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The drawer system concept for the ATLAS Tilecal readout

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Abstract

One strong constraint in ATLAS is the easy and fast access to the Tile calorimeter readout without any destructive interference with the rest of the detector. Therefore the drawer system has been designed to place all PMTs and associated electronics on a movable system inside the TILECAL girders which provide both, the structural support to the individual modules and the solenoid return flux. In case of faulty readout elements, these elements can be replaced because of the motion of the endcaps. In this note, the complete system from the manufacturing technique up to the readout components, is described. Each drawer is considered as an autonomous subsystem which requires a dedicated test bench.

1 Design specifications

One of the major interest of the Tile calorimeter cell configuration is to have all readout components outside the active part of the calorimeter. However, at this place there is no space for access available without removing the muon chambers. The drawer concept described below offers a possibility for fast access to the readout which is fully housed inside theses drawers. In case of faulty readout elements, the drawers affected could be easily replaced because of the 2 m recessment of the endcaps, leaving enough space to remove a 1.4 m long drawer (see figure 1). Depending on the needs, one or two drawers could be extracted.

As the girders are carrying the fibre bundles, the air gap between the bundles and the light mixers (inside the drawers) is well adapted to the longitudinal drawer movements. It is useful to outline that the TILECAL prototypes were designed and tested with such air gaps. The optics in ATLAS will be the same, therefore, there will be no light yield changes with this drawer design.

The main constraints on the specifications of the drawers are discussed in the next chapters in the following order:

- the PMT location versus the main components of the residual magnetic fields,
- the girder dimensions,
- the number of readout channels and the size of PMTs assembled in PMT Blocks containing other pieces,
- the tolerances of the PMT positioning in front of the fibre bundles,
- the location of the electronics,
- the electronics cabling or fibres links with the Trigger/DAQ system and power supplies,
- the general cooling,
- the compatibility with the return yoke pieces in contact with the girders,
- the access to the drawers, including at some places the location of tubes for the Argon cryogenics, which needs specific arrangements of drawers,
- the simplicity for the handling and the cost,
- the possibility of sliding the fibre polishing tool using the same supports as for the drawers.

All the drawers should have the same components, but there are four kinds of filling depending upon the associated calorimeter cells. From the electronics point of view, a group of two drawers in each half-Barrel or each External Barrel will be considered as a Super-Drawer with parts of the electronics located only in the external drawer (see figure 2).

The Drawer Test Bench will be dedicated to a Super-Drawer assembly.

2 Constraints on the drawers

2.1 PMT location

The first constraint to be taken into account, is the position of PMTs in the residual magnetic field environment due to the two ATLAS magnet systems. Realistic simulations [1] provide the magnetic field map including both the toroidal and the solenoidal fields, at the location of the TILECAL. These show in particular that the return flux of the solenoid passes mainly through the girder structure in which the drawers will be installed. In the worst case, the residual field at the PMT locations does not exceed about 20 Gauss. Magnetic field studies of the TILECAL PMTs have been performed with PMTs (R5600 Hamamatsu) of circular shape [2]. Full magnetic shielding is achieved up to 1700 Gauss in the transverse direction (field perpendicular to the PMT axis) and 600 Gauss in the longitudinal direction (field parallel to the PMT axis). New developments are in progress with PMTs of a square shape fitting the TILECAL specifications (R5900 Hamamatsu). Actually shieldings of 825 and 250 Gauss have been obtained in the transverse and in the longitudinal directions, repectively. Further studies will be made with the aim of shielding 500 Gauss in every direction. In spite of the large shielding safety factor already obtained, the drawers are designed in such a way that the largest residual field components is perpendicular to the PMT axis (see figure 3), which provides the most efficictive shielding.

Such an arrangement is well adapted to the left and the right readout of the tiles, as shown in figure 4. To have all the PMTs arranged at the same radial distance from the beam axis, the left and right PMTs are staggered.

2.2 Girder dimensions

A cross section in the transverse plane of the girder is shown in figure 5. Theoretically the full space could be used for the drawer organization, but it is better to position the PMT axis in the medium part where the stray magnetic field components are minimal. The lateral size of a drawer is constrained by several things:

- by the internal girder space of 175 mm, and the total height of about 175 mm, and by the tolerances on these dimensions,
- by the space taken by the fibre bundle passing through the girder,
- by the tolerances for sliding of the drawer,
- by the dimensions of the PMT Block, resulting from a compromise between the light mixer, the PMT sizes, the location of the electronics and the magnetic shielding [3].

The lengths of the girders supporting either the Barrel or the External Barrels and the 2 m possible displacement of the End Caps, must be considered as the main constraints to optimize both, the lenght and the number of drawers. The other element in this choice is to keep this number of drawers at minimum in order to reduce at the same time the cost of components and the time for assembly. This is the case, if the electronics outside the PMT Block is organized in such a way that the high voltage (using a micro-controller) as well as the frontend electronics is globally distributed to the individual drawers inside a Super-Drawer. The same arguments hold for the cabling and connections, for which the cost is minimized by reducing the number of pieces.

Taking these arguments into account, the optimum number of drawers (of maximum lenght of 1.4 m) per TILECAL module is 4 in the Barrel and 2 in the External Barrels. At fabrication, all the drawers should be identical, but because of the cell granularity (depending on the PMT filling), four types of drawers will be defined, corresponding to the internal and external parts of each half Barrel or External Barrel respectively, which is shown in figure 2.

The total number of drawers is equal to 512:

Half Barrel:	$2 \times 64 = 128$,	multiplied by 2 for the Barrel,
External Barrel:	$2 \times 64 = 128$,	multiplied by 2.

2.3 Number of readouts and PMT Block dimensions

In the longitudinal direction, the cell granularity is not yet fully defined. A possible scheme is shown in figure 6.

In the Barrel, most of the cells are well defined, except for the extremes which have uncomplete parts.

In the External Barrels, the cells are bigger and the fibre lengths associated to a cell can vary a lot depending on the PMT location. The final size of the cells is not yet defined, but the proposition shown in figure 6 gives some indication. Two clear fibres/PMT for the laser monitoring light are included in the fibre bundles.

The numbers of fibres per cell are given in table 1.

	Sampling 1	Sampling 2	Sampling 3
Barrel	$28 \rightarrow 40$	$40 \rightarrow 86$	$60 \rightarrow 92$
External Barrel	$22 \rightarrow 68$	$32 \rightarrow 140$	$142 \rightarrow 152$

Table 1: Numbers of fibres per cell in the 3 samplings of Barrel and External Barrels.

To simplify the drawer production and therefore to save the cost, the drawers should all be identical at fabrication with holes for the PMTs separated by a space of 116 mm between two PMT positions. The different modules will not have all the PMT positions filled, as shown in figure 6.

The possibility to place TILECAL Plugs (which may partially fill the gap between the Barrel and the External Barrels) must also be considered. These 250 mm long Plugs would be supported by the External Barrels sharing the same girders, as shown in figure 7. The lengths of these drawers would be increased, but the same scheme as for the others would be kept.

	Barrel	External Barrel
Without Plug	1400	1305
With Plug	1400	1430

Table 2: Drawer lengths (in mm) without and with the end cap plugs.

Table 2 gives the drawer lengths, without and with the Plug hypothesis. In these calculations, the plate thickness at both ends of a module is removed (1×20 mm for B, 2×20 mm for EB). The maximum length of a drawer is 1.43 m. The drawer lengths are adjusted by cutting depending on the requirements.

Using the numbers given in figure 6 and the drawer design, table 3 summarizes the number of PMTs inside a drawer for the four types of drawers.

Drawer	Internal	External
Half Barrel	24	22
Ext. Barrel	$16 + 2$	12

Table 3: Number of PMTs inside one drawer, including the 2 additionnal PMTs of the Plug (accounted for in the Internal Drawer of EB).

In that scheme, the total number of PMTs is 9728. Only for the internal drawers of the Barrel all holes are fully equipped with PMTs.

A possible design of the PMT Blocks is shown in figure 8 [3]. The constraints for the drawer design are given by the total length of 145 mm and the external diameter of 54 mm of a PMT Block. The position of the connectors on the printed board is not yet finalized.

2.4 PMT positioning tolerances

The PMTs have to be positioned in front of the fibre bundles of various sizes, depending on the readout cells, to the light guides which mix the light coming from the fibres. Due to the usual fact that the PMT photocathodes exhibit variations in response over their surfaces, the light guide must merge the light coming from the fibres with the same efficiency, independently from the fibre position. In addition, the shape and the size of the light mixer should match the biggest fibre bundles.

It is known that a square light guide does offer the best performance [4]. The best matching is obtained by using square PMTs. The study of the PMT Block [3] based on the square PMT (R5900 Hamamatsu) shows that the acceptance of the light guide for various fibre positions is constant up to 1 mm from the mixer border (using 1 mm diameter fibres). This results has been obtained from both, simulations and measurements. Simulations show also the importance of air gaps before and after the mixers. In front of the light guide, there is no light variation if the gap is of the order of, or less than 1 mm. In front of the PMT window the effect is similar. By minimizing this gap it is possible to choose the light mixer with the same dimensions as those of the PMT (a few tenth of a mm is acceptable).

