3. HE MECHANICAL DESIGN AND CONSTRUCTION

3.1. OVERVIEW AND REQUIREMENTS

3.1.1 Overview

The endcap hadron calorimeter (HE) covers a rapidity region between 1.3 and 3.0 with good hermiticity, good transverse granularity, moderate energy resolution and a sufficient depth. A lateral granularity (η x φ) was chosen ~0.087 x 0.087. The hadron calorimeter granularity must match the EM granularity to simplify the trigger.

The basic requirements of the HE design are the following:
- nonmagnetic material for absorber;
- minimal λ of the absorber to have maximum absorption length;
- total calorimeter length about 10 λ to provide sufficient containment of high energy jets;
- sampling must be adequate to the required energy resolution;
- minimal dead zones to measure missing energy.

The basic structure of the endcap calorimeter is the same as for the barrel calorimeter. A crystal electromagnetic calorimeter (EE) of 27 X_0 is placed in front of HE. The total depth of the HE calorimeter (not counting the electromagnetic calorimeter) is about 10 absorption lengths (19 active layers). The absorber sampling thickness is 8 cm. The absorber material is brass (90% Cu+10% Zn), the front and back plates are made of stainless steel to increase strength. The absorber plates are bolted together to form a single monolithic structure, with gaps for scintillator insertion. This structure is conceptually similar to the barrel structure, although differing in engineering details because of the endcap geometry and mounting scheme. The entire HE monolith is fastened from its back stainless steel plate to a 10.0 cm front plate of the Endcap Muon absorber steel (YE1).

The EE electromagnetic calorimeter is attached to the front face stainless steel plate of HE (1.16 times thicker than the brass plate for an interaction length equivalent to that of the brass absorber). The total thickness of the front plate is determined by the dead material introduced by EE cables, electronics etc. (about 0.1 λ). So the thickness of the plate may be reduced by this amount in order not to introduce additional layer of scintillators. The EE is a highly non-compensating calorimeter that introduces nonlinearity of energy response and degrades the energy resolution. To correct these effects in some degree a weighting technique may be used. In this case the expected energy resolution is $\delta E/E = 105\%/\sqrt{E} \oplus 4\%$. The weighted response of the initial layer(s) of the hadron calorimeter is used separately applying a correction taking into account the ratio $E_{H1}/(E_{H1}+E_{H2})$.

Each end cap is an 18 sided polyhedron that covers and closes one end of the barrel calorimeter. The HE is constructed of plates, separated by staggered spacers, that are perpendicular to the beam axis. The basic geometrical parameters of the HE are shown in Fig. 3.1.

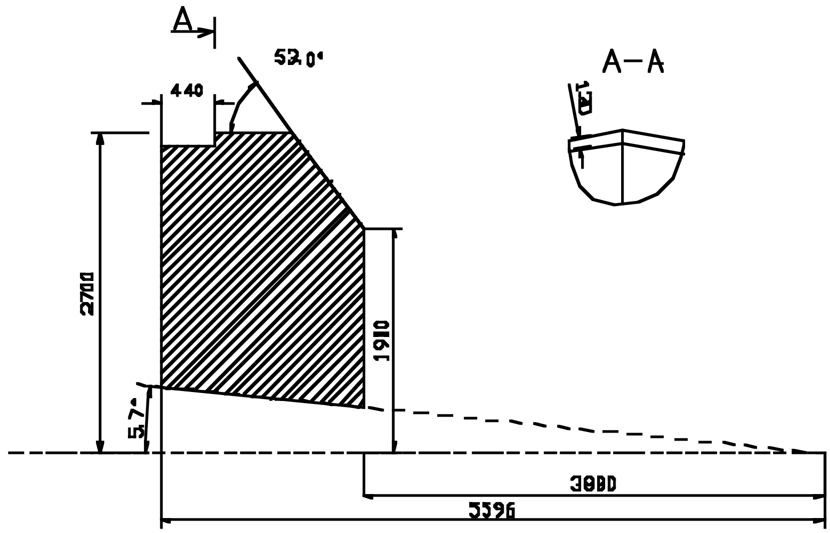


Fig. 3.1: Basic parameters of HE.

Fig. 3.1: Scintillating plates are mounted on aluminum plates forming trapezoidal tray ("pizza pan") structures which are installed in the gaps of the endcap absorber. The construction allows easy access to the pizza pans and provides a rigid structure.

