TECHNICAL DESCRIPTION

Edition 1.00

4-QUADRANT-SERVO-AMPLIFIER

TYPE

MTR 5K

MTR 20K

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Dear customer,

We always try to guarantee for an optimum of security measures and to inform ourselves about the latest developments in technical research. However, it is necessary that we pass on the following further information to you as the user of our components:
The appliances are supply parts meant for processing by industry, trade or other factories specialized in electronics.

Safety precaution !!

Attention - do not touch! The appliances have unprotected live parts. The voltage may be highly dangerous.

We also have to inform you that, for your own security, only an expert should work on the appliances.

In order to comply with the safety precautions, open connections must be protected against contact with cases, coverings or anything similar. Even after the appliance had been disconnected, there may still be a dangerous voltage (discharges of the capacitors).

Due to an error in handling or unfavorable conditions, the electrolytic capacitors may explode. If you have to work on the open appliance, do protect your body (hands!) and your face!

Make sure that there is enough ventilation because of the fire risk in case of overheating.

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1. Technical Description

1.1 General Information

The Series 5K and 20K transistor servo amplifiers are pulse width modulated amplifiers which have been conceived primarily for driving DC servo motors with permanent excitation. These devices operate in four-quadrant mode, i.e. the connected motor can drive or brake in both senses of rotation, whereby a boosted pulse torque greater than the continuous torque is available for short periods. This feature makes these servo amplifiers particularly suitable for driving machine tool feed spindles, but other applications are possible too (especially for the series 20K units), e.g. antenna drives.

1.2 Special Features

A new kind of modulation technique is used, in which no audible modulation sounds are emitted from the motor or from chokes, i.e. the objectionable whistle or howl emitted by many conventional chopper amplifiers, is here completely absent. The iron losses in the motor and chokes (magnetic hysteresis losses in the magnetization cycle) are smaller by an order of magnitude compared with those involved in conventional modulation methods.

The series 20K devices incorporate electrical isolation between the open loop control input side and the load side, so that a single-wound transformer may be used instead of a double-wound transformer for power supply. The case is electrically insulated with respect to the device.

The series 5K devices feature self-cooling, i.e. a blower is not required for forced air cooling. These units employ essentially open construction, i.e. with no special case to contain them.

Both series of units contain a three-phase bridge rectifier for power supply and a generously dimensioned ballast circuit to dissipate the braking energy. Power supply is optional with three-phase alternating current or with direct current. A 230V / 50Hz auxiliary supply is required only to power the blower fan in series 20K units. The control electronic circuitry is powered directly from the principal supply via incorporated voltage converters.

Supply voltage fluctuations within wide limits are tolerated in operation (60V – 150/200V; briefly 50V – 175/230V). This permits full battery operation for the series 5K units, and an “emergency run” operating mode for the series 20K units, for example to steer to a safe position in battery operation without blower fan on mains voltage failure. Both types of unit contain storage chokes permitting direct connect-up to any motor or other kinds of load. Self-heating is very small, by virtue of the high power efficiency (95 – 96% at 200V nominal voltage). Thus the required cooling facilities for the equipment cabinet remain within reasonable limits even when several drive shafts are incorporated.

The units incorporate protection circuits for current overload, overvoltage, undervoltage and overheating, as well as an optional plug-in commutation current limiter (I_{Amax} = f(U_A)) and standard feature I^2t current limitation. Furthermore, inputs are provided for direction-dependent limit switches, output stages enable and cut-out of the integral control function. Response of the I^2t current limiter is signaled via an open collector output. When the unit is functional, a floating relay contact closes.

1.3 Summary of Types

Unit Designation	Nominal Voltage (V)	Nominal Current (A)	Pulse Current (Ampere, max.3s)	Series
MTR 150 / 10-B	60 – 100	10	18	5K
MTR 150 / 25-B	60 – 150	25	40	
MTR 150 / 35-B	60 – 150	35	60	
MTR 200 / 10-B	60 – 200	10	18	
MTR 200 / 25-B	60 – 200	25	40	
MTR 200 / 35-B	60 – 200	35	60	
MTR 150 / 50-B	60 – 150	50	100	20K
MTR 150 / 70-B	60 – 150	70	150	
MTR 150 / 100-B	60 – 150	100	200	
MTR 200 / 50-B	60 – 200	50	100	
MTR 200 / 70-B	60 – 200	70	150	
MTR 200 / 100-B	60 – 200	100	200	

1.4 Technical Data

Voltage range of control inputs	±10V
Internal impedance of the control inputs	20kOhms
Setting range of the input attenuator	0.18 … 1.1
Maximum tachovoltage for U_i = ±10V	±100V
Internal impedance of the tacho-input (min.)	11kOhms
Setting range of the tacho-attenuator	0.065 … 0.65
Maximum input drift	±15µV / °C
Output current form factor for nominal current	max. 1.01
Bandwidth of subordinate current controller	1kHz
Clock frequency of output stage	8.5kHz
Isolation voltage between preamplifier and output stage	±1500V DC
Pulse currents of ballast circuit (5K / 20K)	40A / 120A
Continuous duty power dissipation of the ballast circuit (5K / 20K)	275W / 4.4kW
Contact rating of signaling relay	100V / 0.1A / 10W
Power supply outputs for external auxiliary circuits	±15V / 20mA

Action mode of inputs for limit switches and output stage enable: -10 / 11 / 16 -	Normal run only when contact closed. The function of the particular input is true when the contact is opened (e.g. pos. Stop). Reference potential M2.
Armature current monitor output: - 19 -	±10V corresponding to the device pulse current, Ri = 1kOhm. Reference potential M1.
I²t signaling: - 20 -	For active current limiting, sinking to 0V; otherwise open circuit voltage +15V. Reference potential M1.
Control output for dynamic brake:	Open collector, sinking to 0V only when unit is operational and the output stage is active.
Message output for “ready for operation”: - 23 / 24 -	Reed contact, closed when unit is ready for operation, also when output stage is switched clear.
Storage temperature:	-10°C … +60°C
Ambient temperature for nominal operation:	0°C … +45°C
Ambient temperature with max. 80% load:	0°C … +55°C
Mounting instructions (only 5K):	Wall mounting, cooling fins vertical, ballast resistor at top
Tolerated further run time at nominal current without fan (only 20K):	2 minutes starting in normal operating temperature state
Power dissipation at nominal current:	10A: 80W 20A: 250W 35A: 280W 50A: 500W 70A: 700W 100A: 1100W
Mechanical attachment:	With 4 screws on flat surface
Dimensions (length x width x height):	Series 5K : 210 x 260 x 216 mm Series 20K : 440 x 218 x 255 mm
Weight:	Series 5K : 3.5kp Series 20K : 18kp

Transistor Servo Amplifier, Series 20K, Block Diagramm

1) Input 1
2) Input 2
3) Tacho-input
4) Difference amplifier
5) Difference amplifier
6) Tach-matching
7) Pulse current
8) Nominal current value
9) CW – limit switch
10) CCW – limit switch
11) Output ±15V / 20mA
12) Integral off (inv.)
13) Output stage enable (inv.)
14) Armature current monitor
15) I²t signaling
16) Relay for brake
17) Message contact for “ready” (closed when ready)
18) Enable delay 30msec
19) External enable
20) Limit switches logic
21) Soldered jumper connection B1
22) Open an closed loop control electronics
23) Plug-in location for special circuit
24) Offset
25) Speed control amplifier with limiter
26) Electrical isolation ±1500V DC
27) Drift (for limit switches) and switch-on jerk suppression circuit
28) Negative feedback network
29) Gain
30) Analog buffer amplifier and power supply for preamplifier
31) Speed controller enable
32) Output stage enable
33) Optocoupler
34) Optocoupler
35) Protection circuits for current overload, overvoltage, undervoltage, overtemperature, blocking (control enable function)
36) General enable
37) Ready for operation
38) Current controller and driver enable
39) 8kHz clock generator, pulse width modulator and delay circuit
40) Nominal current value limiter
41) PI-type current regulator
42) Armature current measuring circuit
43) Plug-in module for speed-dependent current limiting
44) I²t measuring circuit
45) Armature voltage measuring circuit
46) Armature current actual value
47) I²t signaling
48) DC/DC voltage converter 60 – 200V to ±15V
49) Driver electronics
50) Output stage driver circuit
51) Four-quadrant output stage
52) Safety chokes output
53) Blower, 230V
54) I_A sensing lines
55) U_A sensing lines
56) Control electronics for ballast circuit
57) Ballast resistor
58) Reservoir electrolytic capacitor
59) 3-phase power supply
60) 3-phase bridge rectifier, 100A

