The 2.6 MJ. Capacitorbank at Garching - Arrangement and Collector System

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Two years ago at the Symposium in Paris the 1,5 MJ-bank was mentioned to be under construction. Meanwhile it has been completed except for the discharge circuit of which one sixth is now ready. The maximum voltage has been raised to 40 kV thus getting 2,6 MJ stored energy for the large theta-pinch main discharge. P 005 P 012

The main bank arrangement has been designed rather compactly according to building dimensions given. The capacitor racks form six rows, each row representing about 450 kJ with 40 kV. Each row consists of three identical racks, which are connected to the collector by special pulse cables of three different cable lengths respectively. In total there are 252 single circuits connected by 756 cables. The spark gaps are of the three-electrode type triggered by 18 master gaps. The main bank with all auxiliary equipment has been built by the German firms AEG and Siemens, while the collector system has been designed under co-work of members of the theoretical, experimental and engineering department at Garching. It is being manufactured by the German firm Krauss-Maffei and will be mounted by the Institute. P 006

The collector arrangement to be described has been designed for the following data: Charging voltage of the capacitor bank maximum 40 kV, maximum current across the collector about 22.10^6 Amps with a frequency of about 27 kilocycles and 85% reversal. The load will be at first a one-turn coil of 10,5 cm diameter and 1,5 m length. To get as much as possible flexibility of the system and with the area given for the connection of the pulse cables, the following arrangement was chosen: The collector consists of two parts. The energy coming from the capacitor bank first enters through the pulse cables into 18 socalled precollectors which act as sandwich-conductors carrying a corresponding part of the bank's energy respectively. In order to get the pulse cables on their way from the bank to the collector in good order, the precollectors were put upright. Thus the cables enter the precollectors almost in the same level they run horizontally in the region of the bank. The 18 precollectors are arranged in one row in front of the bank, forming at their lower ends a rather wide intersected sandwich-conductor of about 5,5 m width. In the second part of the collector arrangement, the rectangular socalled main collector, the electrical current flow is compressed from 5,5 m width to the width of the load, namely 1,5 m. With maximum current the magnetic flux density is about 80 kG in the precollectors, whereas it will be about 200 kG in the region of the main collector. Therefore the construction has to withstand considerable electro-magnetic pulse forces. The precollectors which are manufactured from ordinary double-T steel profiles contain a large number of insulators which hold the inner conductors under mechanical tension. The inner conductors which are also made of steel are connected to the inner braids of the pulse cables whereas the outer braids are connected to the double-T profile directly. For the main collector a dynamic solution

P 011

P 008

P 007

has been chosen, in which heavy lead blocks press from above and below against steel pressing plates backing up the current conducting copper sheaths. The upper lead blocks lie freely under the gravitational force, the lower ones are pressed up by springs exerting double the force equalling their weight. Thus the system is nearly completely symmetrical and will exert very small pulse forces on its ground frame. As the mechanical force pulse is shorter than the acoustic paths in the lead blocks the backing up steel plates will move nearly not at all while the lead blocks will jump about 0.7 mm. P 009
In order to get pieces easy to handle and to be able to start with one row of the capacitor bank the main collector was divided into six sections. On each section the lead masses were distributed in such a way that the force centers of the electro-magnetic pulse force and the weight of the lead masses were in good accordance. The force centers of the electro-magnetic forces resulted from model measurements and it turned out, that for a range of coil lengths between 1,5 and 3 m the mass distribution of the lead blocks only has to be changed by one of the 5 cm thick lead plates which form the blocks. Because of the separation of the sixths of the collector arrangement it is in principle possible to build also more complicated coil forms as cusps etc.
In order to get good control over the current distribution, especially at the edges of the coil, it is foreseen to have special current conducting copper sheaths for each coil length. In case of changing the coil length the upper lead blocks must be removed which can easily be done in a couple of days. Throughout the collector arrangement foils are used as insulation. The outer sheaths consist of polythene, the inner ones of mylar, the insulation thickness is 1,7 mm. In principle the insulation of the collector system consists of the U-bent insulation of the precollectors which overlaps with the P 014

straight insulation of the main collector. At the overlap point additional insulated electrodes have been placed in order to avoid sliding discharges. The upper end of each precollector can be fitted with a crowbar switch. Only at these points moulded polythene pieces must be used. At present a first crowbar switch of the Los Alamos type is under development. It will be tested with original conditions at one precollector with a dummy load coil.

The contacts within the collector system are all of the same "copper on steel" type which has been tested in model measurements with original stress at probes of 1 cm width. It turned out that they withstand line densities as high as 200 kAmps/cm during several hundred discharges without considerable destruction. Only tiny welding spots are to be found. The contacts can be easily loosened if required. In the contact junctions at first the parts to be combined are mechanically fixed and then the contact pieces are fastened with definite contact force, which P 015
can be calculated according to thoughts developed by Hilgarth.

The voltage wave form during the first microseconds of the discharge can be influenced by using a certain number of matching units which have been developed. These R-C-series units with low inductance will enable us to make an optimum voltage wave form by connecting them across certain precollectors. Because of their series capacitor they will draw negligible main frequency current.

The 1.5 m coil will consist of five 30 cm long sections P 010
consisting of 3 rigid copper pieces each. Because of the negligible movement of the backing up steel plates the coil sections can be screwed directly to these steel plates.

