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A MODULAR DRIVE SYSTEM FOR NEUTRON CHOPPERS WITH DIGITAL SPEED AND PHASE-CONTROL

by

J. EDER and D. RÖBBELEN

1972

Joint Nuclear Research Centre
Ispra Establishment - Italy

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ABSTRACT

A modular drive system for synchronized multiple neutron choppers is described. Brushless reluctance synchronous motors supplied by solidstate converters are used to give the system a high degree of reliability. A digital quartz reference generator provides the control signals for speed of the master chopper and serves as a pilot time base for all other systems. Phasing between different chopper rotors is achieved by digitally delaying the pilot signal. Since all drive modules are locked to the same frequency drift problems due to fluctuations of electrical power and temperature are practically eliminated. An analog P - I - control loop reduces short time phase fluctuations caused by mechanical effects. Start-up and synchronization procedures are semiautomatic.

KEYWORDS

NEUTRON CHOPPERS
MOTORS
DIRECT CURRENT
SPEED REGULATORS
DIGITAL CIRCUITS
PHASE STABILITY
SPECIFICATIONS
ELECRIC GENERATORS
CONTROL SYSTEMS
ELECTRONIC EQUIPMENT

CONTENTS

A modular drive system for Neutron Choppers with digital speed and phase-control

J. Eder - D. Röbbelen
C.C.R.Euratom - Ispra, Italy

-:-:-

1 - Introduction

The widespread of neutron chopper experiments claims for a versatile and flexible drive system with tight specifications on speed and phase-control. For multiple chopper systems the requirements are even more stringent and a modular construction is desirable to improve interchangeability and to simplify maintenance.

After not very satisfying experiments with DC-motors and with a motor-generator converter we decided to develop a modular system entirely solid-state and as far as possible in digital techniques. This system is used with brushless reluctance synchronous motors (see fig. 1).

The advantage of this configuration is that problems of wear out (brushes, electronic components) are reduced to a minimum. The digital design of the reference generators ensures that temperature drifts or power supply variations have no influence on the stability. The precision of speed and phase-delay settings is determined only by the stability of a quartz-clock and is free of any drift effects. Though synchronous motors require more sophisticated procedures for start up, once they are locked to the reference frequency, no additional control loop for speed stabilization is necessary.

We adopted reluctance motors instead of hysteresis motors because they lock always at the same angle between field and mechanical rotor to the reference source. The rotor of a reluctance motor has fixed poles given by its geometrical shape, whereas the pole-position on the rotor of a hysteresis motor tends to shift and introduces a source of phase errors.

2 - Principle of operation

Fig. 2 shows the blockdiagram for one or more drive modules. Each drive module consists of a set of power converters which provide the appropriate electrical power for the synchronous motor and of a chopper motor control logic. A reference oscillator (fig. 3) provides a pilot frequency which determines the desired chopper speed. This pilot frequency drives the master chopper and serves also as a time base for all systems. Phase angles between different rotors are always referred to this pilot. A delay generator produces, by digitally delaying the pilot pulse frame, the reference signal with the necessary frequency and phase-relation.

A module driving a chopper, the aperture time of which is delayed in respect to the master chopper, gets its reference signal via a delay generator.

3 - Power supply

The circuitry of the power supply is shown in Fig. 4. It is a classical 3-phase bridge rectifier delivering 250 V/ 25 A max. and it works from industrial mains 3 x 380 V / 50 Hz. Fast line switch-off is provided via Rel 2 in case where an unsafe operating condition is detected inside the motor drive unit (overvoltage, excessive current or temperature etc..) or anywhere externally in the facility via interlock contact (excessive temperature of chopper and motor bearings, failure in the vacuum system etc.).

4 - DC-DC converter (Fig. 5)

The chopper motor requires a supply voltage, which depends on its operating conditions e.g. speed, load etc. Thus, a power supply with variable voltage output is necessary. Since high currents (up to 30 A) are involved, series regulators would become impractical while power consuming, a switching regulator was developed. The principle is shown in Fig. 6. The non regulated DC voltage from the power supply is applied to a buffer condenser C_1. When the SCR_1 is fired the series resonant circuit L_1 C_2 is connected to this voltage, charging the condenser C_2 with the charge ΔC. The SCR_1 is switched off when the current through L_1 attempts to reverse. During the non conducting state of the SCR_1 , C_2 is discharged via inductance L_2 into condenser C_3 and the load. Herein L_2 and C_3 are forming a second series resonant circuit with a period time much longer than that of the first one.

Assuming a repetition rate of the SCR firing pulses of r_f the mean current delivered to the load is given by

$$I_{mean} = \Delta C \cdot r_f$$

By properly controlling the repetition rate r_f a practically lossless conversion of the input voltage to the desired value of the output can be performed.

The DC-DC converter delivers a stabilized output voltage from 15 V to 200 V and a maximum current of 30 A.

The control circuit shown in Fig. 7 contains the feedback loops for stabilization and produces the SCR firing pulses. Current and voltage trip circuit are incorporated which detect unsafe operating conditions and activate the circuit breakers in the power supply.

The output voltage can be controlled by means of a potentiometer or an external control voltage.

5 - DC-AC converter (Fig. 8)

The DC-AC converter is a static 3-phase converter. It delivers a staircase waveform to the load. The peak-value of this voltage is given by the voltage of the DC-DC converter, the frequency depends on the switching sequence of the SCR'S (see Fig. 9, 10).

Since this circuit works in a wide frequency range a forced switching off of the power SCR'S is foreseen by a second set of 6 switch-off SCR'S. The timing of the SCR firing pulses is explained in Fig. 10. 6 pulses are necessary for one complete period. Thus the control frequency has to be 6 times the output frequency. The ignition pulses for the 12 SCR'S are generated in the chopper motor control logic.

6 - Chopper motor control logic

To understand better the task of the control logic let's have a look back to Fig. 2. The logic circuits control 4 different operating modes of the motor :

1 - asynchronous start up
2 - autosynchronous mode
3 - locked to reference signal
4 - loss of synchronism

6.1. Asynchronous start up

(The numbers in brackets refer to the detailed logic diagram Fig.11)

The synchronous motor starts asynchronously. The logic circuit (2) enables the upper gate (8) and the start up generator (6) delivers its pulses via delay circuit (9) and (10) to a 6-stage ring counter (12) which decodes the input pulse train in 6 ignition pulses for the SCR'S of the DC-AC converter. Thus 6 ring-pulses form one period of the motor supply frequency.

To start the motor, the DC-DC converter is adjusted to its minimum voltage. Depending on the motor type additional series-resistors are provided in the motor start-up unit (see Fig. 12) in order to limit the initial current. The acceleration of the motor can be adjusted by means of the DC-DC converter voltage. This is of importance in cases where mechanical systems with thin rotor shafts are used.

After the motor has reached a certain minimum speed the series resistances are shunted.

The motor is equipped with 2 magnetic pick-ups, which generate 1 and 6 pulses per revolution of the rotor (M and 6 M).

6.2. Autosynchronous mode

At approximately 1000 rpm the switch S1 is set to autosynchronous mode and the start up logic (2) is enabled to change mode and to gate now the 6 M pulses to the ring counter. Pulse M assures that the motor is locked to its own frequency only with the correct phase relation between rotor and electrical field. The motor behaves now like a brushless DC motor. Its acceleration and frequency depends on the electrical power which can be controlled by the DC-DC converters voltage.

6.3. Locked to reference signal

A digital frequency comparator (5) gives indication whether the motor speed is equal, smaller or higher than the reference frequency. The motor speed can be made equal to the reference by properly adjusting the DC-DC converter. At that time switch S3 is set to locked to reference mode (position F) and the synchronization logic (4) is enabled to change mode. Likewise as the motor pickups, the reference oscillator (see Fig. 13) delivers two signals, 6F and F. The commutation to the locked to reference mode takes place when F and M coincide. The signal 6F is now gated to the ring counter and the motor is thus locked to the reference frequency.