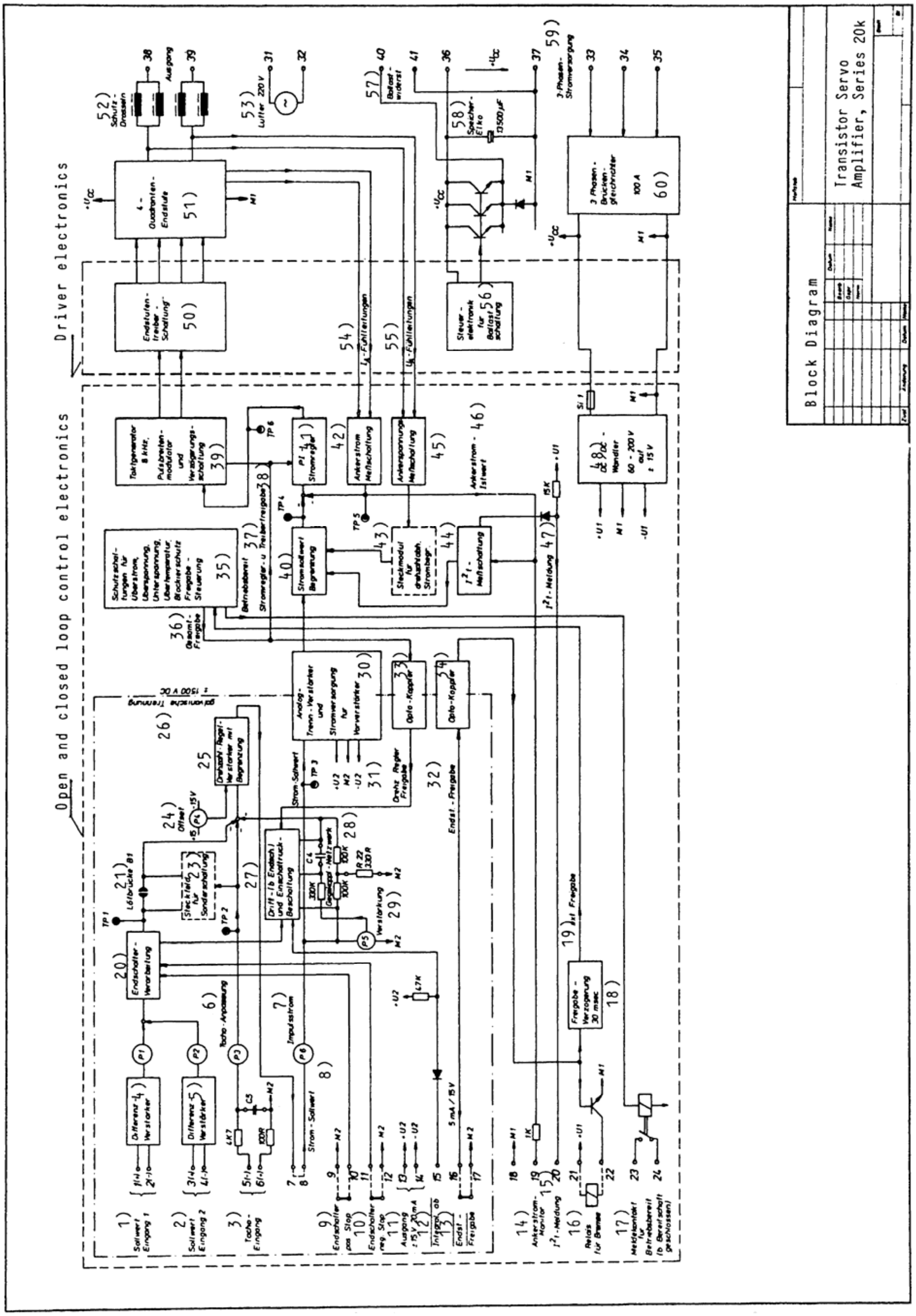

Figure 1: Block Diagram, Transistor Servo Amplifier, Series 20K

1.5 Functional Principles and Basic Circuit Diagrams

The following explanations are chiefly confined to the special features and technical innovations of these units. In this section it is assumed that the reader is familiar with the general principles and possible applications of servo amplifiers. The basic circuit diagrams, respectively for the series 5K and 20K units, form the basis for the description.

1.5.1 Free Nominal Voltage Choice

The standard version servo amplifiers (150Volts) may be operated with any nominal supply voltage in the range from 60 to 150Volts. The series with extended power supply voltage range (200V) permits nominal supply voltages from 60 to 200Volts. The particular chosen nominal supply voltage is determined by the secondary voltage of the mains transformer. It is important to ensure that rectified voltage can not drop below 50V even when full pulse current is being drawn, and that the worst case open circuit voltage is never greater then 175V (or 230V for 200V). The corresponding rms voltages for the highest allowed values are 125V rms and 163V rms respectively in idle state. The ballast circuit may become damaged if these limits are not observed.

Depending on the particular application, the mains transformer rating is usually much smaller than the product of nominal current and nominal voltage, especially when speeds are required only rarely.

This is permissible because the output stage draws only the power level from the transformer which it actually passes-on to the motor. This power is not only a function of the output current, but also of the output voltage. The output stage of the unit performs a kind of impedance transformation, i.e. at slow motor speed it transforms the relatively large intermediate circuit voltage at low current drain to the low armature voltage at high armature current. Thus, for example, in the extreme case of “short circuit across the motor terminals”, even 100Amperes output current causes only about 4.5A rms current to flow the transformer to the rectifier circuit.

The possible saving is 50% without any problems, in the case of a single-shaft system and predominantly dynamic load. In a multiple shaft system, the saving may be much greater still, depending on the load distribution in time. Therefore it may be useful to measure the actually required transformer power in system operation.

1.5.2 Auxiliary Voltage

Both series of units (5K / 20K) contain an auxiliary power supply for the control electronics and driver circuit. This power supply circuit is connected in parallel to the DC intermediate circuit and automatically matches itself to the voltage specified in Section 1.5.1. For the series 5K units, this obviates the need for an external auxiliary power supply voltage.

However, the series 20K units contain a blower fan which must run on 230V AC supply. When the system is connected to a mains circuit without neutral line conductor, the blower fan can be connected either to its own auxiliary winding on the principal mains transformer, or it may be connected in parallel with one of the three primary windings (only for mains voltage 3 x 400V, transformer primary operated in star circuit).

For emergency operation on a battery, the series 20K units may be operated a short time without the blower fan (max 2minutes at 100A nominal current). A considerably longer running time without forced air cooling with considerably reduced load is permissible only when the inductive component of the load is not smaller than 0.3mH. On account of the danger of overheating inside the unit, operation without blower fan must be confined to short periods in real emergency situations.

1.5.3 Function Principles of the Output Stage

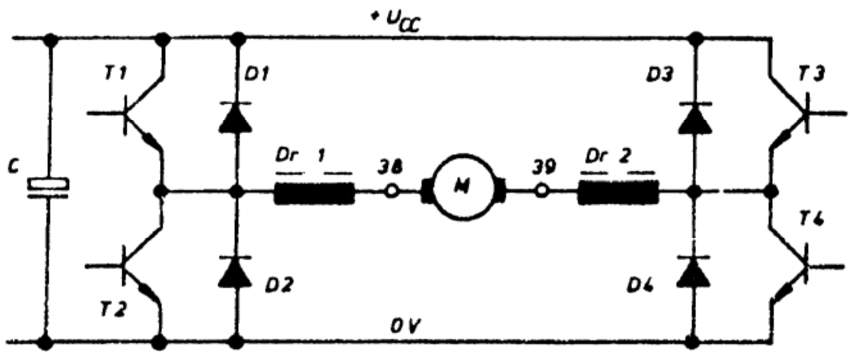

Figure 2: Basic circuit diagram of the output stage

The output stage of the units essentially consists of the 4 sets of transistors T1 – T4, each with a parallel-connected inverse current diode D1 – D4, and the intermediate circuit capacitor C as well as the storage chokes Dr1 and Dr2.

For the following explanation of the circuit action, it is assumed for simplification that each half of the output stage behaves like an ideal switch (without commutation break or overlap)(see Figure 3).

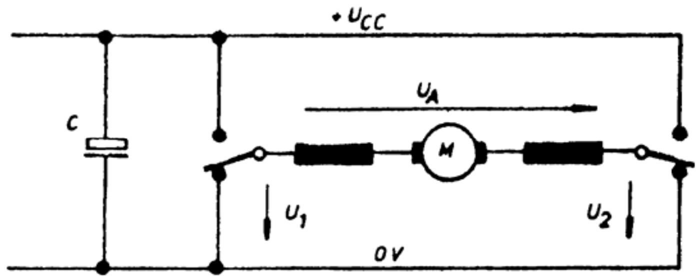

Figure 3: Simplified basic circuit diagram

This way of looking at the circuit is correct, because in actual operation, one transistor and one diode at a time (e.g. T1 with D2 and T4 with D3) function like such a changeover switch. Depending on the power and current direction, the rest of the output stage thereby is “blind”, so that the actual switch-over pauses between the transistor conduction phases are not evident.

The output stage operates with impressed voltage, i.e. the motor is connected at all times to a certain direct voltage source with low internal impedance. The inductance of the storage chokes is dimensioned such that, on the one hand, the harmonics content (undulation, form factor) of the output current is small in spite of the rectangular voltage waveform and, on the other hand, the inductance is still small enough to ensure negligible disturbance of the motor behavior. Therefore only the arithmetic mean value of the difference voltage U1 – U2 = U_A (averaged over one clock cycle) is of importance for the motor.

Figure 4 shows typical voltage waveforms for three different output voltages. Of particular importance here is the fact that the voltage/time waveform of the output voltage U_A shows a frequency-doubling effect with respect to the voltage waveform at each one of the two output lines U1 and U2. This means that the current undulation has a fundamental frequency of 17kHz in spite of the relatively low clock frequency of 8.5kHz. Sine 17kHz lies above the audible limit for human ears, the modulation whistle of former circuit concepts is absent here.

Nevertheless, these servo amplifiers do not fall into the category of radio frequency devices, which would be subject to approval for operation when the operating frequency lies above 10kHz. When these amplifiers are properly connected-up and operated as specified, the total generated radio interference level is only the sum of the individual interference levels on the output lines with respect to ground, and the fundamental frequency in this sum is only single clock frequency of 8.5kHz (see U1(t) + U2(t) in Figure 4).