3.1.2 Engineering design requirements

The basic design guidelines are:

- the absorber must be made of brass plates with minimal gaps (± 0.5 mm) in φ;
- mechanical assemblage of the absorber plates with bolts ;
- design must provide for the required insertion of megatiles and easy removal;
- back flange is made of stainless steel;
- dimensions of the absorber plates in ϕ must correspond to minimal cost, minimal waste and maximum machinability;
- absorber design and all interface elements must satisfy the safety requirements to sustain about 300 tonnes and provide stable position of endcap in space during all operation time;
- safe operation during access to EE and HE and to the interior of the detector;
- provide the required precision of muon chambers ME1 alignment, with the possibility to replace separate chambers without interfering with other end cap systems;
- HE design and the interface zone must correspond to the requirements of the standard assembling procedures and time schedule at the CERN assembly hall on the surface;
- the cost must be within the allocated sum;
- the safety factor for the most loaded elements (taking into account all combined stresses) must be greater than 2;
- the calculations of stresses and deformations must take into account dynamical forces equal to 0.15g.

3.2 HE ABSORBER GEOMETRY

The endcap hadron calorimeter covers the rapidity region between 1.3 and 3.0 and is an 18 sided polyhedron in shape. The HE consists of the absorber plates with 19 sampling gaps filled with scintillator trays. The scintillator response signal is transferred via optical cables to megatiles decoder boxes in which the signals from tiles forming a single (η x ϕ) tower are optically mixed together. The decoder box also contains the readout photodetectors, the frontend amplifiers, as well as the initial signal digitizers. This figure shows a cut through the vertical plane of the HE cross section in y-z plane. Fig. 3.2 presents the endcap segmentation (HE and EE) in ϕ and Fig. 3.3 shows the longitudinal structure of HE.

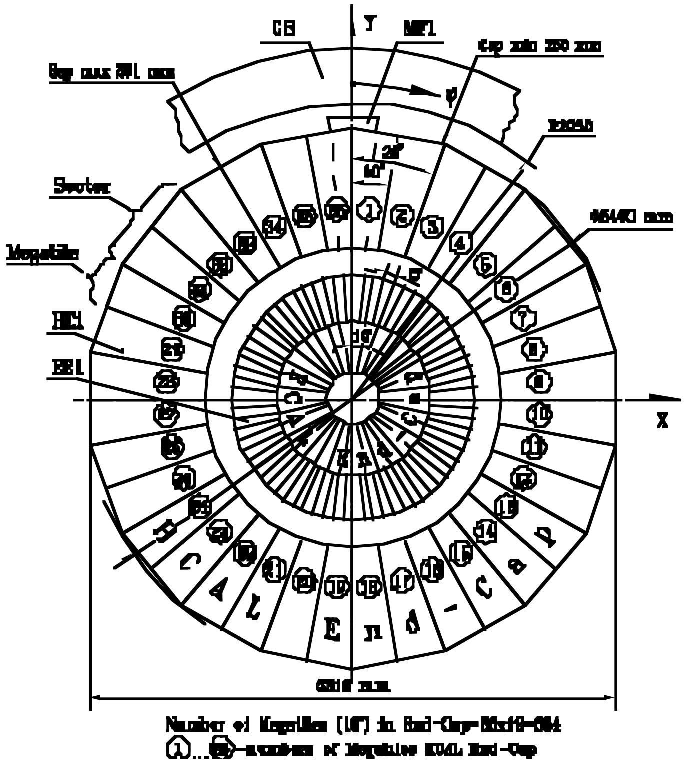


Fig. 3.2: End cap segmentation.