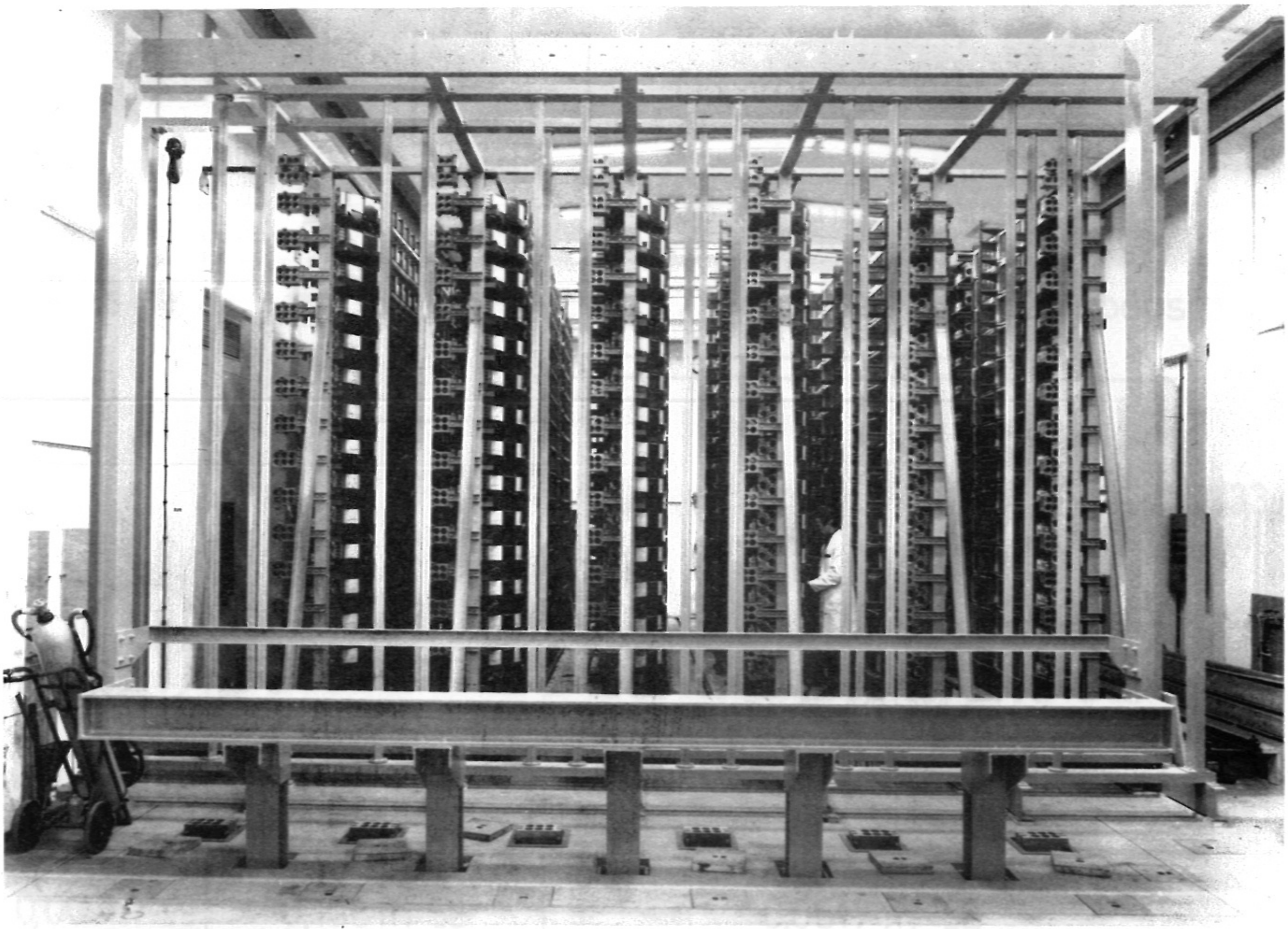
In the region of the feed-in slot of the coil additional measures for a correct field density distribution in the free coil space can be taken. Until now only parallel slots have been foreseen which we think will not be sufficient. Perhaps we shall add in the manner of Culham some sort of magnetic lens.

As to model and analogue measurements the following further works should be mentioned: The current distribution on the main collector plates has been taken from D-C-models which gives sufficient accuracy. The current distribution at the feed-in line at the coil had to be evaluated by a model considering eddy currents. A model in scale 1 : 5 was fed with the twentyfive-fold frequency that is about 600 kc. It turned out, that the maximum current density at the edges of the coil was about 115% of the average value.

In order to predict the field density distribution in and in the neighborhood of the 1,5 m coil we shall use the following method in the electrolytic tank. When considering, that in most shorttime experiments the current carrying sheath in any metal piece is of the order of one tenth of a millimeter or several tenths one can treat the field density distribution problem as a shielding problem. Approximately all the magnetic energy is in the air volumes surrounding the coil and the adjacent collector parts. If any symmetry plane of the discharge coil arrangement is known, one can build an insulator model of the metal masses and measure in the electrolytic tank the potential field distribution around these insulating pieces. By evaluating the tangential component of of this field at the surface of the model one finds also directly the current distribution at the surfaces. The method works rather quickly and is valid for even complicated discharge coil shapes which are hardly to calculate.