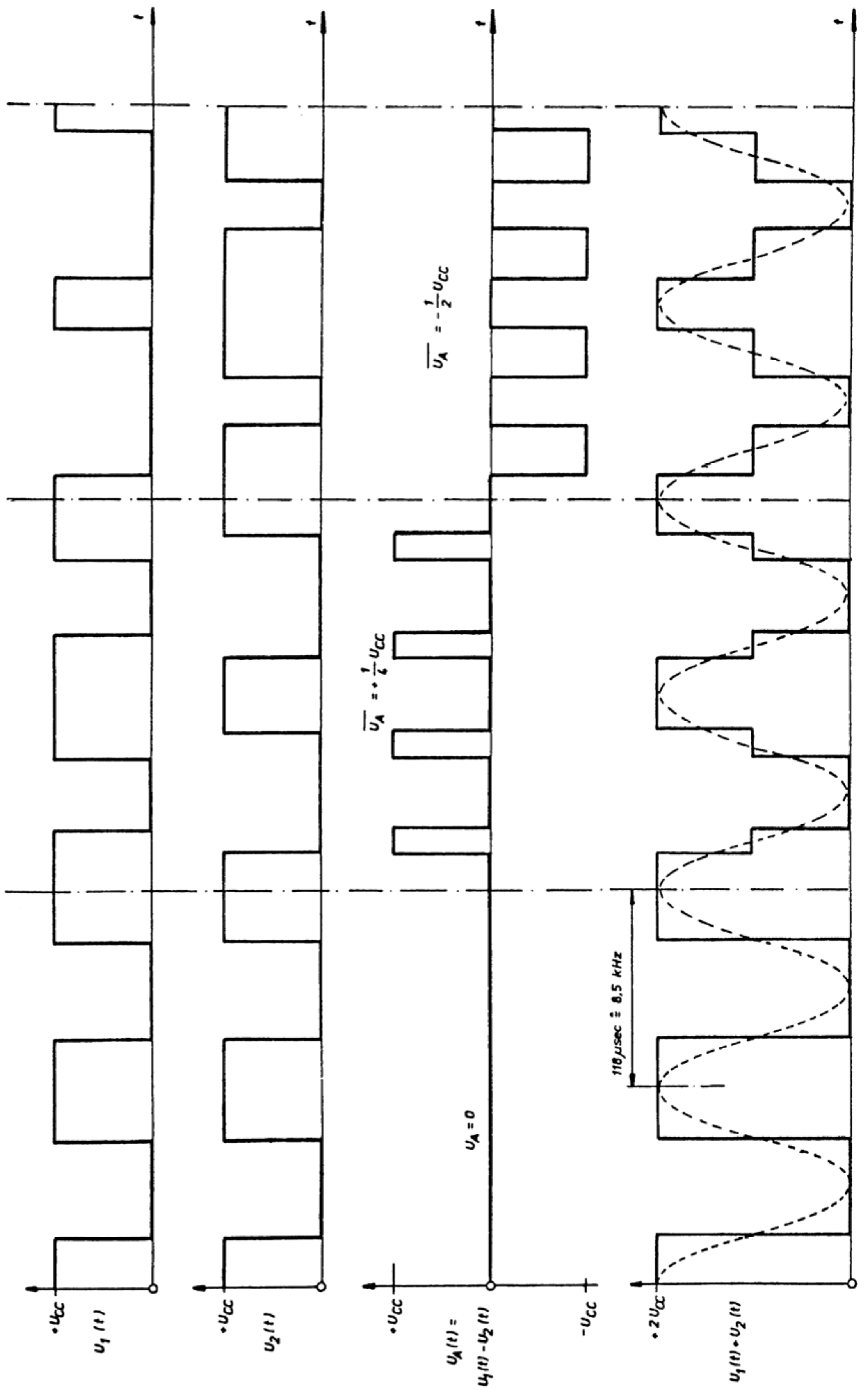

Figure 4: Voltage waveforms in the output stage

Further important features here, compared with conventional modulation procedures (with simple diagonal commutation) are the facts that no AC loading at all is present when the motor is at rest, and even in the worst case (when U_A = ½ U_{cc}), the alternating voltage across the load is not equal to the doubled, but only the single supply voltage. This almost eliminates motor heat-up by magnetic hysteresis losses (for motors with armature containing iron), whereas this consideration was formerly a serious load limiting factor. This also makes it possible to use storage chokes of so small physical size that they can still be accommodated inside the amplifier case even for 20kW nominal power rating.

1.5.4 Electrical Isolation

The series 20K units contain an analog buffer (isolating) amplifier which electrically isolates all major control inputs from the remainder of the unit. This makes possible the use of a low-cost single-wound mains transformer for the power supply. The entire power section is then tied to mains potential (or to $-U_{cc}$ / 2 measured with respect to ground), whereas the entire preamplifier circuit can be tied to any other desired potential (usually signal ground potential of the numerical control system). The stray coupling capacitance between the preamplifier and the basic unit is only a few picofarads. The analog data (nominal armature current value) is transmitted magnetically and the digital commands (output stage enable, speed controller enable) are transmitted via optocouplers.

The heat sinks of the output stage, the cores of the storage chokes and the cans of the intermediate circuit electrolytic capacitors are mounted electrically insulated with respect to the case. To fulfill safety requirements, the amplifier and motor case must be grounded. Failure to comply with this requirement can lead to a dangerous situation (electric shock hazard).

It is also important to ensure that the preamplifier is not operated with floating potential. Apart from the danger of damage to the optocouplers by static charge build-up in the floating state, in most cases stray RF currents on the input lines would interface with proper operation of the output stage, manifest as unstable zero point, jerky running, “scratching” noises and other effects. Therefore the entire input circuitry must be tied to some well defined potential which is grounded with respect to RF signal voltages. Terminal 17 can be used for this purpose.

If electrical isolation is not required, a jumper connection must be placed between terminals 17 and 18.

1.5.5 Limit Switch Input with Automatic Braking

When a limit switch is reached, i.e. when the corresponding limit switch circuit is broken, a braking process is initiated immediately, whereby the motor is braked down to rest with the maximum possible current defined by the current limiters. This is effected by switching off the nominal speed value (speed set point) to zero. The motor is thereby braked on an essentially linear characteristic, so that it comes to rest much sooner than with a resistor brake which operates on an exponential characteristic to a first approximation.

When a limit switch is in the actuated state, the amplifier responds only to nominal values (set point commands) for the opposite direction of movement, i.e. the motor can be driven away from the limit switch again without any problems. To prevent drift, the integral control function of the speed controller is suppressed as long as a limit switch is in the actuated state.

In contrast to the function “output stage switch clear” (kl.16), the output stage remains in the operating state when one or both limit switches are in the actuated state. Thus switching operations in the armature circuit are not permitted at such times under any circumstances.

1.5.6 Blocking Protection

Many servo motors will tolerate full rated operating current only for short times when at rest. For example, if the motor comes inadvertently against a mechanical stop or brake, it may suffer damage even though the **I²t** current limiter responds after some time. Therefore the units incorporate a monitor which is triggered by response of the **I²t** current limiter and switches the output stage clear with current overload status signal output if the **I²t** current limited status persists for 30seconds in one uninterrupted stretch.

1.6 Overview of Terminals

Nominal Value Input 1 (Kl. 1-2):

These are the input terminals of the first difference amplifier. The maximum permissible voltage is ±10Volts, whereby neither one of the two terminals may ever carry a higher voltage than +20Volts or a lower voltage than –20Volts with respect to terminal 17 (preamplifier ground), since otherwise the amplifier would be overdriven. Terminal Kl.1 functions positive with respect to terminal Kl.2.

Nominal Value Input 2 (Kl. 3-4):

These terminals have the same function as for the terminal value input 1. The two inputs act on the servo amplifier in superimposed manner without mutual back-interaction. When the potentiometers P1, P2 are turned up to maximum, the sum of both nominal values must not exceed 10V. Terminal Kl.3 functions positive with respect to terminal Kl.4.

Tacho-Input (Kl. 5-6):

These terminals are provided for connecting a direct voltage tachogenerator as motor speed transmitter. The tacho-voltage at nominal motor speed an with 10V control voltage, should be at least 17Volts and must not exceed 100Volts. The negative pole must be connected to terminal Kl.5.

Speed Controller Output and Nominal Current Value Input (Kl. 7 and 8):

In normal operating mode, these two terminals must be connected together. If pure current control is not desired, the jumper connection must be removed and the nominal current value signal (±10V for full pulse current, with respect to terminal Kl.17) must be injected at terminal Kl.8. The current limiter circuit are operative in this circuit mode too.

Limit Switch “Positive Stop” (Kl. 9-10):

For normal operation, these terminals must be connected together by the limit switch contact. When this connection is broken or when +15V is applied to terminal Kl.10, the amplifier no longer responds to positive nominal speed value signals (for definition of polarity, see “nominal value input”). The actual input terminal is Kl.10; the terminal Kl.9 lies at amplifier ground potential (like terminal Kl.17).

Limit Switch “Negative Stop” (Kl. 11-12):

Same function as for “positive stop”, but for negative nominal values. The input terminal is Kl.11; terminal Kl.12 lies amplifier ground potential.

Auxiliary Voltages +/-15V (Kl. 13-14) :

External auxiliary circuit or nominal value transmitters can be connected here. If used for nominal value definition, the voltage must be stabilized additionally in the external circuit, e.g. to 10Volts with a Zener diode and series resistor. The maximum permissible current loading is 20mA for each terminal. Terminal Kl.13 is for +15Volts and terminal Kl.14 is for –15Volts, in each case witch a tolerance of ±5%.

Control Input “Integral Control Function Off” (Kl. 15):

Particularly in a system with higher priority position controller, the integral characteristic control function is not desired in all phases of a positioning process. It could lead to overshoot especially when homing to the zero position after a fast run process. To suppress such unwanted effects, the integral characteristic control function of the motor speed controller can be inactivated via this input for the duration of the shaft control process in which it is not required. The integral function is enabled when this input is open. When 0V applied (short circuit connection to terminal Kl.17), the integrating capacitor is shorted by a field effect transistor.

Output Stage Switch-Clear (Kl. 16-17):

The servo amplifier operates only when the terminals Kl.16-17 are shorted together. When this connection is broken or when +15V potential is connected to terminal Kl.16 with respect to terminal Kl.17, the current is switched off in the output stage after not longer than 1mseconds. At the same time a switch transistor cuts-off at terminal Kl.22; this can be used, for example, to control a braking circuit (see control output for dynamic braking”). When the connection between terminals Kl. 16-17 is broken or when 0V is connected to terminal Kl.16, the aforementioned switch transistor conducts immediately and after elapse of not longer then 30mseconds, the output stage is enabled.

All integral characteristic control functions are disabled for the duration of actuation (open circuit input), so that a switch-on jerk is prevented.

Preamplifier Zero Potential (Kl. 17):

The preamplifier circuitry must be tied to a definite zero potential in all operating modes, preferably to ground potential or to the potential of the output stage. This can be established via the terminal Kl.17.

Output Stage Common (Kl. 18):

This is the terminal for the jumper connection to terminal Kl.17 when operating the system with a double-wound mains transformer. It is also the reference zero potential for the armature current monitor, for the I^2t status signal and for the second auxiliary voltage +15Volts (terminal Kl.12) for the braking relay.

Armature Current Monitor (Kl. 19):

The armature current actual value signal is connected to this terminal (±10Volts correspond to the respective data sheet pulse current rating with a tolerance of about ±3%). The terminal impedance is about 1kOhm; a short circuit at this terminal or long unshielded line connected to it may lead to improper functioning.

I^2t Status Signal (Kl. 20):

In the normal operating state, this output is pulled down to 0V. A few milliseconds after response of the I^2t current limiter, this output goes to high impedance state. This status signal can be used to inform a higher priority controller, whether or not the servo amplifier is overloaded.

Control Output for Dynamic Brake (Kl. 21-22):

The control relay for a dynamic brake (resistor brake) can be connected here. Actuation is by the already described input for the output stage enable/disable. In the normal operating state of the unit, a transistor conducts to pull terminal Kl.22 down to 0V. +15Volts potential is terminal Kl.21. The current loading and sinking capability is 20mA.

Status Signal Contact for “Ready to Operate” (Kl. 23-24):

A floating reed contact is connected to these terminals. It is closed only when the unit is ready for operation. The enable input (terminal Kl.16) has no effect on the state of this contact. The maximum contact ratings are: 100V / 0.1A or 10Watts.

Auxiliary Power Supply 230V AC (Kl. 31-32, only for series 20K):

Nothing is connected here apart from the blower fan, so that the unit may be operated in an emergency for a short time without this auxiliary power supply, by virtue of its thermal inertia. However, proper temperature supervision of the unit is not possible in such operating mode, so that operation without blower fan must never be prolonged until the thermal cut-out operates. The power consumption of the blower fan is about 40VA.

Main Power Supply 3 x 50V to 3 x 115/145V (Kl. 33-34-35):

Normally the power supply input for the entire amplifier is taken via these terminals. An essential condition is that medium delay fuse cartridges with about ⅔ to ¾ of the nominal full current rating for the unit, must be interposed in the input circuit. These fuses do not protect the amplifier in the case of overload, but they minimize consequential damage in the case of output stage failure.