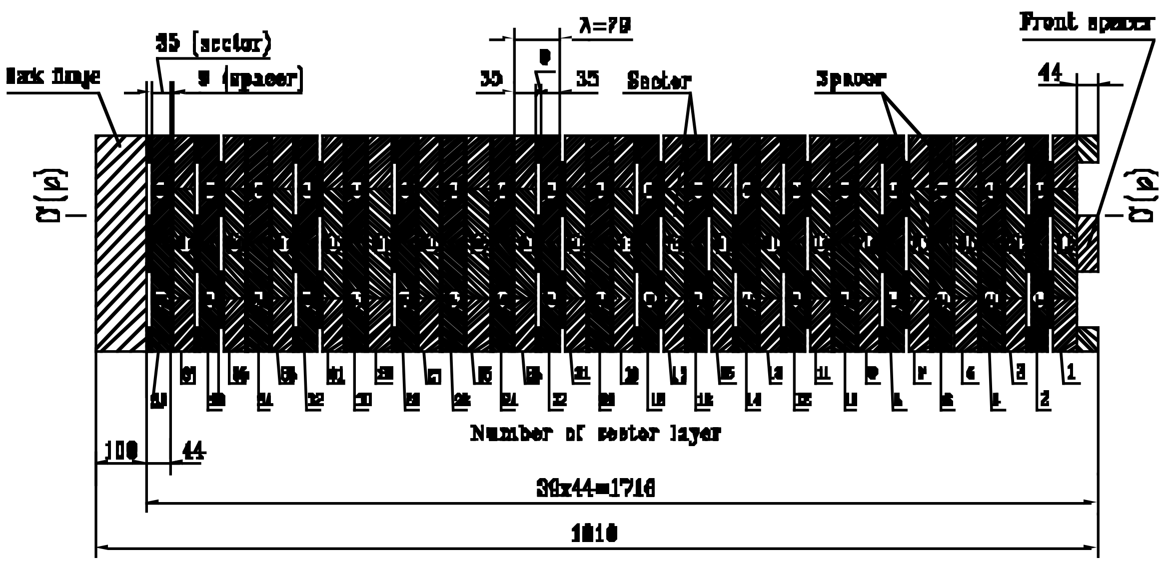


Fig. 3.3: Longitudinal structure of HE.

3.3 HE ABSORBER DESIGN AND MANUFACTURE

The HE design with mechanical connection of elements is presented in Fig. 3.4. Absorber elements and spacers are connected with bolts M24x2 with cylindrical head. To eliminate a relative shift of absorber elements in the vertical plane under the shear forces due to the HE weight, a large number of collets with diameter 36mm are used for interplate connection and stabilization.

The calorimeter is formed by assemblage of sector and spacer elements. Each layer consists of 18^0 brass sectors 35 mm thick. The sector layers are separated by 18 brass spacers 9 mm thick covering 10^0 in ϕ for the scintillator insertion gaps.

From the production point of view the following requirements were taken into account:

- to cut the cost of the absorber plates produced by industry the sector plate cover 20^0 in ϕ;
- minimization of the absorber plate dimensions allows to use standard industrial equipment with required precision of machining;
- to control the quality of all industrially produced absorber elements a control assemblage is planed;
- an analysis of sector absorber production from rolled plates with width 600, 1060, 1200, 1250 and 1500 mm shows that the most economical option is 20^0 sectors;
- several producers of rolled plates were considered: Bulgaria (produces plates up to 1060 mm wide); Orsk plant OTM, Russia (produces plates up to 1200 mm wide); “Krasnyi Vyborzhets” plant in St.Petersburg, Russia (produces plates up to 1500 mm wide); metallurgical plant in Bendzin, Poland; KGHM Poland copper; firm “Outukumna”, Finland.