Therefore, the drawer has been designed to have the gap tolerance of 1 mm in the longitudinal sliding direction. For the fibre bundle positioning, the tolerance would be of 1 mm for a hypothetical maximum fibre bundle covering the largest available area.

The calculations of the number of fibres, accepted by a square light guide without acceptance loss, are given in Appendix 1. Taking into account the border of 1 mm thickness without fibres (as explained above), we have calculated the mechanical tolerances accepted by the fibre bundles as defined in table 1. The ranges of mechanical tolerances are given in table 4.

The smallest values of tolerences for the Barrel and the External Barrels are ± 2.6 and ± 1.0 mm respectively. These values which correspond to the extreme parts of the external drawers, are easily adjustable: this fact will be used to set indexors (see figure 7), yet these tolerances are not stringent constraints.

	Sampling 1	Sampling 2	Sampling 3
Barrel	$4.4 \rightarrow 5.0$	$2.8 \rightarrow 4.4$	$2.6 \rightarrow 3.6$
External Barrel	$3.3 \rightarrow 5.3$	$1.3 \rightarrow 4.8$	$1.0 \rightarrow 1.2$

Table 4: Range of mechanical tolerances (in $\pm$ mm) on the PMT Block positioning, depending on the cell type.

2.5 Electronics

As explained in the design specifications (see chapter 1), the easiness of the access to the TILECAL electronics is the main constraint for the drawers.

The Frontend electronics is located inside the PMT Blocks [3] on a board containing the following 3 functions: voltage divider, shaper/compressor, current integrator. The dimensions of the PMT Blocks are defined by the space required by the square PMT (Hamamatsu R5900), the light mixer, and the μ-metal and iron used for the magnetic shieldings. The printed board supporting the base provides electric connections for high and low voltages and the signal outputs.

A pair of drawers (one internal and one external drawer) is organized in a Super-Drawer [5]. The two drawers are electrically linked with one or two connectors, without the use of cables. The Frontend parts (High Voltages, FERMI, current measurements) associated to the 3 functions are located in the external drawers, allowing for easy access without removing the drawer.

Two large printed boards, located on top of each drawer, distribute the HVs. They are supervised by a microcontroller on a third board [6].

Other boards on the bottom of each drawer contain the electronics pipeline and the electronics for the current measurements.

Metallic covers protect all these electronics elements and provide electrical shielding.

To connect the Frontend boards to the PMT Block on one side, and to the external world on the other side, careful manipulation is needed.

2.6 External cabling

How the external links (cabling) between each Super-Drawer and the ATLAS experiment will be realized, needs further study. A single cable supplies the HV per Super-Drawer. Flat cables could be used to supply the power of the low voltages. Optical fibres should be used to transmit the electronics signals (Data, LHC clock and other signals). The corresponding connectors could be installed on a patch panel placed on the external plate of each module (figure 9). The cooling should be located also at this level.

3 Manufacturing technique

3.1 Overall design

The overall design of the drawer system is shown in figure 10. The main components are numbered from (1) to (7). A drawer (1) carries the readout system: the PMT Blocks (2) and various printed boards (High Voltage, electronics pipelines). It is centered on the PMT axis. and supported by the girder-rings (4), on which it can slide with a tolerence of a 1 mm gap. The girder (cross section of the built-up iron (3)) is carrying the fibre bundles in fibre-rings (5) which are glued to the girder-rings.

As explained in section 2.3, the PMT Block pitch is 116 mm. The size of the PMT Block diameter (about 54 mm) allows to keep the left and right sides of the tile readout system in the same plane, but each PMT is staggered by half a pitch.

Two metallic covers (6) are protecting the electronics boards and the cabling. Because these covers do shield each drawer fully, they could take part in the cooling system.

Glue (7) is used to fix the girder-rings on the girder.

3.2 Girder-ring glueing

The girder-ring is made of two pieces: a ring to hold the fibre bundle and a washer to support the sliding motion (see figure 11).

Glue is used as packing material to fill the gaps between the internal part of the girder and the washer and between the girder holes. Due to the fact that the constraints on the rectitude and on the flatness of this part of the girder are not very big, the first gap $g1$ is about $\pm$ 6 mm. The second gap $g2$ allows to compensate the accepted tolerances on the girder drilling ($\pm$ 2 mm on the drilling, $\pm$ 3 mm on the pitch). The holes have a diameter of 45 mm. This value could be smaller depending on the bundling techniques used.

A dummy-drawer is used to position the gider-rings. This dummy has all the washers in the correct position with the exact pitch and good rectitude. After positioning the dummy inside the girder, the rings are put through the holes of the girder inside the washers. A rubber gasket or foam can be put around the washer from the outside of the girder, to prevent leaking during the glue drying. After glueing the girder-rings on both sides the dummy is removed.

The reference planes R1 and R2, shown in figures 10 and 11, correspond roughly to the external parts of the washers, which are in contact with the drawers.

The girder-rings can also be used as a guiding system for the fibre bundle machining tool (see Yerevan and Lisbon studies).

Note that no access is required to the upper part of the girder. Yet with some holes in the upper part, the dummy-drawer fixing and the fibre machining could be made easier.

The main tolerances on the girders are summarized in table 5.

Planarity and rectitude on the girder lateral faces	$\pm$6 mm
Rectitude on the girder drilling and diameter tolerance	$\pm$2 mm
Pitch tolerance on the girder drilling	$\pm$3 mm

Table 5: Main tolerances on a 6 m long girder.

Some points still need to be decided. We propose the following:

- It is assumed that the glueing operation on the girder is done before its assembling on the TILECAL module.
- For the External Barrels, the dummy-drawers will have the full length of the modules (about 2.8 m). For the Barral, it is not clear whether the dummy will be about 5.6 m long or 2.8 m. The interest of having the full length is a guarantee of a very good alignment over the full length of the girder. This is

only useful in some cases (because of large tubes used by Argon cryogenics), namely when a train of 4 drawers is removed on one side.

3.3 The PMT Blocks

The PMT Blocks have been described in a separate note [3]. They are briefly recalled here.

A PMT Block is a tube with many different elements inside. It will be fully tested outside the drawers (figure 8).

This tube, made of mild steel (8), contains the following components:

- the square PMT (9),
- the square light guide (10),
- the rings and washers used for the centring (11,12),
- the electronics board (13),
- the magnetic shieldings: μ-metal (14) and iron (8,15,17),

All square elements (PMT, Mixer,rings...) are fixed against rotation using marks in order to assign their relative positions with respect to the mild steel tube.

The spring wire (18)- or a piece made of foam - is used to push the PMT and its base towards the mixer, keeping an air gap given by the mixer-ring (11). The PMT-ring (12) and the foam washer (16) ensure the centring of all elements inside the PMT tube (8). An end-cap (15) closes the tube.

The total weight of one PMT Block is about 1 kg.

3.4 The drawer

Figure 12 shows a general view of a drawer (19) inside a girder (3). The girder-rings (21) including the washers (22) and the covers (23) are also shown.

The main part of the drawer is manufactured by sand-casting with an aluminium alloy (figure 13). Machining is required at the level of the sides and of the transverse holes used as recipients for the PMT Blocks.

The tolerances on the drawer diameters are:

- (+ 0.2 mm, 0 mm), for the internal diameter of these holes,
- (0 mm, −0.2 mm), for the external diameter of PMT Blocks.

The other tolerances on the drawers are given in table 6.

The relative positions between the PMT Block and the fibre bundle are controlled by indexors. Only one sensor per Super-Drawer is required for the longitudinal positioning, located at the most unfavourable place corresponding to the largest bundle (see figure 7).

The mold is optimized to lighten the drawers and to favour the cooling.

Planarity and rectitude on the drawer sides	±0.1 mm
Rectitude on the hole drilling	±0.1 mm
Pitch tolerance on the hole drilling	±0.1 mm

Table 6: Main tolerances on the 1.4 m long drawers.

Dedicated erecting tools are used to have access to the drawers in every position in the ATLAS environment. They are also used to remove the drawer from the girder as illustrated in figure 14.

The total weight of the heaviest drawer fully equipped is about 50 kg.

3.5 Quality control

In addition to the mechanical controls of the various elements of the drawers, some independent test benches are foreseen to test the PMT Blocks (optics and electronics) and the drawers (motion and complete readout system), and to test spare pieces.

As already outlined in section 2.3, there are 4 kinds of drawer fillings. We propose to make 7 additional spare drawers for each filling giving in total $(512 + 4 \times 7) = 540$ drawers.

A full scale drawer mock-up has been made. The movement inside a girder model on a large marble has been studied to check the concept and to verify the tolerances.

3.6 Production and interoperation storage

The assembly and test of the 540 drawers will take about 3 years (see next section). In the assembly hall, the operations will be shared in three places:

- storage of drawer components and finished drawers (about 50 m^2),
- two assembly lines of the Super-Drawers (about 40 m^2),
- test bench of two Super-Drawers (about 40 m^2).

This work would be done by two teams, each having an electronics specialist and a mechanician, supervised by a physicist and an engineer. Some help in the preparation will be provided with additional manpower.