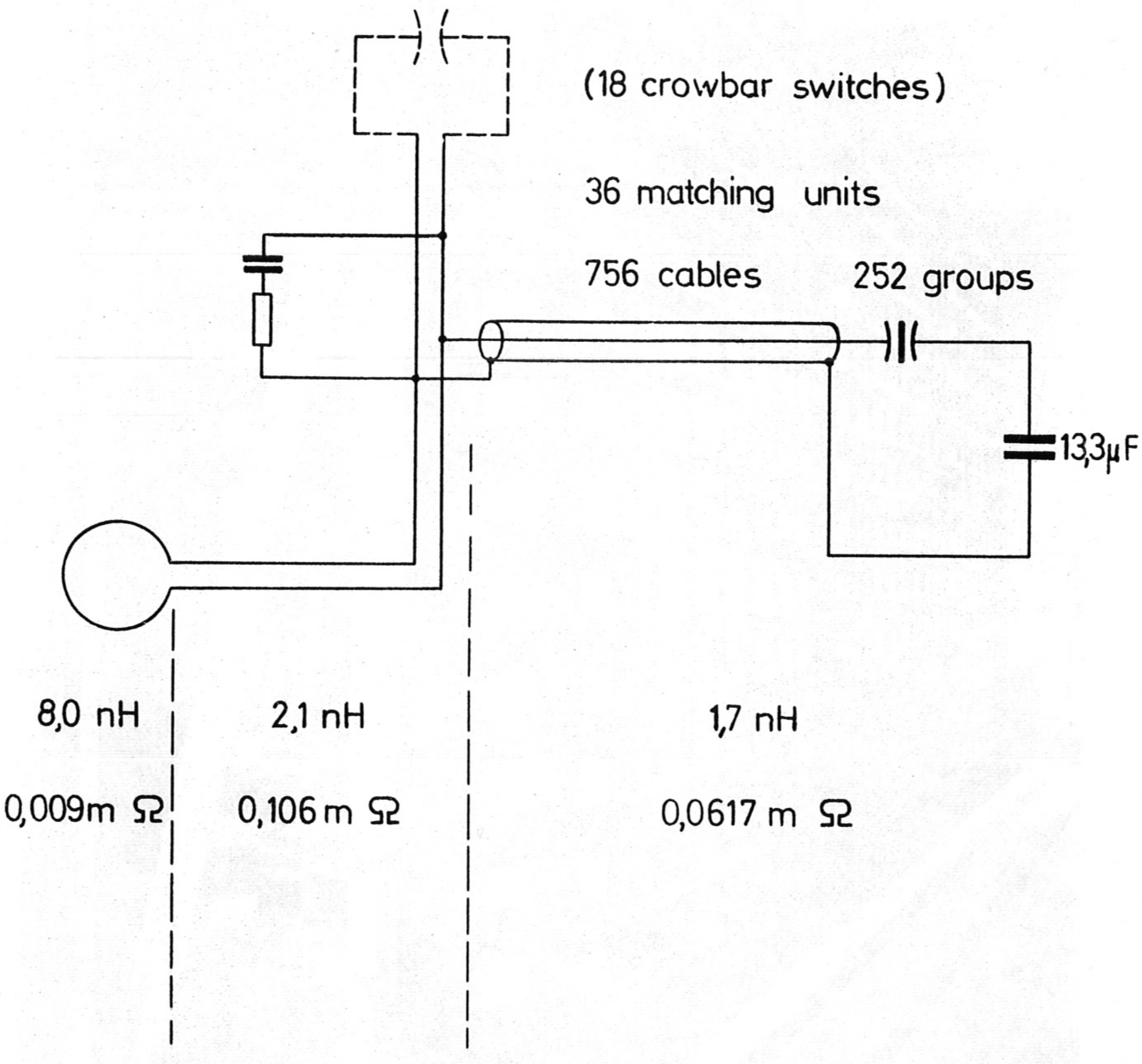
A further analog measurement set is the switching circuit analog model which has been built here with mercury switches. In this system we use original time scale and for instance for measurements including cables also original components. Time delays between the several P 013 switched circuits are produced with original timers normally used in our banks. With a special current supply for the mercury switches we arrived at a jitter of about $\pm$ 0.5 µs which is sufficient for many model applications. For instance the data for the mentioned matching units have been evaluated in this model.

As first stages before manufacturing the collector system also scale 1 : 1 measurements were made with a 150 kJ - 40 kV bank at models of a precollector and a corresponding section of the main collector arrangement. Thus the collector system can be built up in definite stages and now we arrived at one sixth of the complete system that is at an energy of about 450 kJ. In these days we make the first discharges into a 30 cm coil having almost the same specific data as with the whole bank and the 1,5 m-coil.