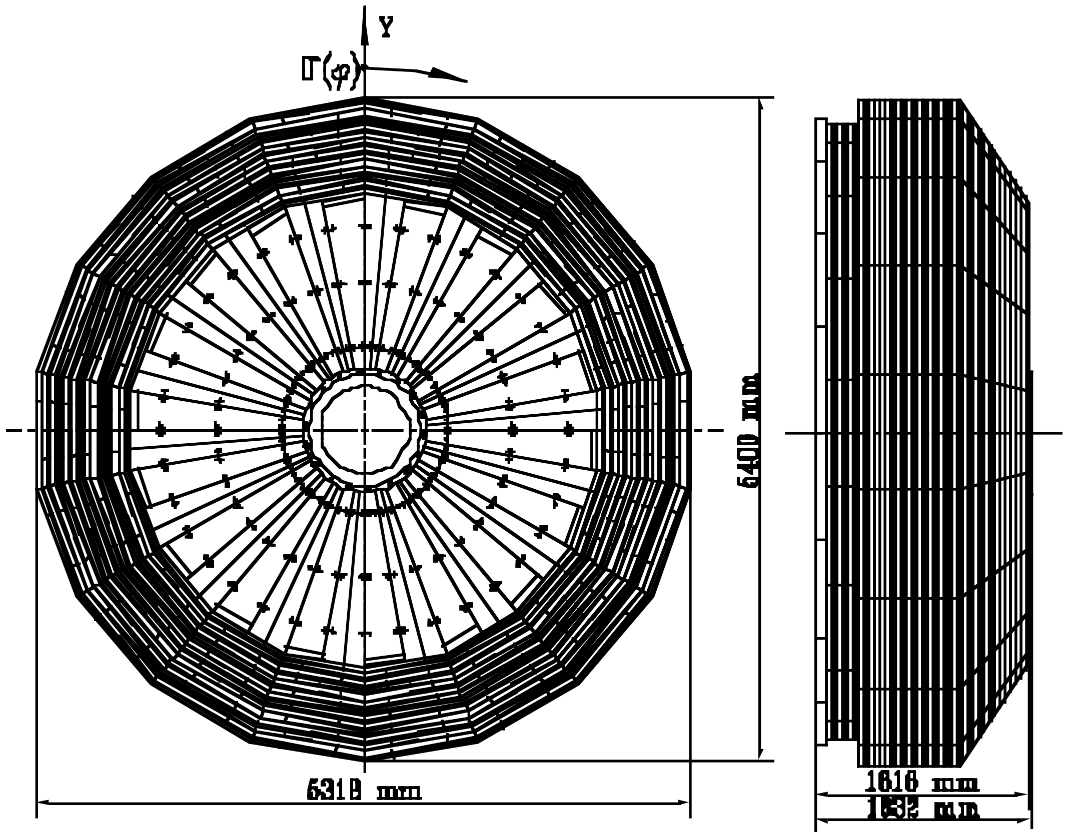


Fig. 3.4: Absorber of the HE.

3.3.1 Sector and spacer layout

The HE absorber consists of alternating layers of sector and spacer plates connected with bolts and collets (see Fig. 3.5). The arrangement of the even and odd layers is shown in Fig. 3.6. The numbering of the layers starts from the layer closest to the interaction point and is shown in Fig. 3.7. The layer numbering scheme is the same as that in the barrel, namely that the layer immediately following the innermost stainless steel plate is numbered as layer one, while the layer following the outermost stainless steel plate is layer 19. Plates in front of the innermost stainless steel plate of HE will be numbered zero (and -1). The geometry of the sector and the spacer is presented in Fig. 3.8.

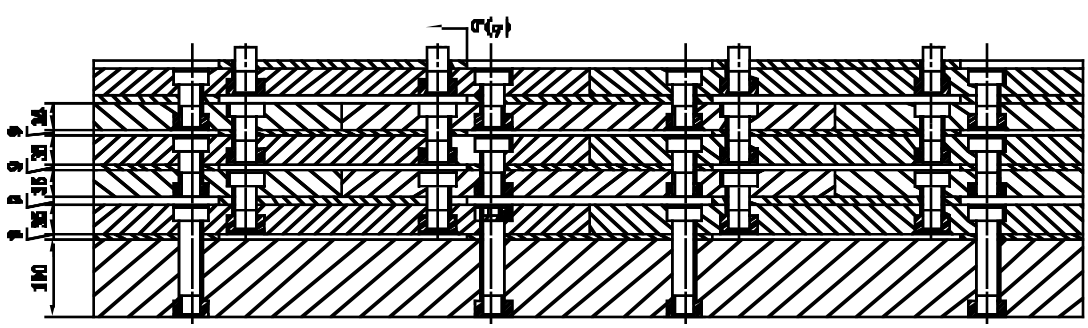


Fig. 3.5: Scheme of HE layer joints.

