

Power supplies and power lines of K2K magnetic horns

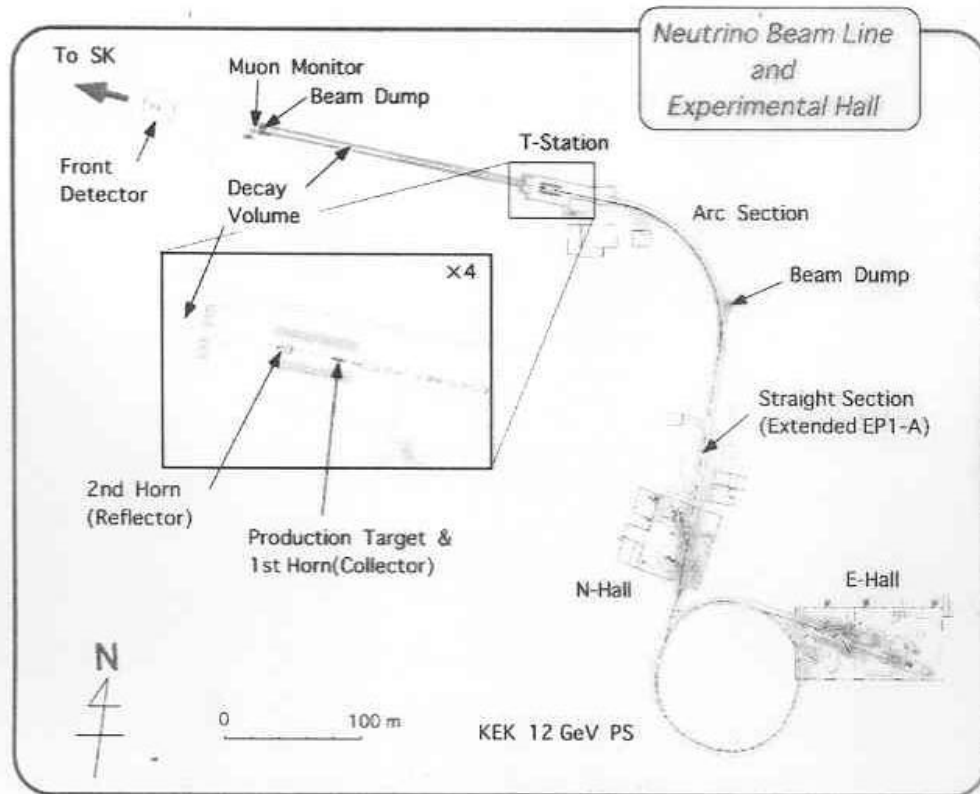
KEK

Beam Channel

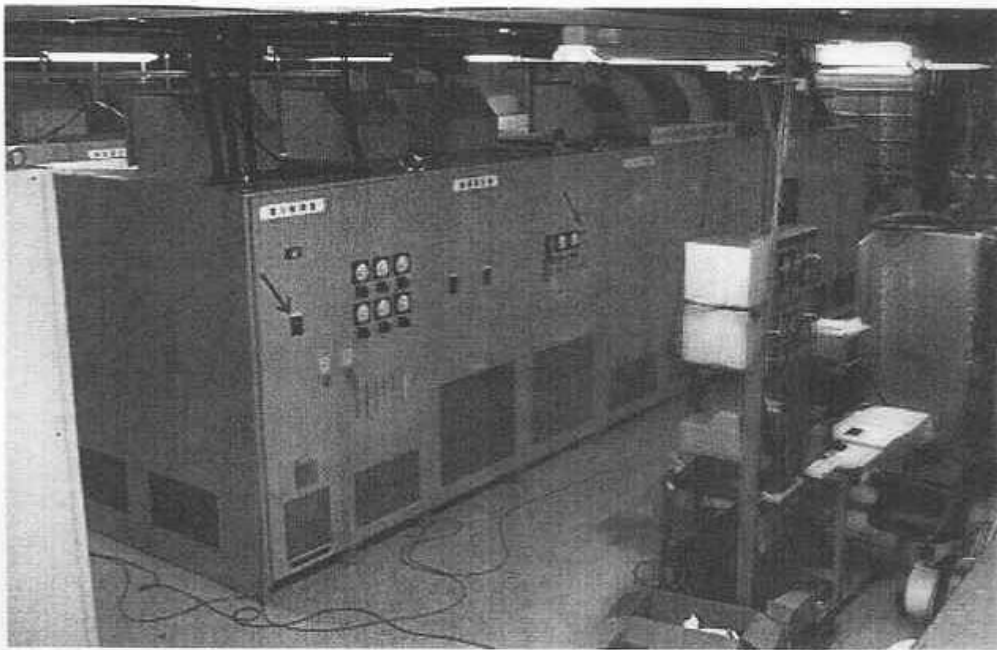
Group

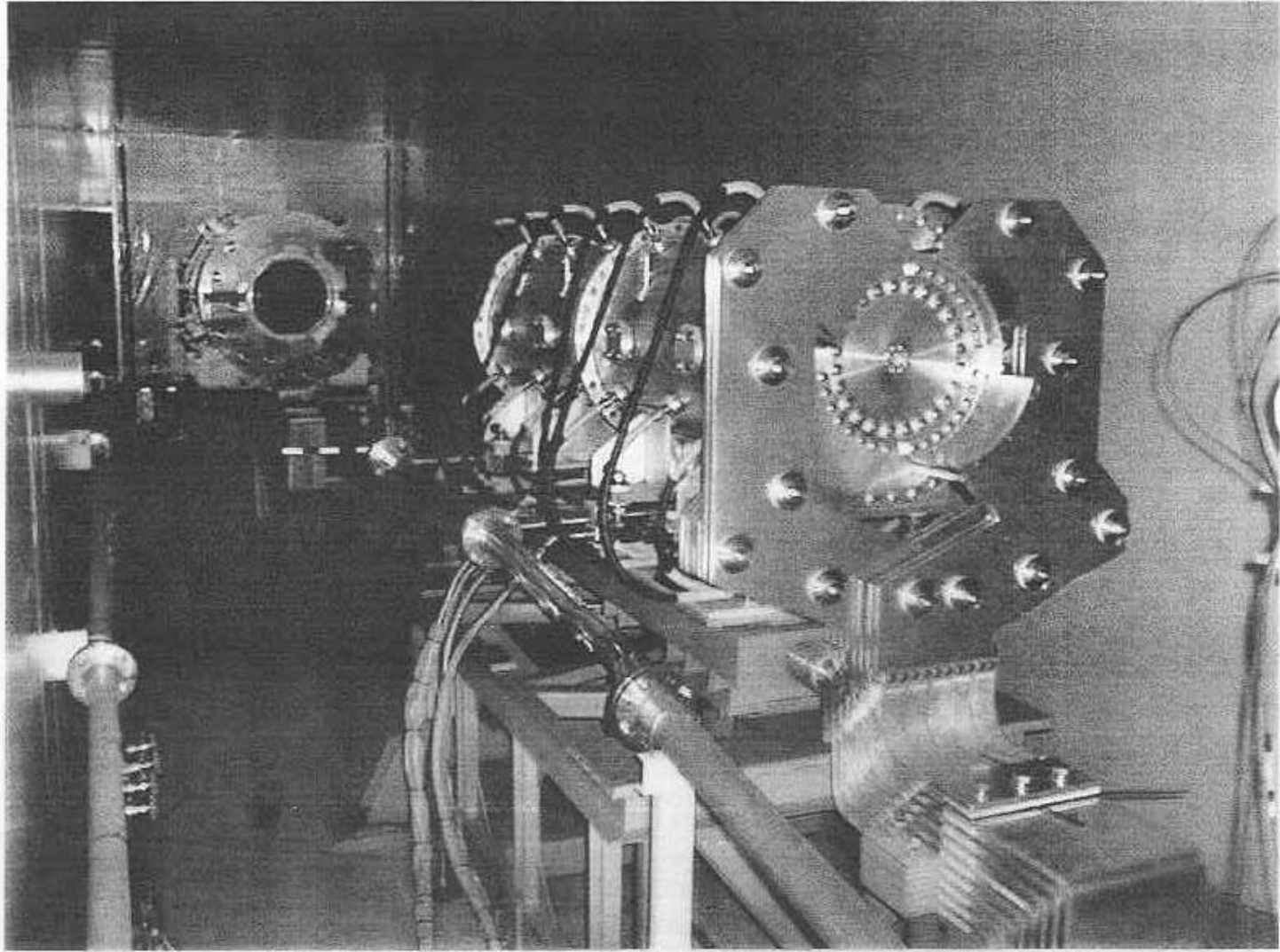
Yoshihiro Suzuki

Neutrino Beam Line



250kA pulse power supply
with pulse transformer
turn ratio 10





Design
Construction
Operation
Result

- 1995, Design work. Official notice of tender.
- 1996, Mar. Pulse transformer and power supply completed.
- 1996, Jun. test operation with dummy load. 250kA, 2s-cycle, 4 hours.
- Test and improvement
- 1999, Jan. Neutrino beam line start
- 1999, Mar. first beam on horn target