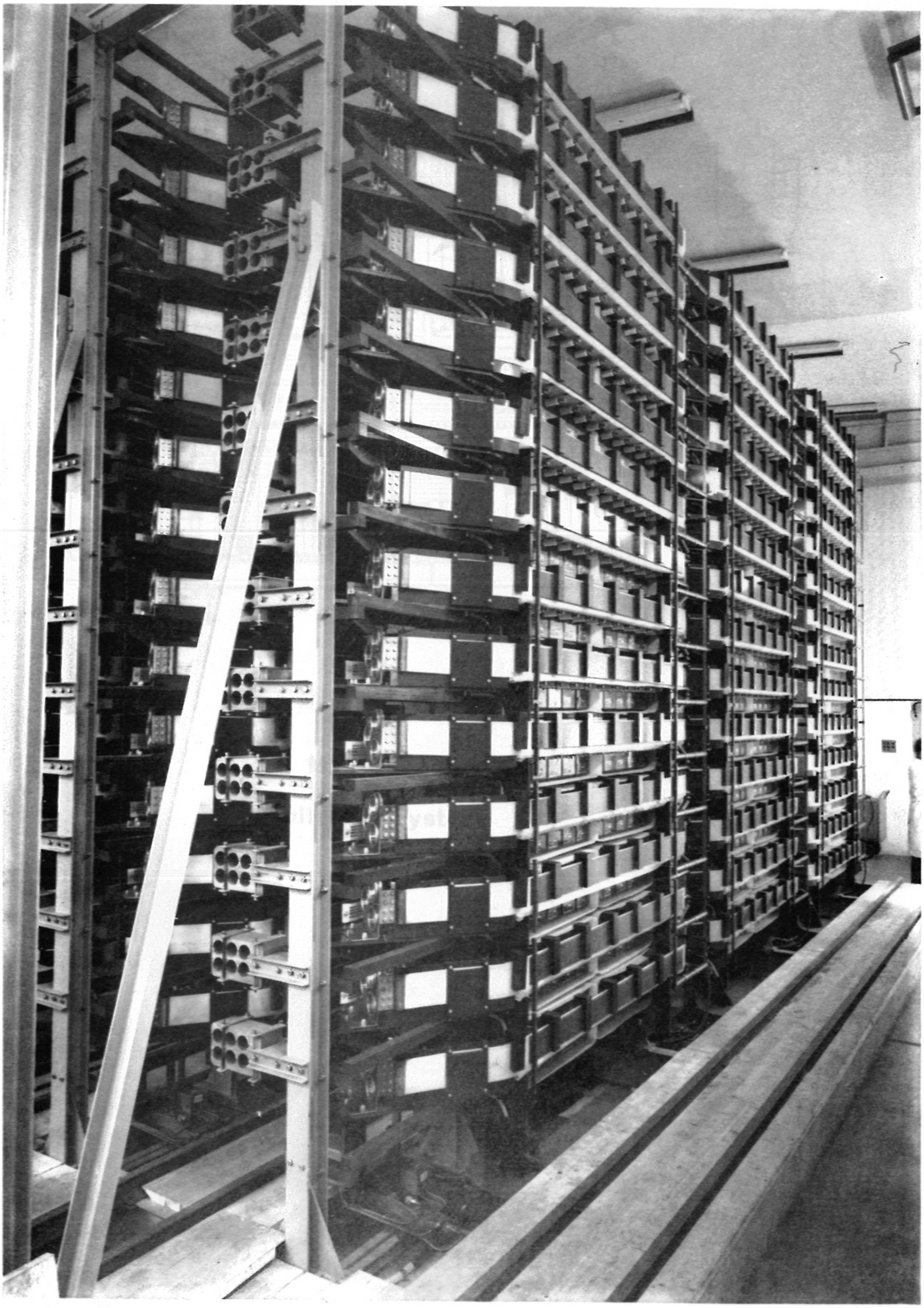


2.6 MJ Capacitor Bank

front view without cables and collector

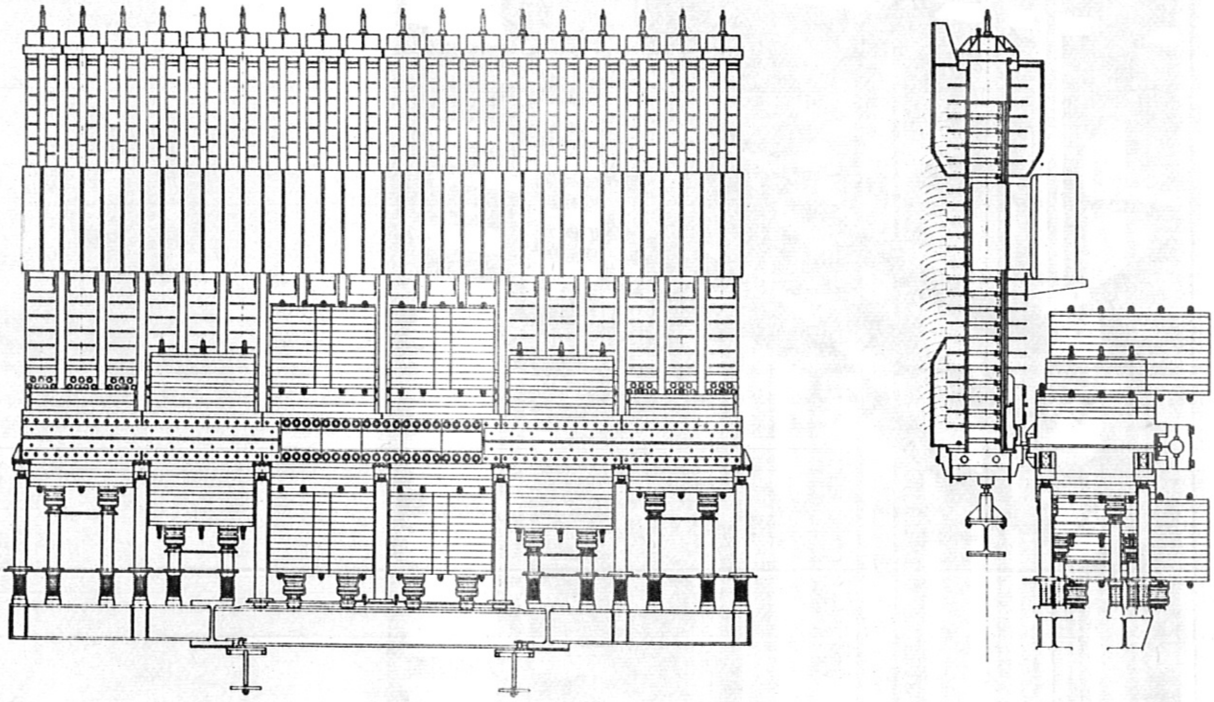