Direct Current Intermediate Circuit (Kl. 36-37):

Direct access to the power supply for the output stage is provided via these terminals. As an alternative to an AC mains supply, the units can be powered directly with a DC supply via these terminals, or several units can be connected in parallel here to a common supply. If the motor has field excitation winding, it may be connected here too. Terminal Kl.36 is positive with respect to terminal Kl.37.

Motor Connections (Kl.38-39):

All kinds of servo motors with suitable nominal current rating can be connected here. Since the servo amplifier units already contain storage chokes, it is not necessary to comply with any minimum inductance specification for the servo motor (with one exception: L_{min} = 0.3mH for operation of series 20K units for any appreciable time without blower fan).

Ballast Resistor (Kl.40-41, only for Series 20K):

On account of the large heat dissipation of up to several kilowatts, the ballast resistor for series 20K units is not incorporated inside the amplifier case. Depending on actual power dissipation, any high-power resistor with a value of 1.8 or 2.2Ohms may be connected to these terminals. Terminal Kl.40 is the actual output of the ballast output stage whereas terminal Kl.41 is always connected to 0V (for resistance value calculation, see Section 2.6).

2. Projecting and Dimensioning

2.1 Load Category

Two categories of applications may be distinguished: feed drive and main drive. A typical feed drive, such as may be attached to the spindle of an xy-coordinates table, is characterized primarily by relatively short acceleration times (some tens to hundreds of milliseconds) and by the predominance of a dynamic load component over the static load component. Current is required primarily for acceleration and for braking, and only to a smaller extent for overcoming friction or other continuous load.

In contrast hereto, a typical main drive is required to cope with very large moments of inertia, which come in part from the driven load but which may also originate from the motor itself. Therefore customary acceleration times have the order of magnitude of seconds. Furthermore, the static load components (friction, wind load, wire tension, etc.) usually represent a considerable friction of the total required torque.

As far as the servo amplifier is concerned, a feed drive constitutes the less critical application case, by a long way, and this remains true in general even when very high clock frequencies are demanded with full exploitation of pulse current and rms current capability. The reason is the only slight thermal alternation loading of the output stage transistors by brief current pulses.

In the case of main drives, however, with full pulse current the transistors are heated to the thermal limit and cooled down again on each load cycle. Although this thermal stress does not give rise to any imminent danger of failure (each unit is tested on continuous duty in the extreme case of this kind loading, before delivery, the failure safety margin is nevertheless reduced, particularly in continuous operation. Reduction of the allowed pulse current to about 150% of I nominal is therefore recommended. The further prolongation of the run-up times entailed thereby are no longer critical for the amplifier.

This reduction is made automatically by the I^2t current limiter after a few seconds (cf. diagrams in Figure 5 and 6), but at this time transistor chips are already hot. Therefore it is advisable as a matter of course for main drives, to reduce the pulse current at the potentiometer control provided for this purpose (P6) or with a fixed resistor (R144). In most cases response of the I^2t current limiter can be avoided thereby, and this also avoids the accompanying change of acceleration.

2.2 Optimizing the Drive for Given Amplifier Power

If it is possible at the time of planning the drive, to provide matching by gears or other form of speed transformation (cog chain, spindle, etc.), then this speed reduction should always be chosen such that load moment of inertia as reflected into the motor shaft is equal to the input moment of inertia of the motor. This gives the shortest possible load run-up time with a given accelerating current. An exception to this rule is found only if the speed transformation ratio required for this matching would exceed the maximum possible motor speed. In this case the speed transformation must be based on the maximum available motor speed.

Another kind of matching is possible for some motors by choosing the appropriate nominal motor speed. Such motors usually have various windings, and the relationship between speed and torque factor is approximately one of inverse proportion. Since the moments of inertia are the same, in most cases the better choice is the slower running motor.

2.3 Determination of the RMS Current for Dynamic Load

When the motor type and speed reduction transmission have been chosen and the overall moment of inertia has been calculated, the armature current as a function of time can be determined in relation to the given pulse current and torque factor. Neglecting friction, the run-up time is given by:

$$t_b = \frac{J\,total}{I_b * K_M} * n * \frac{2 * \pi}{60}$$

where:	t_b	= Run-up time in seconds
	J total	= Sum of motor and load moments of inertia in kgm²
	I_b	= Acceleration output current provided by the amplifier
	K_M	= Torque factor of the motor in Nm/A
	N	= Speed change in rpm

The same formula also holds for braking. According to the particular application, a working diagram like Figure 7, for example, may be obtained.

Therewith the probable rms current can be determined according to the following equation, provided that the complete cycle is actually taken into account:

$$I_{rms} = \sqrt{\frac{I_1{}^2 * t_1 + I_2{}^2 * t_2 + \ldots + I_n{}^2 * t_n}{t_1 + t_2 + \ldots + tn}}$$

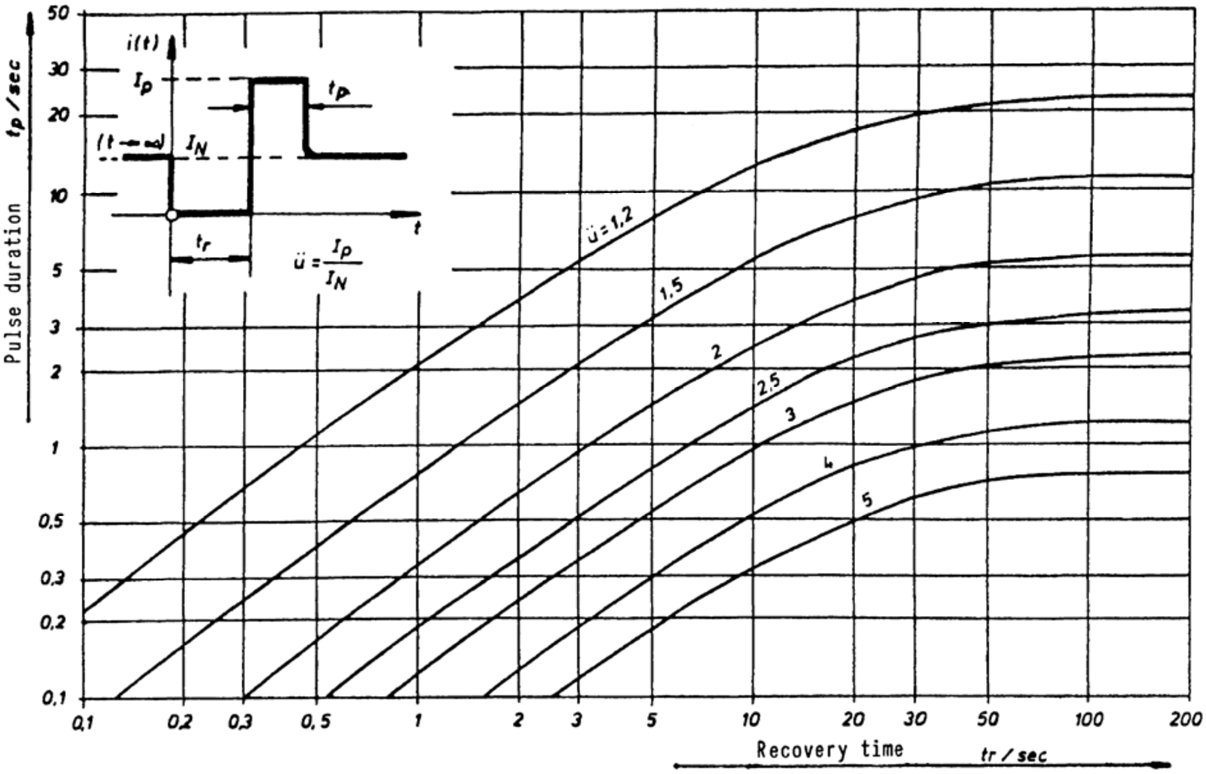

Figure 5: maximum pulse current duration as a function of the recovery time an the current boost factor

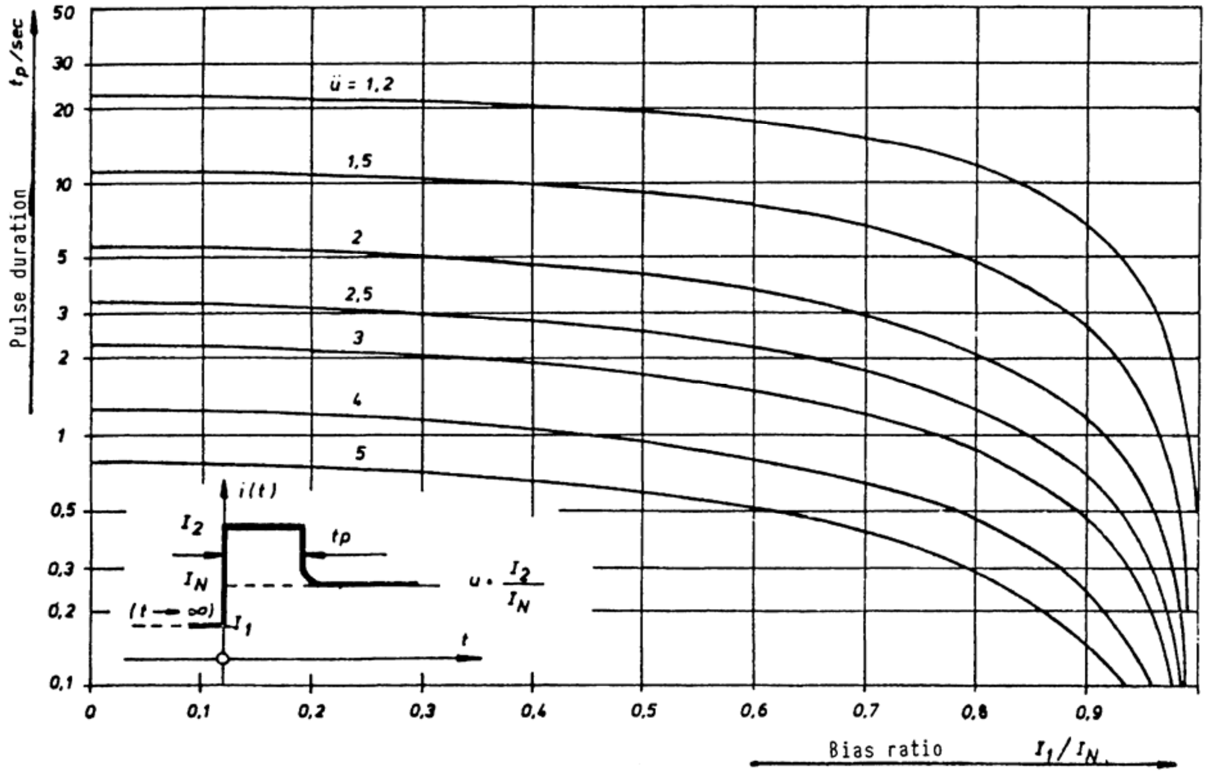

Figure 6: maximum pulse current duration as a function of bias and current boost factor