Reference

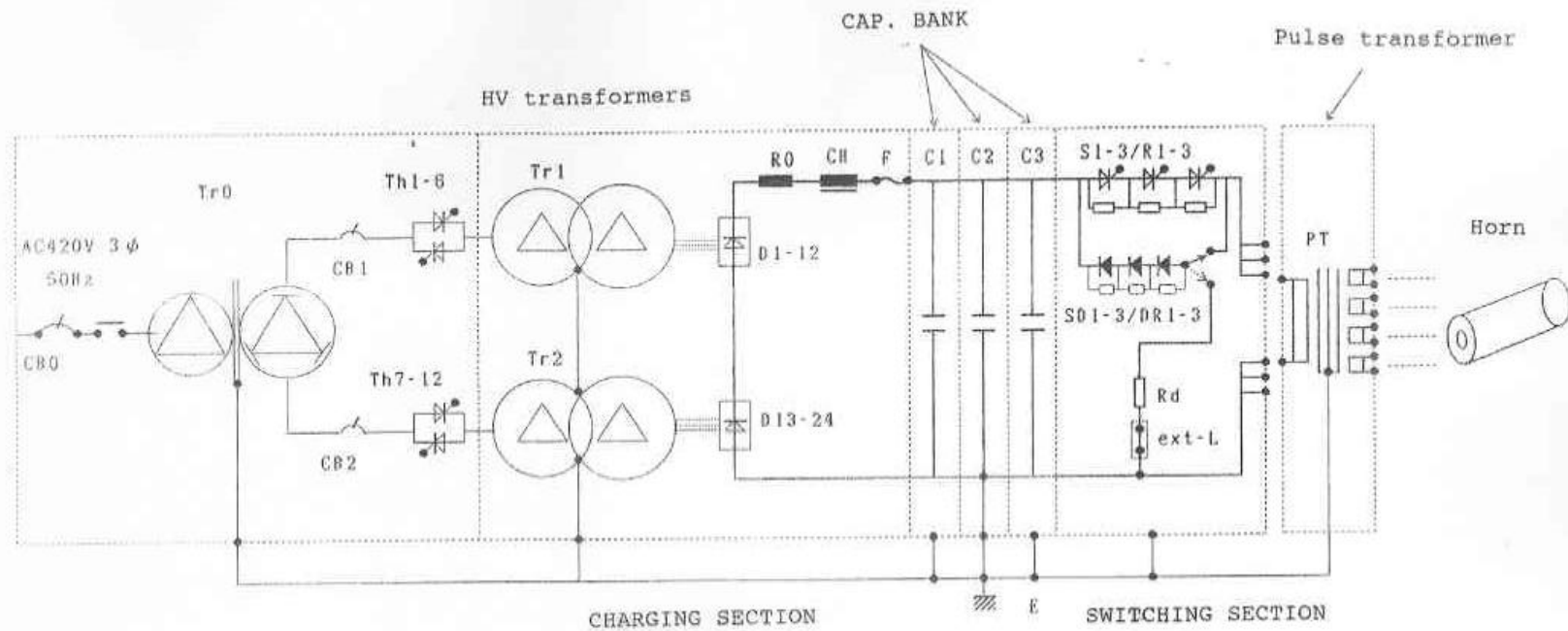
- CERN/PS/S9-61 (PO) October 1989. F.Voelker
The 200kJ pulser and power converter for the
36mm lithium lens for the antiproton accumulator
and collector (ACC) at CERN
- CERN/ECP-EDI-CL-Neutr. 28 October 1991
Technical specification
For the construction of two dry type pulse
transformers with four identical primaries and
secondaries

Demand

- Two magnetic horns
- 250kA peak current
- 2 sec cycle
- High reliability

Design of the Pulse Power Supply

- Characteristics of the load
(estimated at the start) horn 1
 $217 \mu \Omega$
 $1.14 \mu H$
Including 8m stripline
- Requirement and limitation
 1. 250kA.
 2. Less heat loss in the horn:
narrow pulse current
not reverse



Circuit diagram of the 250kA pulse power supply

Horn 1

Heat loss in the target

Φ 2cm, 50cm long Al

(56 μ Ω)

250kA

- Pulsed current (*half sine wave*)

Pulse duration	4	3	2	msec
Heat loss	7	5.3	3.5	kW

Horn 2

$$69.8 \mu \Omega < \text{Horn 1}$$

$$0.75 \mu \text{H} < \text{Horn 1}$$

Heat loss

$$\text{Horn 2} < \text{Horn 1}$$

Study Item

- Switching element
- Voltage
- Capacitor
- Transformer
- Reliability
- Simplicity
- Safety

Discharge current through transformer and HORN

Horn+stripline
 Peak current 250 kA
 Inductance 1.14 μ H
 Resistance 217 μ Ω
 Transformation ratio 10

Primary feeder line : 325mm² 70m (9.06m Ω , 7.91 μ H)
 Pulse transformer : secondary circuit *10%

Characteristics of the primary circuit							P (kW)		Limit on the thyristor rating				
kA	L(μ H)	R(m Ω)	C(mF)	ts (msec)	E (kV)	$CV^2/2$	A/ μ s	A ² *s	Unit (500 μ F)	A ² *s parallel	A/ μ s parallel	Voltage series	Total
25	133	33	10	1.66	3.54	62.8	15.0	1.04E+06	20	0.058	0.050	0.886	1
25	133	33	5	1.2	4.73	56	20.8	7.53E+05	10	0.042	0.069	1.184	2
25	133	33	3	0.95	5.92	52.6	26.4	5.91E+05	6	0.033	0.088	1.480	2
25	133	33	2	0.78	7.10	50.4	32.1	4.87E+05	4	0.027	0.107	1.775	2
25	133	33	1	0.56	9.77	47.7	44.9	3.48E+05	2	0.019	0.150	2.442	3

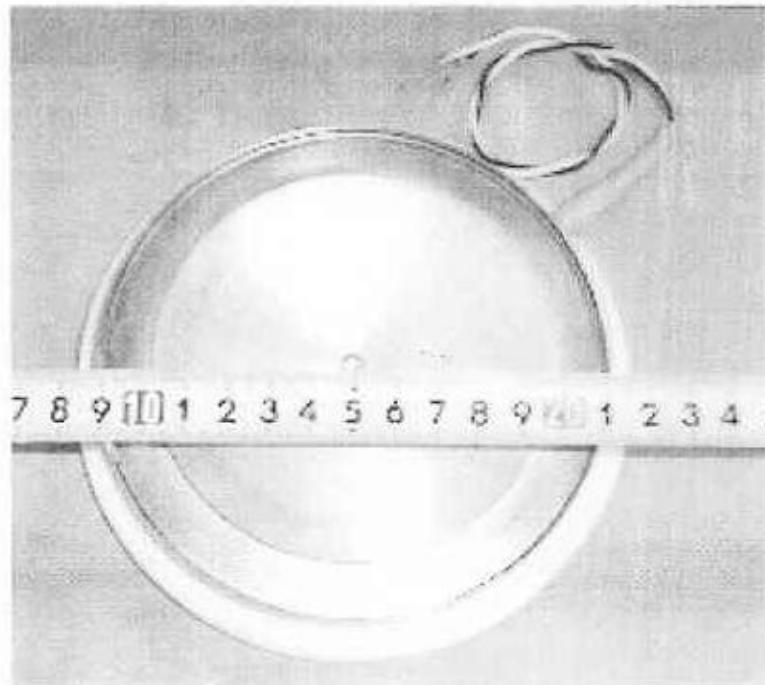
Thyristor rating			Capacitor/unit		
Voltage	4000	V	Voltage	8.5	kV
Effective ON current	4710	A	Capacitance	500	μ F
	1.80E+07	A ² *s	Dimension	540W, 310D, 1015H	
	300	A/ μ s	Weight	220	kg