2,6 MJ Capacitor Bank electrical data



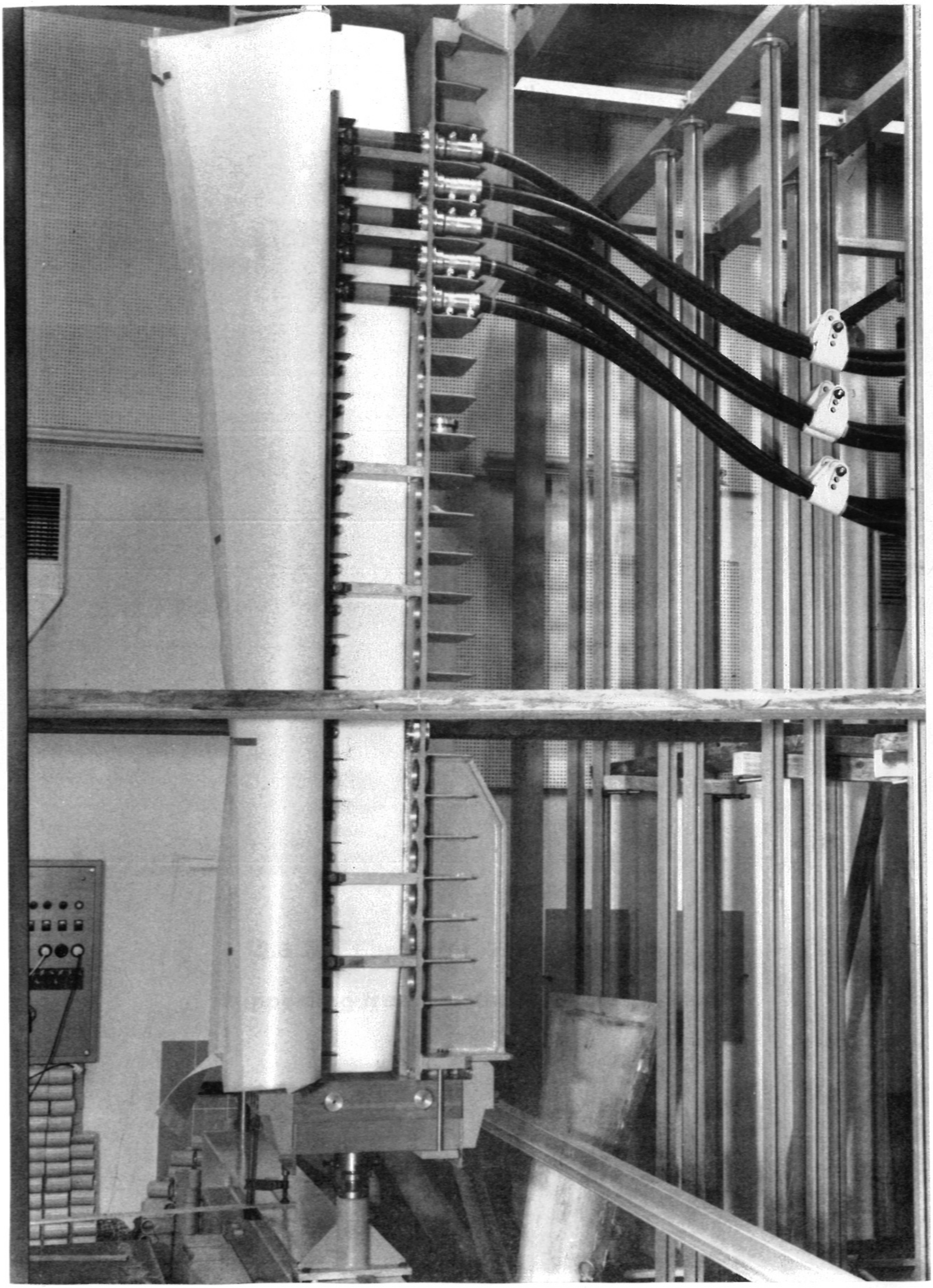
2.6 MJ Capacitor Bank

view from right hand side without cables