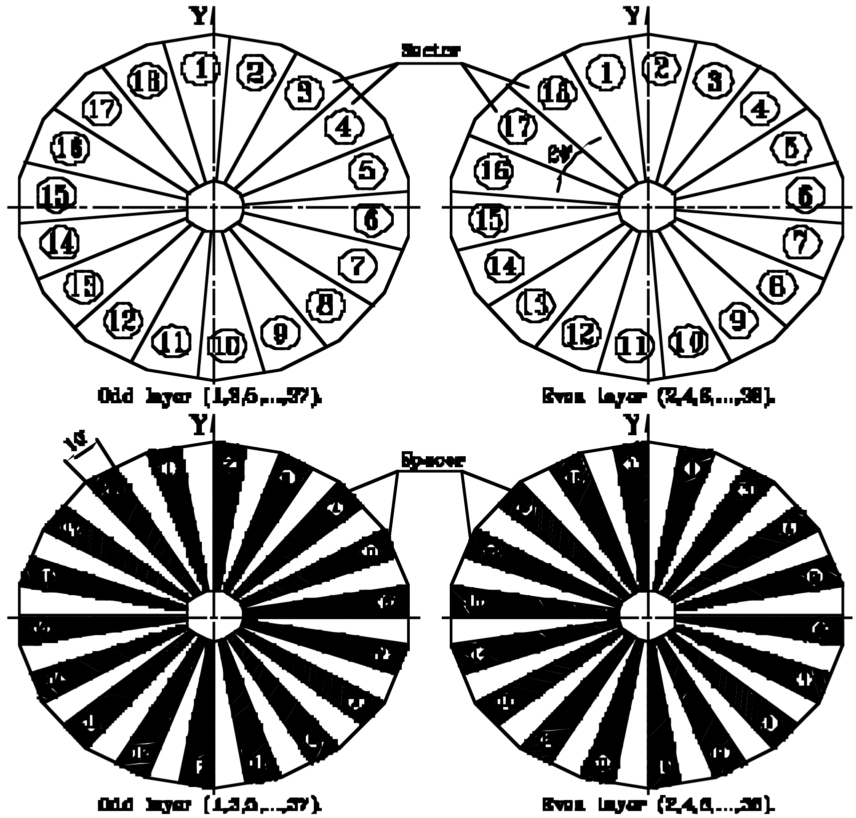


Fig. 3.6: Sector and spacer arrangement in odd and even layers.

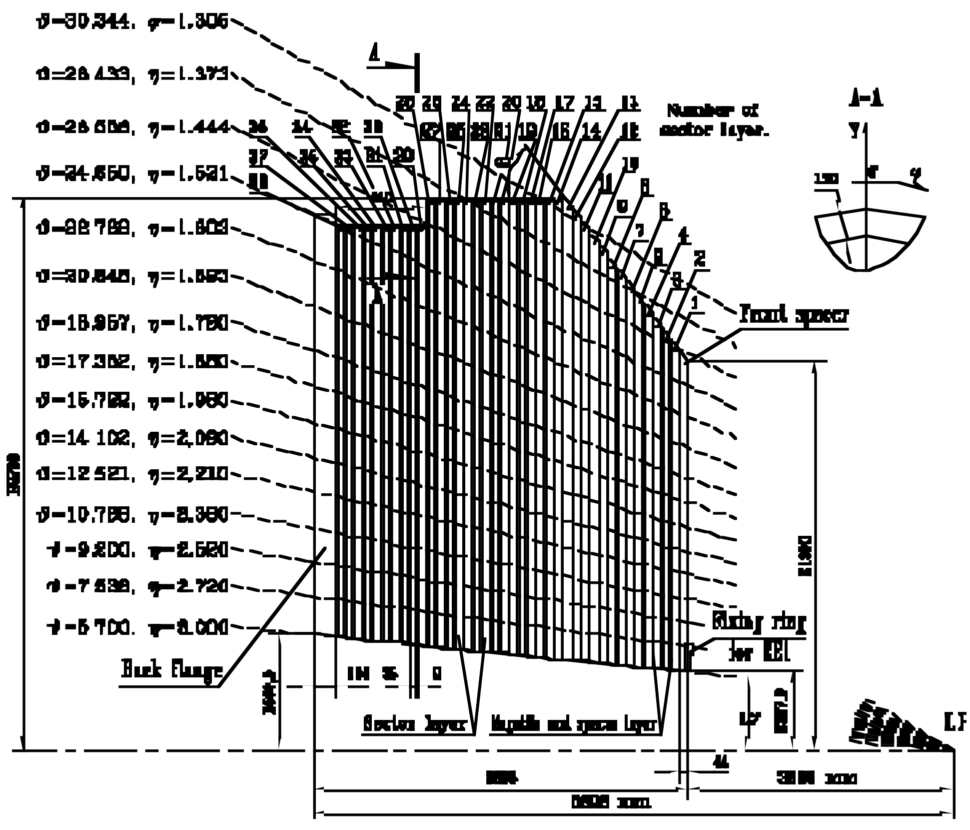


Fig. 3.7: Longitudinal section of HE absorber.