Capacitor Lifetime (Pulses)		
2000	30,000	300,000
60kA	40kA	20kA

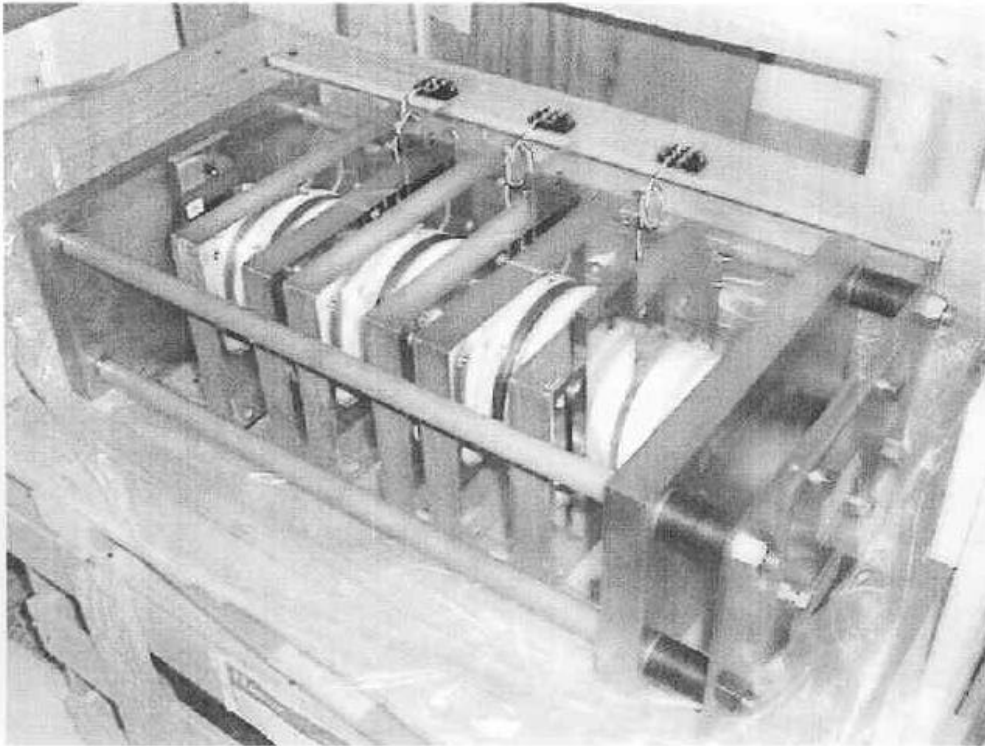
Thyristor

SF3000GX21

- 4000V
- 4710A rms
- $1.8 \times 10^7 \text{ A}^2\text{s}$
- $300\text{A}/\mu\text{s}$



Switching Thyristor



Capacitor

- 8.5kV
- 500 μ F
- 220kg
- 540w, 310d,
1015h
- High energy
density capacitor
- Metal evaporated
electrode
- Polyester film



Pulse transformer

Rating (nominal)

- Turn ratio 20/2
- 10kV/1kV
- 25kA/250kA
- Frequency ~ 167 Hz
- Iron section 0.5m²
- Weight 11.3 t