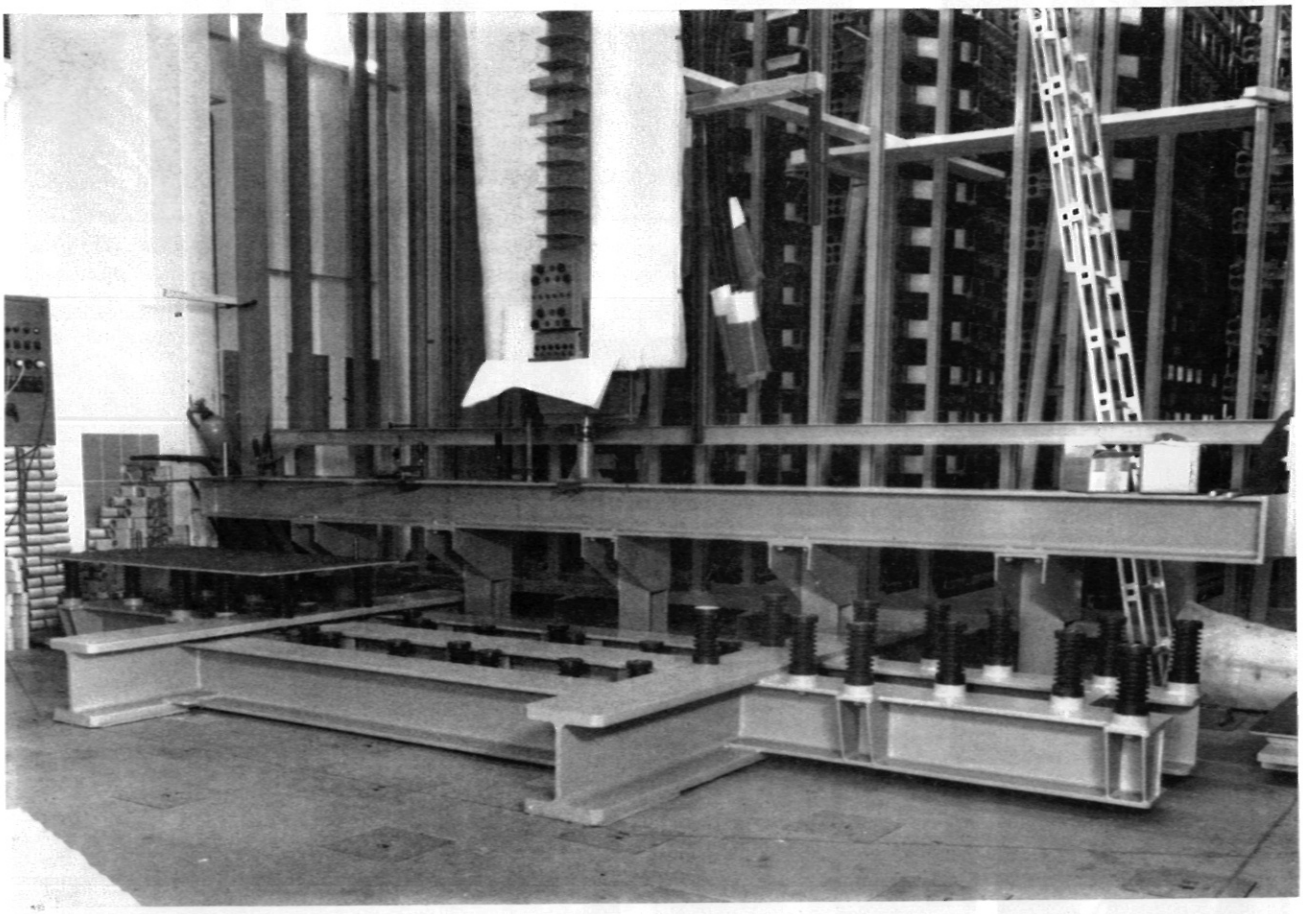
2.6 MJ Capacitor Bank

collector system



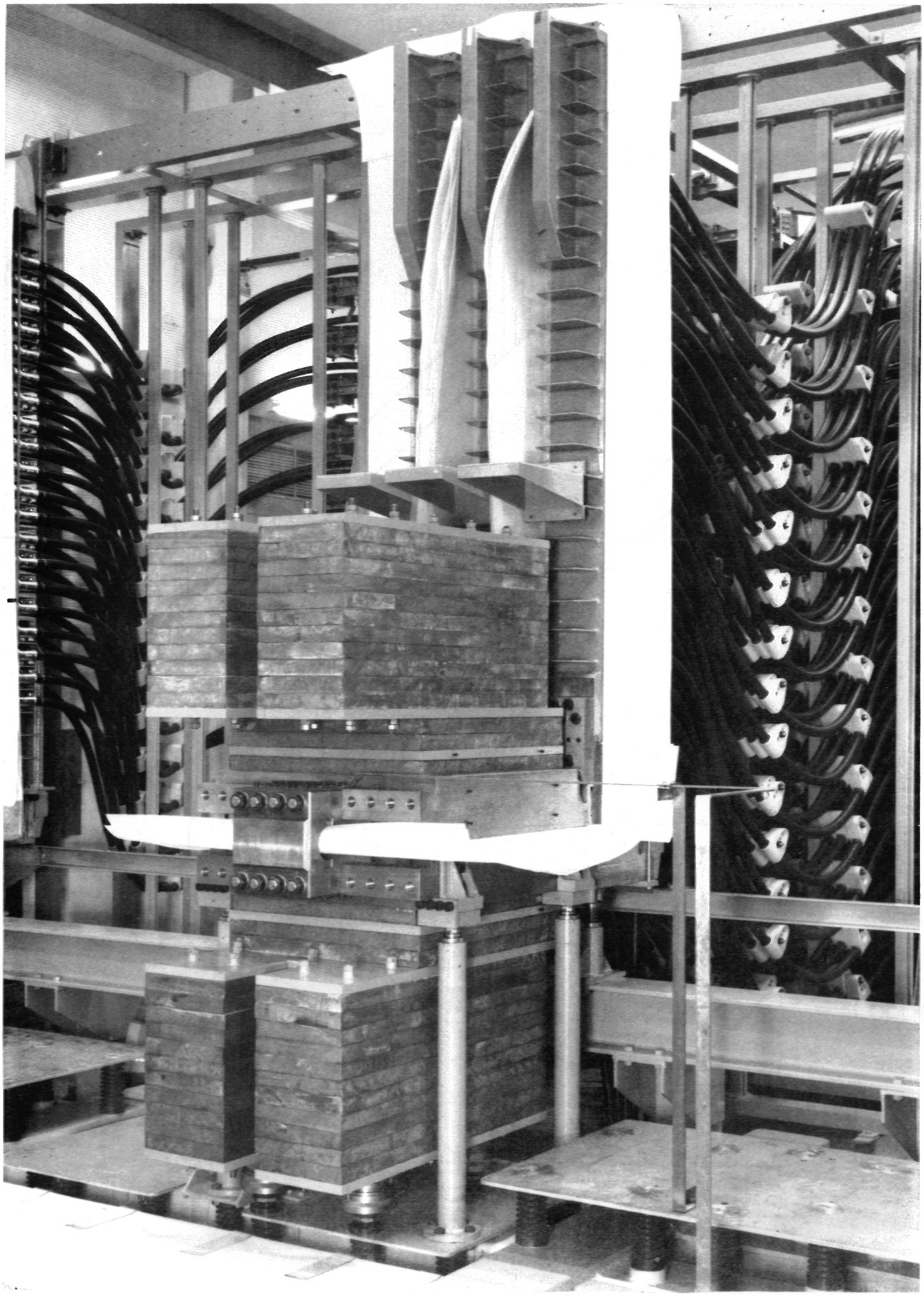
2.6 MJ Capacitor Bank

single precollector in mounting status