The synchronization of the motor to the reference frequency is possible at relatively low speeds (eg. 3000 rpm). Any variation in speed is then made by means of varying the reference frequency. Multichopper systems once locked to the pilot can thus be brought to the desired speed alltogether.

The reference oscillator is equipped with a digital speed presetting. An automatic acceleration limiter is incorporated which automatically changes the frequency as slowly that choppers can follow without loosing synchronism.

In the locked to reference mode the speed stability of the motor corresponds to the quartz clock of the reference oscillator

A computer interface is available for the automatic transfer of speed and phasedelay-settings, as well as for the readout of the operating values of all chopper speeds and delays.

6.4. Loss of synchronism

Mechanical or electrical errors may cause the loss of synchronism of one or more drive modules. This operation mode is signalized to the measuring equipment by means of a computer control signal (20) in order to inhibit false measurements.

For safety reasons we have provided an asynchronous pilot frequency (7) to which the ring counter will be connected after the loss of synchronism. This frequency is choosen such that the maximum permissible motor speed cannot be exceeded. The motor runs in asynchronous mode and may be synchronized again.

7 - Phase control system

Each drive module is equipped with an autonomous phase control loop. Phase-fluctuations are detected in the digital phase-error detector (16). The error-signal is fed to a voltage controlled delay (10), where short time fluctuations are damped by a proportional control (14) and longtime drifts are compensated in an integral control (15). A signal is derived in the circuit (17) which indicates that the phase errors are within $\pm$ 10 μs.

With this control philosophy of relating the rotor phase position to the corresponding pilot an independency between different drive modules is achieved. Phase-fluctuations of one system cannot propagate to another system.

In a multichopper system the phase delay between different drive modules is implemented only by the corresponding delay generator. Every delay generator is triggered by the reference pilot and delivers the delayed reference signals for the respective drive module. Delay values may be preset digitally in steps of 1 µs from 0 up to 1 period of the reference frequency.

8 - Remarks

At the Ispra-1 reactor actually 3 drive modules are installed. Two of them are in operation since 1968 at the double chopper facility. The mechanical details of this installation have been published in [1]. The third drive module has been delivered recently for a rotating crystal spectrometer. A 4 rotor installation for the Institute Max von Laue - Paul Langevin at Grenoble will be ready in summer.

Some of the characteristics of the double chopper facility are given below :

- Speed	8000 ÷ 14000 rpm.
- Speed stability	10^{-4} (quartz)
- Short term phase fluctuations	< 10 µs
- Long term phase drift	0
- Electrical power	2 KVA

General characteristics of one drive module :

- Output frequency	÷ 24000 rpm.
- " voltage	15 ÷ 200 V_{peak}
- " current	÷ 30 A_{max}
- " power	÷ 2,5 KVA_{max}

[1] K. Krebs, Proc. of Symp. on "Neutron Inelastic Scattering", Kopenhagen 1968, Vol. II, p. 289, I.A.E.A. Vienna.

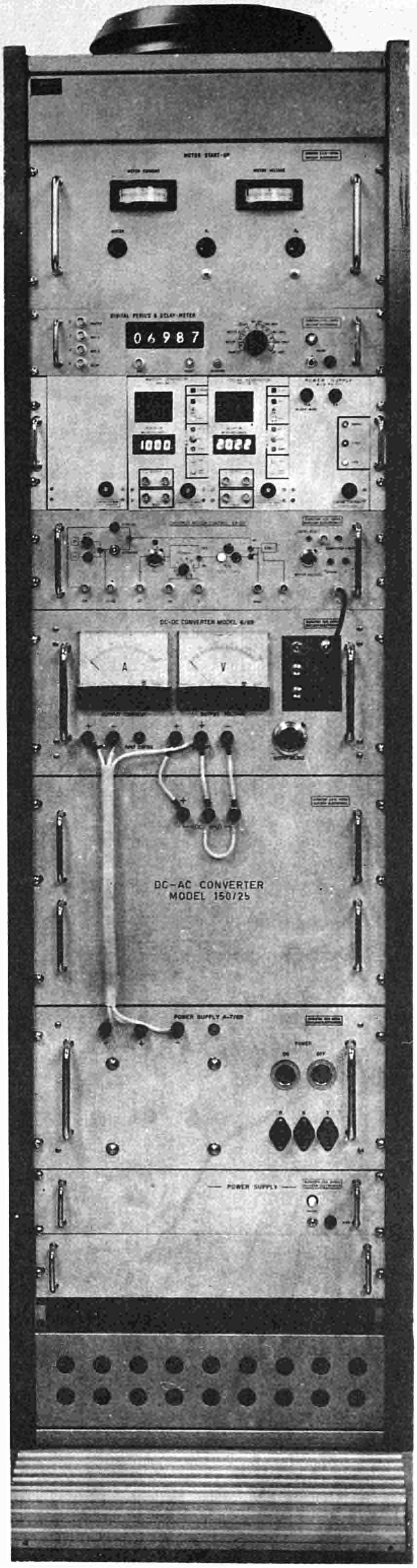
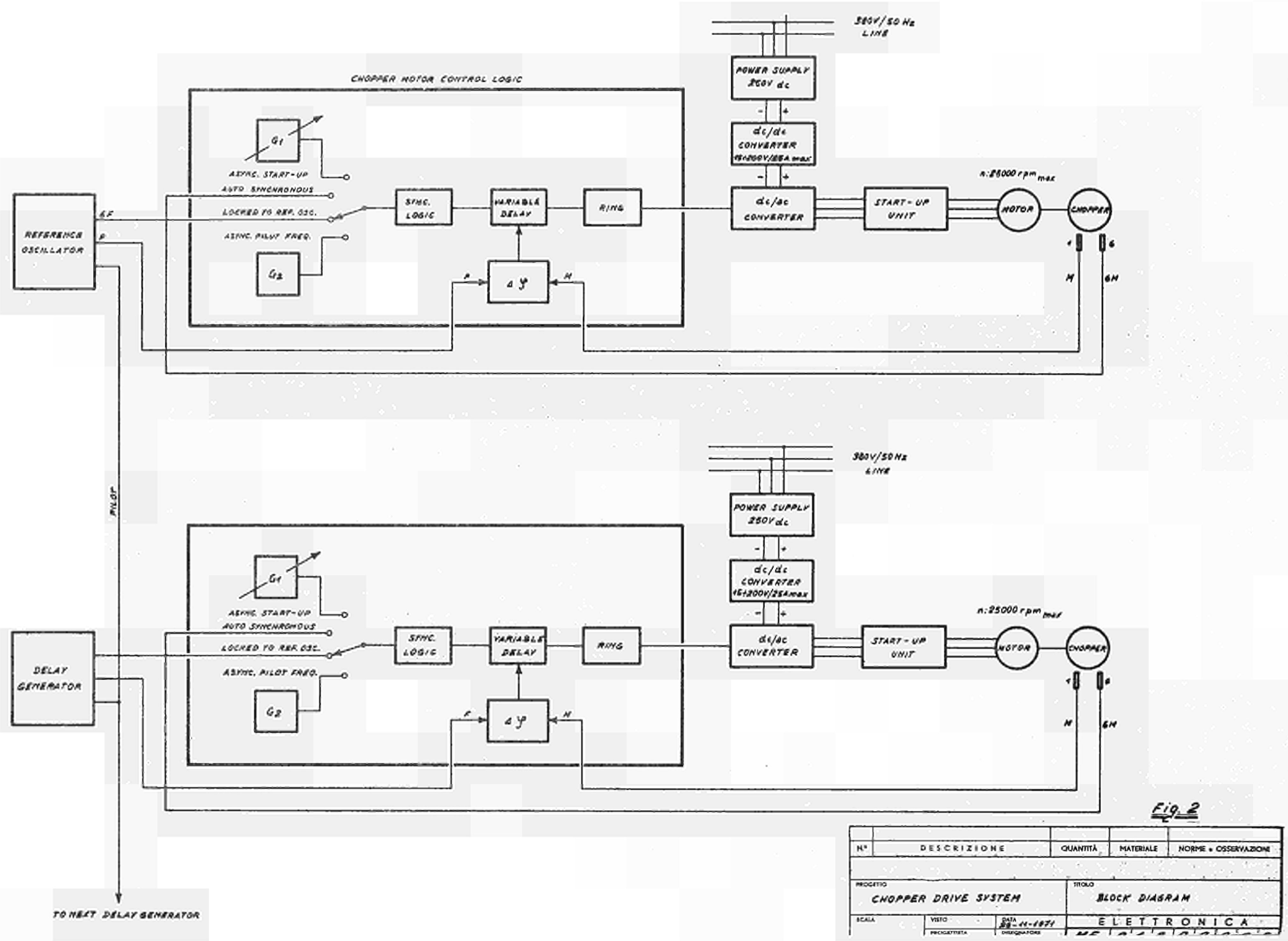