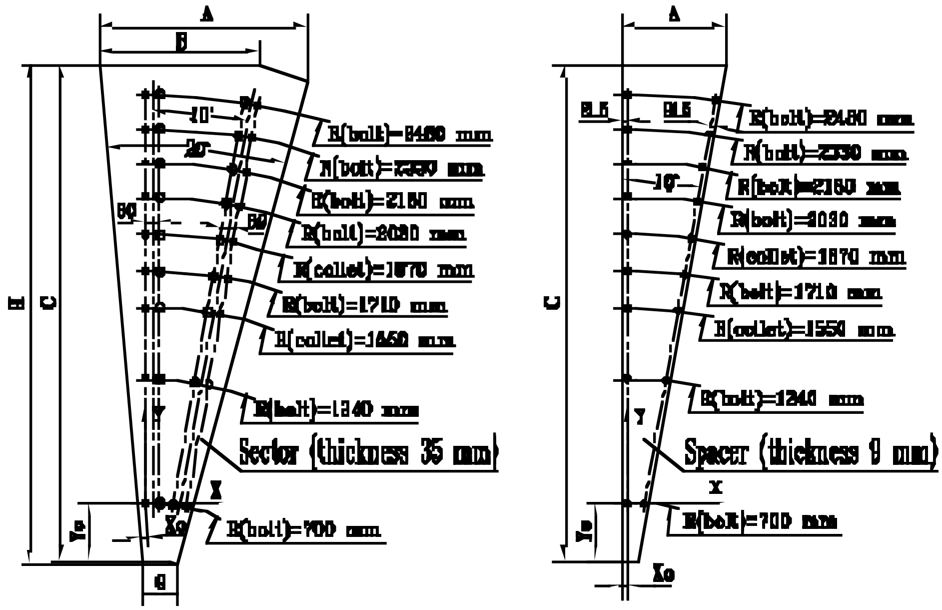


Fig. 3.8: Geometry sector and spacer.

3.3.2 Fastening elements of HE

All absorber plates are connected with bolts and collets. The general layout is shown in Fig. 3.5. The collet design is shown in Fig. 3.9, while Fig. 3.10 presents the bolted connection.

The number of fastening elements along the z-axis (HE depth) is optimized (see Fig. 3.11). The most loaded layer # 38 (next to the back flange) has 468 bolts M24x2, the less loaded layer #1 has 216 bolts. The number of collets with diameter 36 mm and cross section 756 mm^2 is 72 in the last layer. The layers assemblage is made with torque indication wrench that allows to increase static load on the bolts by a factor of 2.