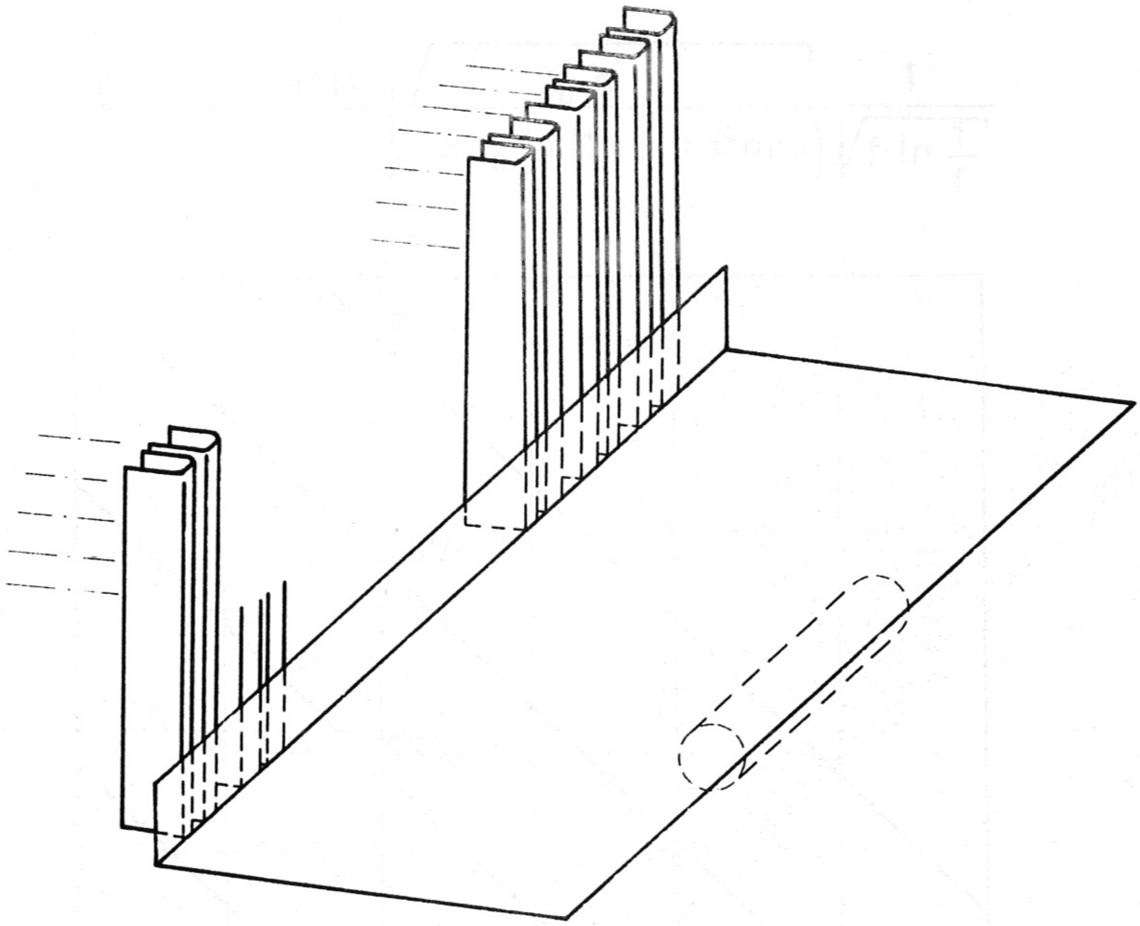
2.6 MJ Capacitor Bank

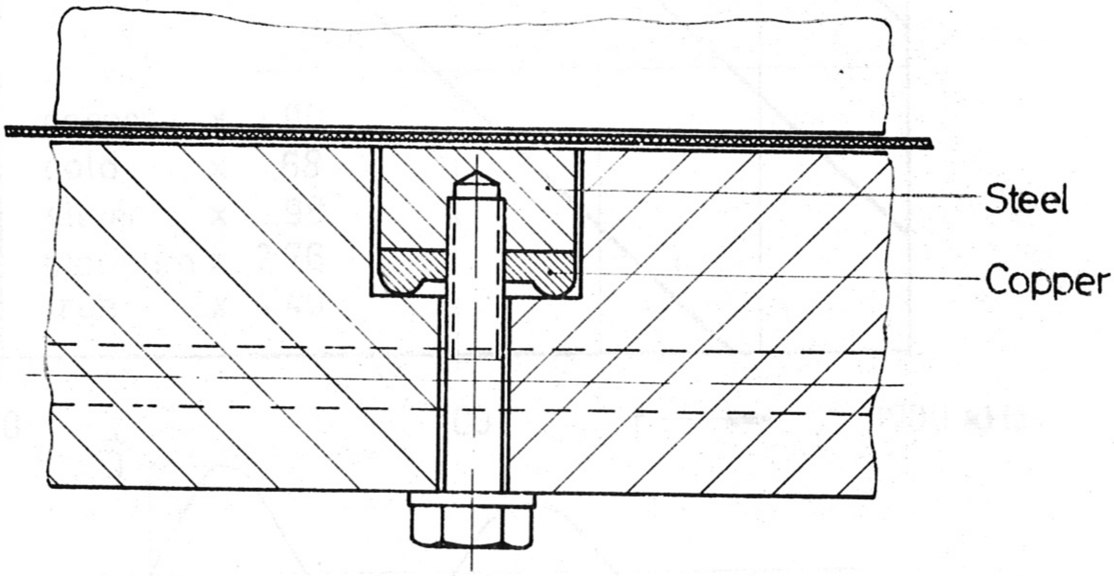
supporting frame of the collector system