Fig. 1



380V/50 Hz
LINE
CHOPPER MOTOR CONTROL LOGIC
POWER SUPPLY
250V dc
dc/dc
CONVERTER
15÷200V/25A max
G1
ASYNC. START-UP
AUTO SYNCHRONOUS
LOCKED TO REF. OSC.
ASYNC. PILOT FREQ.
G2
SYNC.
LOGIC
VARIABLE
DELAY
RING
dc/ac
CONVERTER
START-UP
UNIT
n:25000 rpm max
MOTOR
CHOPPER
REFERENCE
OSCILLATOR
ΔF
F
Δφ
M
6M
PILOT
DELAY
GENERATOR
TO NEXT DELAY GENERATOR
N°
DESCRIZIONE
QUANTITÀ
MATERIALE
NORME e OSSERVAZIONI
PROGETTO
CHOPPER DRIVE SYSTEM
TITOLO
BLOCK DIAGRAM
SCALA
VISTO
PROGETTISTA
DATA
DISEGNATORE
ELETTRONICA

Fig. 2

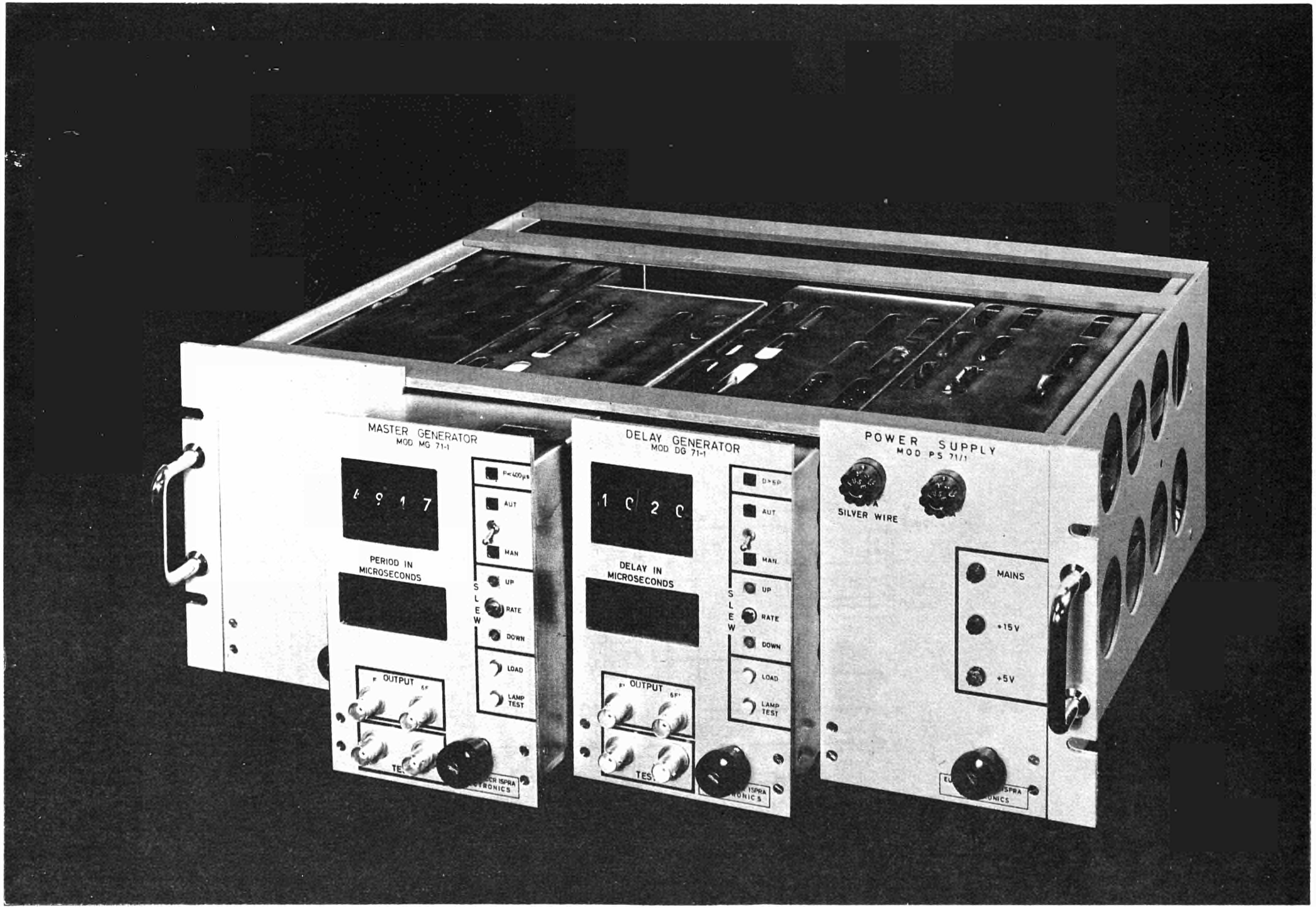
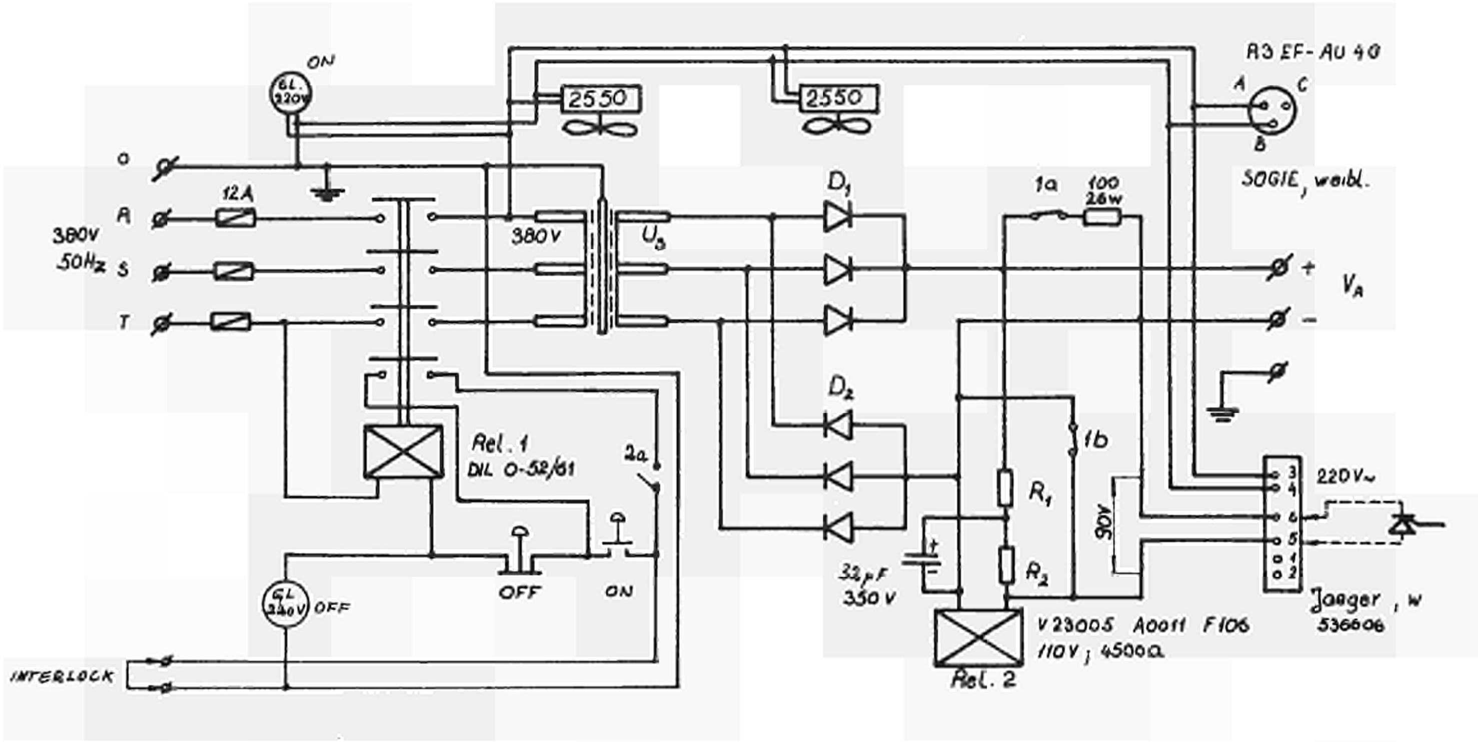