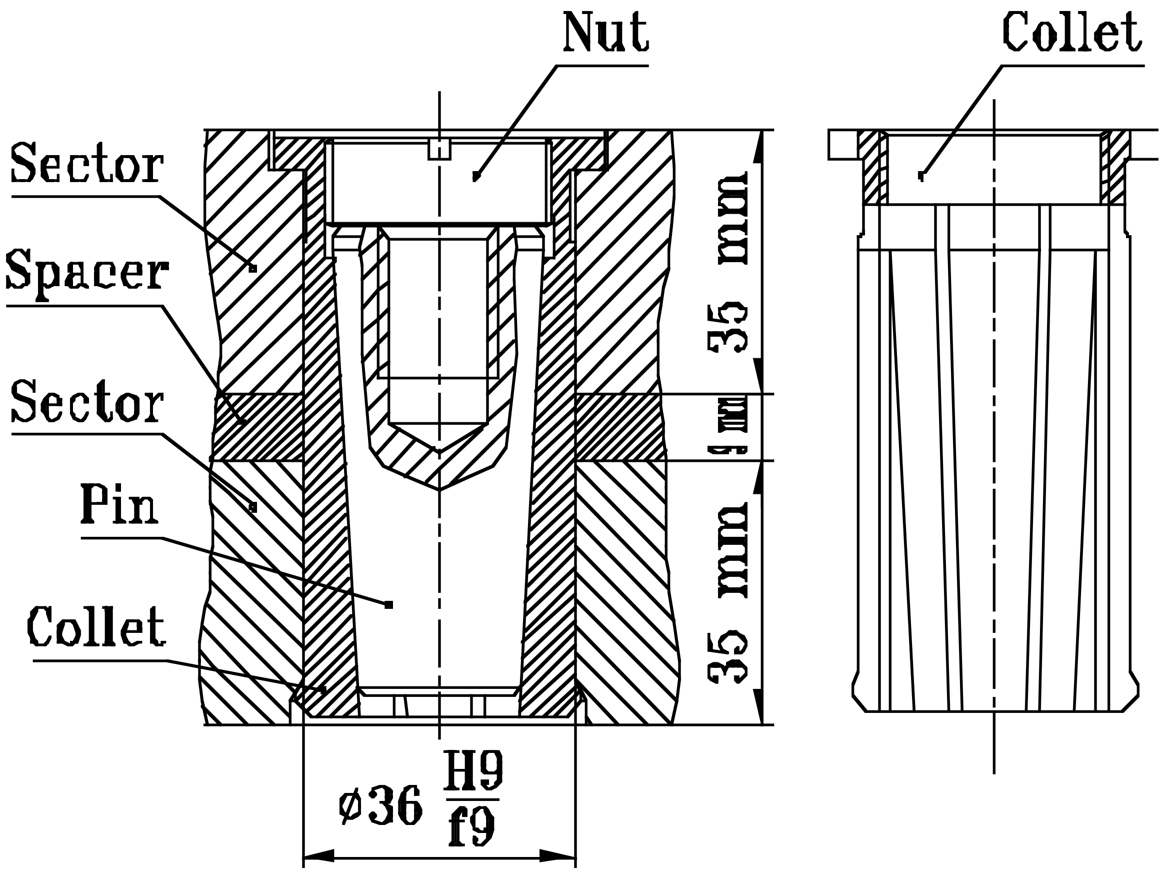


Fig. 3.9: Collet connection.

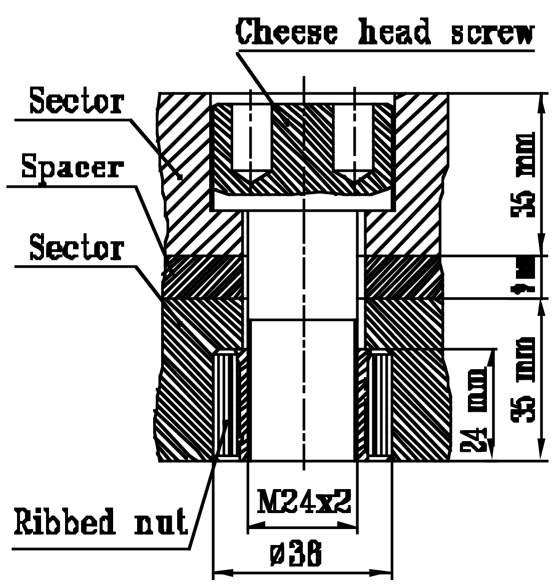


Fig. 3.10: Bolted connection.

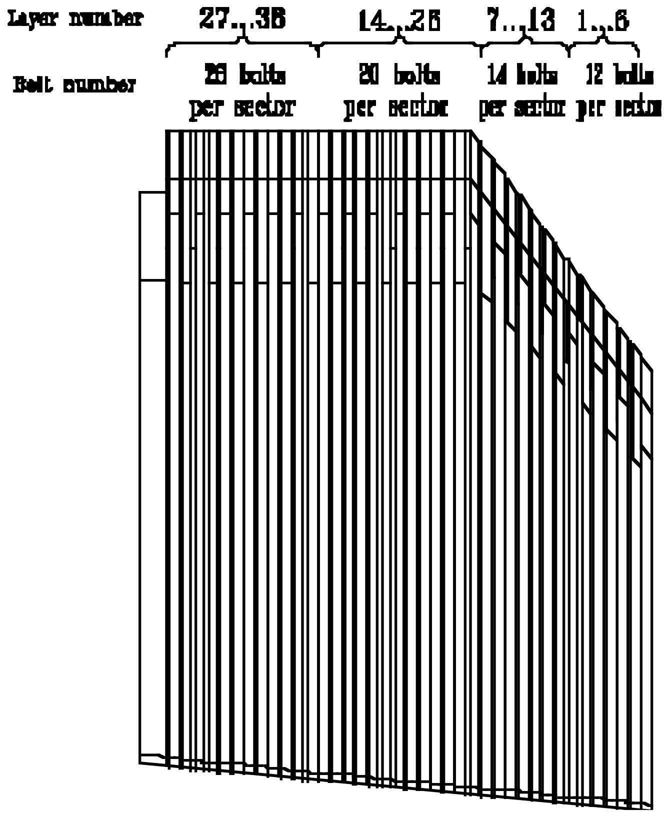


Fig. 3.11: Minimised number of bolts in z direction.

