CERN/LAB II/EA/SPEC. 74-1
18th January 1974

TECHNICAL SPECIFICATION

OF THE POWER RECTIFIERS

FOR THE SPS EXPERIMENTAL AREAS

(Power Circuitry)

The 300 GeV European Accelerator (SPS) will be equipped with two large Experimental Areas, where beams of particles (normally called secondary beams) and experiments will be installed.

This Specification is concerned with the D.C. power supplies (power circuitry) to feed the magnetic elements of the beams.

CONTENTS

DRAWINGS

I. GENERAL DESCRIPTION

1. Description of the equipment and working conditions

The secondary beams in experimental areas undergo important modifications and will therefore require a highly flexible supply system. After careful study and experience with existing experimental areas the following system has been chosen :

a) Rectifier units, with thyristors and the necessary control equipment representing the current stabilizing elements.

b) Diode units operating in conjunction with the larger thyristor rectifier types as voltage boosters.

The rectifier types with higher power are also arranged for possible series and parallel operation with other units of the same type.

TABLE 1

Type	Output voltage (V)	Nominal current (A)	No. of phases	Series conn.	Parallel conn.	No. of units per cubicle	
R11	150	500	6	-	-	2	Thyristor units
R12	300	500	12	x	not envisaged	1	
R21	300	1000	12	x	x	1	
R22	250	1500	12	x	x	1	
D21	200	1500	12			2	Diode unit

The regulation and control system is required to be compatible with the various combinations of the above supplies, to offer a high degree of precision (not normally required for other applications), and also to be suitable for manual or computer control with different operational modes. These conditions (especially the latter ones) give rise to a rather complex electronics system. Since it would be difficult and uneconomical for a company to develop this specialized equipment, CERN has decided to design and build it internally and to test it first under real working conditions.

CERN would like all the power supplies to have basically the same mechanical design features with a certain standardisation of cubicles. These cubicles will be installed in buildings constructed by CERN.

The cubicles will be placed on a false floor (1.10 m depth). The space between this false floor and ground is used for the cabling, and will also be under air pressure. The units with forced air cooling will draw cooling air from beneath and expel it upwards. The inlet air temperature varies between a minimum of + 12°C in winter and a maximum of + 32°C in summer.

The cubicles must be able to be lifted by a fork truck (Clark) and they should also be fitted with lugs for transport by crane bridge. In the power supply buildings the cubicles will rest on a structure of metal girders adequately arranged across the buildings. It is therefore necessary that all cubicles have the same depth, namely 1500 mm.

Since units will be installed side by side, components in the cubicles have to be arranged in such a way that easy access from front and rear is assured. The width of each cubicle should not exceed 1500mm.

The supplies will be connected to a three-phase 380 V cable led to the units through the interspace beneath the false floor. The mains voltage may increase to 110% of nominal : this should be considered while designing the magnetic circuit of the transformers.

The d.c. output cables leave the supply at the bottom and go to the inter-space below : the connections are made by means of M16 bolts.

2. Equipment to be delivered

Each power supply consists of a heavy current part, and a regulation and control part. The latter does not belong to the equipment to be delivered : nevertheless the manufacturer must provide the space for an electronic crate and its supporting rails in each power supply.

The equipment to be installed in the cubicles includes, in addition to the usual elements (transformers, thyristors, etc), a few items less commonly used. Examples are :

- d.c. current transformer of very high precision and stability,
- motor-driven polarity reversal switch,
- AMP Faston terminal strips.

3. Components and execution

3.1. A.C. switchgear

The main circuit breaker must have three contacts and be able to be switched on manually and remotely. It must be able to protect the power supply against overload, overcurrent and internal faults in the supply. The latching and release mechanism should be adjusted for proper operation. The cables arriving at the supply are protected by circuit breakers or fuses in the substation.

3.2. Transformers

The transformers will all be air-cooled and care must be taken to ensure that the temperature of the hottest spot does not exceed 120°C (insulation class B). The transformers must be impregnated. The windings must be made of copper. In order to adapt the voltage to the load, the rectifier units will have the

possibility to connect an auto-transformer to the primary. All terminals for this should be clearly marked and it should be possible to introduce easily the necessary cables. In order to have very uniform short circuit voltages, care should be taken with the pow cabling. The rectifier transformers (for R units) are special in that a double primary winding is used to reduce the coupling between the two secondary windings so that the transformer behaves as two separate transformers. This reduces the mutually induced commutation notches. Furthermore, some R units (see Table 1) are intended to operate in parallel (common gate pulse generation for master and slaves). Unit to unit tolerance should correspond to a current sharing better than 10%. The rectifier transformers which supply thyristor or diode bridges not protected by fuses (see details in section 3.3.), should withstand at least 10 short circuits on each secondary winding. It should be possible in the event of a failure to remove the transformers sideways, after removal of the side panels.

3.3. Thyristors and diodes

Properly designed thyristor and diode circuits have nowadays a failure rate as low as conventional power circuit components (transformers, circuit breakers etc.). We have therefore decided to omit the fuses in rectifier circuits for beam transport supplies and in case of a reverse blocking failure to replace two thyristors instead of one (the third will be blocked by electronic overcurrent protection). In such a case the semiconductor device should not disintegrate and cause additional damage. Short circuit tests made with disc cells proved that this arrangement (cells clamped together by anode and cathode cooling fins) is sufficiently safe. Therefore the thyristors and diodes to be offered in the proposed fuseless circuit are restricted to double-sided cooled disc cell types. Because of the limited space in the cubicle, a two-layer arrangement with one blower per 12-phase circuit would be advantageous. Thyristor and diode dimensioning should take this into account together with the fact that the inlet air is warmed by the power transformer underneath. Furthermore, supplies should be able to operate in parallel with an unbalance of 10%. Under these conditions a 200 Ampere thyristor (120° con-

duction angle) would be necessary for the R21 and a 300 Ampere thyristor for the R22 unit. The smaller types R11 and R12 can be designed for nominal current. The thyristor pulse transformer and associated diodes and resistors should be mounted on a card, and the assembled card should be able to withstand a 5,000 volt (50 c/s) test voltage between the primary and secondary of the pulse transformer. The RC protection circuit for the thyristors and the gate current limiting resistor values are as shown in the relevant bridge drawing.

The thyristor with its cooling fins, pulse transformer and RC network should form an integral part which will be replaced as a whole in case of failure. Diodes can be arranged in such a way that a complete half bridge has to be replaced in case of failure.