MASTER GENERATOR
MOD MG 71-1
PERIOD IN
MICROSECONDS
AUT
MAN
SLEW
UP
RATE
DOWN
LOAD
LAMP TEST
OUTPUT
DELAY GENERATOR
MOD DG 71-1
DELAY IN
MICROSECONDS
AUT
MAN
SLEW
UP
RATE
DOWN
LOAD
LAMP TEST
OUTPUT
POWER SUPPLY
MOD PS 71/1
SILVER WIRE
MAINS
+15V
+5V

Fig. 3



Power Supply A FOR CHOPPER DRIVE SYSTEM		Datum:	
Type :			
V_3 : V~	D_1 :	R_1 :	
V_A : V=	D_2 :	R_2 :	

Fig. 4

N.	DESIGNAZIONE	DIMENSIONI FINITE	QUANTITÀ	MATERIALE	TRATTAMENTO	NORME E OSSERVAZIONI

SCALA	MODIFICAZIONE 7. 12. 70 Weber 10. 12. 70 Weber		
FINITURA	DESIGNAZIONE SCHEMA ELETTRICO	SERVIZIO N. 70 – 1211	GRUPPO
TOLLERANZE GENERALI	TITOLO Power supply DC DC Converter	per Servizio:	Prog. N.: E
	DATA / NOME / FABBRICAZ. N.: DISEGNATO 19/10/70 Blanchard VERIFICATO 19/10/70 Weber F CAPO DI GRUPPO	NOMENCLATURA N.: N – INSIEME N.: 70 – 1200 a b	

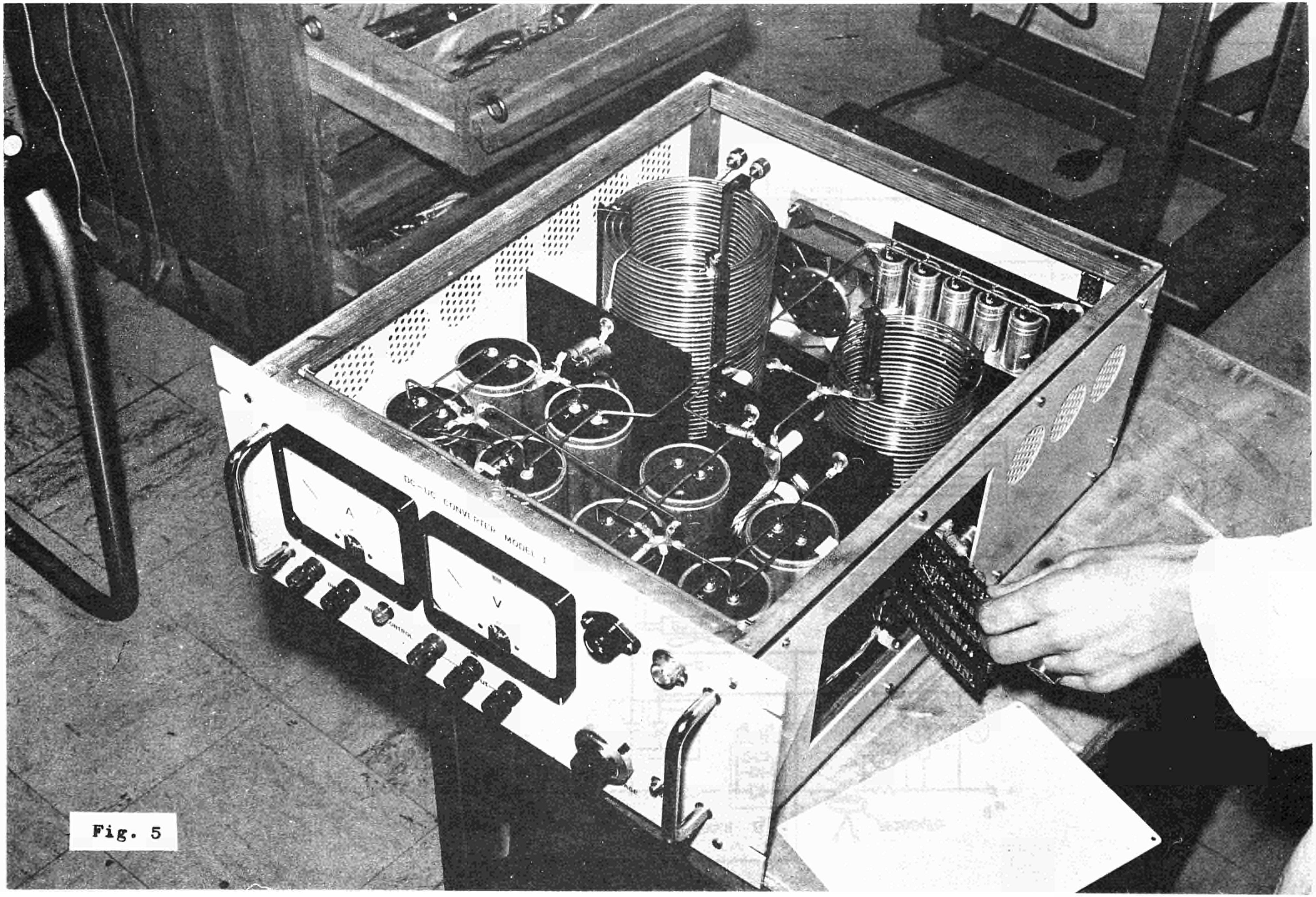
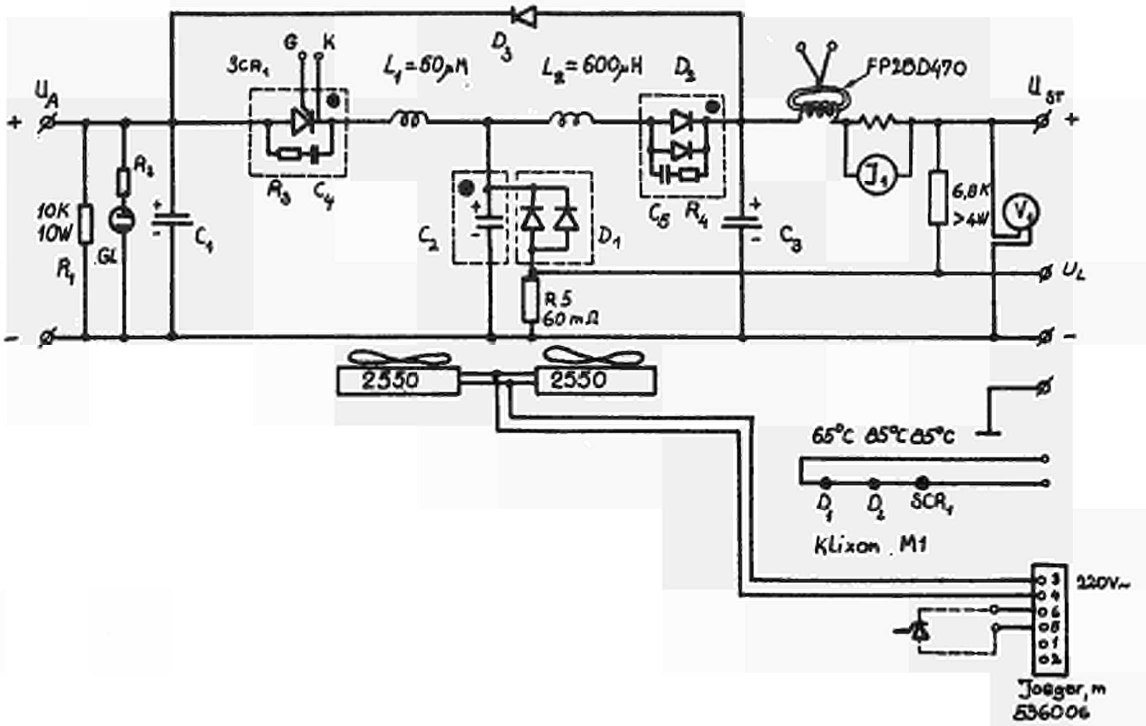