3.3.3 Forces, stress, deflection

The input data for the calculations are:

- the schematic location of the center of gravity and weight of the endcap components including the endcap crystal EE and its mounting frame (Fig. 3.12);
- the material of the bolts, nuts and collets is brass (yield limit equals to $2.94 x 10^2$ MPa);
- the sector material is brass;
- the bolt and collet dimensions are presented in Figs. 3.9 and 3.10.

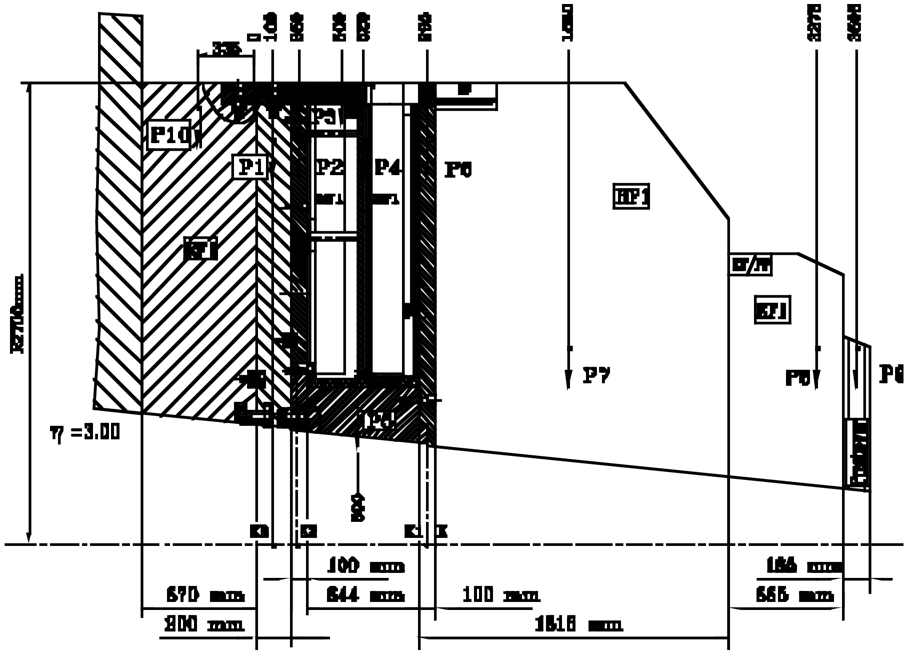
Strength analysis of the bolt joints

The rating scheme is based on the layout presented in Fig. 3.13. The calculation results of the stress values and the safety factor are presented in Fig. 3.14.

The absorber material and construction elements (bolts and nuts) were tested with a machine made by Instron. The machine could develop a force of up to 20 tonnes. The main results of this testing are the following:

1. Force for the beginning of the plastic deformation for M24*2 bronze BrX1 bolt Fpl = 14.2 tonnes. That is much more than the required load Fa = 5767 kg.
2. The bolt elongation before bolt break down = 6 mm (15% of length).
3. Force for break down of bolt thread = 16 tonnes.
4. Force for break down of absorber material (for copper) under bolt head surface = 17.5 tonnes. For brass, the required force is 1.5 to 2 times more.

Thus the materials (brass for absorber and bronze for connecting elements) meet all requirements.



P1=55000 kg (RF1 disk weight)
P2=18000 kg (MF1 disk weight)
P3=6000 kg (Brackets total weight)
P4=10000 kg (MF1 and RPC total weight)
P5=9000 kg (Ring weight)
P6=18000 kg (HF1 flange weight)
P7=290000 kg (HF1 copper weight)
P8=10000 kg (EMC weight)
P9=3000 kg (Preshower weight)
P10=117000 kg (RF1 disk weight)

Fig. 3.12: Weights and center of gravity of the end cap components.