After testing, the drawers should be protected by cardboards along the fragile sides, then stored close to the production place in an individual plastic foil. A small number of drawers will be delivered to the institutes, which make the final assembly of calorimeter modules, for debugging and testing. The major part of the production will be transported to CERN twice or three times.

4 Time table

The schedule for further studies on the drawers, until the final assembly for the ATLAS detector, will be in two steps, from the final prototyping to the construction.

- **Final design studies and Modules 0 for the Barrel and the External Barrels**

Drawer mock-up tested inside the 6m Module mock-up	December 1995
Final drawing for the drawer system	February 1996
Start of drawer construction for Barrel Module 0	March 1996
One Super-Drawer ready to work in Barrel Module 0	May 1996
Two Super-Drawers for two External Barrel Modules 0	1997

- **ATLAS construction**

Drawer mechanics	October 1997 - October 1998
Drawer assembly	October 1998 - January 2001
Drawer installation	October 1999 - September 2001

The drawer assembly includes the full test bench controls.

The time scale above does not give details of the time delivery of the various components assembled inside the drawer: PMT Blocks, digitizing electronics, high voltages distributors, fiber links and electrical connections. These have to be fully externally tested before the assembly in the drawers.

It shows that five years are needed to complete this job after the mechanical part has started.

5 Outlook

The drawer concept as described in this note is an elegant way to house and support the readout of the Tile calorimeter by taking into account many constraints, in particular to have an easy access to the readout.

The next step is the final design of the TILECAL Module 0 before production. It is planned to build first 1 Super-Drawer for the Barrel Module 0 (fully equipped), then 2 Super-Drawers for two External Barrel Modules 0. By February 1996 a technical note will give all the details, including the description of the drawer test bench, the general cooling and the specific arrangements of some drawers due to Argon cryogenics.

References

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[2] Z. AJALTOUNI et al.,
ATLAS Internal Note TILECAL-N0-42 (1994)

[3] Z. AJALTOUNI et al.,
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[4] E.C. DUKES and J. WHITE, FNAL Report (1990)

[5] Design of TILECAL Super-Drawers, TILECAL Note (in preparation).

[6] HV distributors, TILECAL Note (in preparation).

Appendix 1

Calculation of the number of fibres accepted by a square light guide (A1) and of the tolerances (A2).

A1) Number of fibres

From experience of the ordering of round fibre bundles depending on the equilateral pattern (figure a1), we have established the following formula:

(1) $$D = d\sqrt{kM}(1+\varepsilon)$$

which gives the bundle diameter D as a function of the number of fibres M (with $M \gg 1$), where

d = fibre diameter

(2) $k = 2\sqrt{3}/\pi$ corresponds to the ideal geometry and

$\varepsilon = 0.08$ is an empirical correction factor corresponding roughly to the degree of filling.

For fibres of 1 mm diameter, formula (1) gives:

(3) $$M = 0.778\ D^2$$

A2) Mechanical tolerances

Keeping a 1 mm safety margin all around the mixer border (see figure a.2), the mechanical tolerance t is given by:

(4) $$L = D + 2(1+t)$$

where L is the size of the square PMT photocathode, and D is the diameter of the fibre bundle.

For $L = 18$ mm, the tolerance for fibres of 1mm diameter is given by:

(5) $$t = 8 - 0.567\sqrt{M}$$

Figure captions

Figure 1: Schematic view of the TILECAL Barrel and External Barrels showing the drawer locations, with one External Barrel in a recessed position to give access to the drawers.

Figure 2: Schematic view showing the Super-Drawer concept.

Figure 3: Main magnetic components from toroidal (T) and solenoidal (S) fields acting perpendicular on the PMTs located in the drawers.

Figure 4: Principle of a TILECAL module.

Figure 5: Girder dimensions.

Figure 6: Schematic view of the TILECAL readout cells in the longitudinal plane without Plug (the x and y scales are different).

Figure 7: Same as figure 1 including the Plugs.

Figure 8: Possible design of the assembly of a PMT Block.

Figure 9: Location of the patch panel for the electronics connections of the Super-Drawers with the ATLAS detector.

Figure 10: Transverse cross section showing the main components of a drawer inside a girder.

Figure 11: Reference planes of the girder-rings and some details.

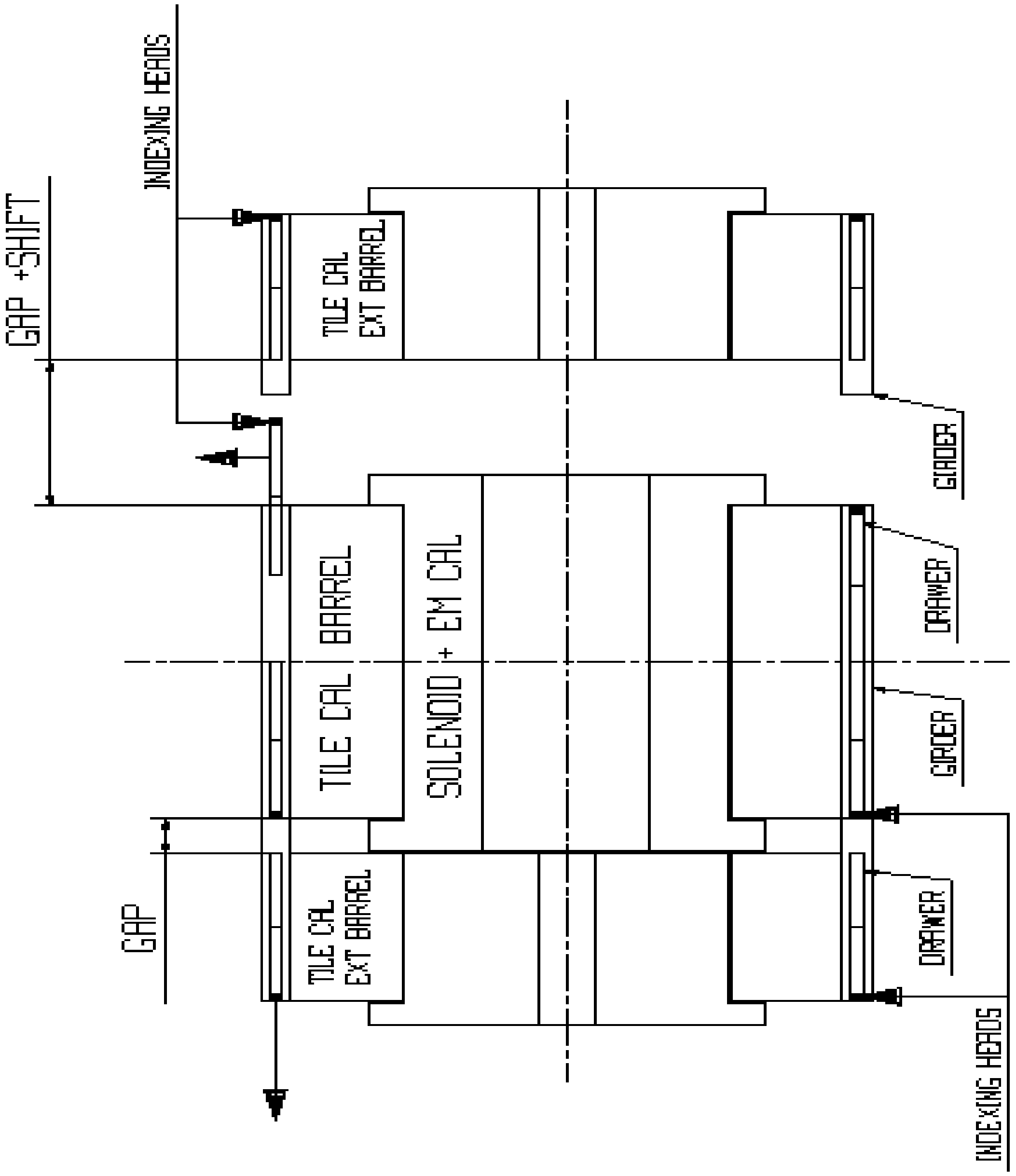
Figure 12: General view of a drawer fully equipped.

Figure 13: Master piece of a drawer manufactured by sand-casting.

Figure 14: Schematic view of the tools used for installation of the drawer.

Figure a.1: Fibre ordering depending on the equilateral pattern (d = fibre diameter).