Fig. 5



C_5 =

R_2 =

R_3 =

R_4 =

J_1 =

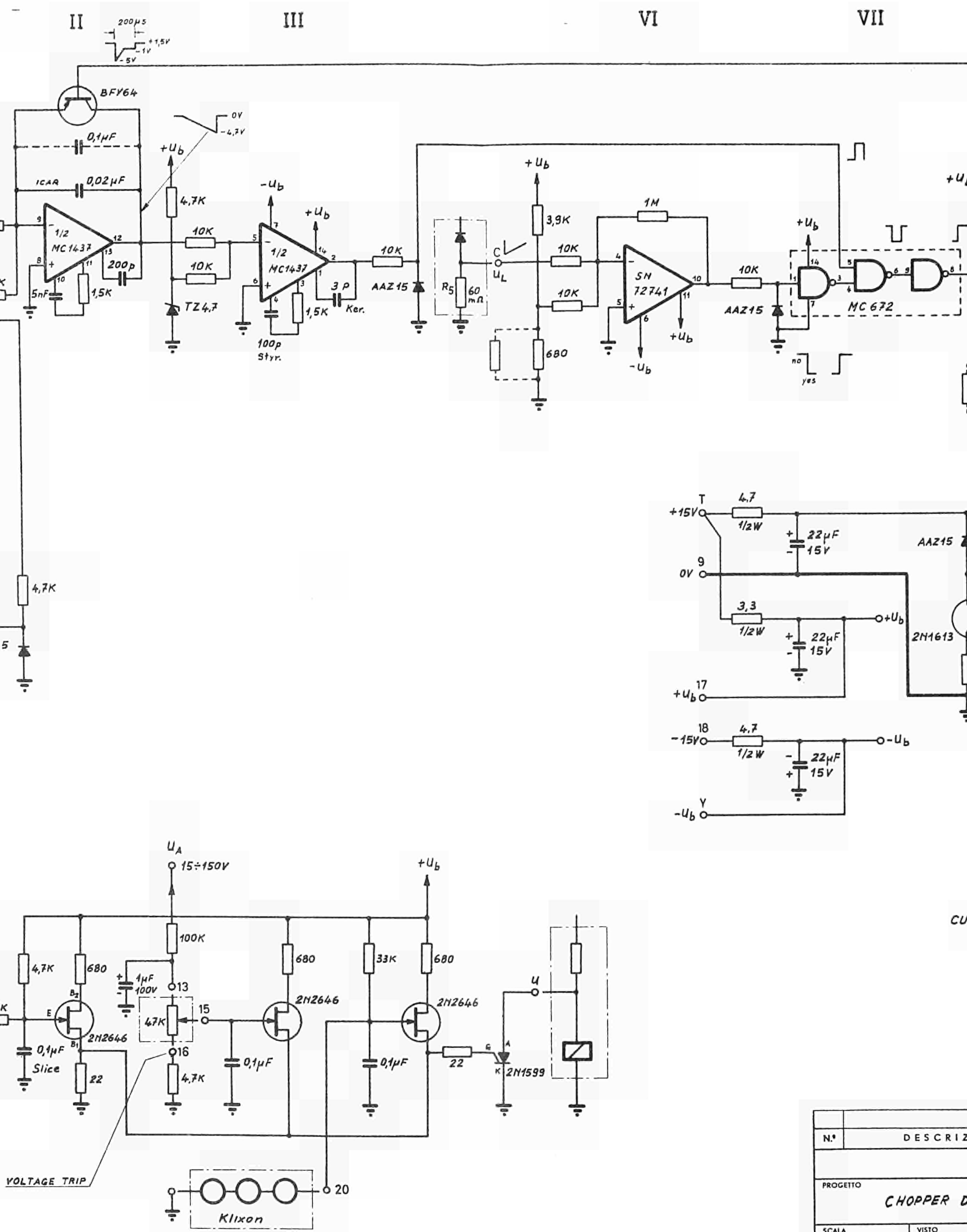
V_1 =

DC-DC CONVERTER	
Type :	

Fig. 6

N.	DESIGNAZIONE	DIMENSIONI FINITE	QUANTITÀ	MATERIALE	TRATTAMENTO	NORM

SCALA:	MODIFICAZIONE 16.11.71	
FINITURA:	DESIGNAZIONE SCHEMA ELETTRICO	SERVIZIO N. 70- 1313
TOLLERANZE GENERALI:	TITOLO DC DC CONVERTER	per Servizio: Prog. N
	DISEGNATO DATA 19/10/70	NOMENCLATURA N.: N -
	VERIFICATO DATA 19/10/70	
	CAPO DI GRUPPO	FABBRICAZ. N.: F INSIEME N.: 70- 1



