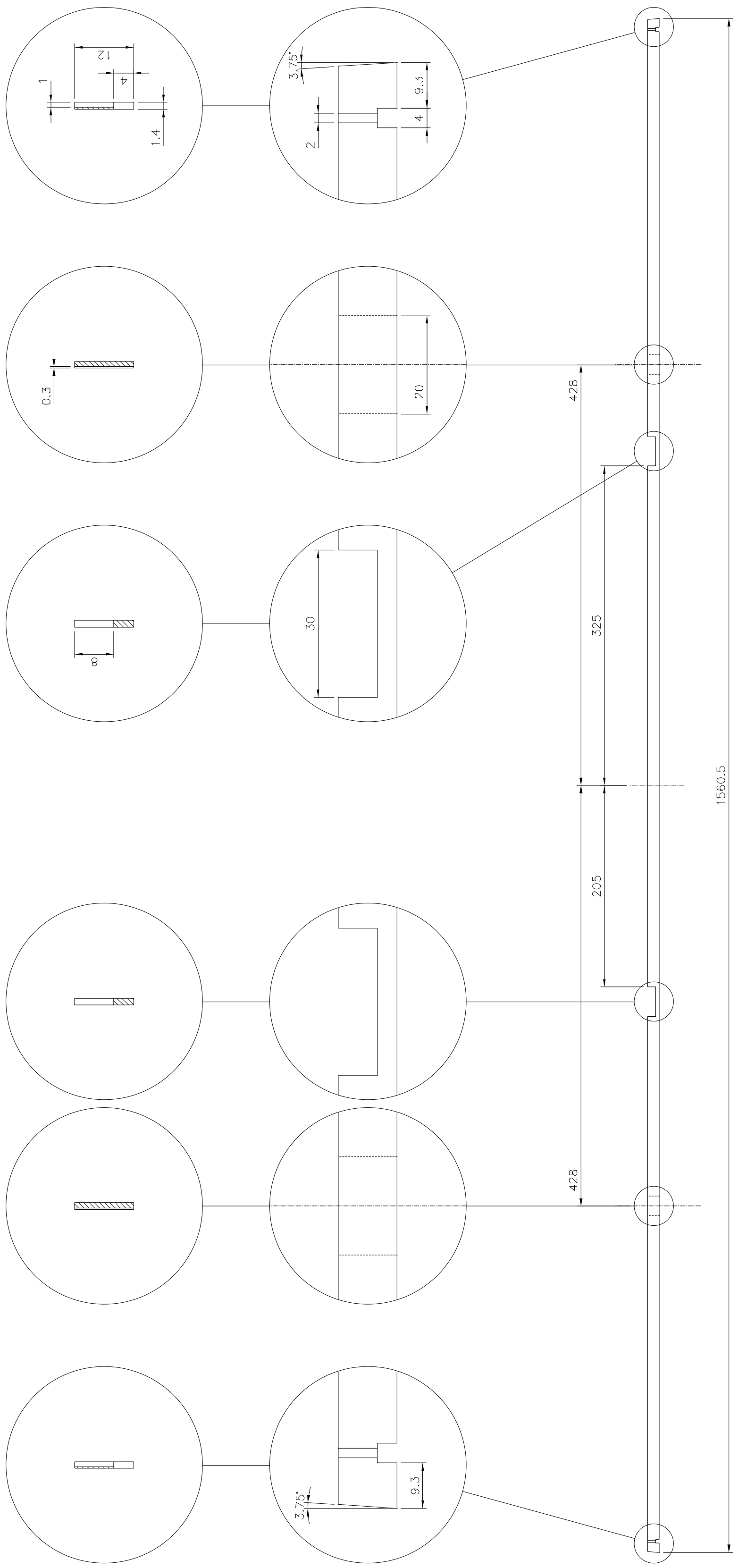

Figure 7-19 7.4.1.2.5.1.6.1.7. Gas frame

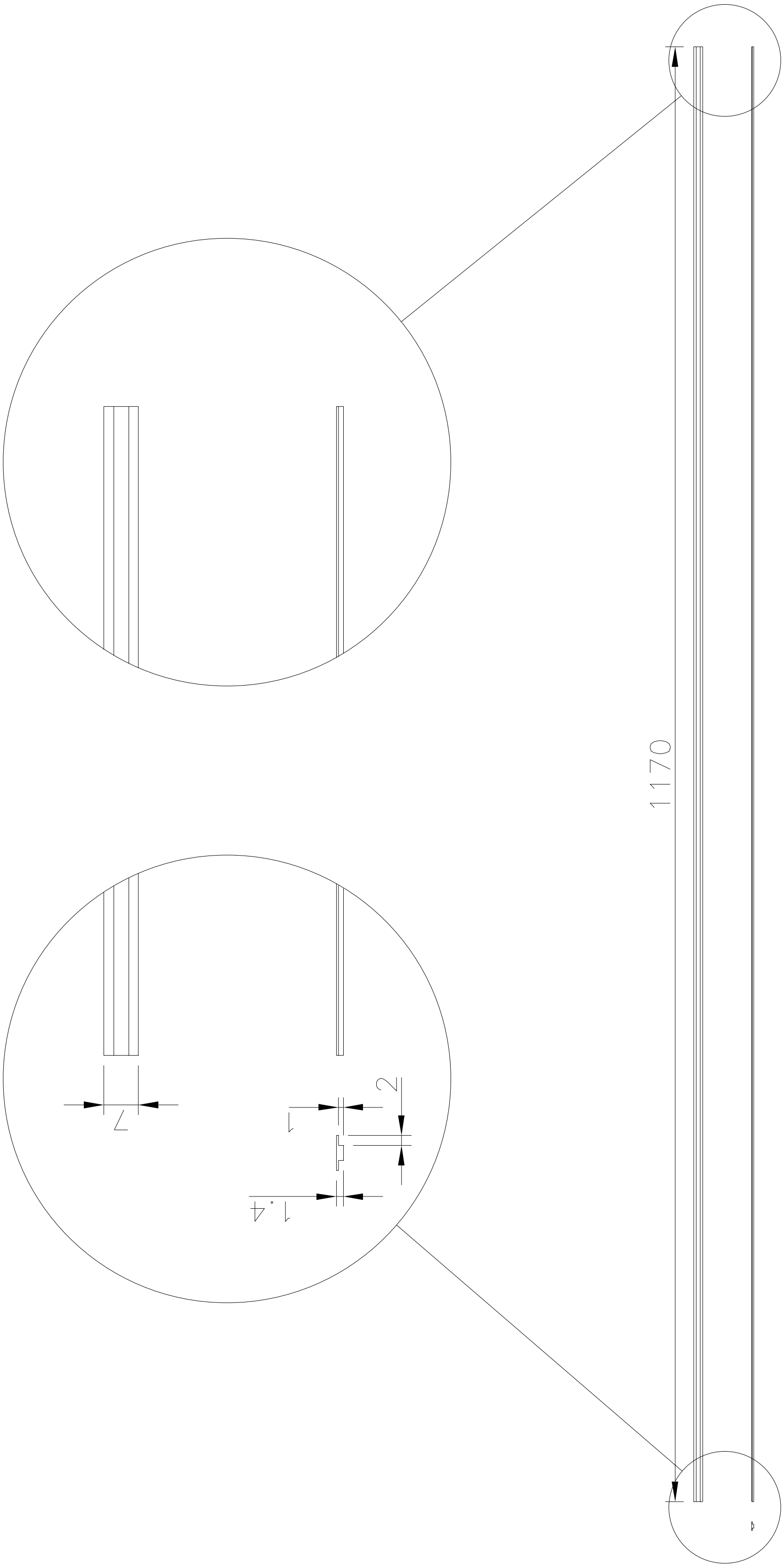