Figure a.2: Definition of the mechanical tolerance t on the fibre bundle (L = light mixer side, D = fibre bundle diameter).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INDEXING HEADS
TILE CAL
EXT BARREL
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SOLENOID + EM CAL
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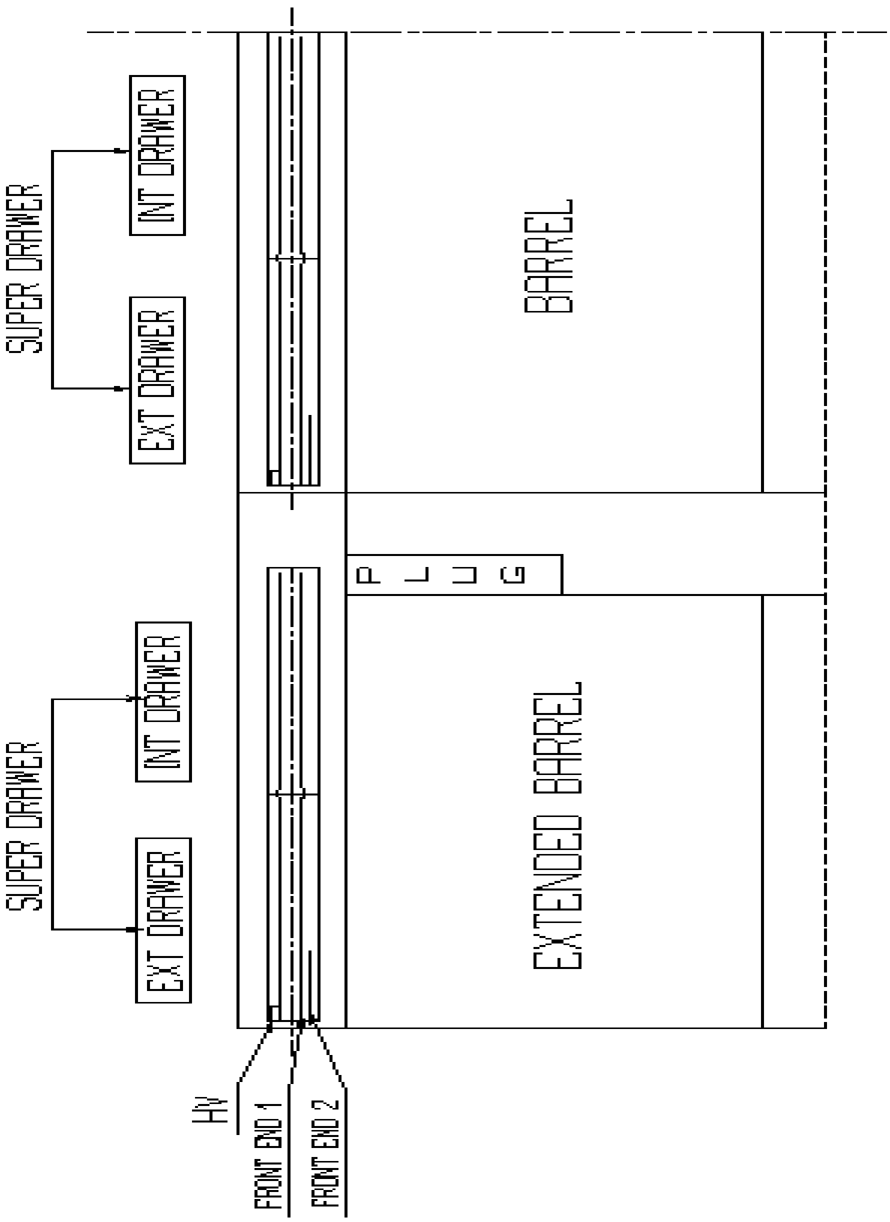
FIG 1


SUPER DRAWER
EXT DRAWER
INT DRAWER
SUPER DRAWER
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INT DRAWER
BARREL
PLUG
EXTENDED BARREL
HV
FRONT END 1
FRONT END 2