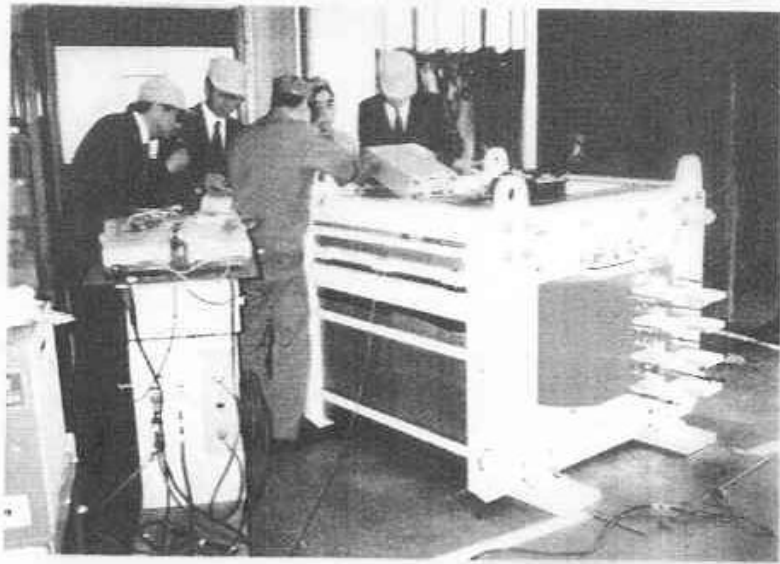
On the primary side

Resistance 3.19m Ω

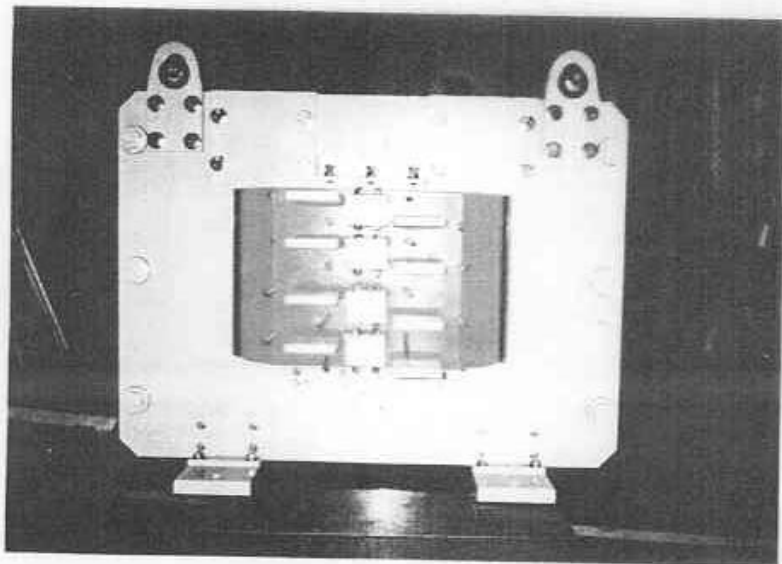
Leakage inductance 12.8 μ H

250kA Pulse Transformer





完成御立会検査

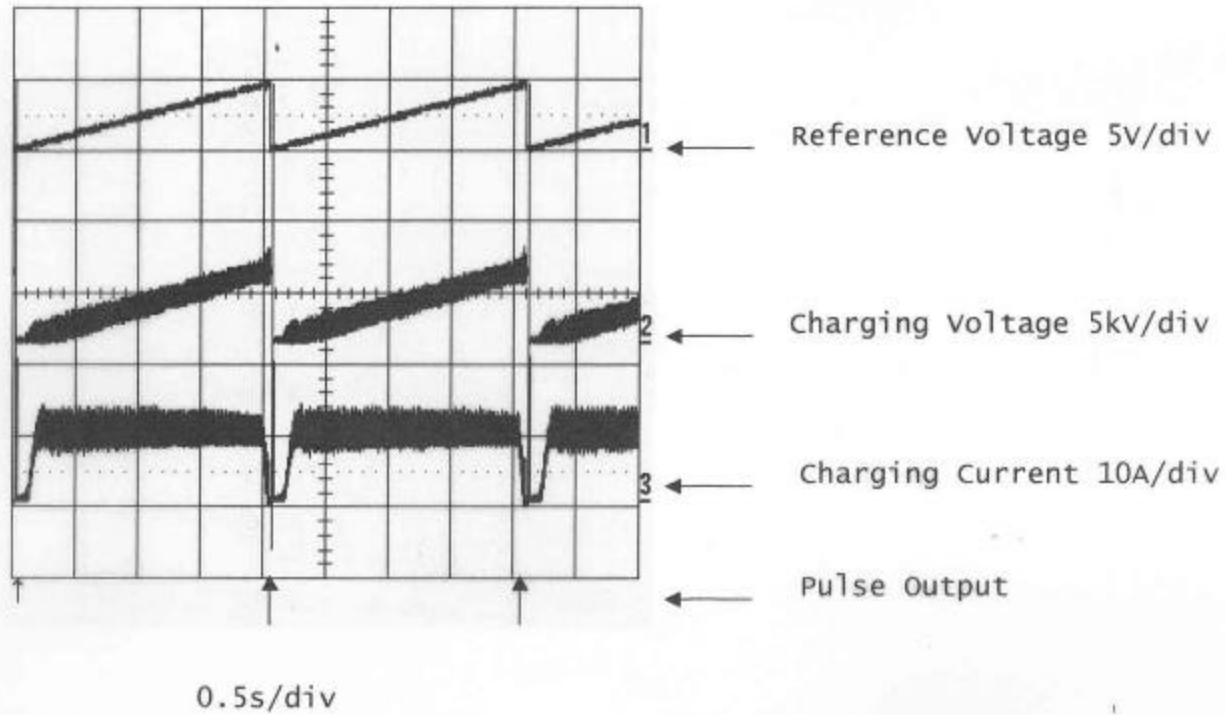


二次コイル側正面

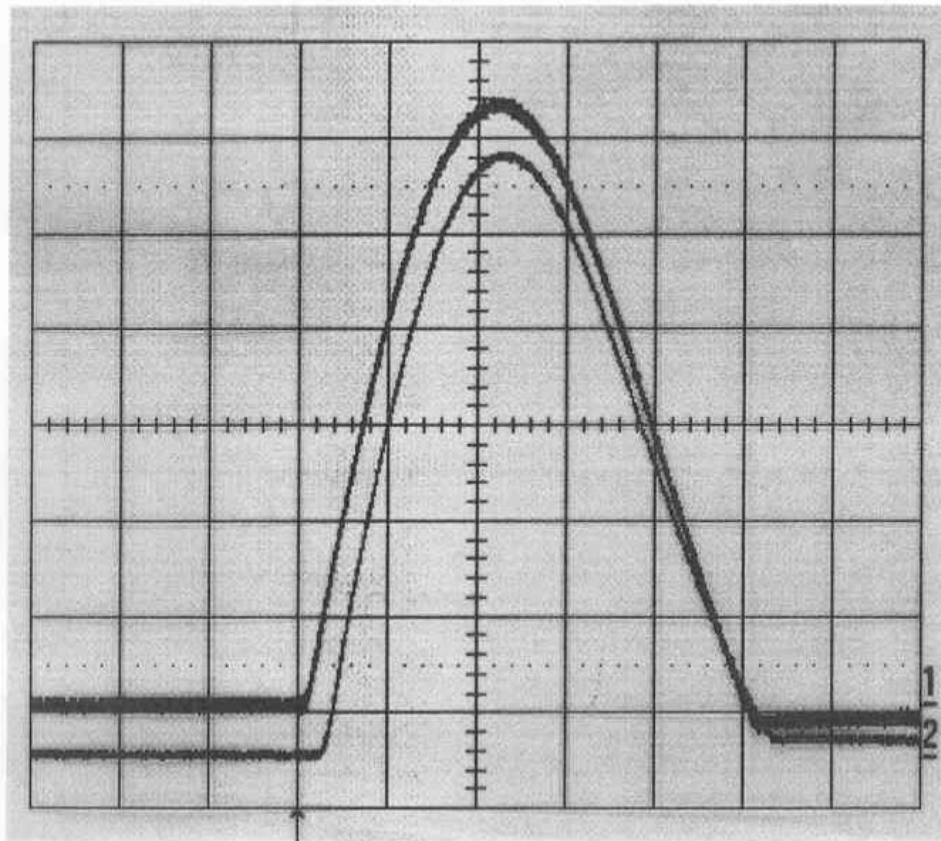
250kA Pulse Power Supply

- Charging unit
8.5kV 26A
- Capacitor
2~6mF (500 μ F x 12 units)
- Switching thyristor
SF3000GX21 x 3 units
connected in series.

High-voltage capacitor charging unit



250kA Output pulse HORN1, HORN2

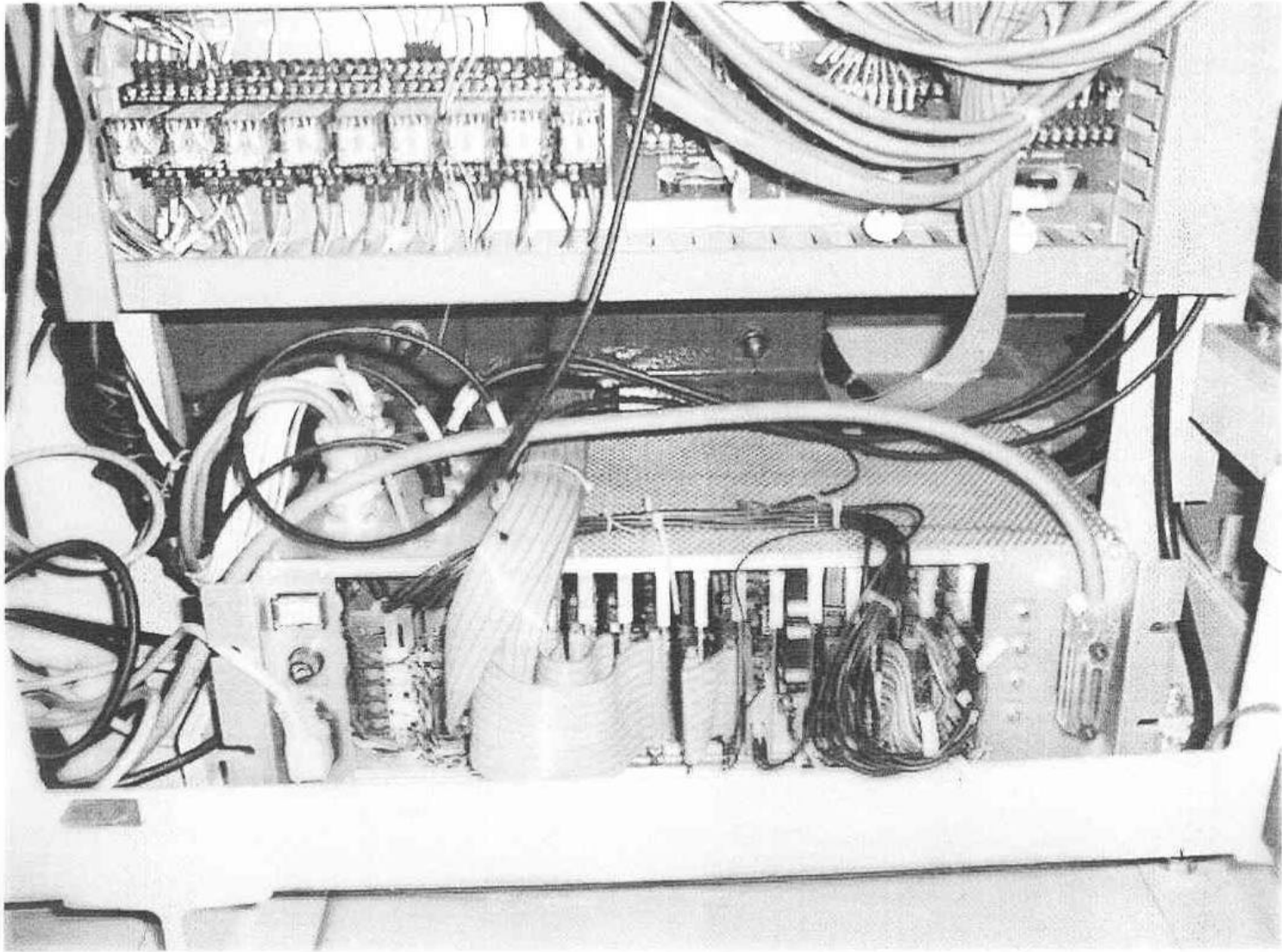


HORN 1 output current

HORN 2 output current

100-microsecond delay

0.5 ms/div



250kA Operation Result

- HORN 1

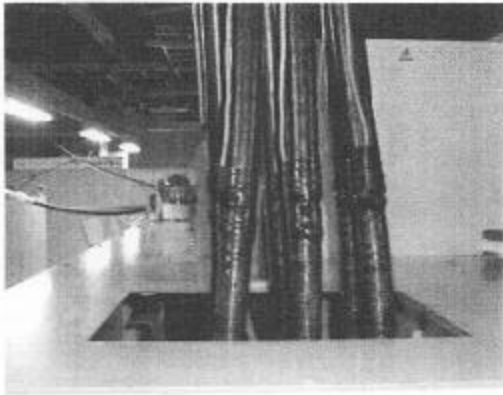
mF	kV	Tp μs
3.5	5.7	1050
3.0	6.1	950
2.0	7.6	792
1.5	(9.0)	690