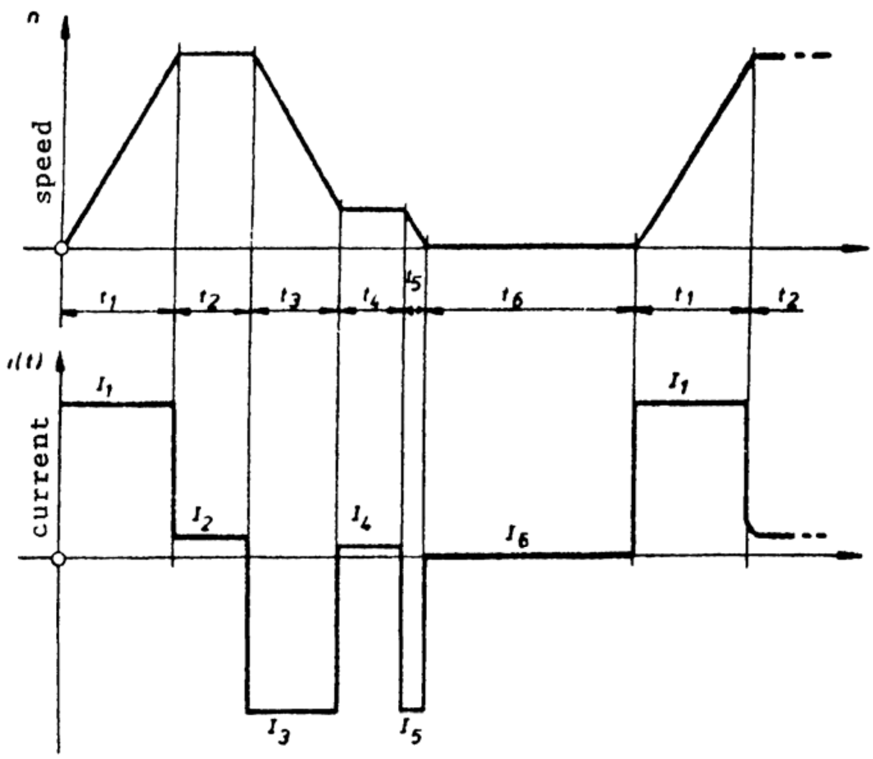

Figure 7: Example of a working diagram

2.4 Nominal Voltage

When the accelerating current and the final motor speed have been defined, the required operating voltage can be calculated too:

$$U_N = n_N * \frac{2*\pi}{60} * K_E + I_b * Ri$$

where:

- U_N = Nominal operating voltage of unit in Volts
- n_N = Final motor speed in rpm
- K_E = Voltage constant of the motor in V/radian sec^{-1}
- I_b = Accelerating current
- Ri = Internal resistance of the motor

In some motor specification sheets the EMF in Volts per 1.000rpm is stated instead of the voltage factor K_E. In this case the formula reads:

$$U_N = n_N * \frac{EMF}{1000} + I_b * Ri$$

Both formulas are a simplified, but for practical purposes sufficiently accurate representation of the behavior.

<u>The following effects are not taken into consideration:</u>

- The voltage drop at the brushes
- Mechanical friction in the motor bearing
- Scatter of the K_E values by up to ±10%
- Change of the K_E value as a function of the motor temperature
- Voltage drop on the armature cables
- Internal resistance of the transformer and the controller

Thus about 10% should be added to the calculated value.

In most cases these considerations lead to voltage values which are larger than the data sheet nominal motor voltages. Run-up is then constant to the final speed and is unaffected by the back-EMF. A back-EMF effect would be, for example, a flattening of the speed characteristic on acceleration close to the final speed. If such flattening can not be tolerated, or if the maximum nominal voltage for the unit would otherwise have to be exceeded, calculations may be made according to the formulas given above, using the nominal current instead of the acceleration current.

This gives smaller voltages. The same applies too when using a commutation current limiter.

2.5 Mains Transformer Calculation

After determining the required nominal voltage, the transformer secondary voltage can be determined according to the formula:

$$U_{TRMS} = (U_N + 6V) * 0.72$$

Where U_{Teff} is the rms alternating voltage between the rectifier circuit terminals 33-34-35.

<u>**Important:** The open circuit transformer voltage with maximum possible mains overvoltage must not be greater than 125V rms (for 150V nominal voltage) or 163V rms (for 200V nominal voltage).</u>

The considerations discussed in Section 1.5.1 hold for determining the physical size of the transformer. For serial applications it is advisable to determine the actually required power by practical measurement, e.g. with an energy counter. The transformer delivers virtually no reactive power.

2.6 Ballast Resistor

The loading of the ballast resistor can vary within wide limits, depending on the particular application. In the case of very short braking pulses (up to about 100msec) and waiving of full nominal voltage for the unit, the intermediate circuit capacitance suffices in most cases to take-up the braking energy. However, considerable amounts of energy can be involved when braking large moments of inertia, so that a rough calculation is advisable. A difficulty involved here is that the power efficiency of the motor as generator is strongly dependent on loading and, above all, on the speed:

$$\eta_{gen} = 1 - \frac{I_b * Ri * 60}{n * K_E * 2 * \pi}$$

where: η_{gen} = Power efficiency of the motor in generator mode
I_b = Braking current in Ampere
n = Motor speed in rpm
K_E = Voltage factor of the motor in V/radian sec^{-1}

For a simple braking process from nominal speed with double nominal current, an average power efficiency of about 70-75% may be assumed. Of course, the design of the motor, in particular its internal resistance, has a large effect on the actual value.

The expected braking energy is then:

$$W = 1/2 * J_{total} * \omega^2 * \eta_{gen} \quad \text{, where: } \omega = \frac{2 * n * \pi}{60}$$

where: W = Braking energy in Watts seconds (Joules)
J_{total} = Sum of motor and load moments of inertia, in kgm²
η_{gen} = Mean generator power efficiency of the motor during the braking process
n = Initial speed of the motor in rpm

In the case of periodic operation, i.e. regularly repeated braking processes, the power dissipated in the resistor, in Watts, is:

$$P = W * 1/2 \quad \text{, in Watts}$$

where T is the repetition period in seconds.

2.7 Commutation Current Limiting

At medium to high speeds, many DC servo motors may be operated with only a fraction of the magnetically permissible pulse current. If this condition is not fulfilled, severe wear results at the sliprings and carbon brushes, in extreme cases all-round arcing and possible early failure of the motor.

To prevent such stress, the servo amplifiers can be equipped with a plug-in module which provides an individual limiting characteristic for each type of motor. The actual speed information is derived from the armature voltage. This entails a certain inaccuracy (because the resistive voltage drop inside the motor is incorrectly interpreted), but it has the advantage of being unaffected by improper manual intervention or by failure of the tacho-generator. Furthermore, as far as the commutation limit is concerned, the motor responds more sensitively on run-up than on braking, and this compensates for shortcomings of this circuit arrangement.

Figure 8 shows the limiting characteristics for three available standard modules. In each case, voltage normalization is with respect to the data sheet voltage rating of the units (150V or 200V), and not to any lower maximum output voltage determined by the transformer. Other characteristics can be realized on request. In such cases the original motor characteristics and the nominal ratings of the unit must be stated with order.

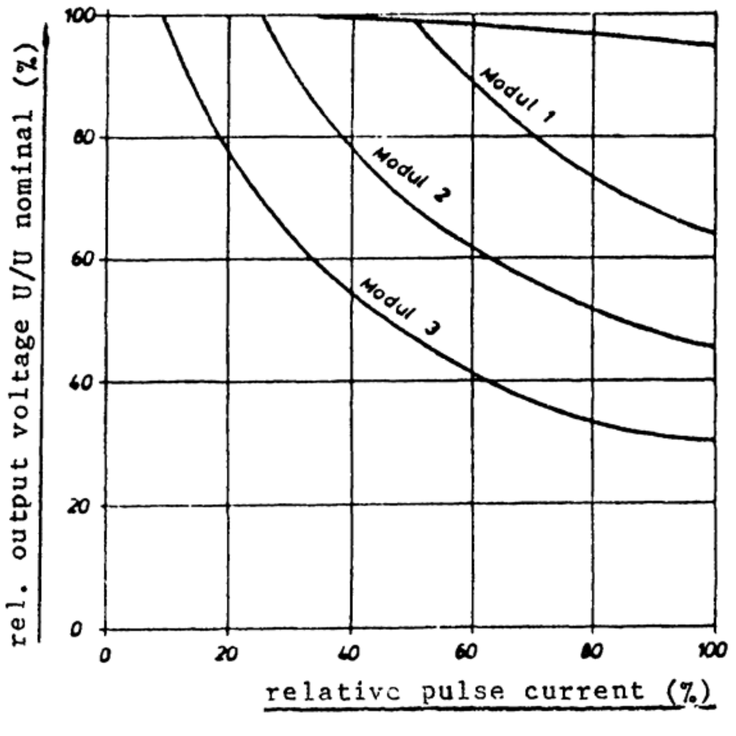

Figure 8: Standard commutation characteristics

2.8 Dynamic Brake (Option)

Many applications require activation of largely independent emergency brake in the case of power failure or emergency switch-off. This emergency brake too can be operated by the controller.

The braking device consists of two anti-parallel connected thyristors with series protection resistors according to Figure 9.

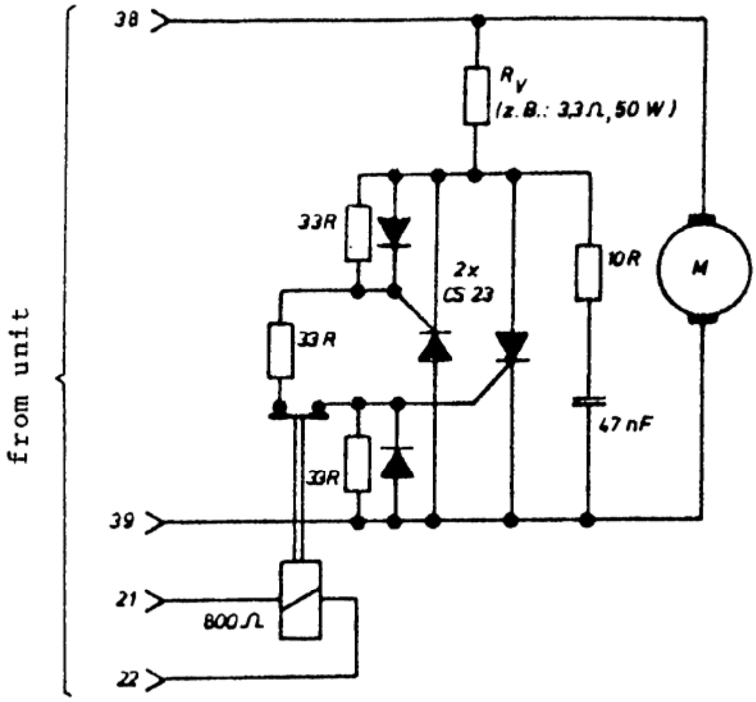

Figure 9: Proposed circuit for dynamic brake

The relay is energized when the unit is ready for operation (not in disabled state), so that the thyristors are cut off. In a fault situation, the disable input (output stage disable, terminals Kl.16-17) must be switched open circuit, so that output stage current is switched off, the relay drops off and one of the two thyristors fires. The series resistor R_v must be dimensioned such that the motor will not be damaged even with the highest possible speed. The RC-combination 10R/0.047µF in conjunction with the chokes contained in the unit, reduces the flank slope of the output voltage (du/dt), so that the thyristors will not be destroyed.