2.6 MJ Capacitor Bank

one sixth of collector for 450 kJ with 30 cm-coil

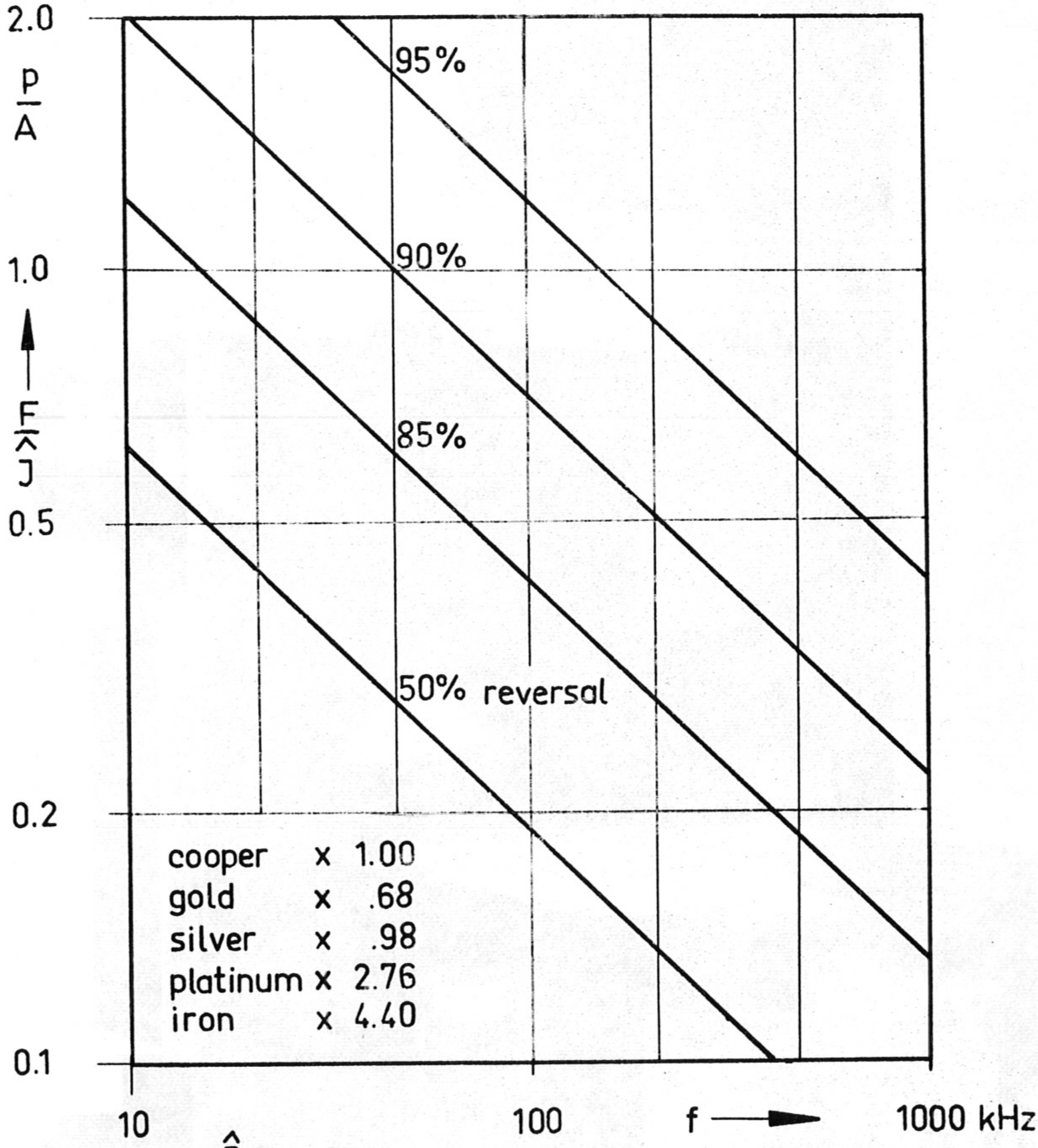


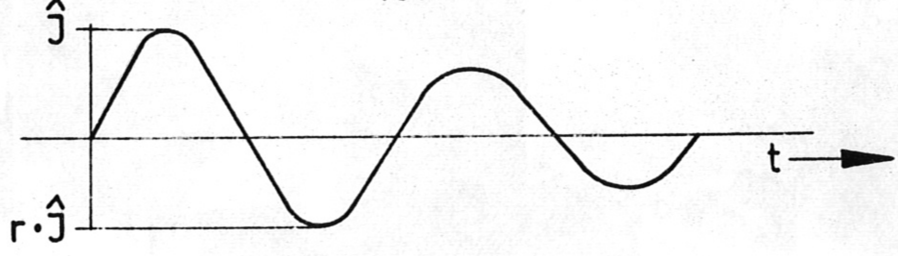


2.6 MJ Capacitor Bank

collector:insulation scheme and contact shape

$$\frac{F}{\hat{J}} = \frac{\pi^2 H}{16} \sqrt{\frac{\rho_0 \cdot \alpha}{3\, c_0 \ln\left(1 + \frac{2}{3}\, \alpha\, \vartheta_{max}\right)}} \cdot \frac{1}{\sqrt{f \cdot \ln \frac{1}{r}}}$$

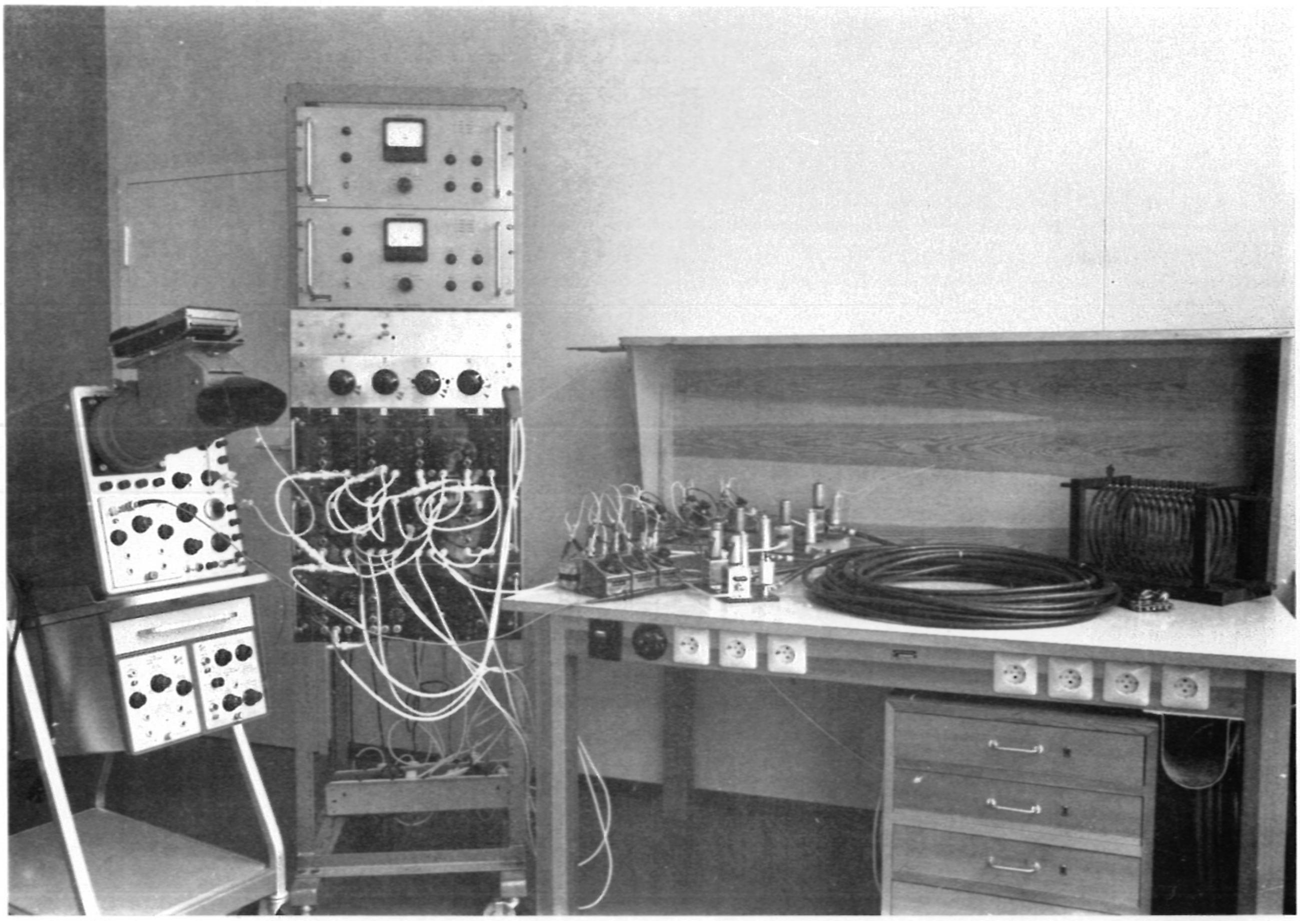




Impulse Current Contacts
ratio contact force/ peak current
(damped oszill) versus frequency

2.6 MJ Capacitor Bank

collector model 8.3 cm - coil



Switching Circuit Analog Model

cable matching of 6 capacitor bank groups

(2.6 MJ - bank)