Due to the limited number of capsule thyristor manufacturers, CERN has undertaken a small survey to facilitate the selection. A list of suitable types may be obtained from CERN on request.

3.4. Interconnection with CERN electronics

The "supply electronics" comprising essentially buffer amplifiers, amplifiers, gate control, protection and control logic, is housed in a 5 unit CAMAC crate with a 5 unit socket panel which requires front access only. Some auxiliary equipment (transformers, load resistors for AC current transformers and mimic diagram conductors etc.) is installed in the 6-unit power control crate. The whole assembly is furnished by CERN, the supply manufacturer has only to provide the horizontal supporting rails and profiles for vertical fixation.

3.5. Auxiliary equipment

All fans should have ball bearings which give at least two years continuous running without requiring greasing. To reduce noise, fans should have, if possible, a 4-pole winding (1450 r.p.m.). Measuring resistors (for the mimic diagram) should be close to the bus-bars.

3.6. Control cables, connectors and terminal strips

The control cables should be of flexible conductors, and the wire ends should be crimped. AMP Faston wire connections to terminal strips should be properly protected.

3.7. Mechanical parts

The cubicles should have a robust frame suitable for crane and fork lift transport. The front doors and for double units also the rear doors, should be made out of steel sheets with suitable reinforcements. The cubicles should have easily-removable side covers (no doors). All doors should open and close easily and all units, even of different types, should have the same locks and keys. The 380 V a.c. and the d.c. output terminals, as well as the AMP terminal strip, should have plexi-glass covers.

II. SPECIFICATIONS

1. Specification for rectifier units type R11, R12, R21 and R22 and diode unit type D21

The R12, R21 and R22 power supplies are 12-phase rectifier sets consisting of two 3-phase bridges connected in parallel through an inter-phase transformer. The two bridges are fed from zig-zag transformer secondary windings which are $\pm 15^{o}$ phase shifted and lie -15^{o} and -45^{o} with respect to the input power vectors (i.e. they lead the input power vectors)(see drawing EA-8083-3918-1).

A current balance system between the bridges uses a Hall plate in the air gap of the interphase transformer, which acts on the gate control set in such a way that the d.c. flux is minimized.

The R11 power supply is only a six-phase rectifier (one three-phase bridge without interphase transformer) using a delta/star connected rectifier transformer (see drawing EA-8083-3919-1).

All units are equipped with a motor-driven polarity reversal switch with several position-indicating contacts.

The d.c. output current is measured by a d.c. current transformer. The transformers and thyristor bridges of the R21 and R22 units are forced air cooled. The transformers of the R11 and R12 units are convection cooled; the method of cooling the thyristor bridges depends on the type of thyristor used.

Complete information regarding the units is given in CERN drawings EA-8083-3918/3919 and the accompanying part lists.

The 12-phase diode rectifier type D21 is composed of two 30^{o}-phase shifted, 3-phase bridges as shown in drawing EA-8083-3920. It is used in series with R12, R21 or R22 rectifiers in order to boost the voltage sufficiently to drive several magnets in series. The diode bridges are forced air cooled.

2. Part List and Component Specification

Part No.	Qty.	Description	Type					Remarks
			R11	R12	R21	R22	D21	
1	1	Main circuit breaker, 3-phase with over current and overload release equipped with auxil. contacts. Motor driven : 220 V Trip coil : 24V dc Nominal current	150A	250A	630A	630A	220V zero volt. release 500A	3 make and 3 break cont. smaller circuit breakers may be switched on magnetically but 220 V ac current should not exceed 5 A.
2	3	Fuses for 3-phase auxiliary circuits.	25A	25A	25A	25A	-	
3	1	Auxiliary mains switch.	25A	25A	25A	25A	-	
4	1	Blowers for forced air cooling 220V, 50 Hz, 4-pole motor.	1 for thyristors if not convection cooled.		1 for thyristors 1 for rect. transformers.		2 for diodes	
5	1	Rectifier transformer Cooling : Rating : (kVA) Primary 380V (+ 10%) (- 0%) line voltage	convection 87.5 1 delta winding	183 2 separated delta windings	forced air 365 2 separated delta windings each prepared for series/ parallel conn.	457	convection 330 open delta	

2. Part List and Component Specification

Part No.	Qty.	Description	Type					Remarks
			R11	R12	R21	R22	D21	
5	1	Rect. trans. continued. Secondary	star as shown in EA-8083-3919 3/1	two ± 15° phase-shifted stars connected as shown in EA-8085-3918-311			star/ delta as shown in EA-8083-3920 3/1	
		Current (I_2) phase to neutral Voltage (U_2)	408A 71.4V	204A 141V	408A 141V	612A 117.6V	612A 91.5V	
		Short circuit volt. 0.06(±5%) copper losses max.	1.7kW	2.6kW	6.5kW	8kW	4kW	
6		AC current transformers 15VA Current Quantity	500:1A 2	250:1A 4	500:1A 4	750:1A 4	-	
7	1	Commutator for series/parallel connection of the primary windings 380V.	-	-	6-pole	6-pole	3-pole star/ delta conn.	
		Current	-	-	200A	200A	300A	

2. Part List and Component Specification

Part No.	Qty.	Description	Type					Remarks
			R11	R12	R21	R22	D21	
8		Quantity:	1	2	2	2	2	
		Three-phase bridge with RC network and pulse transf.		thyristor see drawing EA-8085-3921-3			diode	
			x	x	x	x	-	
		Average current for 120° conduct angle:	167A	83A	167A	250A	250A	See remarks under I-3.3
		Double-sided cooled disc cell type.						
		Repetitive blocking and inverse voltage: (safety factor ≈ 2.5 included)	>450V	>900V	>900	>750V	>600V	
		(dv/dt) 50% U_{DRM}	>100 V/µs	>100 V/µs	>100 V/µs	>100 V/µs	-	
9		Quantity:	2	4	4	4	-	
		Free-wheeling diodes with RC network, double-sided cooled disc cell type.						
		Average current for 180° conduct. angle:	400A	200A	400A	400A	-	See remarks under I-3.3
		Repetitive inverse voltage:	>600V	>900V	>900V	>700V		