If it is desired that the motor shall be braked in the case of an internal fault too (excessive current, overvoltage, excessive temperature rise), then the fault relay (“ready for operation”, terminals Kl. 23-24) must be included in the control line of the output stage disable circuit.

2.9 Ramp Generator (Option, external)

In many applications it is required that, on applying a set point step change, the motor shall not respond with maximum limit current, but that it shall be brought to the new set point with load-independent acceleration. This function is performed by the ramp generator. The circuit is accommodated on an auxiliary card which is connected to the control terminals of the unit in flying wiring, beginning on the left at terminals Kl.3. As in the main unit, the input of the ramp generator is designed as a difference amplifier too. The Voltage gain is unity without voltage inversion.

Acceleration and braking can be set mutually independently with two potentiometers. The setting range is 1:10. In the case of reversal of rotation sense, the setting for braking (potentiometer P11) is valid until zero speed transition and thereafter the setting of the potentiometer for acceleration (P10) takes over control. This behavior is true for both sense of rotation.

The circuit contains a capacitor which is mounted on soldering pins and defines the time range. For a full 10V step change with maximum acceleration (potentiometer P10 at right hand stop), the following relationship is valid:

$$C\ (\mu F) = K * t \qquad \text{seconds}$$

$$K = 1 * 10^{-6} \qquad (A/V)$$

2.10 Fuse Protection for Principal Power Supply

On account of the very short thermal time constant of the bond connections in the output stage transistors, the output stage can not be protected against current overload with a fuse cartridge. The fuses which are here recommended can only give protection against consequential damage in the case of a short circuit fault in the unit. Therefore they are rated primarily with respect to the charging source current on powering the unit up (switch-on). The current rating for this purpose in the smaller power units lies far above the nominal operating current. Only for the 100A controller it may be found necessary to fit a fuse with larger than the specified current rating if nominal current and nominal voltage are demanded for a prolonged period of time (cf. Section 1.5.1).

Nominal Current Rating of the Unit	Recommended Fuse Type Neozed	Type Little fuse 3AB
10A	Neozed 10A	15A
25A	Neozed 16A	25A
35A	Neozed 25A	30A
50A	Neozed 50A	
70A	Neozed 50A	
100A	Noezed 63A	

2.11 Multiple Shaft Operation

The following cases must be distinguished here:

a) Same nominal voltage with mutually independent shafts
b) Non-equal nominal voltages with mutually independent shafts
c) Mechanical coupled tracking of several shafts

Special conditions, which must be observed strictly under all conditions, apply for each one of these cases.

a) For multiple shaft operation with the same nominal voltage, the DC intermediate circuits should be connected in parallel as far as possible. This reduces the stress imposed on the ballast circuit, because more intermediate circuit capacitance is available when individual shafts are braked. Nevertheless, the units should be provided with individual fuse protection, so that the individual fuse ratings remain modest and thus consequential damage in the case of failure is minimized. The connection to the positive pole of the intermediate circuit should be fuse-protected too (terminal Kl.36); the negative pole should be wired directly. The current ratings for all four fuses must correspond to the values specified in the table in Section 2.10.

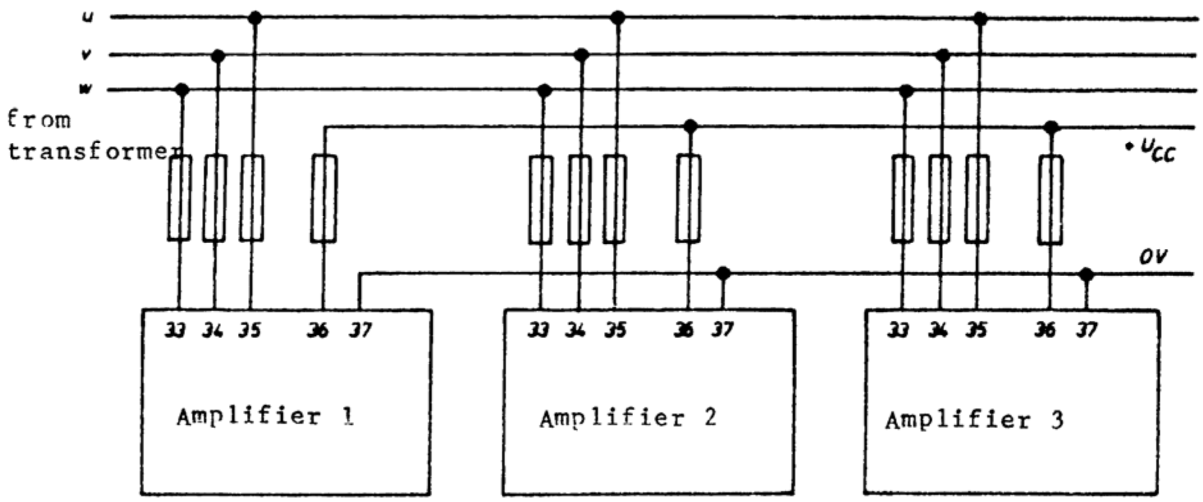

Figure 10: Fuse protection for multiple shaft operation with same nominal voltage

b) In the case of unequal nominal voltage, different circuits are recommended for the two types of units.

For the series 5K, in which there exists a direct connection between the negative pole and the baseplate and this connection is essential for interference suppression, it is imperatively necessary to use a double-wound mains transformer, i.e. one with electrical isolation between primary and secondary windings. The terminal Kl.37 must be connected in parallel and the units treated in all other respects like individual shaft controllers. The three-phase AC power supply inputs must be fuse-protected and positive intermediate circuit terminals (Kl.36) left disconnected.

Simple transformer tapings on a single-wound transformer can be used for series 20K units, by virtue of the electrical isolation and floating input circuits. Under no circumstances is it here permissible to connect-up or mutually link the terminals of the DC intermediate circuit (Kl. 36-37) or the terminals Kl.18 (0V potential of the output stage). Each unit must be fuse-protected individually (see Figure11).

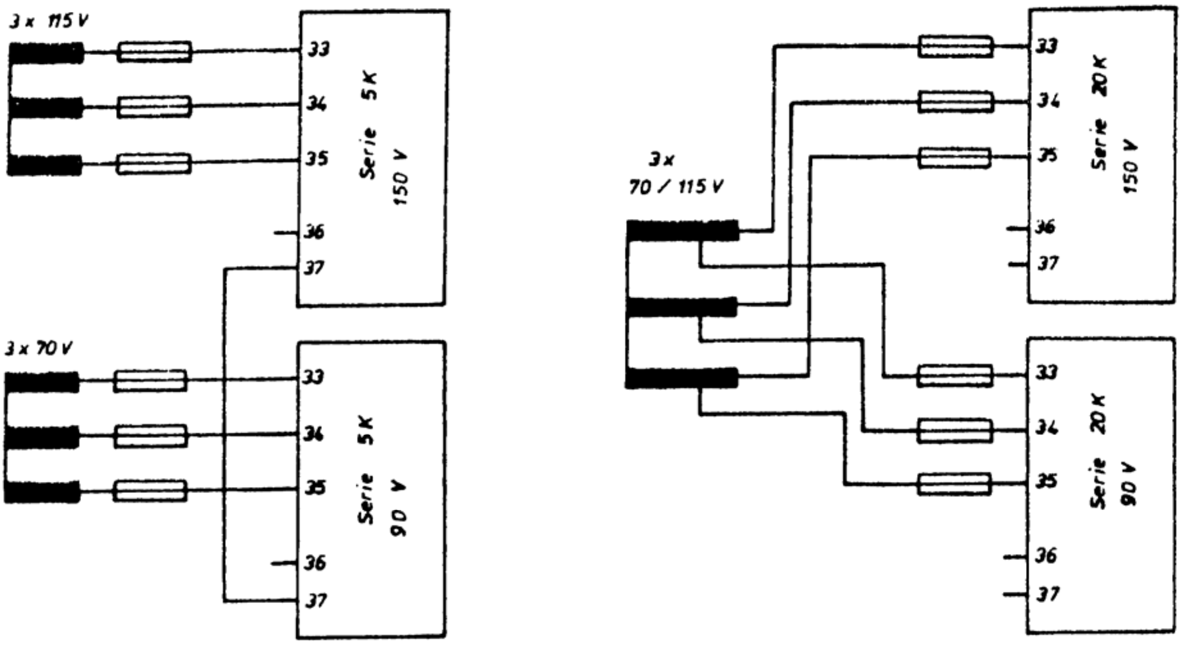

Figure 11: Power supply for unequal nominal voltages

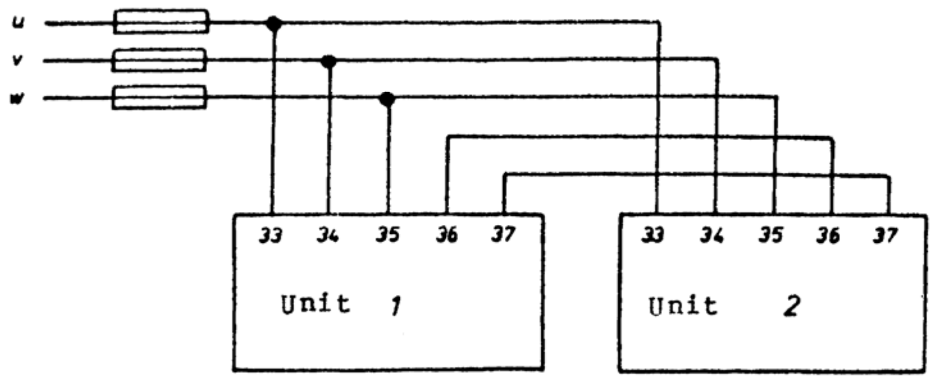

Figure 12: Fuse protection for mechanically coupled shafts

c) For mechanical coupled shafts, e.g. dual motors or opposition motors, the participating units must be connected directly and fully in parallel. Separate fuse protection is of no avail and may even cause damage, because then in the case of failure of one shaft, the other still operational shafts produce an operating voltage in the defective unit originating from the rotating motor. Therefore mechanically coupled units must also have a single common fuse protection (see Figure 12).