FIG 2

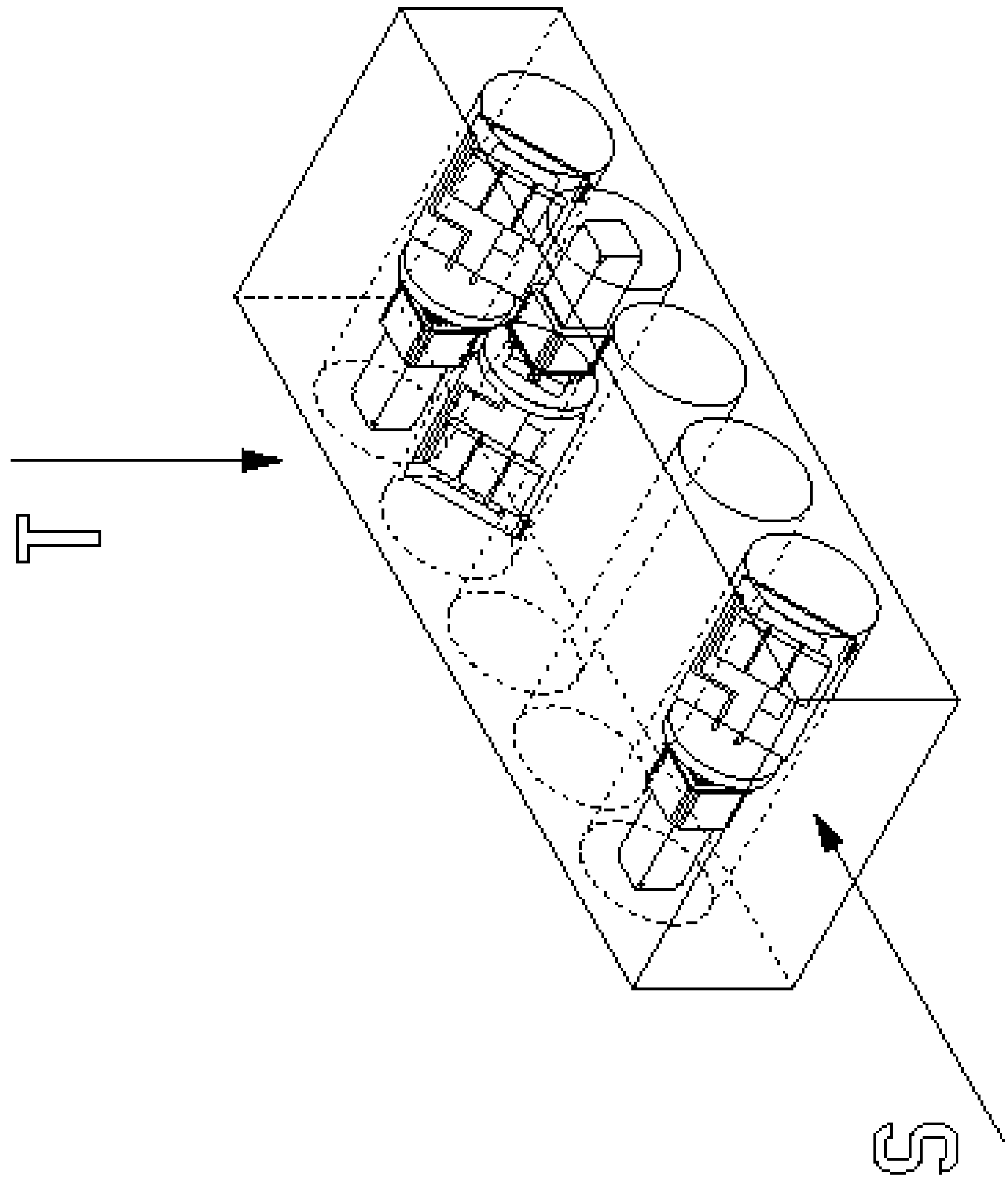


FIGURE 3

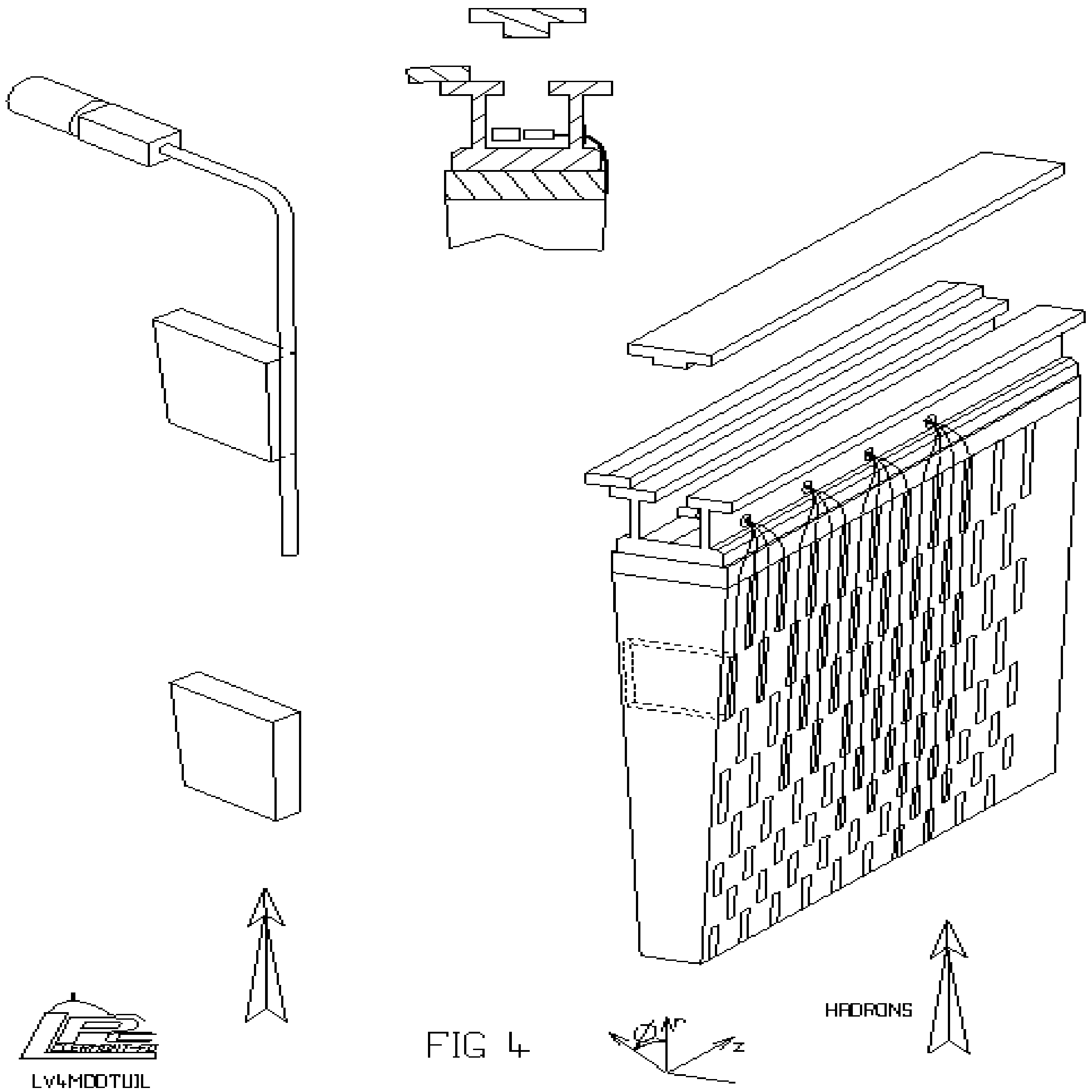
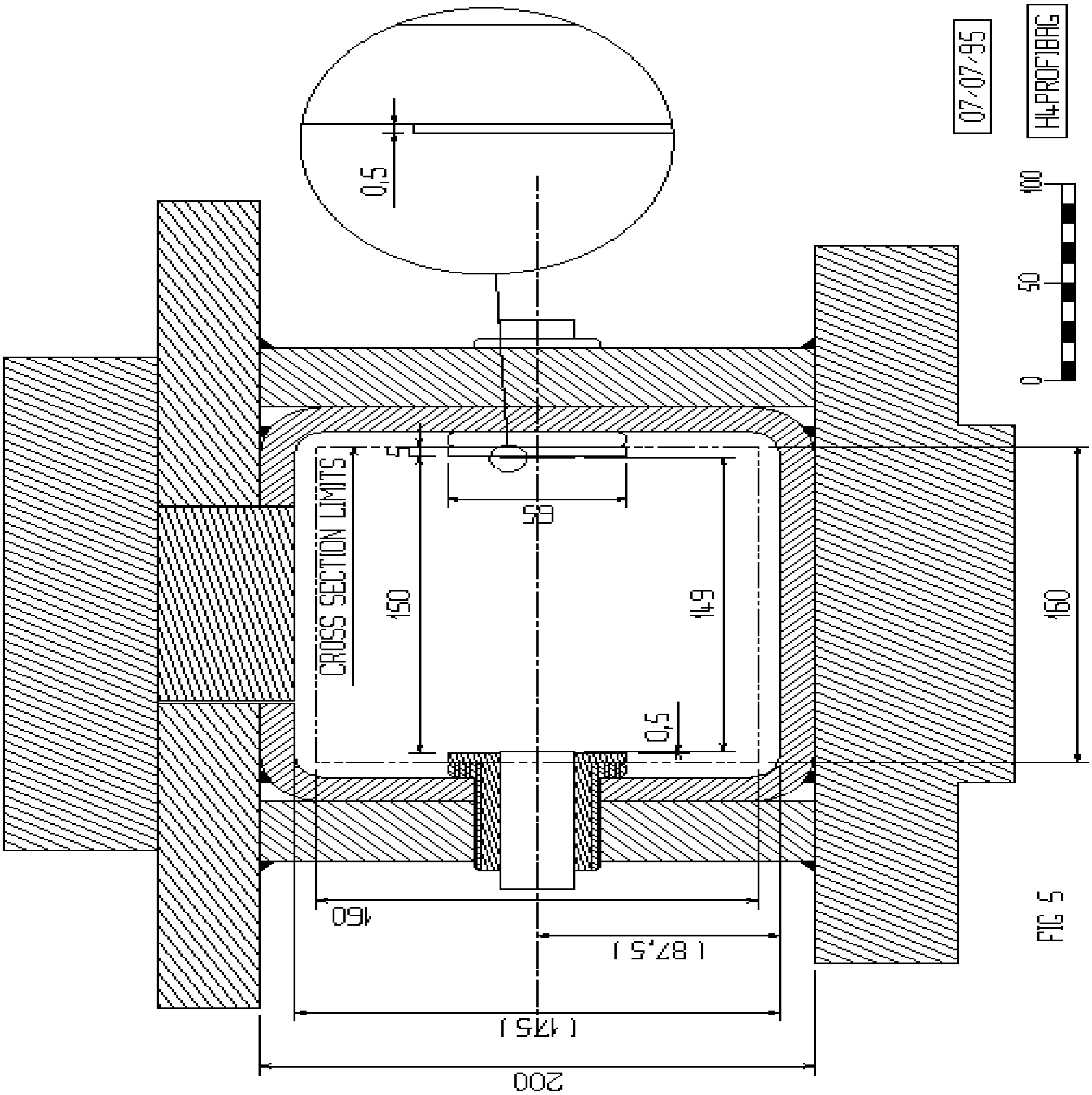


FIG 4



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65
150
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50
100

FIG 5

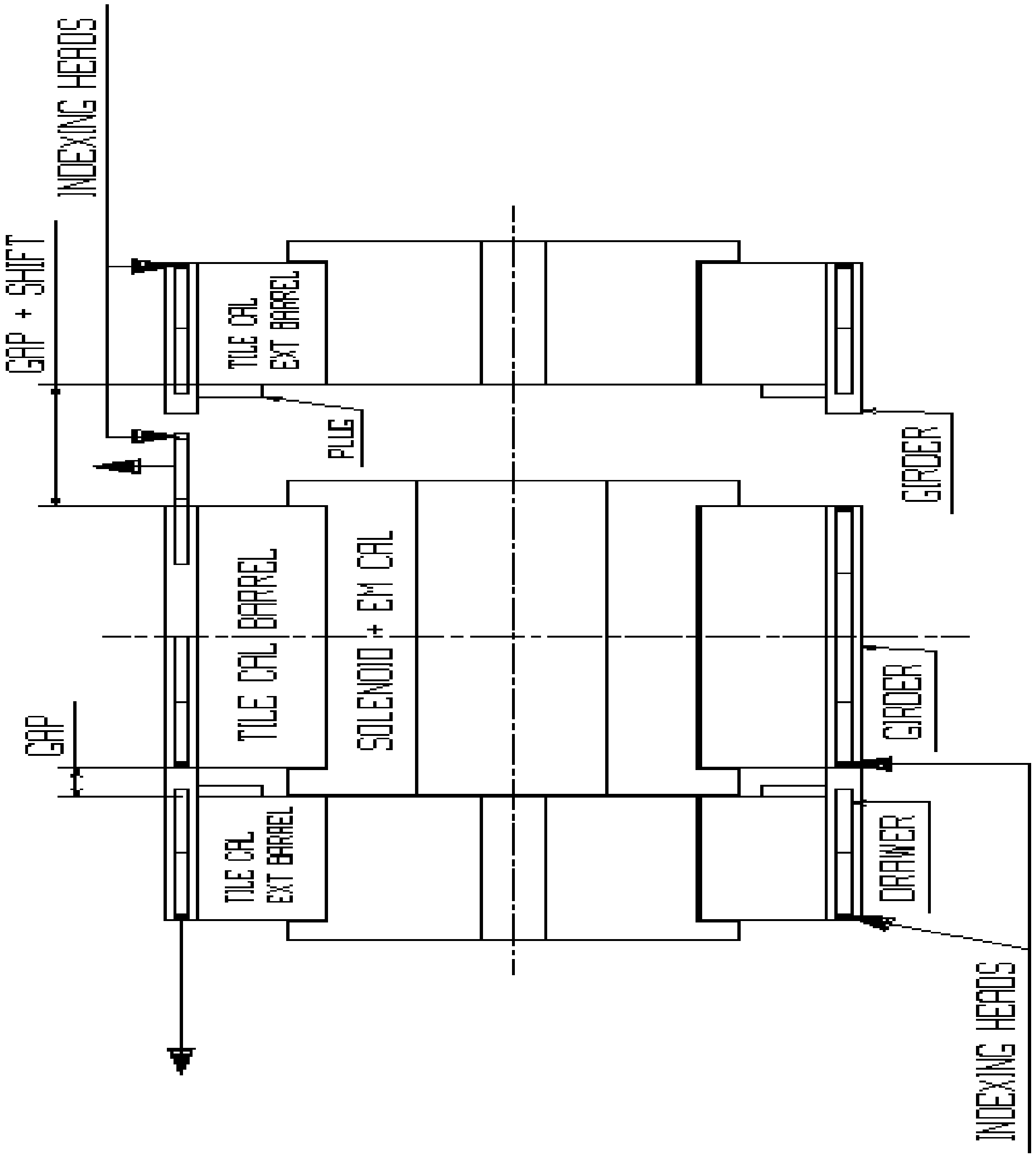
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FIG 7