Figure 7-20 7.4.1.2.5.1.6.1.8. Long supports

Figure 7-21 7.4.1.2.5.1.6.1.9. Small supports

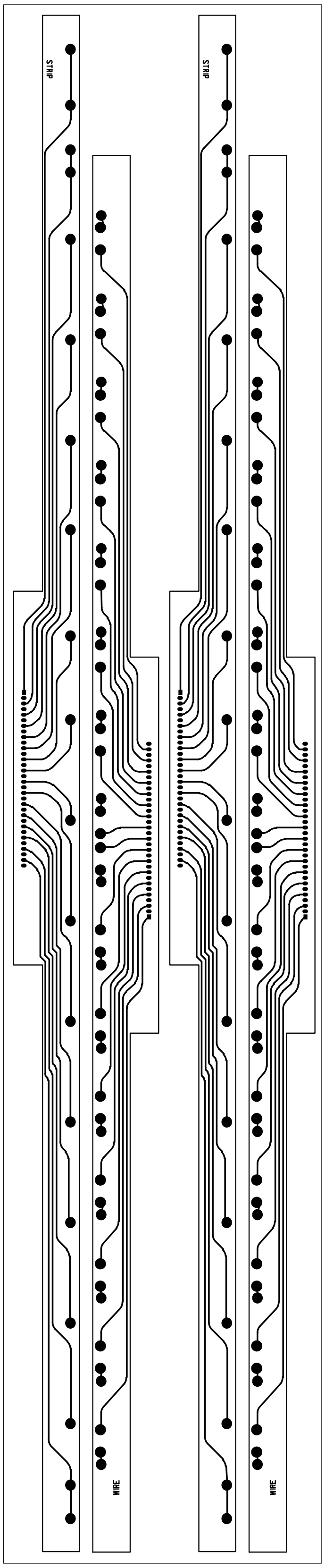

Figure 7-22 7.4.1.2.5.1.6.1.10. Adapter boards