N.°	DESCRIZ
PROGETTO	CHOPPER D
SCALA	VISTO
	PROGETTISTA

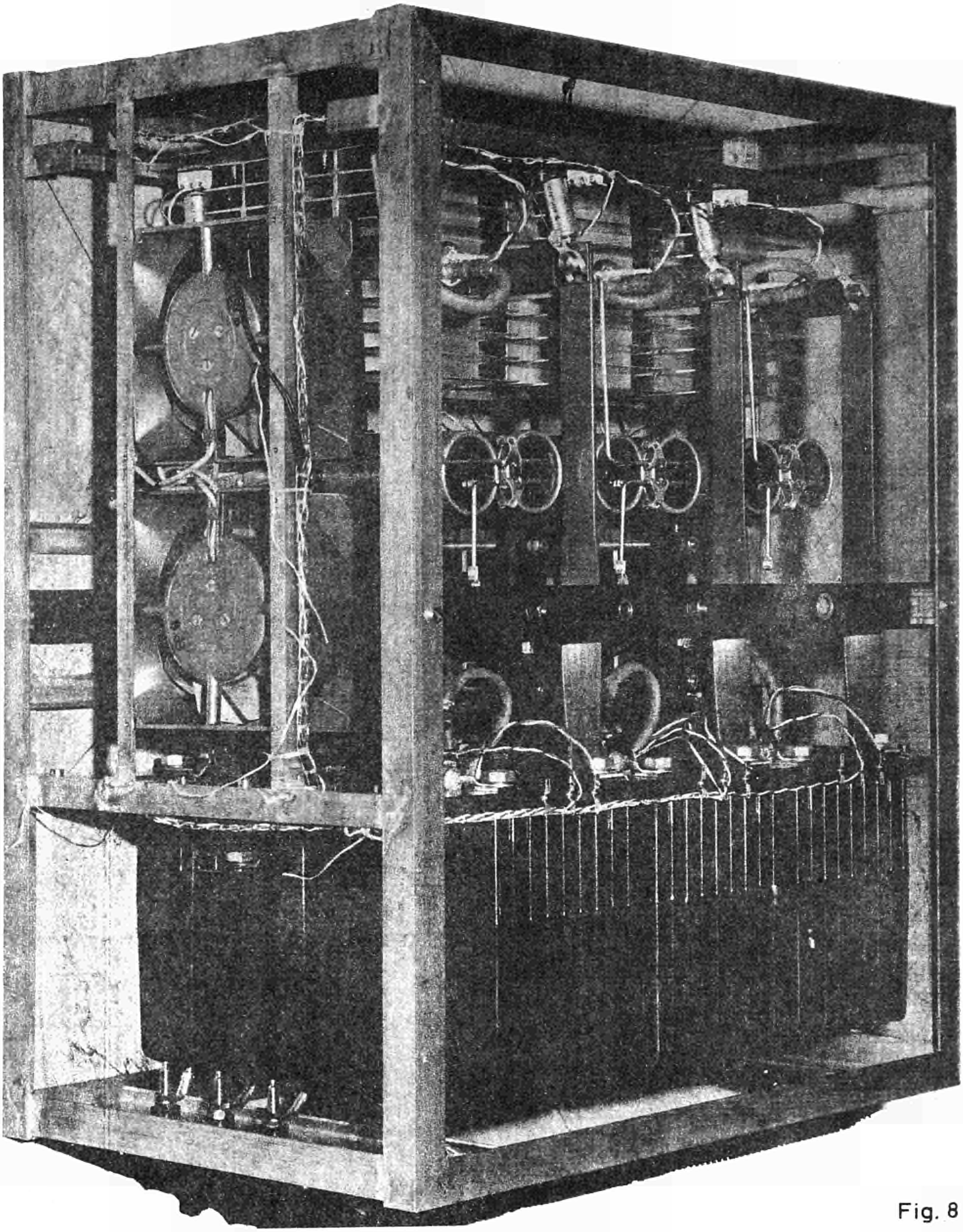
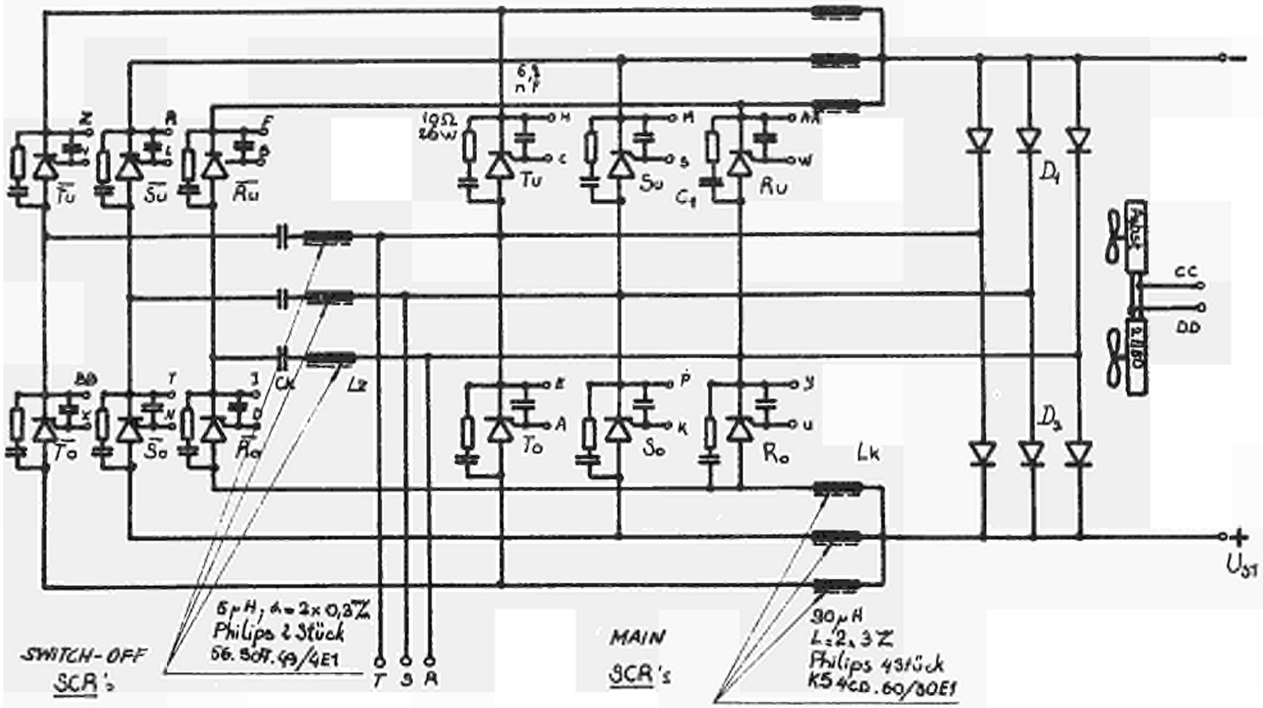


Fig. 8



D_1 :

D_2 :

SCR :

Ck :

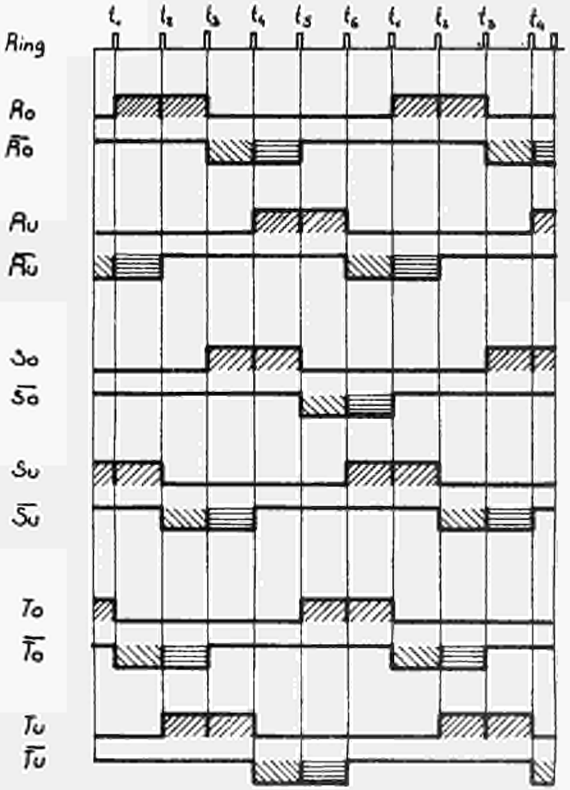
C_1 :

Fig. 9

DC.AC CONVERTER MOD. 150/25	Type:

N.	DESIGNAZIONE	DIMENSIONI FINITE	QUANTITÀ	MATERIALE	TRATTAMENTO	NORME E OSSERVAZIONI

SCALA:	MODIFICAZIONE	
FINITURA:	DESIGNAZIONE: SCHEMA ELETTRICO	SERVIZIO / GRUPPO / N. 70 - 1409
TOLLERANZE GENERALI:	TITOLO: DC.AC CONVERTER MOD 150/25	per Servizio: / Prog. N.: / E
	DISEGNATO: DATA 19/10/70, NOME Blanchard; VERIFICATO: 19/10/70; CAPO DI GRUPPO; FABBRICAZ. N.: F	NOMENCLATURA N.: N –
		INSIEME N.: 70 - 1400