   Here too, the required fuse characteristic is determined chiefly according to the loading imposed by the switch-on current surge. Medium delay characteristic fuses with current rating 1.2 to 2.0 times the values listed in Section 2.9 recommended.

2.12 Electrical Installation, Grounding, Erection

Make sure that all electric power cables are installed with adequate conductor cross-section area according to VDE 0100. Avoid large area loops, especially for the motor cables. The entire cable run right up to the motor should consist of a separate two-conductor cable.

If interference suppression requirements are extreme, it may be necessary to shield the motor cable, in which case only one end of the shield should be connected to the negative pole of the DC intermediate circuit (terminal Kl.37). Only for series 20K units when a very large capacitance is present between the armature winding and ground, it may be satisfactory to connect both ends of the motor cable shield directly to ground.

The units have difference inputs so that reversal of the rotation direction is very simple to achieve. The difference input principle also provides very effective means for eliminating the effects of ground loops, but this makes it quite essential to wired both poles of the difference input right to the controller and only there connect one of the two poles to 0V potential of the controller. The shield of this line should be grounded only at the controller

Also make sure that the input circuits and the preamplifier of the servo amplifier (for series 5K units, the entire amplifier), lie at the same potential. For this purpose, for the series 20K units, a separate connection must be made from terminal KL.17 to zero potential of the input control circuitry. For the series 5K units, this is best achieved by grounding the input control circuitry and the amplifier baseplate. If this condition is not complied with, strong load-dependent feedback effects will be the result, or even completely uncontrollable behavior.

To comply with safety requirements in the case of a motor fault, the motor casing must be grounded too as securely as the amplifier. If only the motor and the control input circuitry are grounded, a fault situation (ground short in the motor) may lead to severe damage to the unit and to the control input circuitry.

The shield of the tacho-cable may be connected to ground potential at the motor and or at the equipment unit end.

The digital control signal inputs, e.g. for limit switches, disable, integral control, etc., are provided with filters. So that the line here connected need not be shielded. However, these lines should not be installed in bunches together with other lines.

Particularly the series 5K units must be mounted vertically so that the cooling air can pass unhindered through the cooling fins. When series 20K units are installed in similar manner, this considerably improves the emergency running characteristics (when the blower fan is not operating, cf. Section 1.4.2). Ensure appropriate size clearance space so that the air circulation is not impaired. Direct draw-in of unfiltered cooling air must not be permitted under any circumstances, particularly when the ambient atmosphere is heavily contaminated (glass factory, steel works, etc.). Instead, the units should always be installed in dustproof equipment cabinets which are cooled either by heat exchangers or by filtered air (for heat dissipation of the units, see Section 1.4).

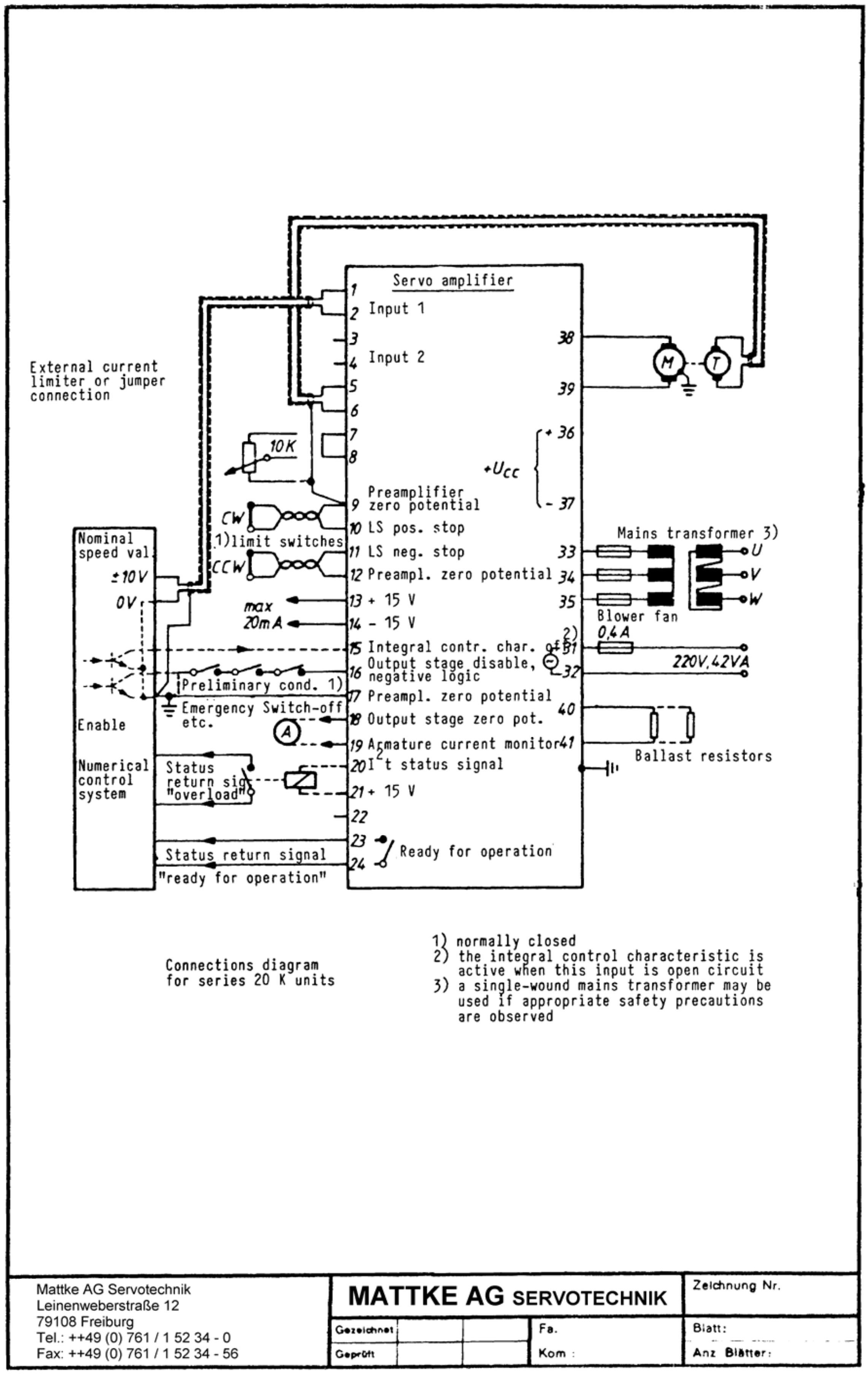

Figure 13: Connections diagram for series 20K units

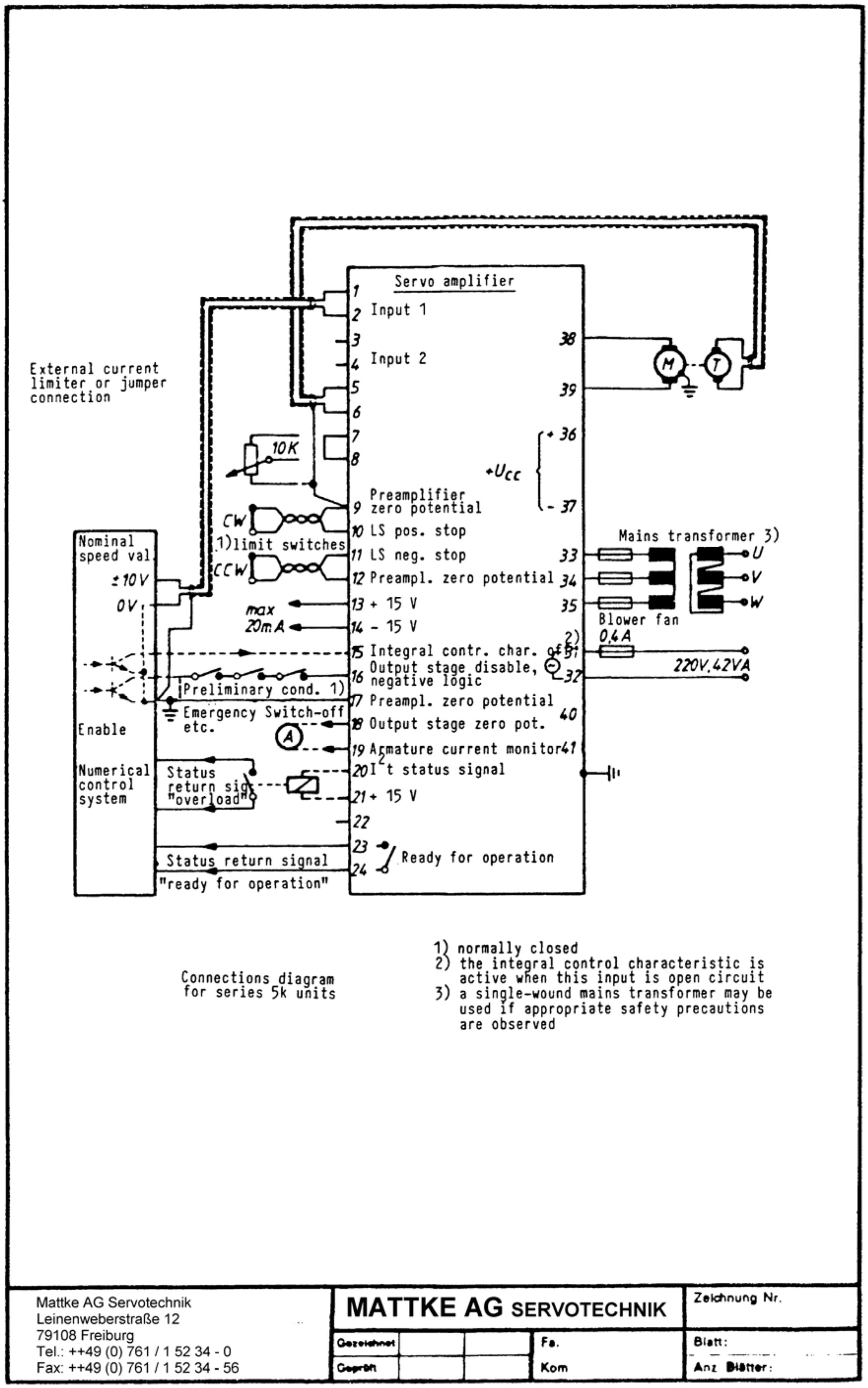

Figure 14: Connections diagram for series 5K units

3. Commissioning and Operation

3.1 Potentiometers, Fixed Components and Test Points (Overview)

Potentiometer P1: <u>Input attenuator</u> after the difference amplifier at terminals Kl. 1-2. Setting range 0.18 … 1.1.