2. Part List and Component Specification

Part No.	Qty.	Description	Type					Remarks
			R11	R12	R21	R22	D21	
10	1	Interphase trans. current	-	250A	500A	750A	-	
		Equivalent 50Hz r.m.s. voltage $2\left[\sqrt{3}/2 \sin \pi/12 (1+\sqrt{3}/2)\right] U_2$		2x60V	2x60V	2x49V		
		$B_{max.} = 0.9T$, Air gap adjusted to magnetizing current: at nominal voltage, but $\delta/2 \geq 1$ mm to permit Hall plate introduction.	10A	10A	25A	40A		Hall plate delivered by CERN (max. temp. 70°C)
		Copper losses max.	-	500W	700W	800W		
11	1	DC current transformer. Output voltage: / At. current :	10V 500A	10V 500A	10V 1000V	7.5V 1500A	-	Delivered by CERN Approx overall dimensions :
		AC supply 220V, 50Hz.						400 x 210 x 200
12	4	10A 500V fuses. (DC measurement)	x	x	x	x	-	

2. Part List and Component Specification

Part No.	Qty.	Description	Type					Remarks
			R11	R12	R21	R22	D21	
13	1	Commutator for polarity reversal. Motor driven, 3-phase 380V with auxiliary contacts showing the positions : normal, inverted, zero (open) and between zero and normal. No. of contacts per pole :	1	1	2	3	-	Suggested manufacturer : W. Berg, Käfertaler Str., Mannheim, W. Germany.
14		Terminals (M16 bolts) Quantity : AC DC	3 2 x 1	3 2 x 1	3 2 x 2	2 x 3 2 x 3	3 2 x 3	
15		Separation links with position micro-switches Quantity: M16 bolts Quantity	- -	5 10	5 12	5 18	- -	

2. Part List and Component Specification

Part No.	Qty.	Description	Type					Remarks
			R11	R12	R21	R22	D21	
16	3	Removable links for introducing a stepping transf.	-	x	x	x	-	Preferably fuse holders with short circuit links.
17	4	Circuit breakers (protection) with overload and short-circuit release.						
		— Earth protection :	0.1 ÷ 0.14A	0.1÷ 0.14A	0.1÷ 0.14A	0.1÷ 0.14A	-	
		Electronics :	1 ÷ 1.5A	1 ÷ 1.5A	1 ÷ 1.5A	1 ÷ 1.5A	-	
		Blower :	1.5 ÷ 2A	1.5÷ 2A	1.5÷ 2A	1.5÷ 2A	-	
			if required					
		Polarity rev. switch :	0.25 ÷ 0.35A	0.25÷ 0.35A	0.25 ÷ 0.35A	0.25÷ 0.35A	-	
18	1	Red lamp (neon) with series res.	x	x	x	x	x	Suggested manufact. Cerebus Socket E14
19	1	Transformer, primary 380V, 50Hz, secondary 220V, 5A.	x	x	x	x	-	

2. Part List and Component Specification

Part No.	Qty.	Description	Type					Remarks
			R11	R12	R21	R22	D21	
20	1	Contactor 10A, 220V, 50Hz coil:	if Pos. 4 exists		x	x	-	
21		Basic load resistor Quantity : Resistance : Power : Free air dissip. to be installed under the thyristor cooling duct.	2 68Ω 200W if Pos. 4 exists	4 200Ω 500W	4 200Ω 500W x	4 150Ω 500W x	-	
22		Protection resistors 2 x 270Ω in parallel to be attached at the measured point. Quantity	9	18	18	18	-	Preferable moulded epoxy resin with 2 angle pieces at the end and AMP spade at the centre.
23	1	Power control crate type:	U7505	U7507	U7507	U7506	-	Delivered by CERN

2. Part List and Component Specification

Part No.	Qty.	Description	Type					Remarks
			R11	R12	R21	R22	D21	
24		Terminal strip. Fast-on 6.3 mm (quadrupole lugs) Firm width. Quantity for : TSA TSB TSC TSD TOTAL	15 - 25 50 90	15 15 25 70 105	15 15 25 70 105	15 15 25 70 105	20 - - - 20	Suggested manufacturer : Entrelec, Lyon-F. TSE is installed in the power control crate delivered by CERN.
25	2	Thermal contacts (normally closed). 2.5 kV isolation mounting surface/contact For thyristor > 95°C For rect. transf. > 112°C	x	x	x	x	x	
26	1	Delay circuit for zero voltage release (≈ 100 ms)	-	-	-	-	x	
27	1	Emergency off button	-	-	-	-	x	

2. Part List and Component Specification

Part No.	Qty.	Description	Type					Remarks
			R11	R12	R21	R22	D21	
28	1	Relay with delay make (≈ 1s) input 200V ac.	-	-	-	-	x	
29	1	Resistor 220Ω, 100W with adjustable tap.	-	-	-	-	x	
30	1	Commutator 6A, 2-pole.	-	-	-	-	x	

3. Mechanical arrangement

The suggested arrangements are shown in CERN drawings EA-8083-3922-3/4 and EA-8083-3923-4. The different supply types can be housed in a 1500 x 1500 x 2300 m cubicle with access by doors from front and rear.

The types R12, R21, R22 are single units (one supply per cubicle), whilst two R11 or D21 units can be installed in one 1500x1500x2300 mm cubicle. These double units installed in the same cubicle are completely independent from each other, and must be arranged in such a way that maintenance work can be done in one unit whilst the other is in operation (separation sheets).

The frame should be sufficiently sturdy, so that a step-down transformer can be installed on the roof (weight ~ 600 Kg). The cubicle should be covered on the top by a grid and a passage has to be provided for the cables between the step-down transformer and the removable links (Pos. 16).

The lower parts of the transformers of type R21 and R22 are enclosed in an air-tight box, which is put under slight over-pressure by a fan. The air forced through the ventilation slits of the transformer windings provide a very efficient cooling.

III. TESTS

(Values for the various tests to be found in the component specification).

1. Tests to be carried out in the factory

CERN requires the following tests to be carried out in the factory :

a) Transformer and interphase transformer tests (separately) :

- Isolation : 3 kV, 50 c/s for one minute between all windings and between each winding and the core.
- In rectifier and diode units : the ratio of the voltages of the transformer secondary windings should be accurately measured ($\pm$ 15° phase shift, star/delta - 12 phase units only).

- The short-circuit voltages on all phases should be measured and short-circuit voltages between the secondary windings.
- The iron and copper losses should be measured.
- The copper temperature (hot spots) should be measured after 3 hours (convection cooled outside the cubicle).

b) Cubicle tests :

- CERN will supply the power control crate and the cable terminal strip/socket panel for each rectifier unit and two sets of the necessary electronics. A representative from CERN will supervise the tests, as follows :
- Cable check.
- System test at low current.
- Test of the power circuitry at full load current including a "temperature run" of several hours for the first units of each type, and one hour for the following units.