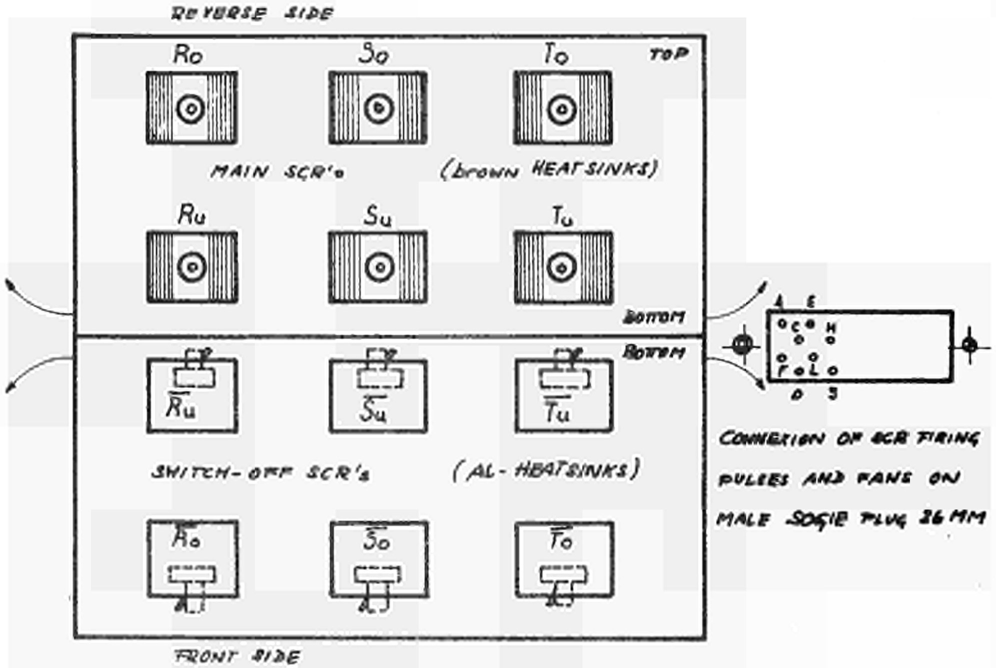
ON 36 pol. PLUG	
RED TO CATHODE	YELLOW TO ANODE
y	u
J	D
AA	W
F	B
P	K
T	N
S	M
R	L
E	A
BB	X
H	C
Z	V
(DD, CC : 220V~)	

POWER SCR's FIRED

SWITCH-OFF SCR's FIRED TO INTERRUPT POWER SCR's

SWITCH-OFF SCR's FIRED TO CHARGE SWITCH-OFF CAPACITORS

SCR FIRING SEQUENCE FOR DC-AC CONVERTER MOD. 150/25



DC-AC Converter	Typ: All Models	Arrangement of SCR's in the Chassis

Fig. 10

N.	DESIGNAZIONE	DIMENSIONI FINITE	QUANTITÀ	MATERIALE	TRATTAMENTO	NORME E OSSERVAZIONI

SCALA | MODIFICAZIONE

FINITURA | DESIGNAZIONE: FIRING SEQUENCE AND POSITION OF THE SCR's

SERVIZIO | GRUPPO | N. 70 – 1410

TOLLERANZE GENERALI | TITOLO: DC-AC-CONVERTER

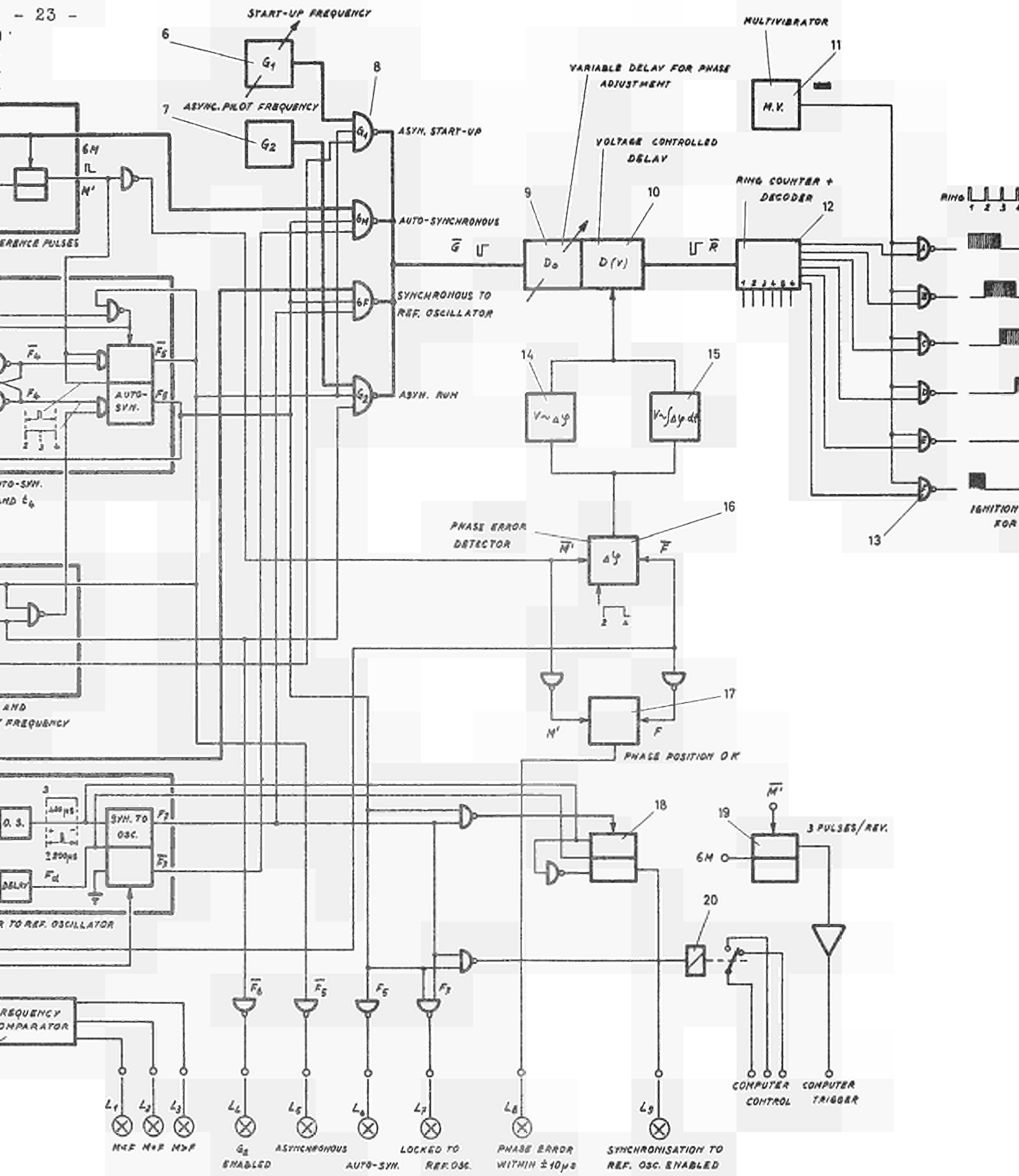
	DATA	NOME
DISEGNATO	20/10/70	Blanchard
VERIFICATO	20/10/70	[signature]
CAPO DI GRUPPO		