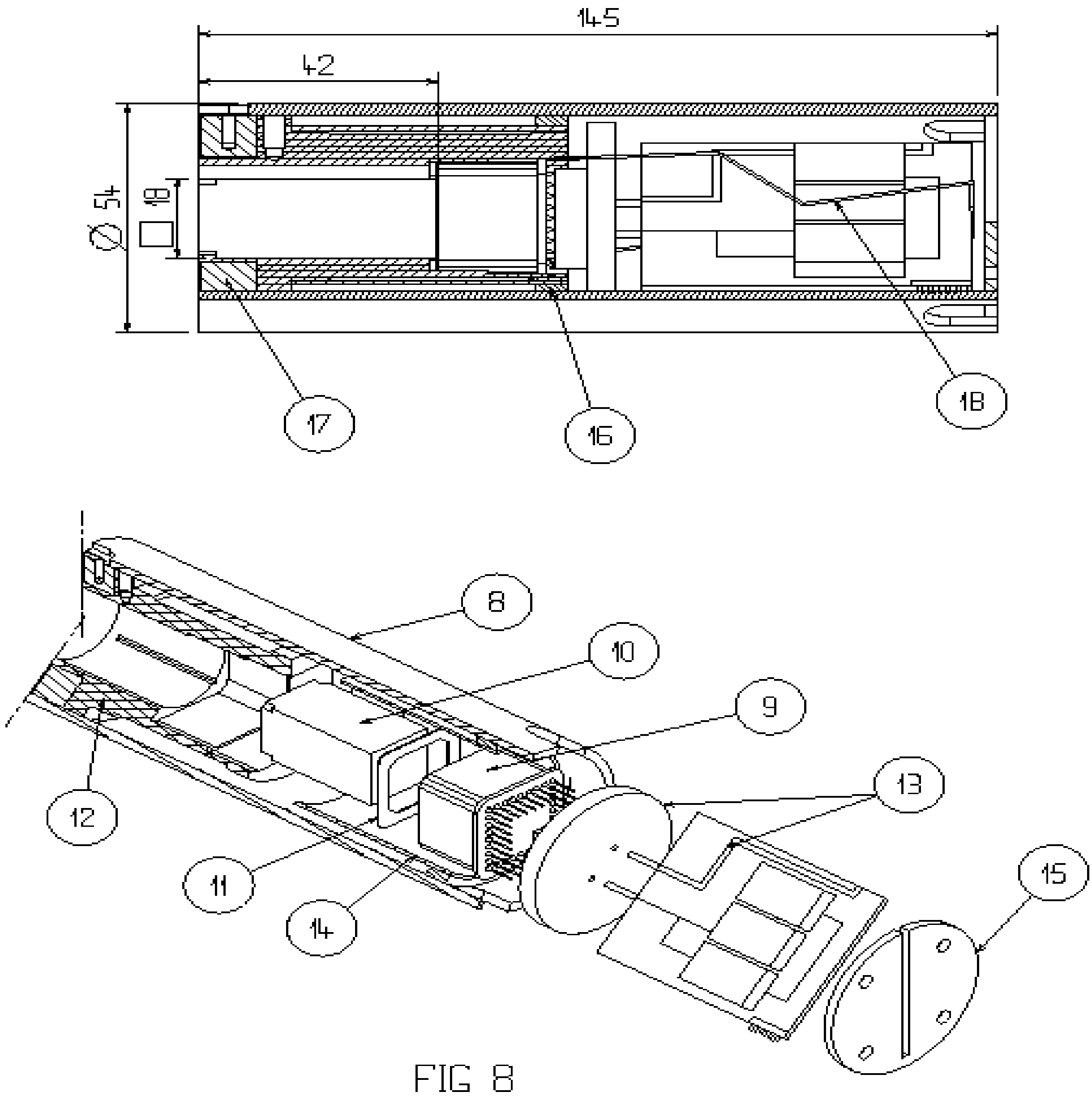
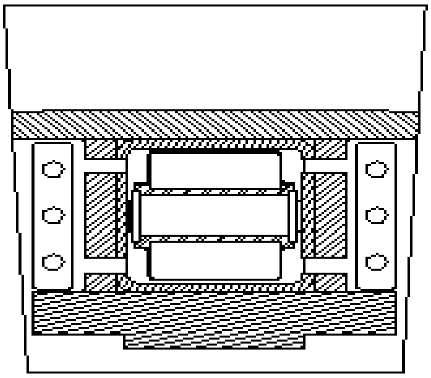
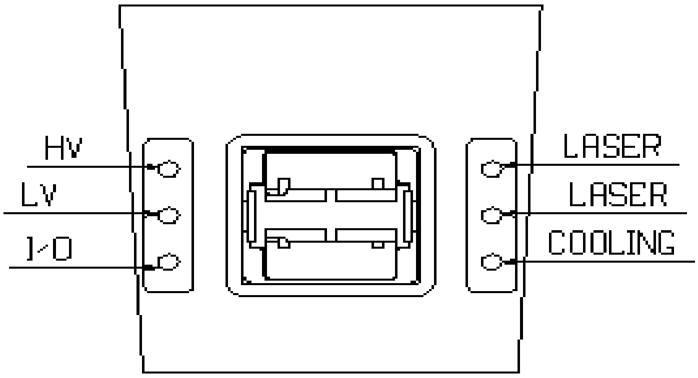