The manufacturer should undertake to supply the following, for the above testing :

- Differential oscilloscope.
- Voltmeters and Ammeters.
- A load (approx. 50V, 1000A convertible to 25V, 2000A, with a time constant of approximately 20 ms). If this cannot be supplied by the manufacturer then CERN will supply it ; the cost of transport being taken into consideration when assessing the tenders (two 1 mH 1000A filter chokes).
- A three-phase roller transformer in order to perform initial tests at low voltage and current.

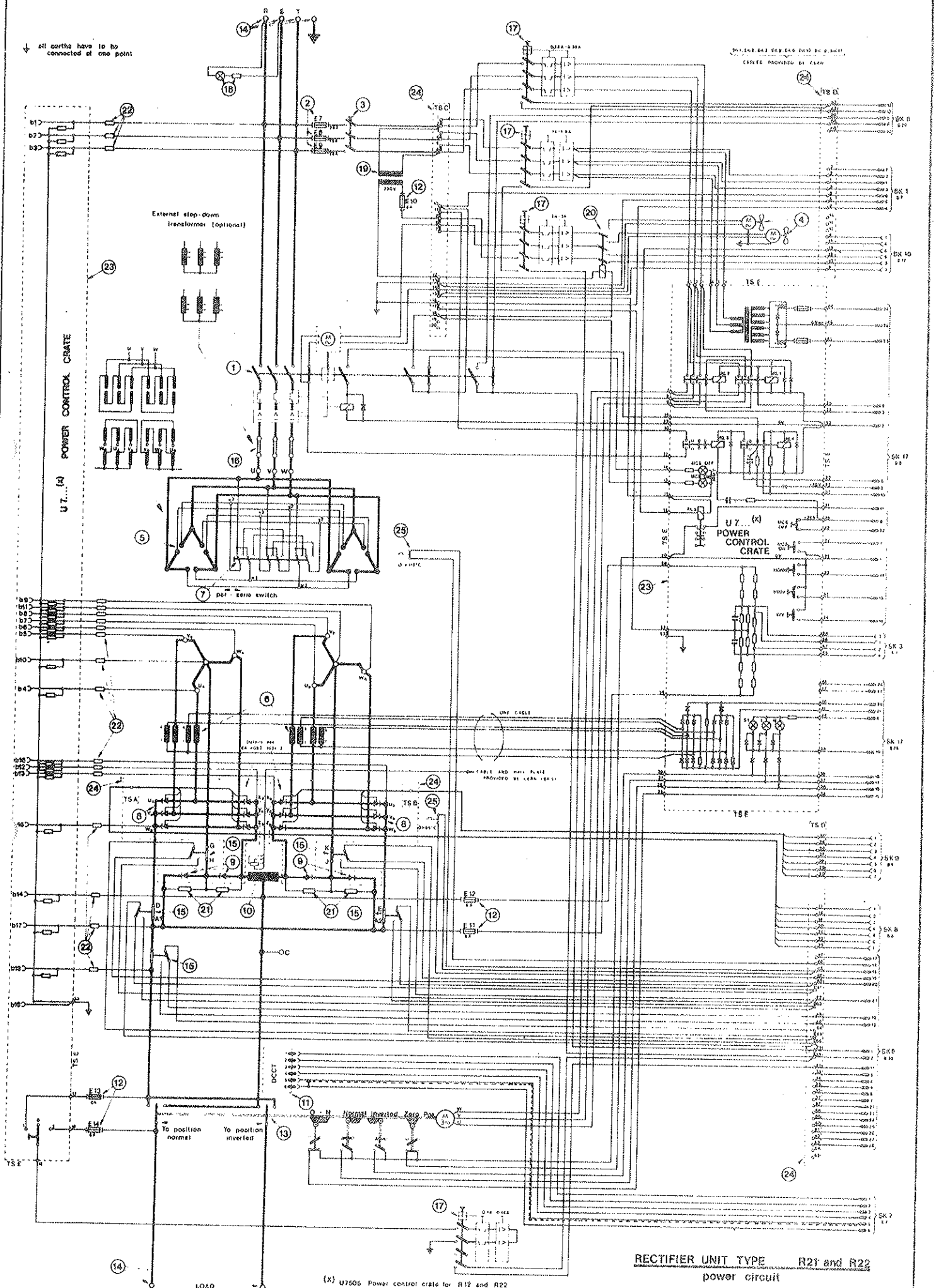
The manufacturer should also during these tests delegate to the CERN representative a competent person to effect any changes due to defects and generally to assist with the testing.

2. Provisional acceptance tests

After completion of successfull factory tests, units shall be delivered to CERN site where provisional acceptance tests will be carried out by CERN personnel. These tests will include :