FABBRICAZ. N.: F

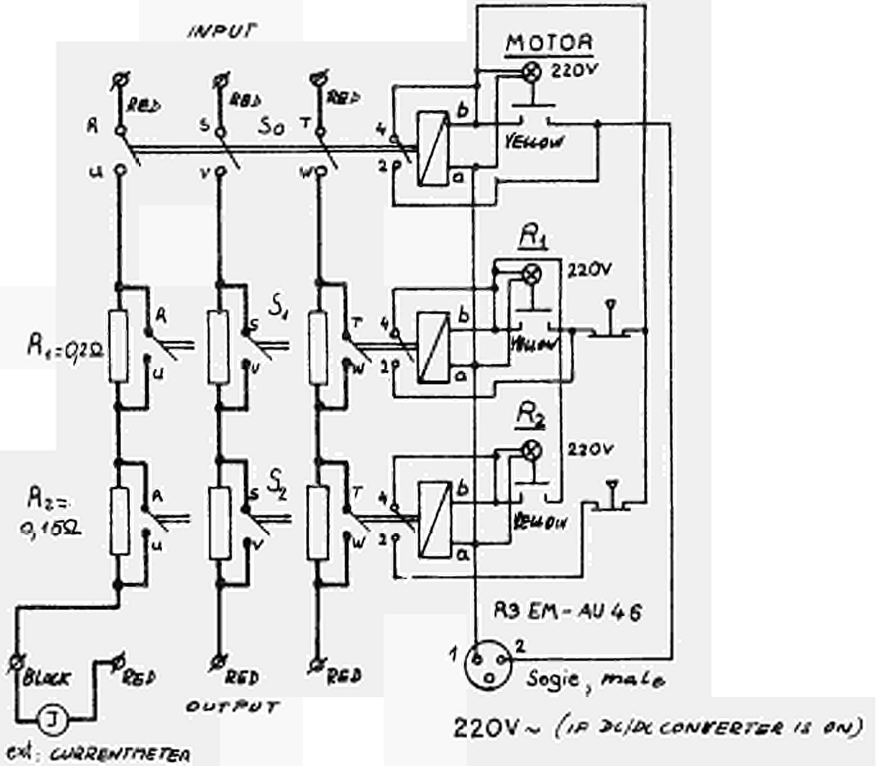
per Servizio: | Prog. N.: | E

NOMENCLATURA N.: N –

INSIEME N.: 70 – 1400



N.°	DESCRIZ
PROGETTO	CHOPPER DRIVE
SCALA	VISTO
	PROGETTISTA



3 Relais Klöckner-Moeller DIL 2vh/61 (Peterlongo)
3 Leuchttasten RAFI 1.15102.144 mit Glimmlampe 220v
2 Djet Ein-Taster P17501

Fig. 12

N.	DESIGNAZIONE	DIMENSIONI FINITE	QUANTITÀ	MATERIALE	TRATTAMENTO	NORME E OSSERVAZIONI

SCALA:	MODIFICAZIONE	
FINITURA:	DESIGNAZIONE SCHEMA ELETTRICO	SERVIZIO N. GRUPPO 70- 1509
TOLLERANZE GENERALI:	TITOLO MOTOR START-UP UNIT	per Servizio: Prog. N.: E
	DISEGNATO DATA 20/10/70 NOME Blanchard VERIFICATO 20/10/70 CAPO DI GRUPPO FABBRICAZ. N.: F	NOMENCLATURA N.: N – INSIEME N.: 70 – 1500

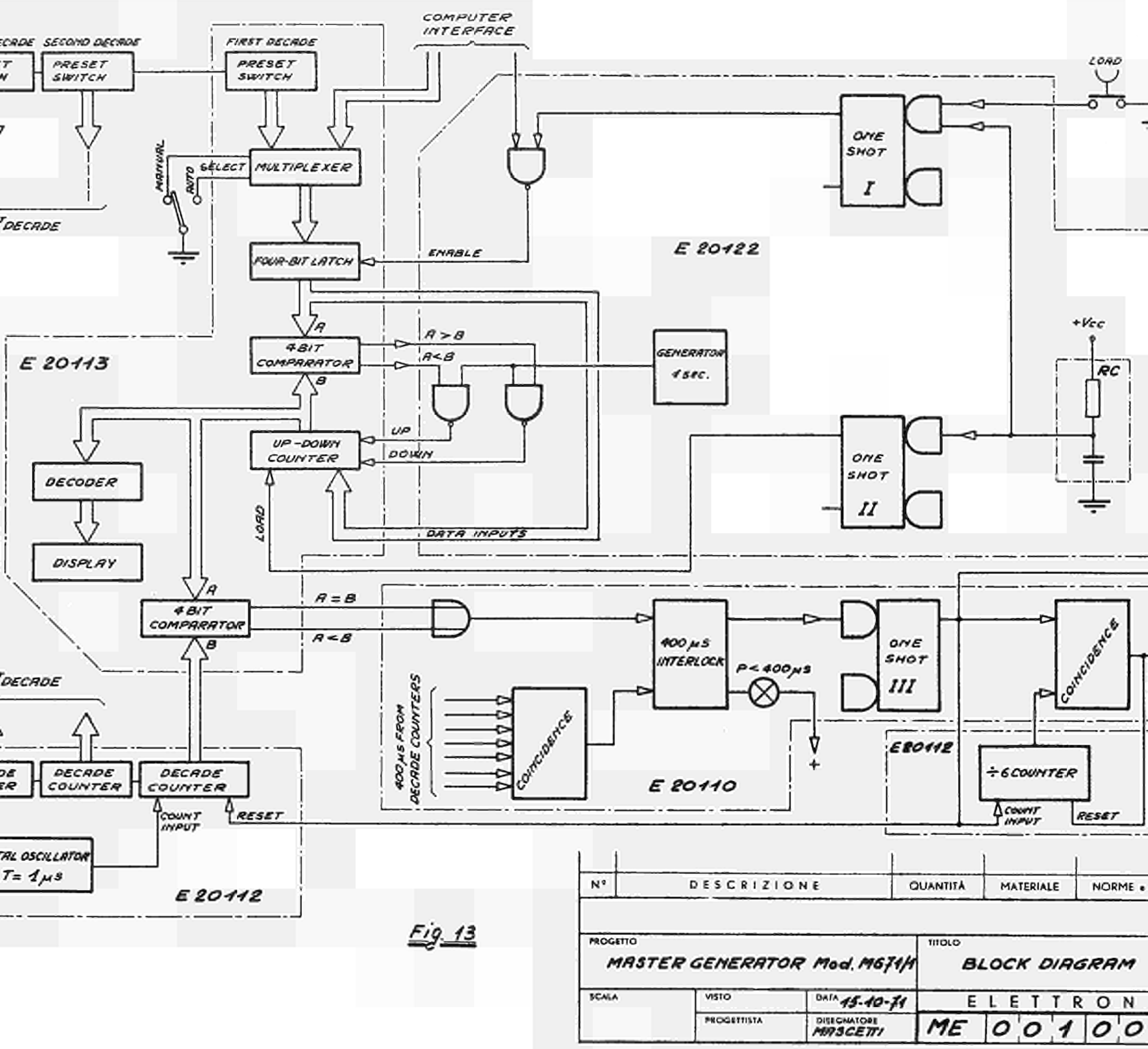

SECOND DECADE
PRESET SWITCH
FIRST DECADE
PRESET SWITCH
COMPUTER INTERFACE
MANUAL
AUTO
SELECT
MULTIPLEXER
FOUR-BIT LATCH
ENABLE
E 20122
LOAD
ONE SHOT I
+Vcc
RC
ONE SHOT II
E 20113
4 BIT COMPARATOR
A > B
A < B
GENERATOR 4 sec.
UP-DOWN COUNTER
UP
DOWN
DATA INPUTS
LOAD
DECODER
DISPLAY
4 BIT COMPARATOR
A = B
A < B
400 μs INTERLOCK
P < 400 μs
ONE SHOT III
COINCIDENCE
400 μs FROM DECADE COUNTERS
COINCIDENCE
E 20110
E20112
÷6 COUNTER
COUNT INPUT
RESET
DECADE
DECADE COUNTER
DECADE COUNTER
COUNT INPUT
RESET
TAL OSCILLATOR
T = 1 μs
E 20112
N°
DESCRIZIONE
QUANTITÀ
MATERIALE
NORME
PROGETTO
MASTER GENERATOR Mod. MG71/1
TITOLO
BLOCK DIAGRAM
SCALA
VISTO
DATA 15-10-71
PROGETTISTA
DISEGNATORE MASCETTI
ELETTRON
ME 00100

Fig. 13

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Alfred Nobel

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