FIG 8





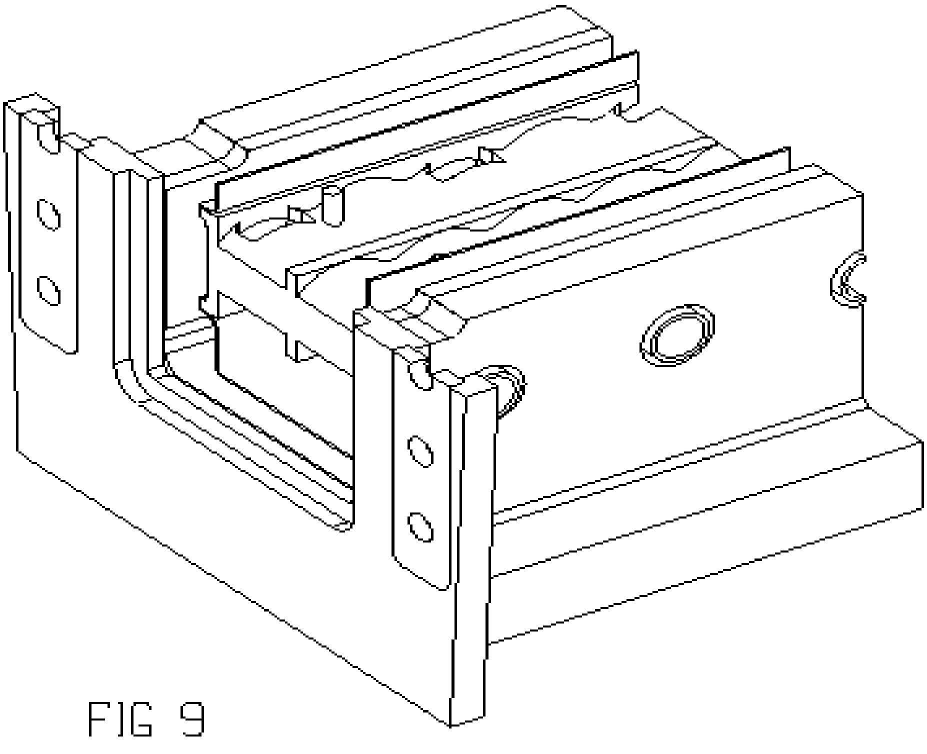


FIG 9

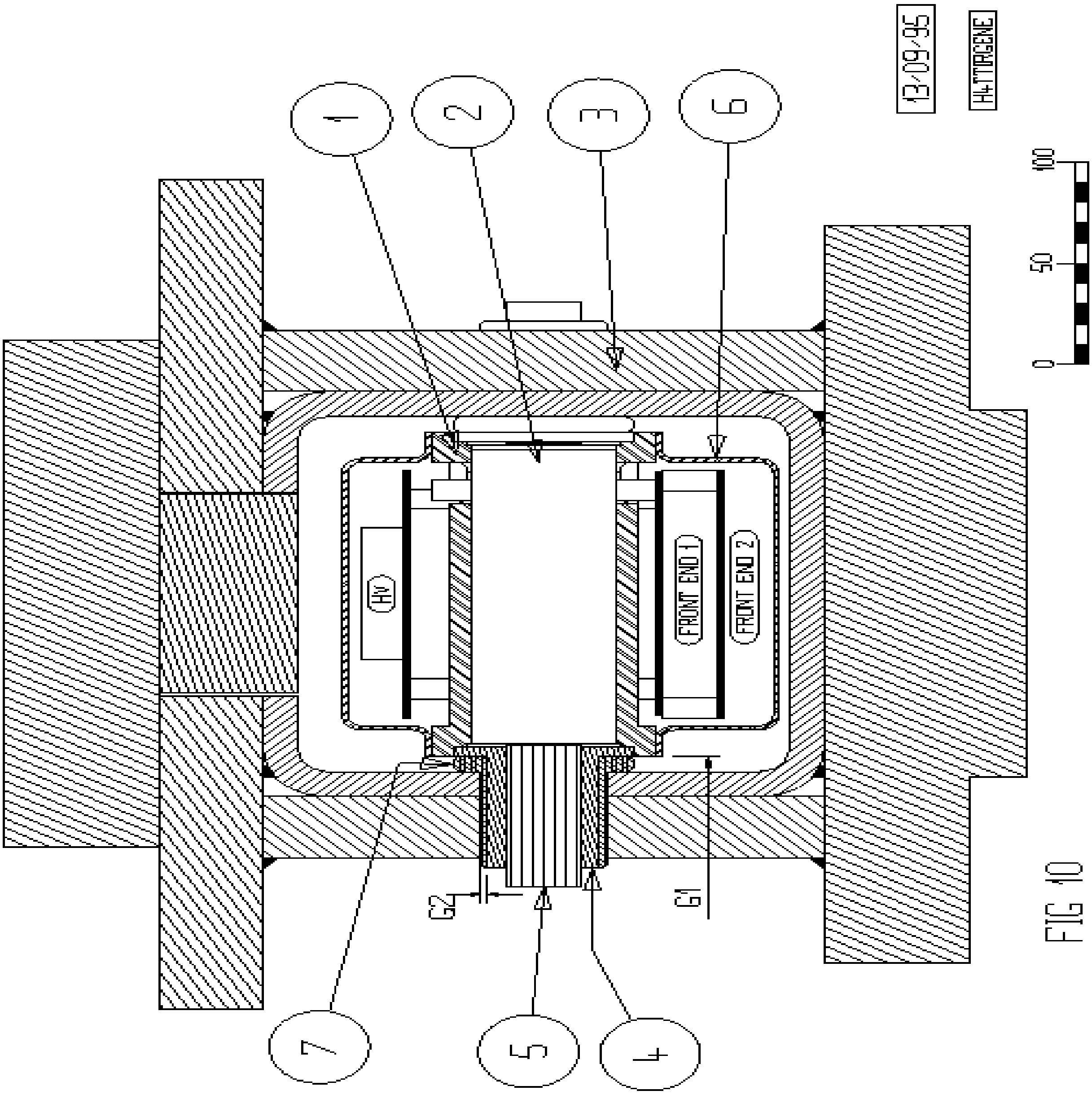


FIG 10

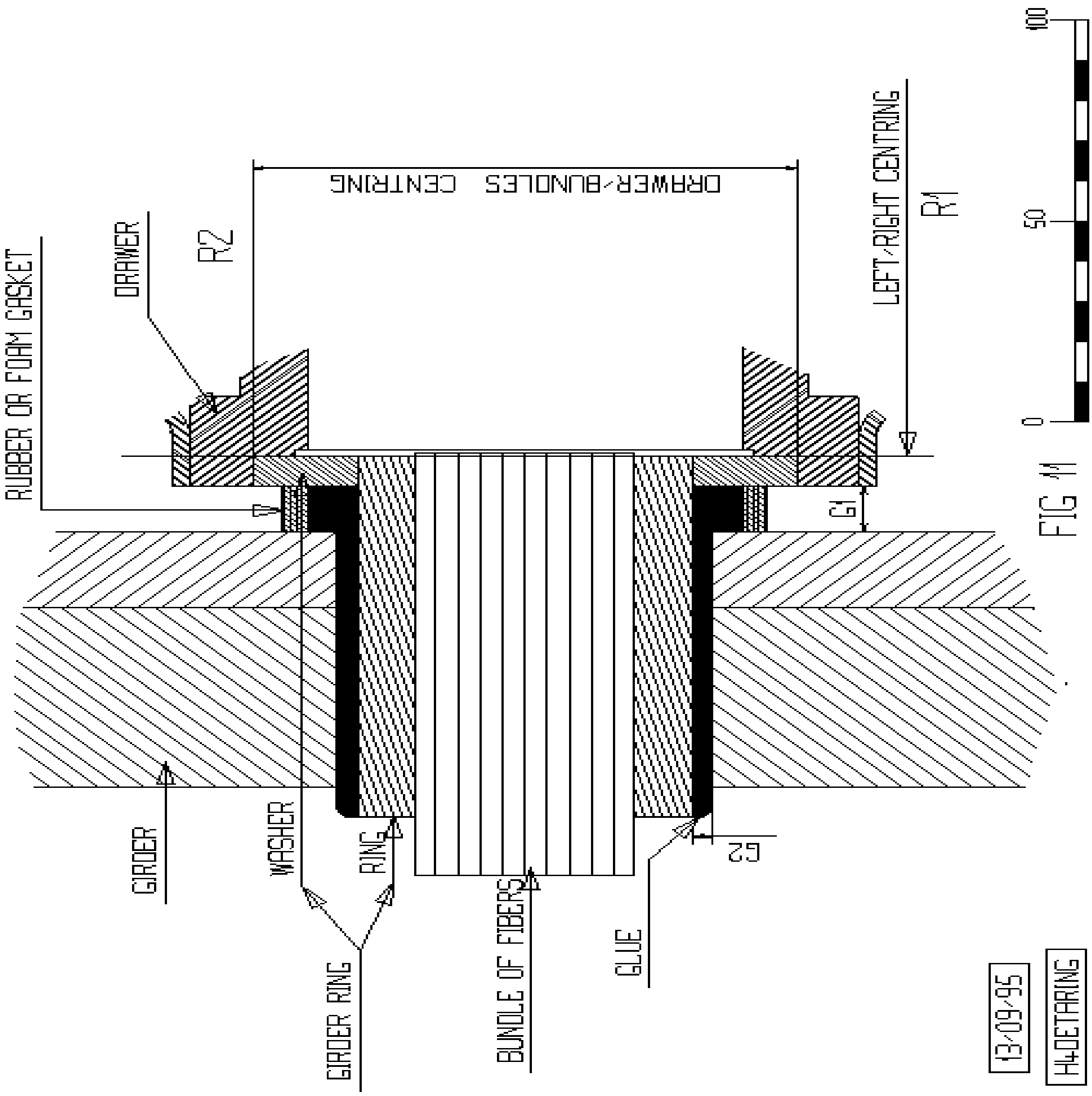

RUBBER OR FOAM GASKET
DRAWER
R2
DRAWER/BUNDLES CENTRING
LEFT/RIGHT CENTRING
R1
0
50
100
G1
G2
GIRDER
WASHER
RING
GIRDER RING
BUNDLE OF FIBERS
GLUE
13/09/95
H4DETRING