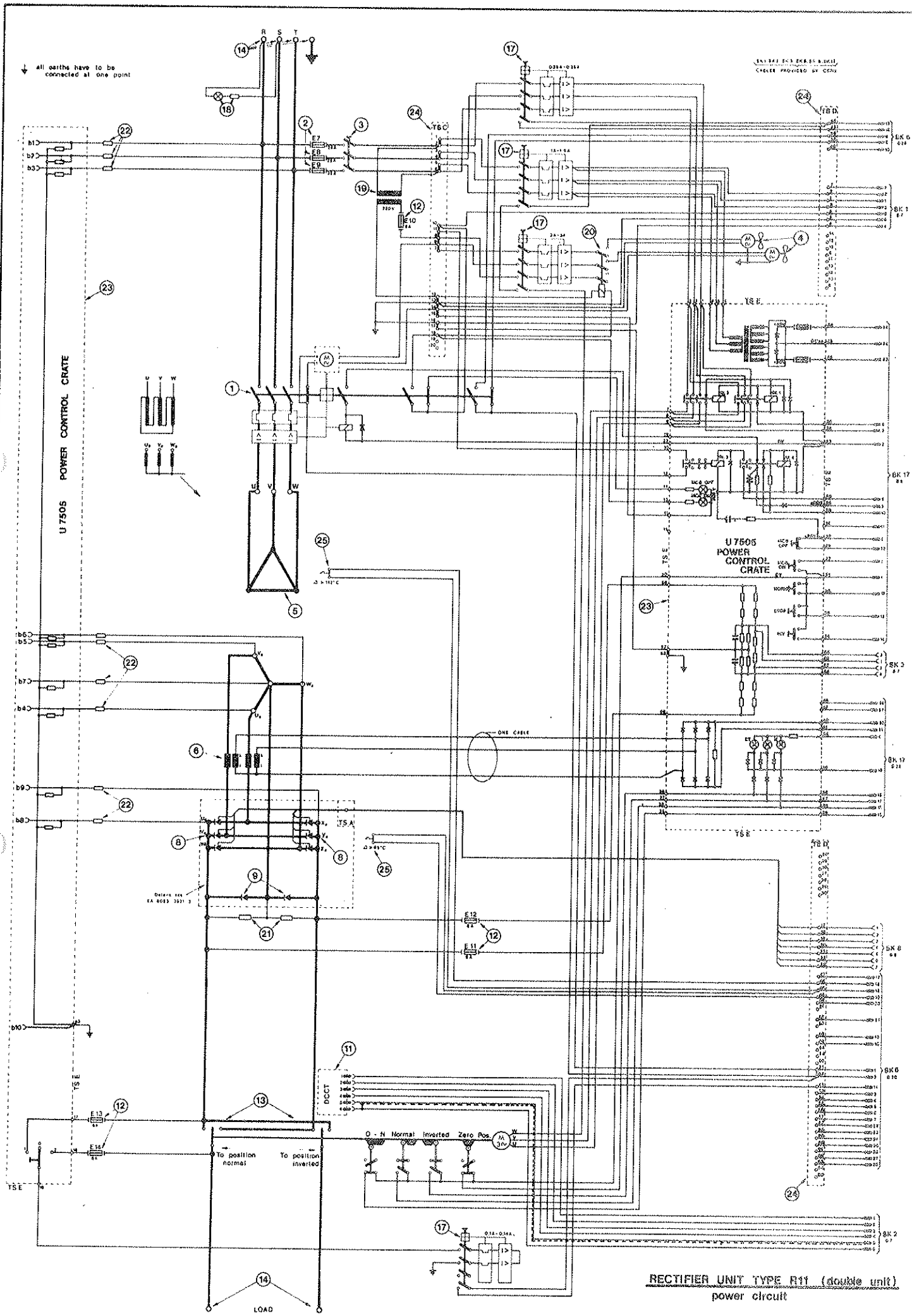
- Mechanical inspection.

- A 24-hour run at nominal ratings using the supply electronics. This test will be carried out within six months of delivery.



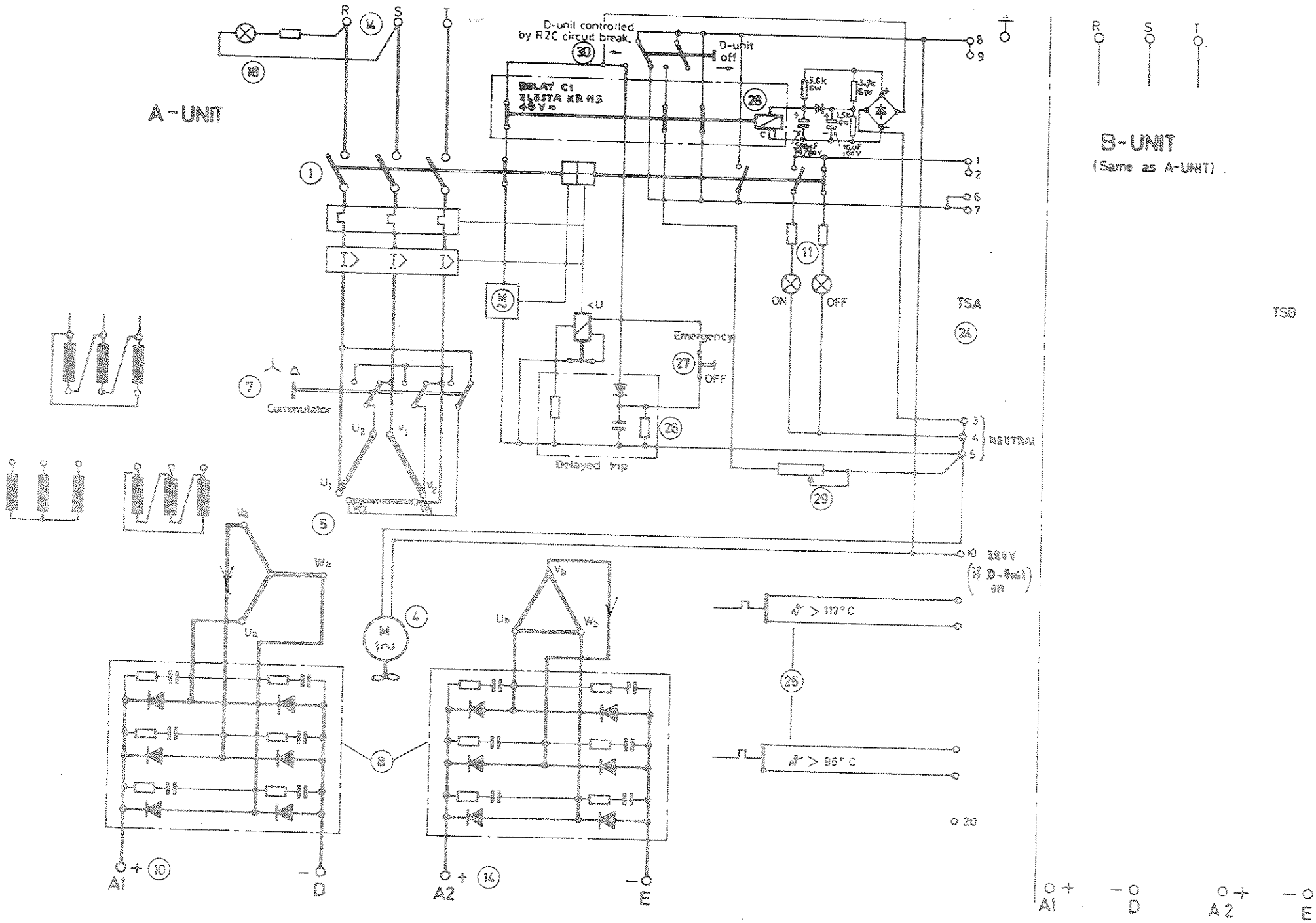
RECTIFIER UNIT TYPE R21 and R22
power circuit