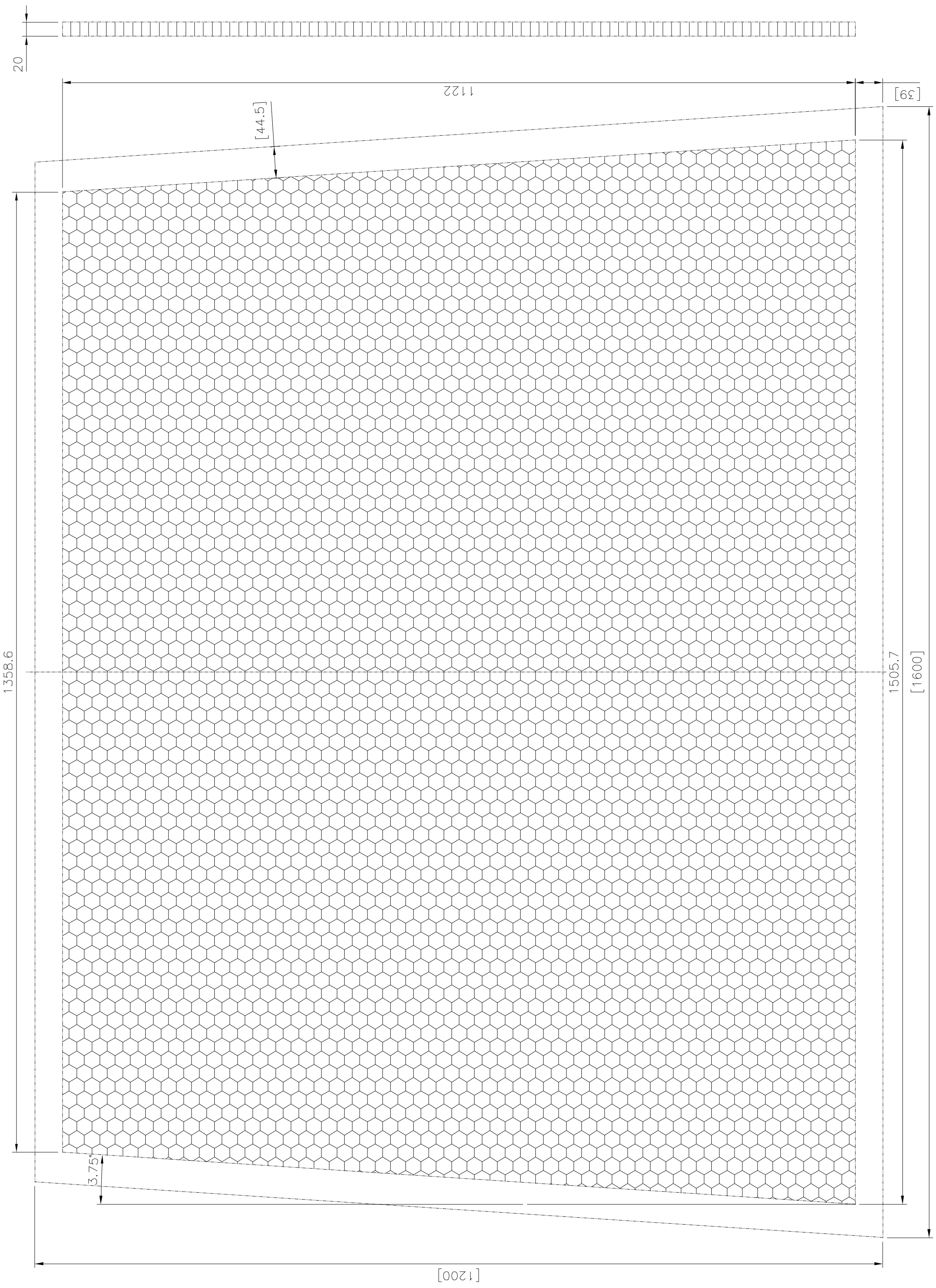

Figure 7-23 7.4.1.2.5.1.7. Joining honey-comb panel

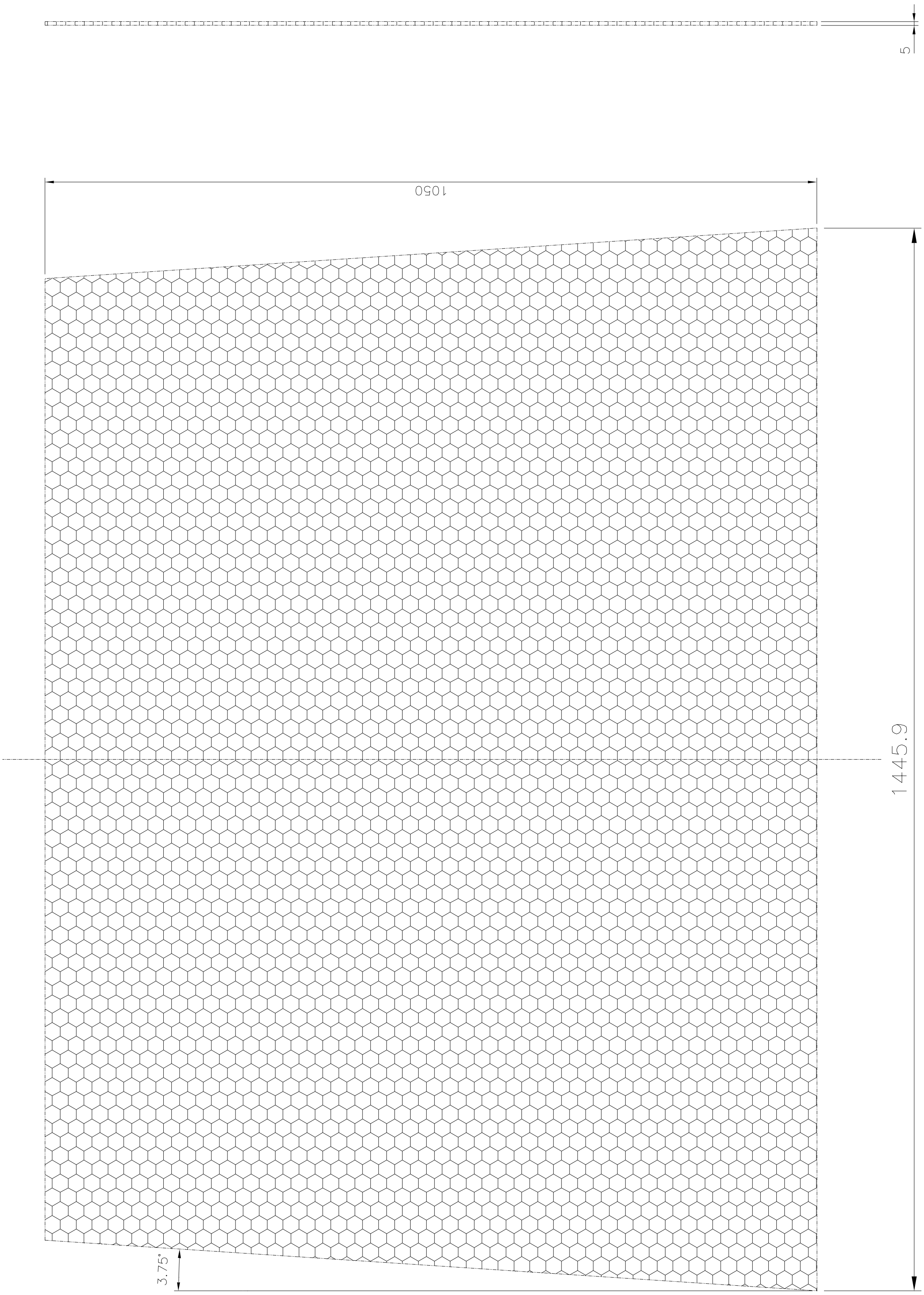

Figure 7-24 7.4.1.2.5.1.8. Over-pressure protection panel

8 Index of step names

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