FIG 11

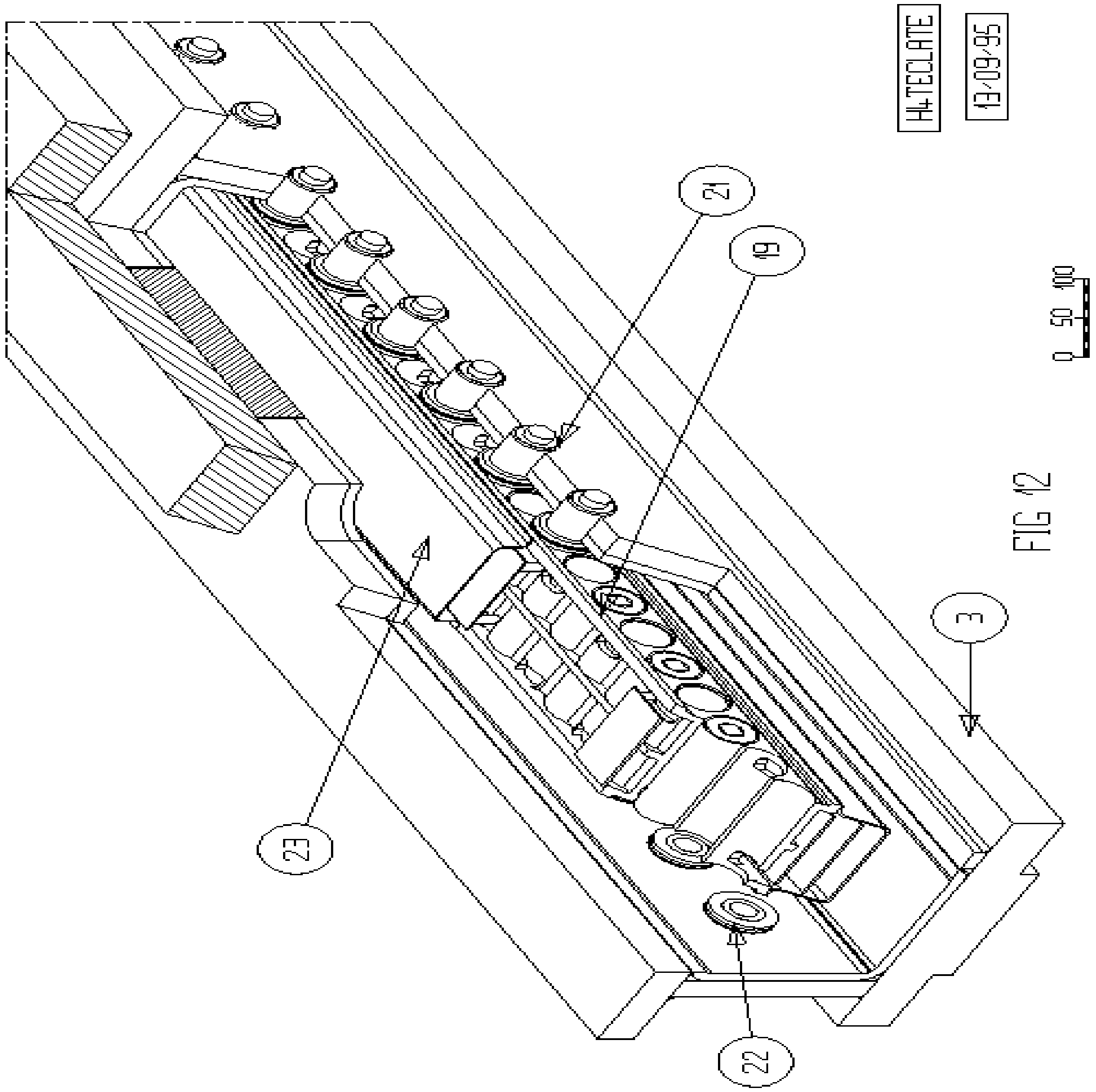


FIG 12

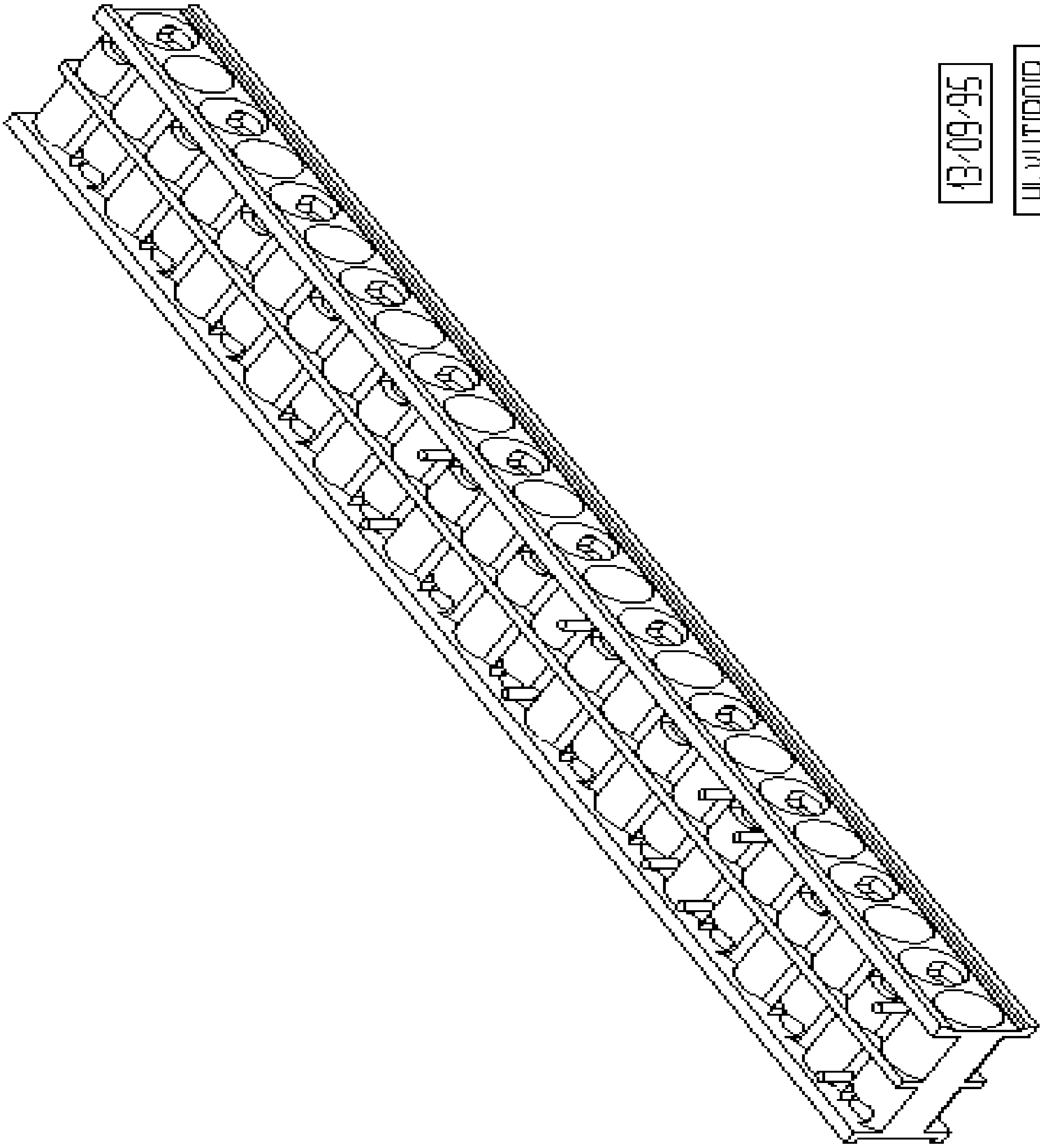
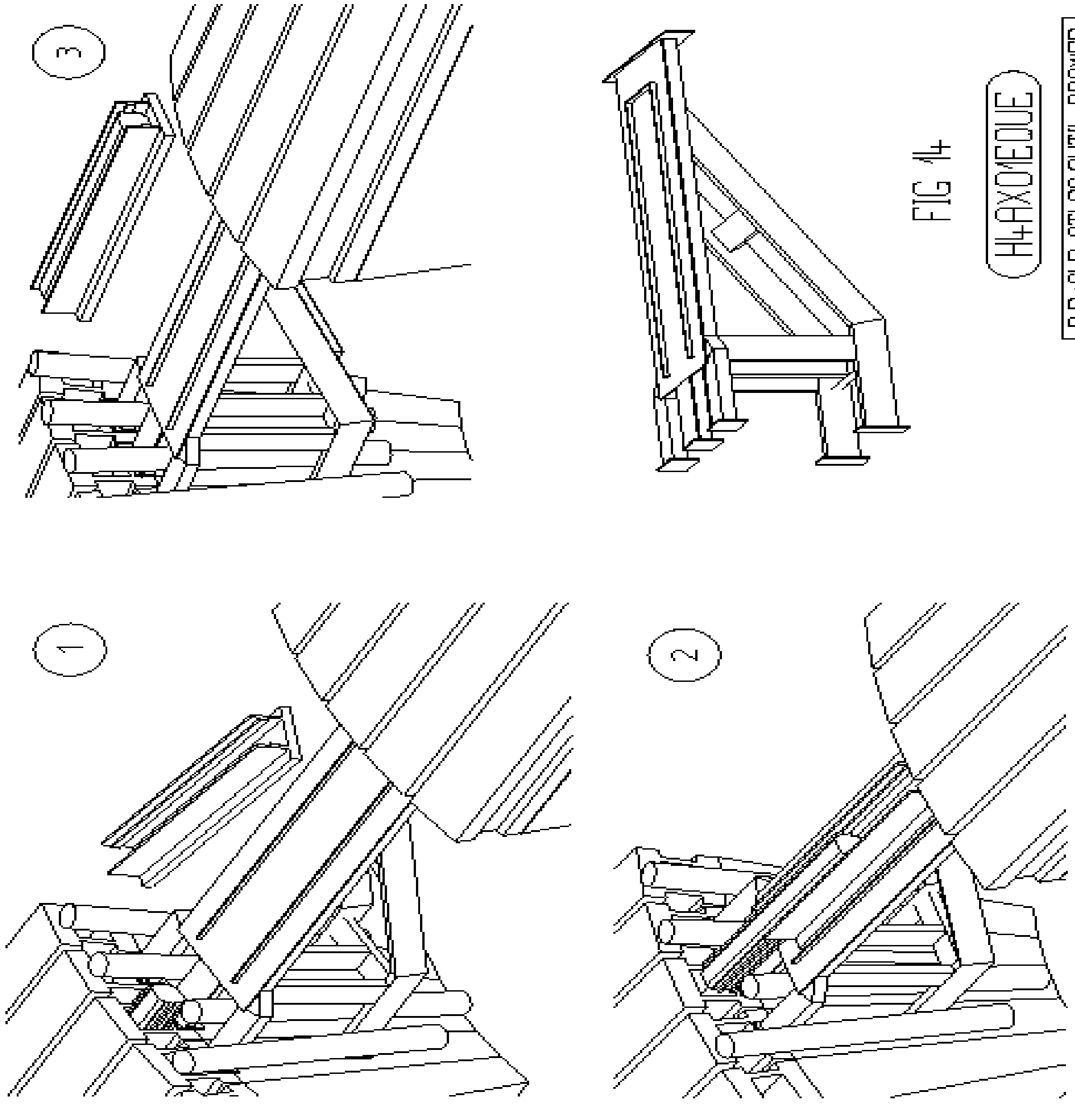


FIG 13

13/09/95

HL+VUTIROIR

0 50 100


3
1
2
FIG 14
H4AXO1EQUE
B.D.:CLR_ATLAS,OUTIL_DRAWER