- HORN 2

4.0	4.5	1003
3.0	5.0	870
2.0	6.3	710

Primary Power Line

Three Triplex High Voltage cables

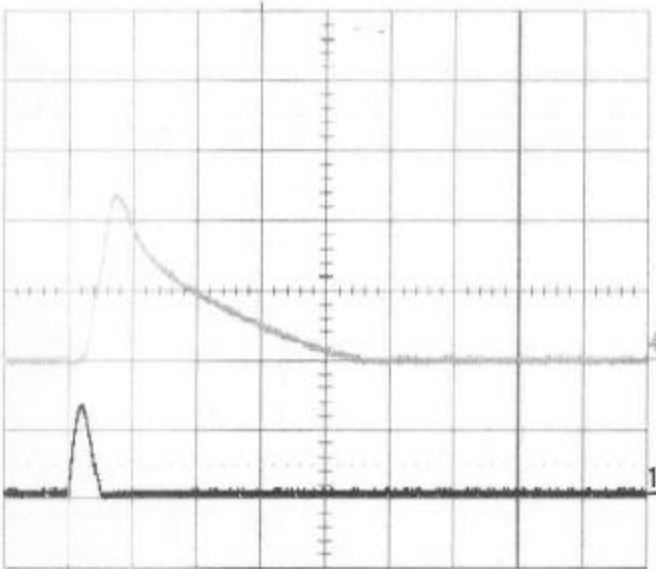


$150 \text{ m m}^2 \times 3$

OUTPUT connection



Capacitor is charged to negative, and it discharged through the dump resistor

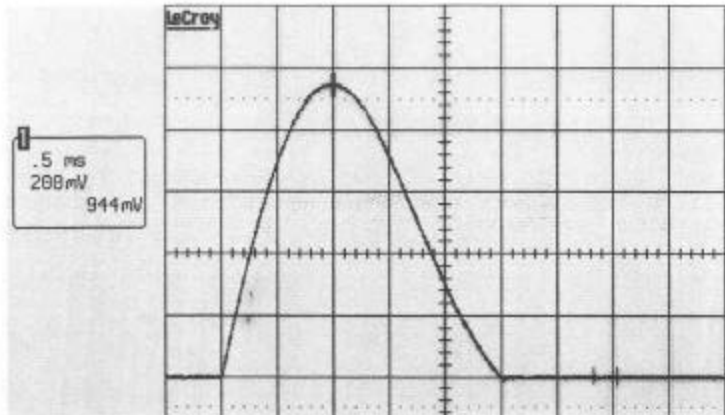


Discharge current through the rectifier; about 60 ampere peak.

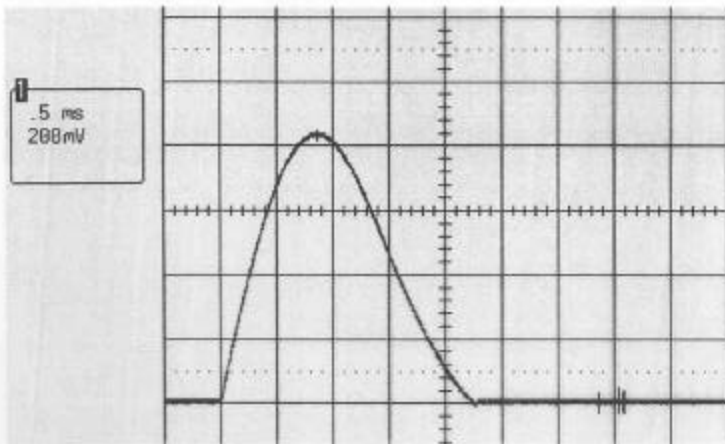
5 msec/div

CH4 : discharge current of reverse voltage 25·A/div
CH1 : 250kA operation, CT1 output (62.5kA)

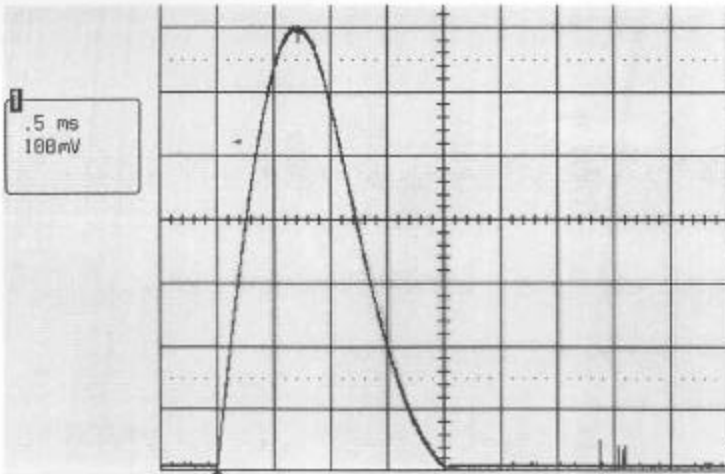
HORN 2



4.0mF

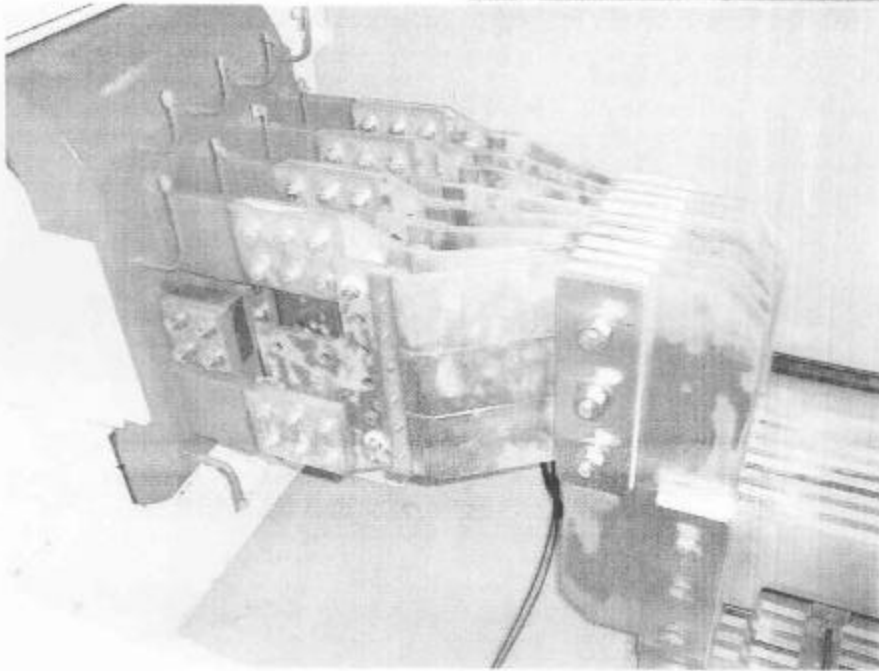
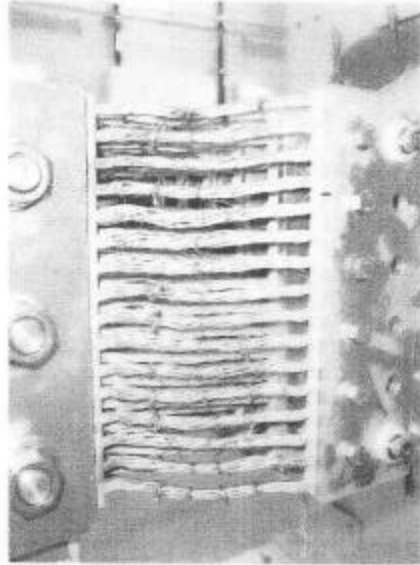
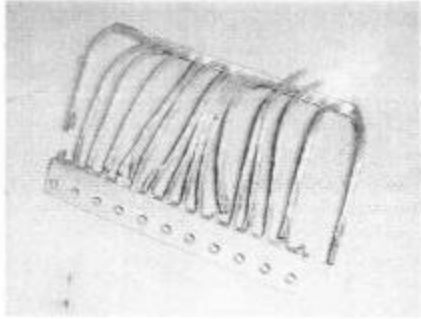