CERN EA 8063-3918-3/1



RECTIFIER UNIT TYPE R11 (double unit)
power circuit

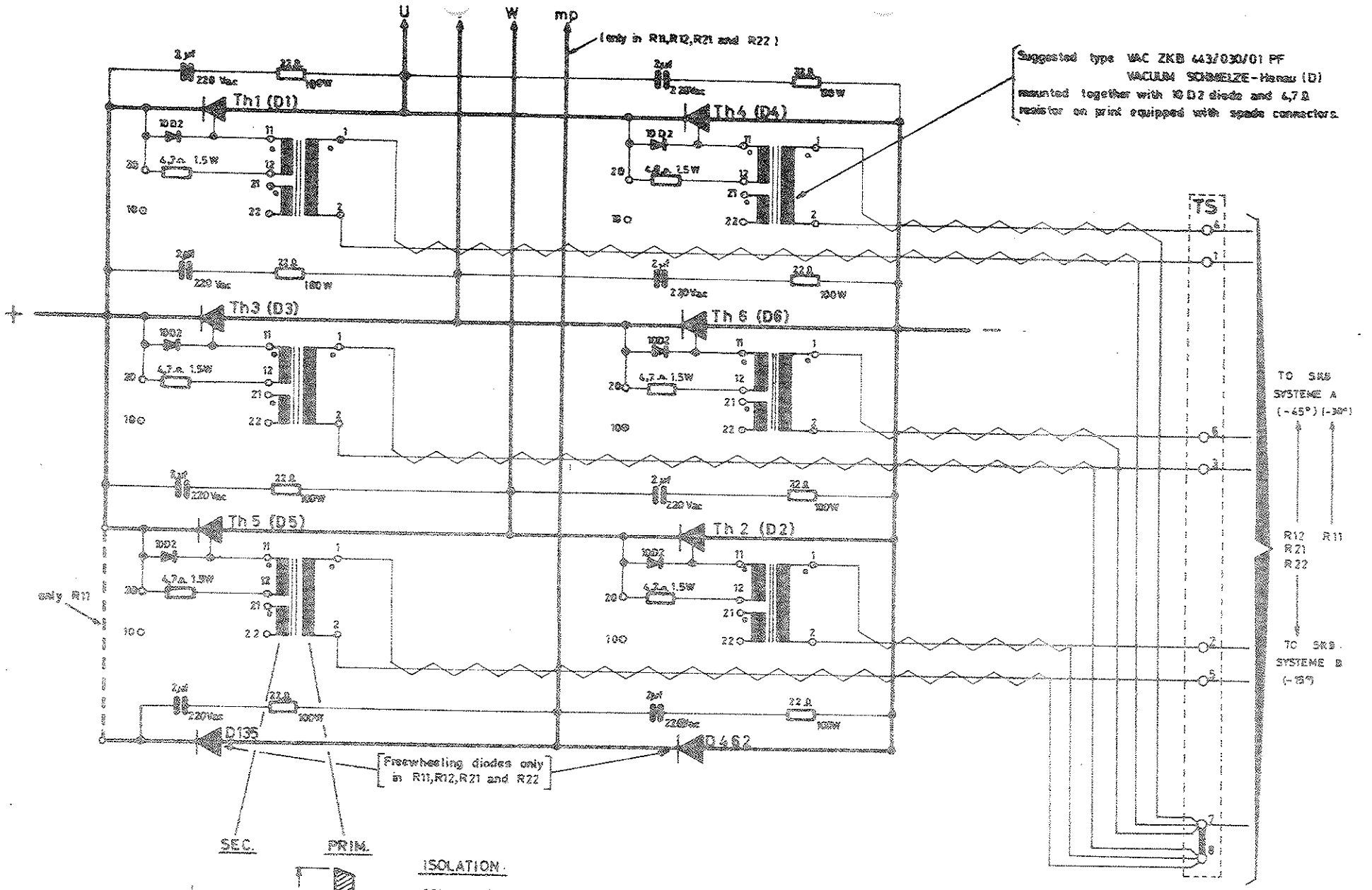
CERN EA 8083-3919-3/1



DIODE UNIT TYPE D 21 (double unit) POWER CIRCUIT

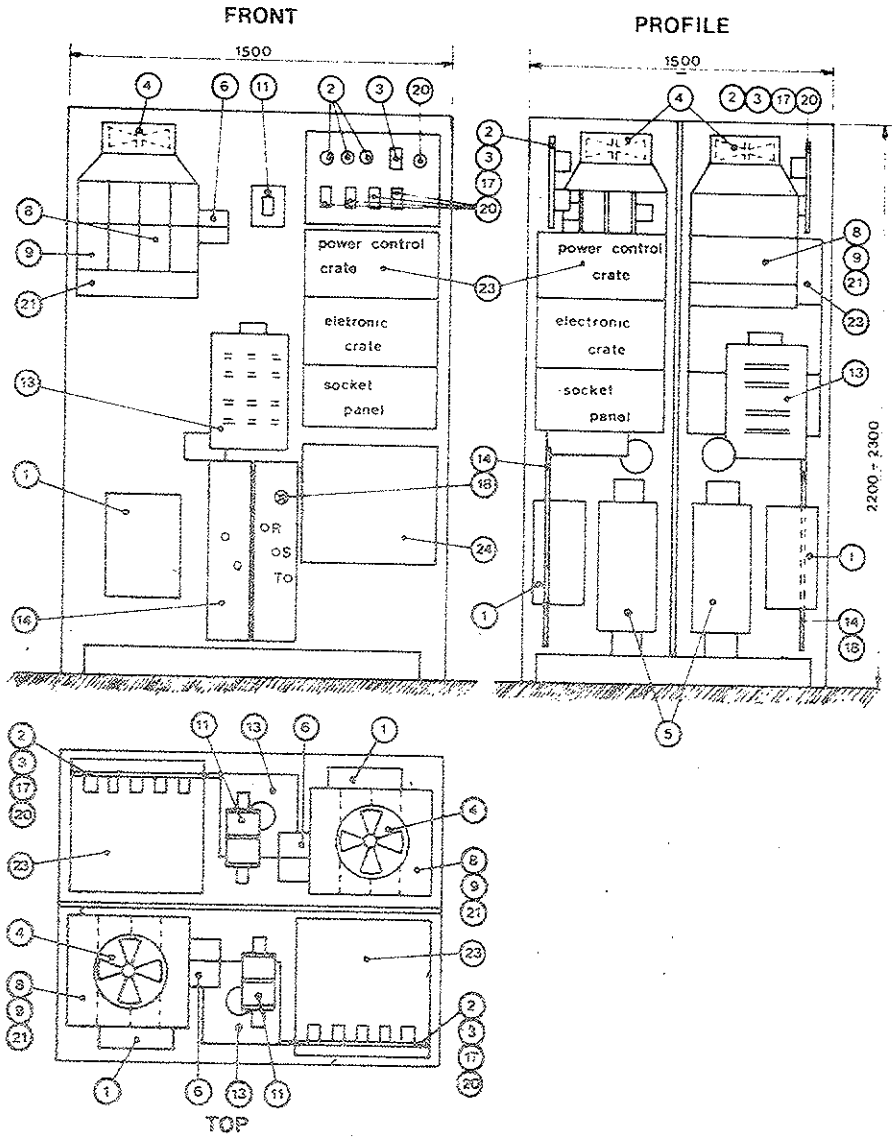
CERN EA 8083-3920-3/4

2-11-73 PIZOT R

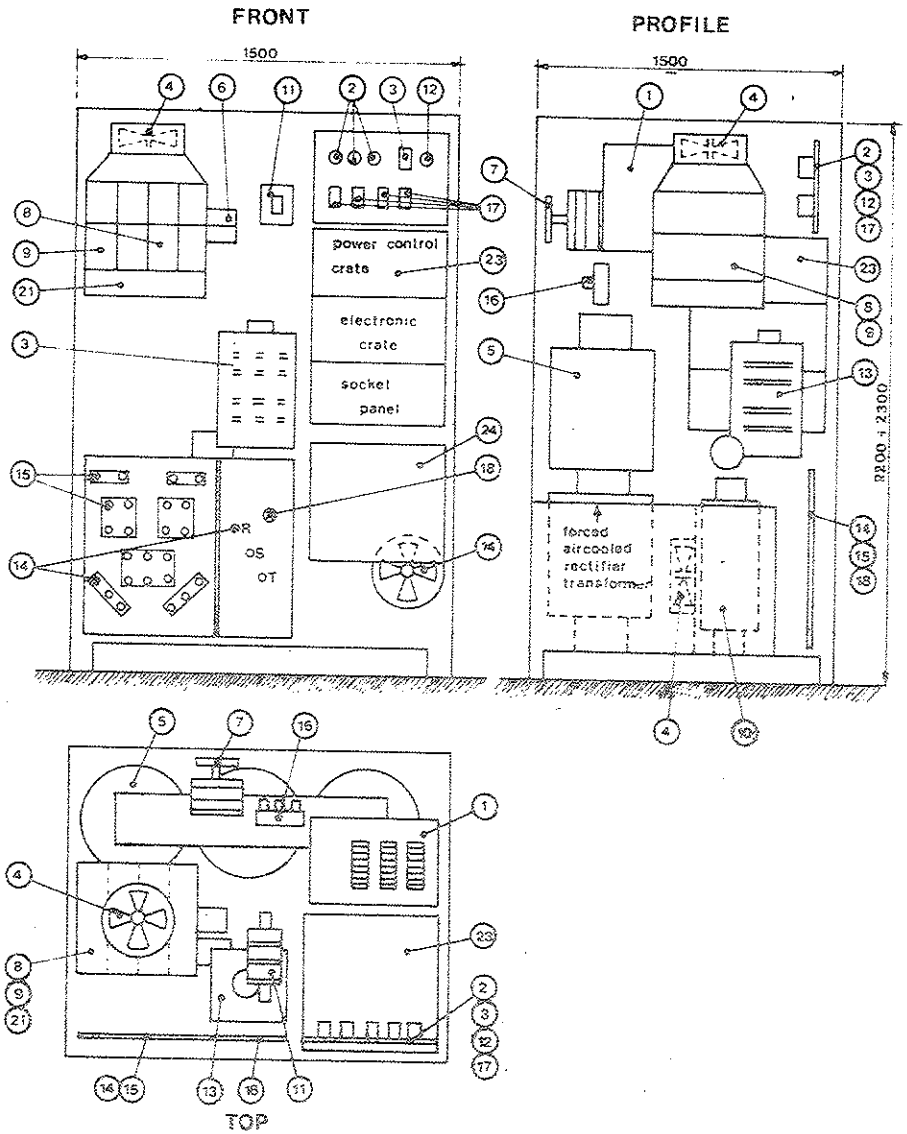


LAYOUT OF CONSTRUCTION / ARRANGEMENT MECANIQUE	MATERIAL LIST / LISTE DE MATERIEL		
POWER SUPPLY WITH THYRISTORS	TITLE - TITRE	DATE	SIGN.
CERN - EA	3 PHASE BRIDGE CIRCUIT FOR ALL TYPES	05/10/73	8083-3921-3/4

THYRISTOR UNIT TYPE R11
(double unit)



THYRISTOR UNITS TYPE R21 and R22
(type R12 similar to R21/R22 but smaller transformer dimensions)