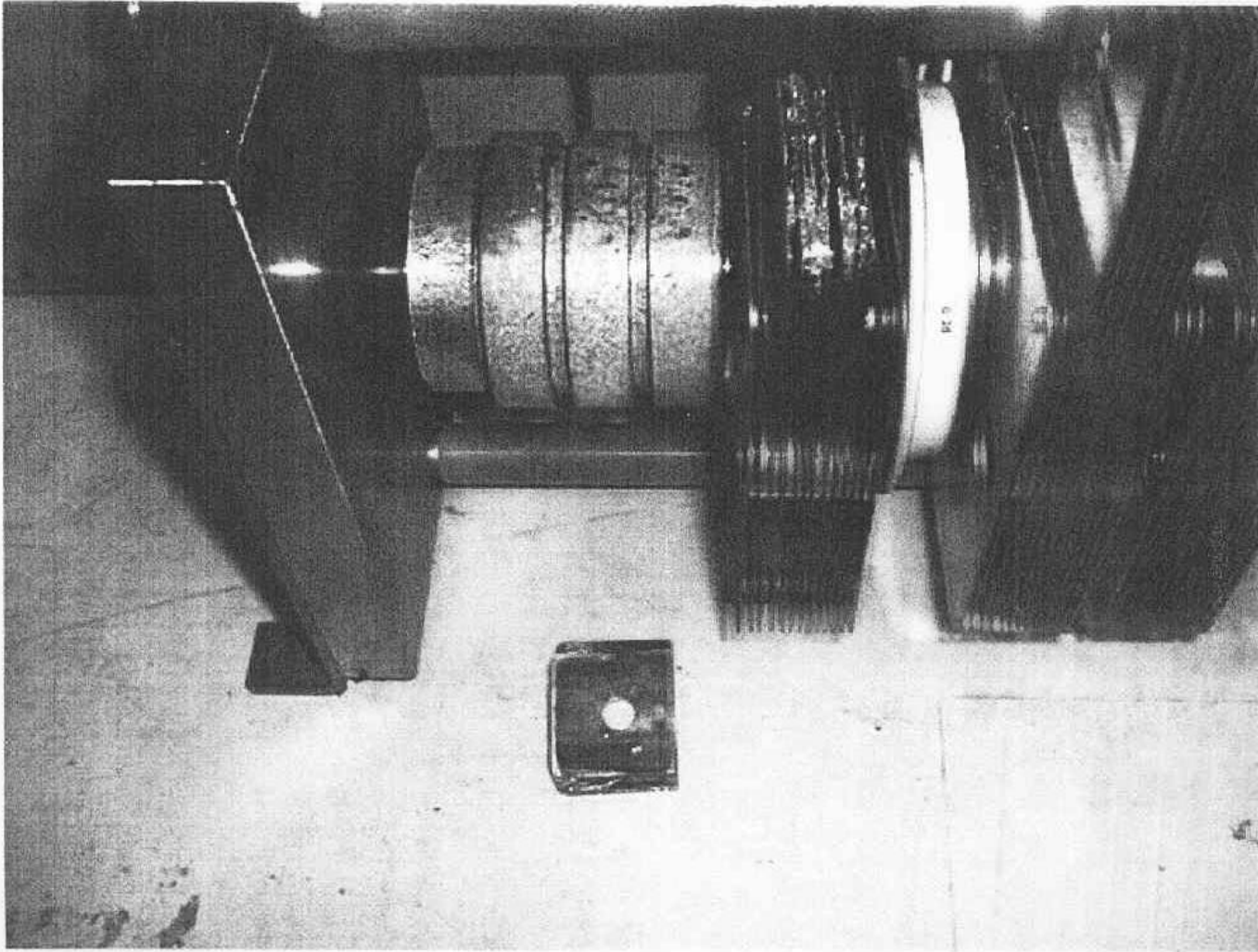
3.0mF



2.0mF

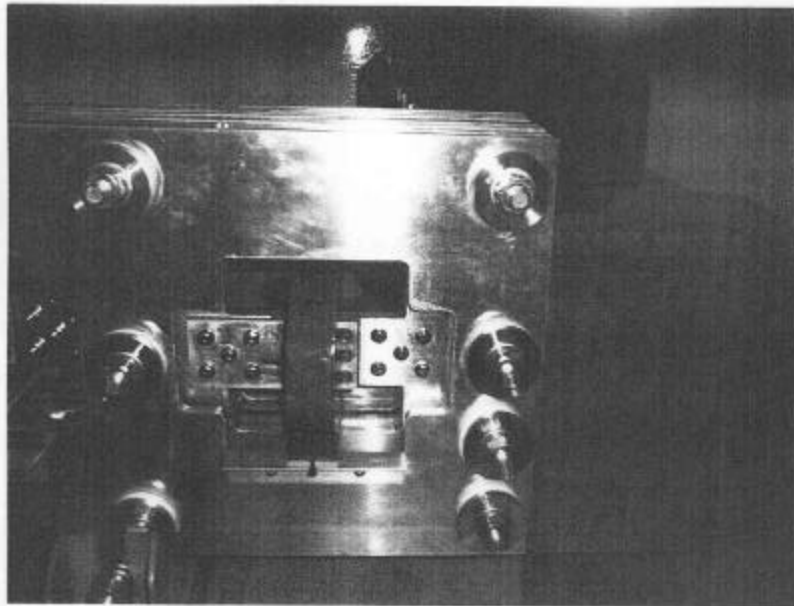
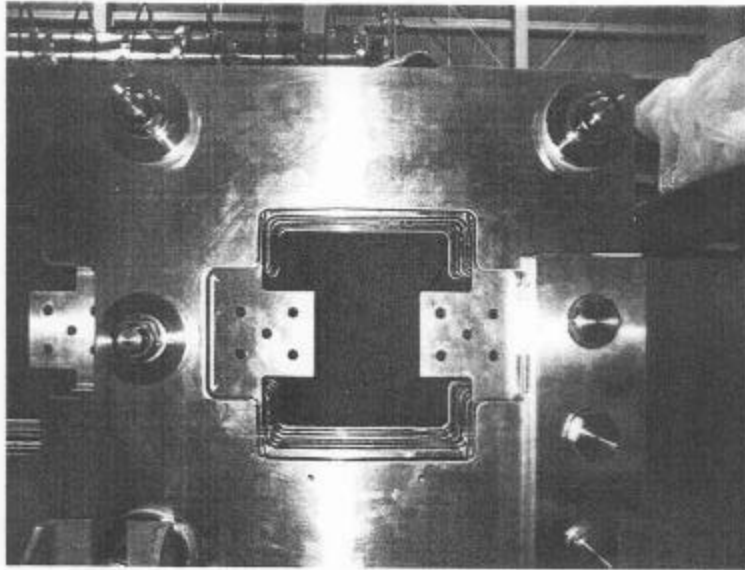
Replace the strands with copper plates



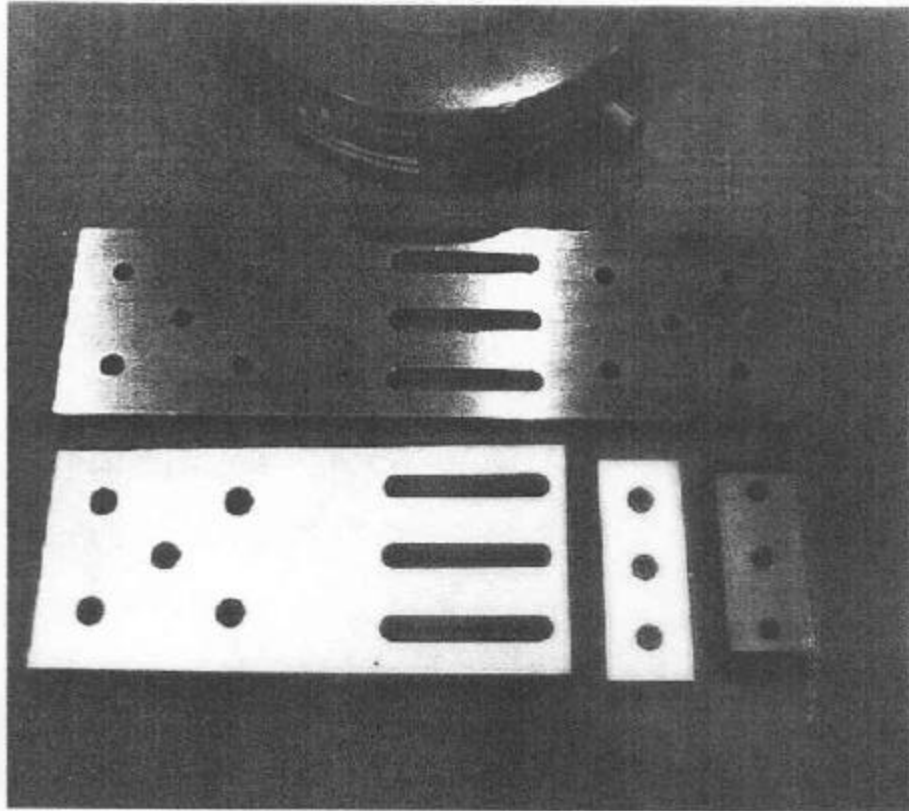


00/02/14

CT mounting window

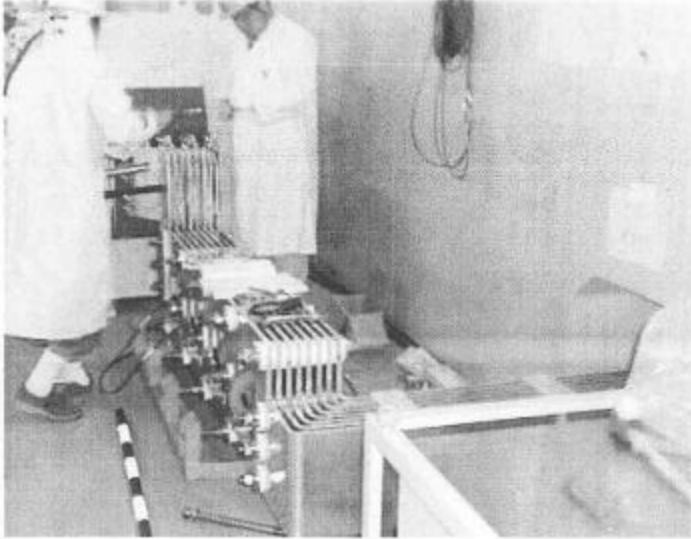


CT & Variable resistor

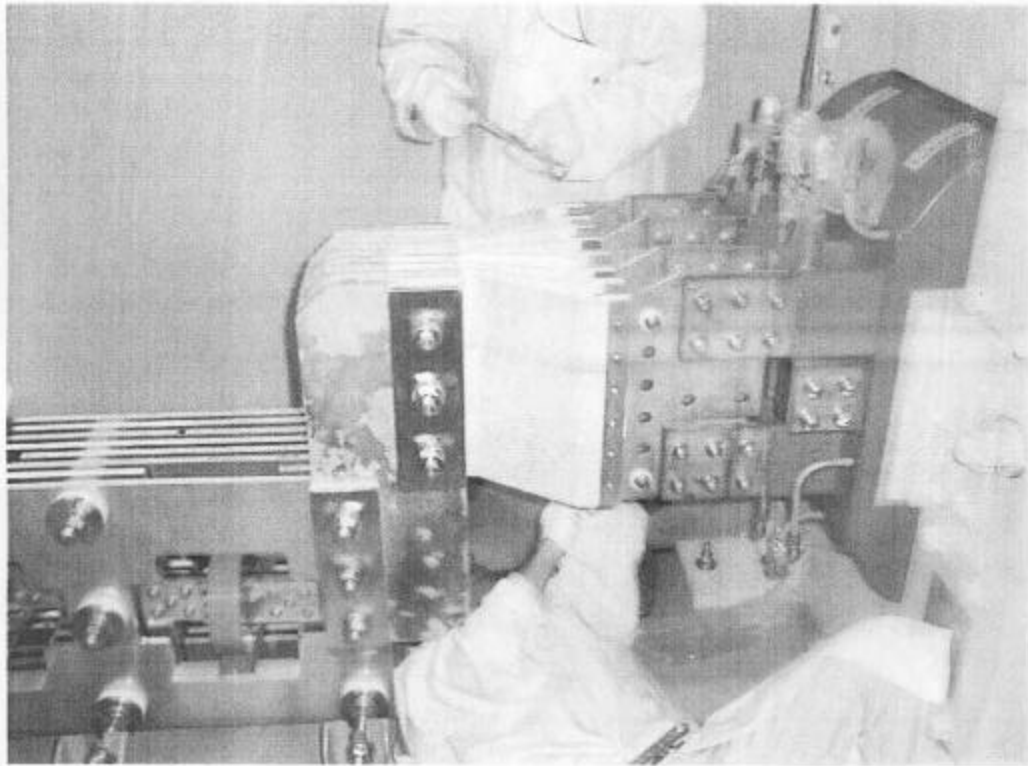


1. CT Pulse current transformer (Stangenes)
2. Resistance plate (SUS)
3. Slider unit

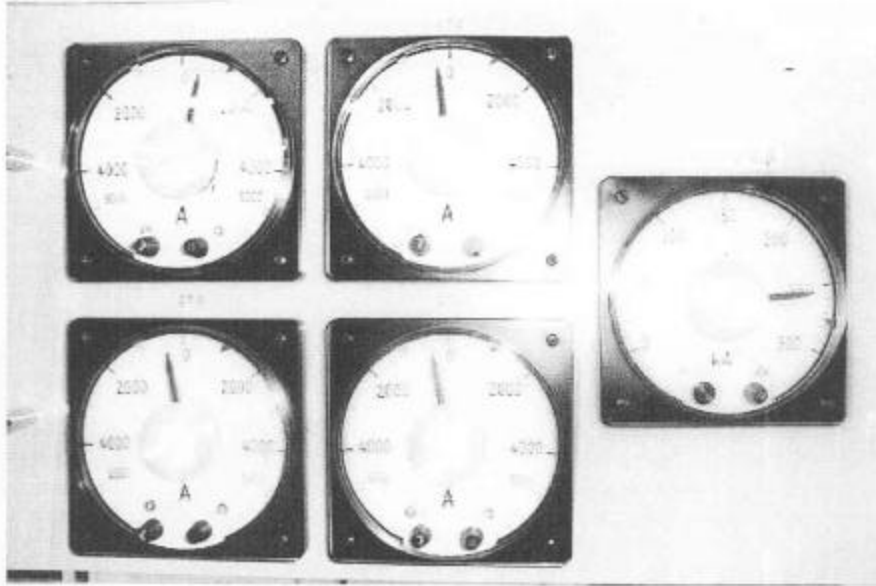
250kA Power Line



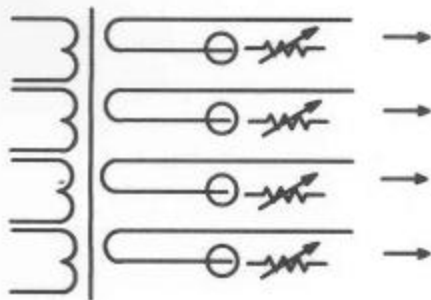
Aluminum
plate
320w, 15t



Current-balance monitor connected to interlock system



TRANSFORMER(10:1)