THYRISTOR UNITS TYPE R11, R12, R21 and R22

mechanical layout

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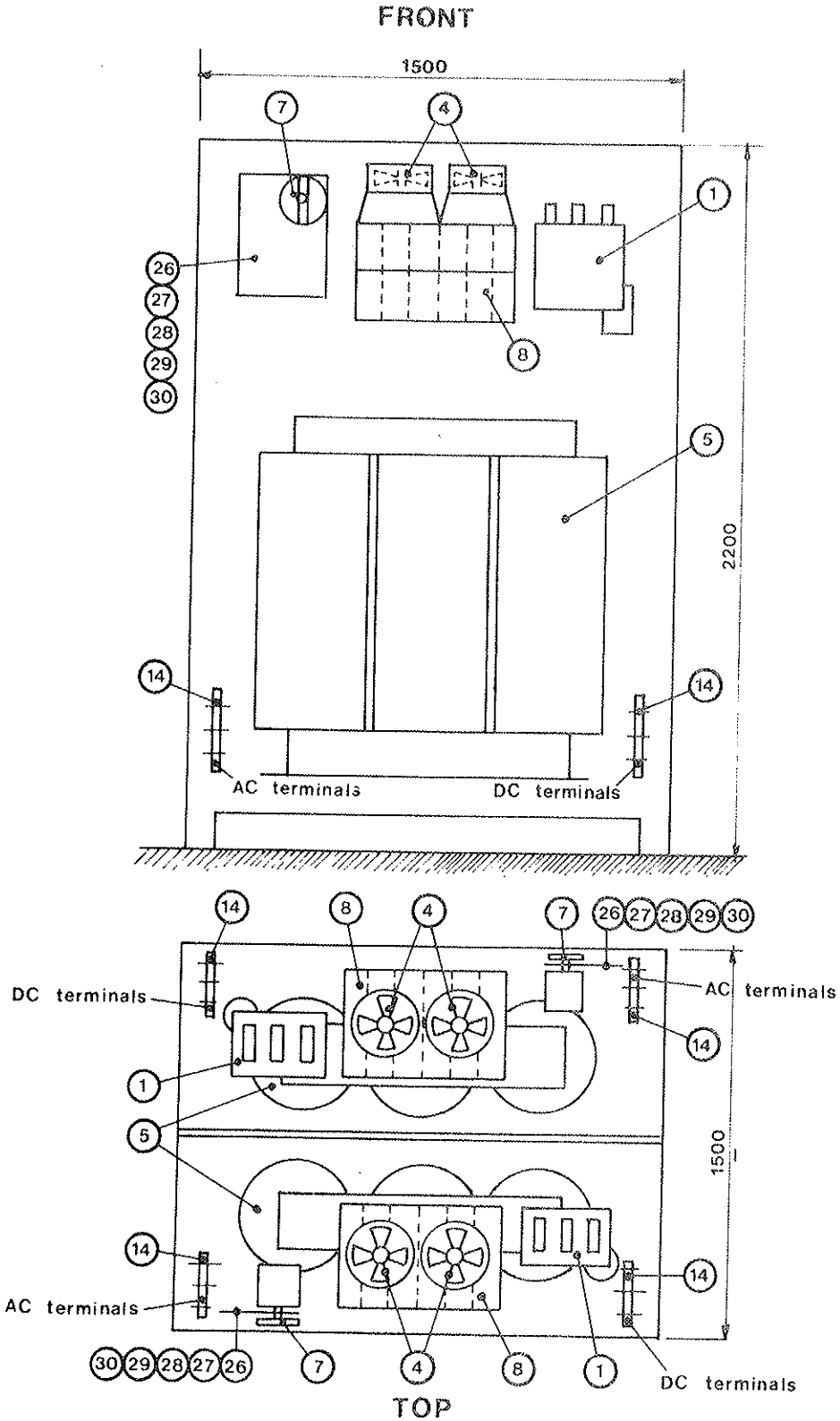
CERN EA 8083 - 3922 - 3/4



DIODE UNIT TYPE D21

mechanical layout

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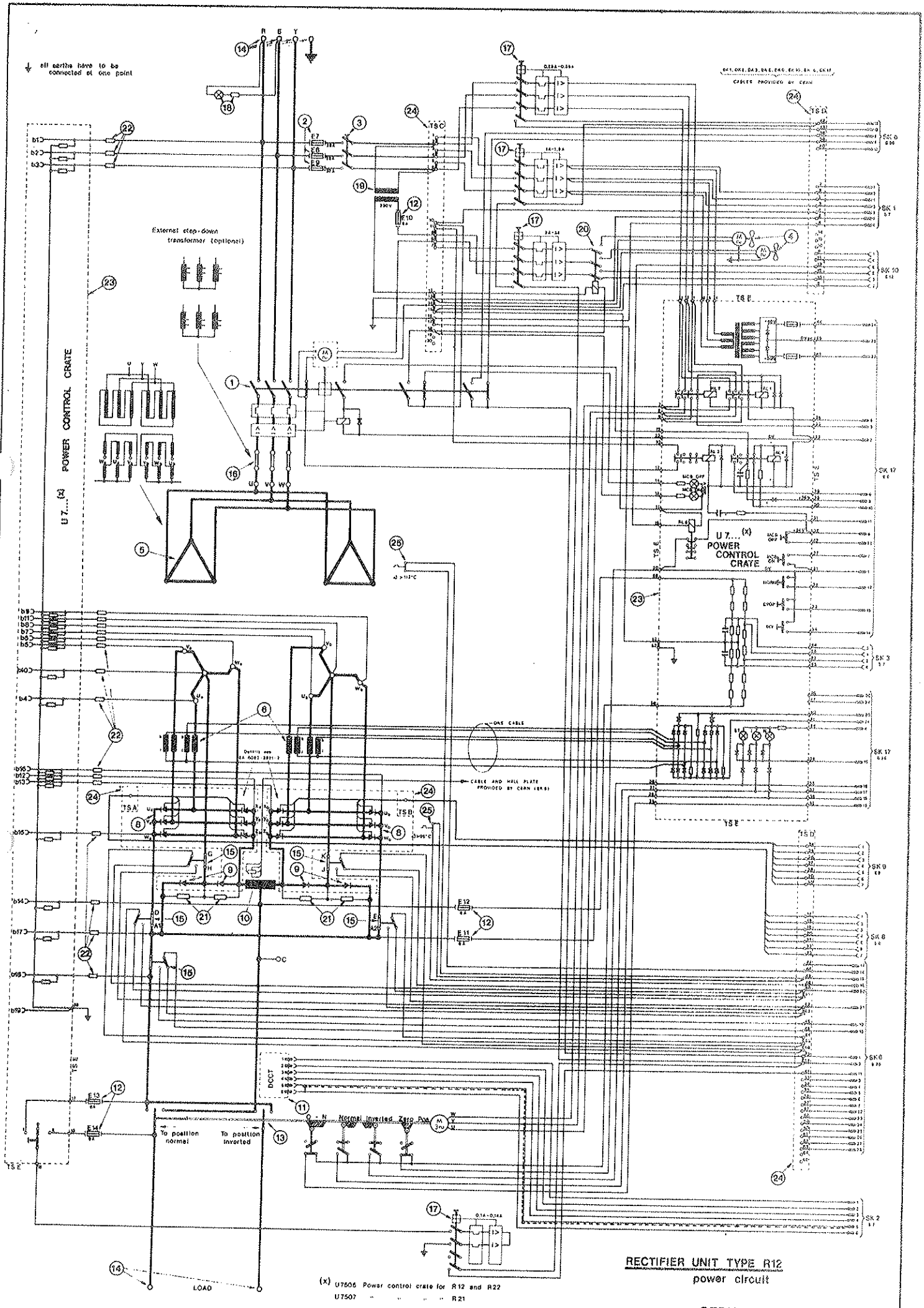
CERN EA 8083-3923-4



RECTIFIER UNIT TYPE R12
power circuit

(x) U7506 Power control crate for R12 and R22
U7507 " " " " R21

CERN EA 8063-4061-3/1