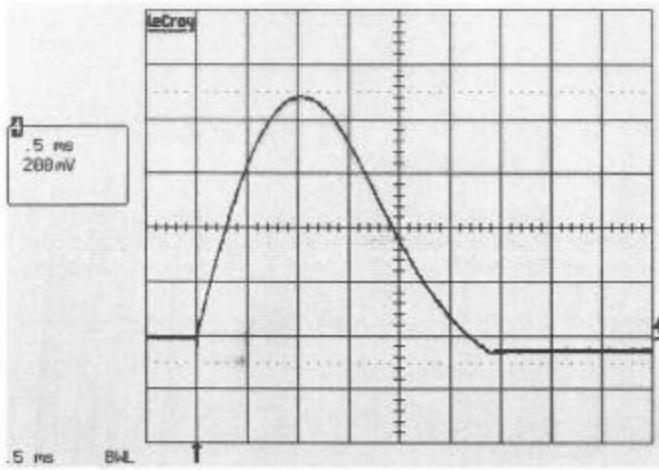


CT1 to 4

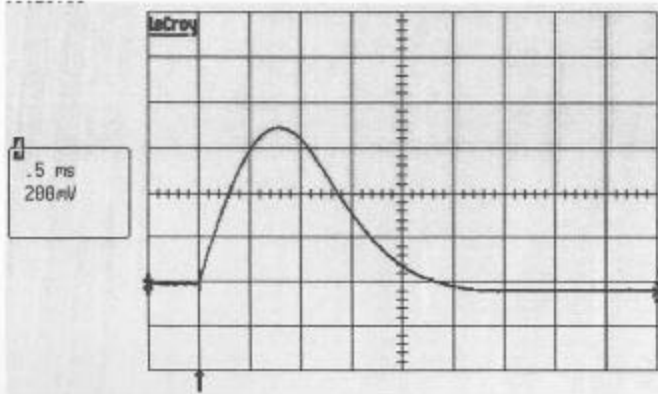


HORN

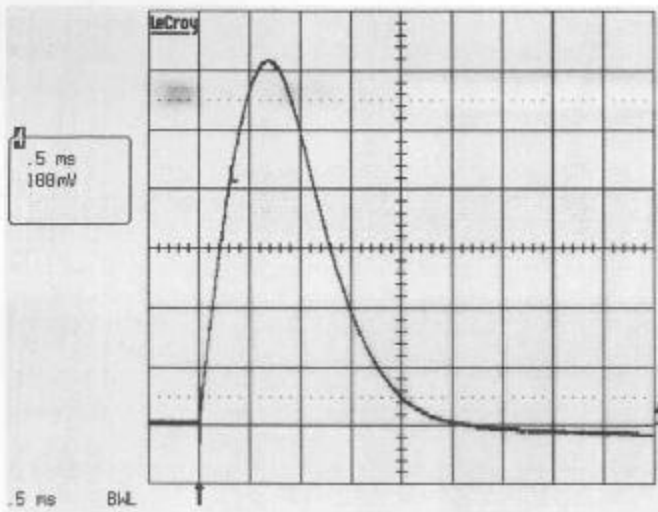
HORN 1



3.5mF



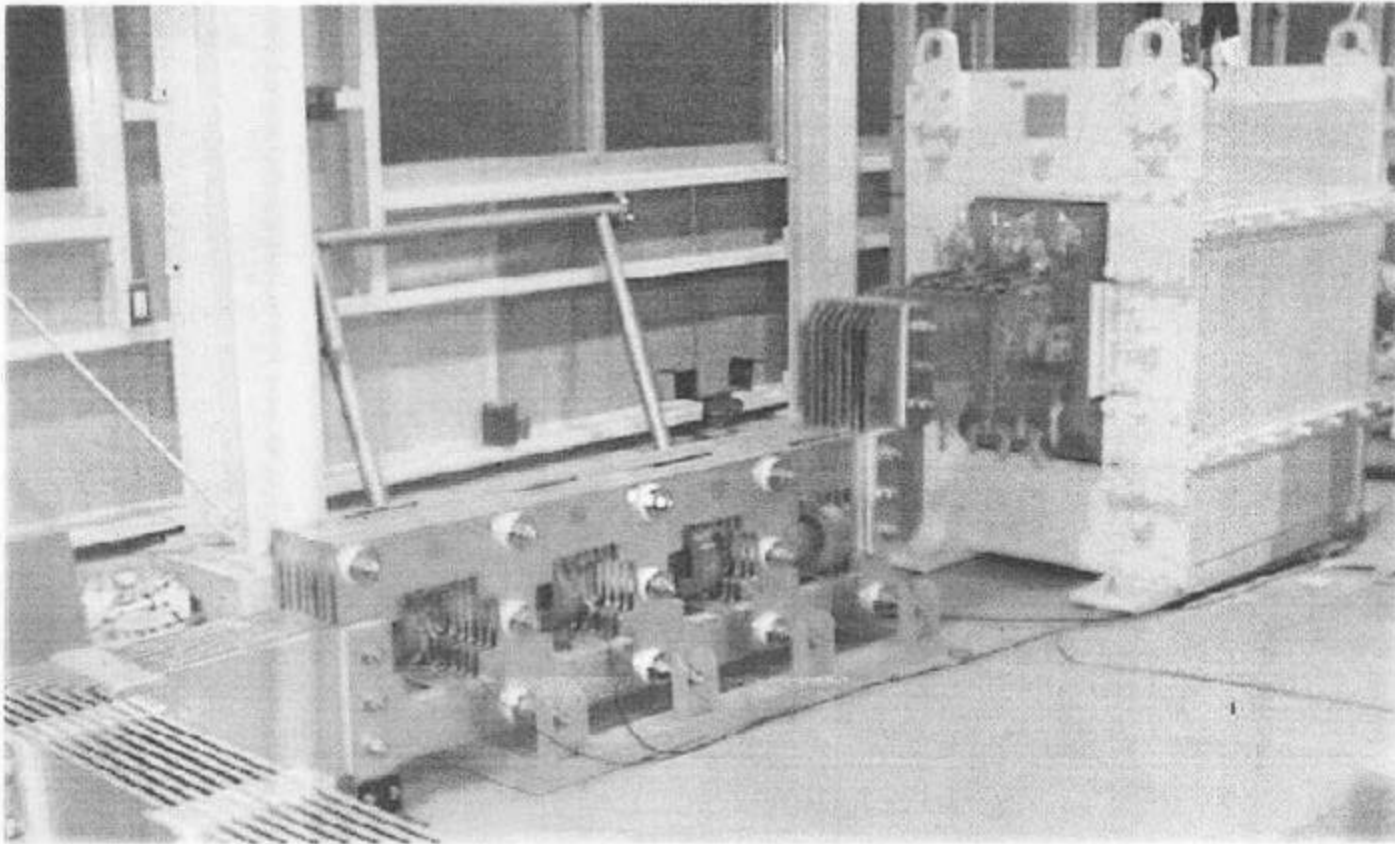
2.0mF



1.5mF

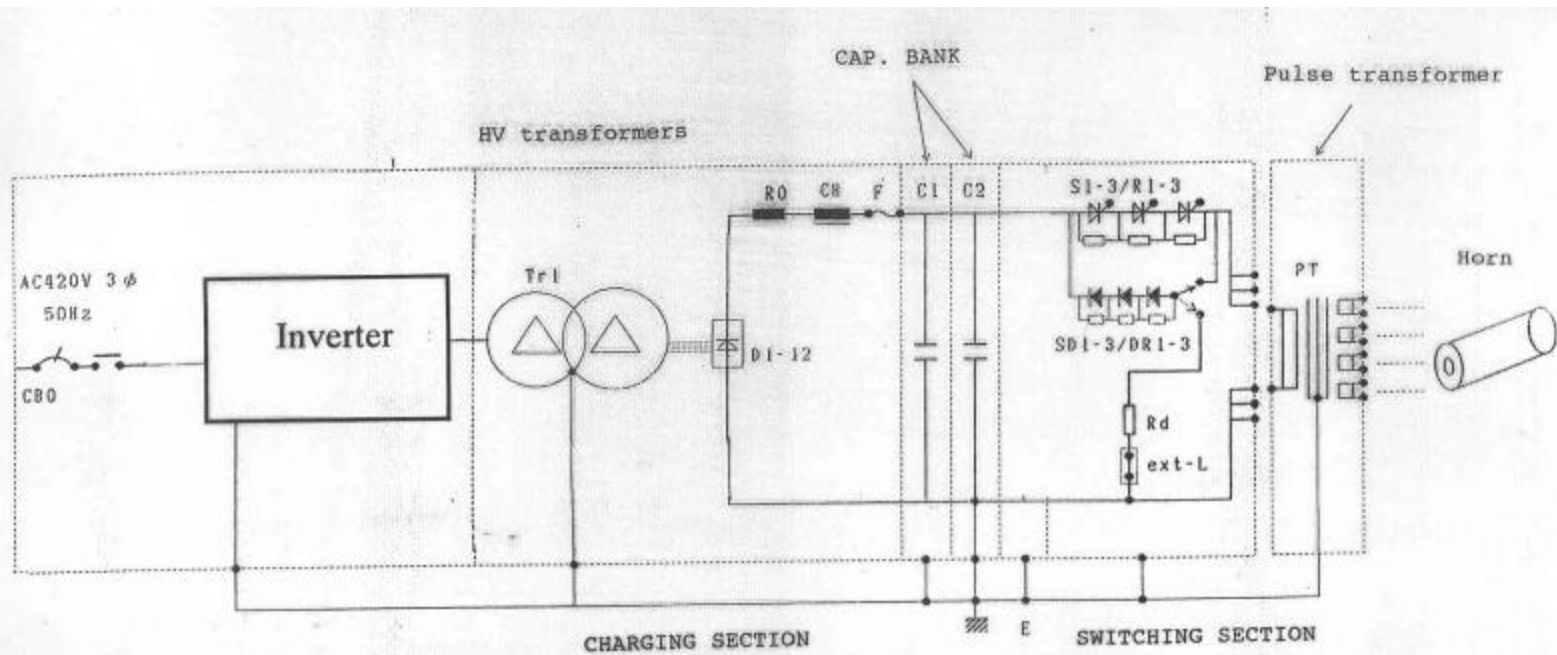
250kA Pulse Current Monitor

62.5kA x 4



Conclusion

- Operation results confirm to the calculation.
- Next plan
 - More fit compact design
 - Cut margin power, voltage, capacitor.
 - Inverter power control
 - 100~200(400)Hz
 - Charging unit
 - 6kV, 10A
 - Capacitor 2~3mF
 - Transformer
 - 6kV, 250Hz,
 - Iron section 0.2m²
 - Wight 5 t



Circuit diagram of the 250kA pulse power supply