Potentiometer P2: As for P1, ‚but associated with terminals Kl. 3-4.

Potentiometer P3: <u>Speed settings</u>; attenuator for the <u>tacho-input</u>. Setting range 0.065 … 0.65.

Potentiometer P4: <u>Offset compensation</u> for the speed controller. Setting range ±15mV.

Potentiometer P5: <u>Speed gain</u> of the speed controller. The setting range extends from full negative feedback by the RC-combination R24 (330kOhms)/C4 at left hand stop, to full gain at right hand stop.

Potentiometer P6: <u>Peak current setting</u>. Setting range 0.085 … 1.0 time pulse current specified in data sheet. The setting is independent of other potentiometers. The fixed resistor R144 must not be contained and the terminals Kl. 7-8 must be linked.

Potentiometer P7: <u>rms current limit value (I²t current)</u>. Setting range 0 … 1.0 times the rms current value specified in the data sheet. The settings is independent of other potentiometers. The resistor R145 fitted in the factory must not be changed.

In addition to the potentiometers listed above, which are accessible for alignment and matching, the unit contains two further potentiometers which are set and sealed in the factory. The settings of these potentiometers must not be disturbed, since this could cause functional disorders or severe damage to the unit.

Potentiometer P8: <u>Offset compensation for armature current monitor</u>. Adjustment is possible only when the nominal armature current value is made zero (terminal Kl. 8 open circuit).

Potentiometer P9: <u>Threshold value of ballast circuit</u>. This potentiometer is located in the driver circuit.

Resistor R144: <u>Pulse current limit value</u>. If a fixed resistor is desired instead of a potentiometer alignment, the required fixed resistor value can be determined by the following formula.
The potentiometer P6 must be set to right hand stop.

$$R144 = \frac{10kOhms * I}{(I_{\max} - I)}$$

Here: R144 = required resistance value in Ohms

I = desired pulse current

I_{max} = pulse current specified in data sheet

Resistor R145: rms current limit value. Analogous to the function of R144, this resistor determines the maximum value of the rms current when potentiometer P7 is set to the right hand stop. The required value can be calculated according to the following formula:

$$R142 = 47kOhms * \left(\frac{I_{rms}{}^{2}}{\left(I_{\max}{}^{2} - I_{rms}{}^{2}\right)} \right)$$

I_{max} is the pulse current value specified in the data sheet, for which the unit is built. This value has nothing to do with the setting of P6 or the value of R144.

C4, C5, R22: These components, which determine the control characteristics, are described in detail in Section 3.8.

Resistors R109, R110: Pulse current normalization for the complete unit. These resistors must not be changed under any circumstance, otherwise the output stage may be overloaded. The values are chosen in the factory for matching the control electronics to the current loading capability of the output stage.

Resistors R120, R121: Current overload switching threshold. These resistors too are selected in the factory and must not be modified. Changes may lead to functional disorders or failure of the output stage.

Test point 1: Nominal speed value. The sum of voltages applied to input1 and input2, after attenuation by the potentiometers P1, P2 and conditioning by the limit switches control logic.

Test point 2: Actual speed value. The tacho-voltage after attenuation be the Potentiometer P3.

Test point 3: Nominal armature current value. Output voltage of the speed controller or nominal current value from terminal Kl.8. Maximum value ±10V, affected by potentiometer P6 and resistor R144 when fitted. ±10V span corresponds to the full pulse current specified in the data sheet.

All test points specified so far are referenced to 0V potential of the preamplifier (ground point M2). The following test points 4 to 14 are referenced to ground point M1 (0V potential of the output stage). In series 20K units, the two ground points may carry mutually different potentials, depending on the connections version used.

Connection of a grounded oscilloscope to ground point M1 when operating with a single-wound mains transformer leads to immediate destruction of the unit.

Test point 4: Nominal armature current value after transmission by the analog isolating amplifier. Additionally limited by the commutation and I²t current limiting functions. Voltage normalization as for TP3.

Test point 5: Armature current actual value. Voltage normalization as for TP3.

Test point 6: Current controller output (armature voltage controlled parameter). ±10V correspond to full output voltage in each case.

Test point 7: Clock oscillator. Triangular waveform voltage, amplitude ±10V, frequency 8.5kHz.

Test point 8: Pulse width modulator for the right half of the output stage. The switching action is non-inverting with respect to the right output voltage relative to 0V potential.

Test point 9: Switch-on delay for the right output stage, negative. On switchover to 0V potential at TP9, the output stage switches to zero current. The negative flank is delayed by about 8 microseconds with respect to the negative flank of TP8.

Test point 10: Switch-on delay for the right output stage, positive. The output stage switches to positive potential on switchover to 0V potential at TP10. the negative flank is delayed by about 8 microseconds with respect to the positive flank at TP8.

Test point 11: Pulse width modulator for left half of output stage. The function is analogous to TP8.

Test point 12: Switch-on delay for left output stage, negative. Function analogous to TP9 with time reference to TP11.

Test point 13: Switch-on delay for left output stage, positive. Function analogous to TP10 with time reference to TP11.

Test point 14: Clock oscillator for driver excitation: 450kHz

3.2 Presetting

The potentiometers must be preset in a certain manner before switching on for the first time, in order to minimize the danger of consequential damage in the case of wiring errors:

- Input attenuators P1, P2 both to left hand stop.
- Tacho-potentiometer P3 must be preset according to the utilized tachogenerator; to right stop position for tachogenerators delivering up to about 10V output per 1000rpm. For higher voltage, turn-back as far as 1/3 with respect to the left stop position may be required.
- Gain P5 to left hand stop position.
- Pulse Current P6 to left hand stop position.
- Rms current P6 to 1/3 with respect to left hand stop position.

If desired, the fixed components R144, R145 can now be selected and fitted (see Section 3.1 for calculation of the required values).

3.3 Correct Polarities

A check for correct polarity of tachogenerator, motor and input connections will prevent uncontrolled runaway after switch-on. For this purpose, with the servo amplifier switched off, inject a positive control signal from the control system or from the battery box. The input terminals 1 (3) must thereby be positive with respect to 2 (4).

Then, with the unit switched off, turn the motor by hand in the direction which has been defined as the positive direction. Thereby a positive voltage must appear at terminal 38 with respect to terminal 37. Furthermore, the tacho-voltage at terminal 6 must be positive respect to terminal 5.

3.4 Commissioning (First-Time Switch-On)

When now switching-on for the first time, make sure that no nominal value signal is applied to the unit. When the unit is switched on this condition, the motor should develop a slight holding torque and should not drift by more than a very small amount. When small nominal value signals are applied, the motor must follow; if necessary slightly increase the pulse current setting of potentiometer P6.

If, however, improper functioning is observed (e.g. oscillation), see Section 3.8 a) and 4.1.

When the unit correctly follows the nominal values, check the function of the limit switches by approaching them slowly. Also check the function of the dynamic brake (option) if fitted.

3.5 Current Adjustment

With the unit switched off, connect an ampere-meter with suitable measuring range in place of the motor. Switch on again, apply a constant nominal value signal (e.g. +3Volts) and then adjust potentiometer P6 to set the desired maximum pulse current. This adjustment must be made quickly, because the rms current limiter responds after a short time. If this happens, the pulse current can be invoked again for a short time by turning up P7.

When the I^2t current limiter has responded (this is evident by light-up of the yellow LED (D19), the setting of potentiometer P7 takes control. To set the rms current, adjust this potentiometer in <u>successive small increments</u> in the desired direction. After such a displacement to the right, the set pulse current flows for a short time (pulse current setting P6); after a displacement to the left, the current reduces to zero for a short time. After elapse of this time, the new rms current appears. Repeat this process of successive small adjustments until the desired rms current value is reached.

3.6 Tacho-Voltage

With the unit switched off again, reconnect the motor and reset the potentiometer (P1 or P2) of the utilized input to the right hand stop position. After switching on again, apply a certain percentage (e.g. 10%) of the maximum nominal value and then adjust potentiometer P3 to give the same percentage of the desired maximum motor speed. Thereafter, briefly apply the full range nominal value to check that the motor responds with full nominal speed. If this is not the case, then either an overload condition exists (I^2t) limiter responds) or the supply voltage is too low.

For tacho-voltages smaller than 17V (for full motor speed), the setting range of P3 is insufficient. In this case P3 should be left in the right hand stop position and the excessively large motor speed is corrected by turning the nominal value potentiometer (P1 or P2) to the left.

In the case of very large tacho-voltages (as from 60V), the setting at potentiometer P3 becomes very coarse, i.e. small changes of the setting of this potentiometer produce large changes of the motor speed. For venire adjustment, the input potentiometer (P1 or P2) can be used in this situation too, as far as possible in the vicinity of its right hand stop position.

3.7 Offset Adjustment and Check for Absence of Feedback Effects

With the unit switched off, once again connect ampere-meter in place of the motor. Switched on an specify nominal value 0V via the control system, turn potentiometer P5 to its right hand stop position and adjust P4 to make the current reading as close zero as possible.

If the resistance value of R22 (DC voltage gain of the motor speed controller) is smaller then 100Ohms, it will probably not be found possible to find a stable and constant zero point in this adjustment. In this case, adjust P4 such that zero drift becomes as slow as possible.

With larger values for R22 (up to 680Ohms), the entire positive and negative current span should be covered in stable and symmetrical manner with P4. Under no circumstances should any instabilities arise here (dwell, abrupt changes, hysteresis, etc.). Any such behavior is evidence for a wiring error in the electrical installation of the complete system, or that some form of stray feedback into the control system is taking place. It is absolutely essential to trace and remedy such improper behavior, in the interests of accurate performance during subsequent operation.

After it has been verified that there are no unwanted feedback effects in the system, the symmetry of the pulse and rms current limiting functions con be checked next. For recovery of the I^2t circuit, make interim reduction of the current to zero. A slight asymmetry may be distributed uniformly between both directions, if the resulting characteristic thereby lies within the specified ± tolerance range. The potentiometer <u>P8 must not be used for correcting any such symmetry error</u>. The proper setting for P8 is dictated by the condition that the current must be zero when terminal Kl.8 is open circuit.

After these checks and adjustments, switch the unit off again, reconnect the motor and set P5 to its left hand stop position.

3.8 Optimization of the Control Behavior

By virtue of the high clock frequency and resulting large transmission bandwidth of the output stage, very little circuit complexity is required in the controller electronics. Therefore for most applications, performance optimization is confined to proper to adjustment of potentiometer P5 for the alternating voltage gain.

In some special cases it may also turn out to be necessary to fit an additional capacitor to filter the tacho-voltage (C5), to fit a different integrator capacitor (C4) or to change the DC voltage gain setting (R22). Proceed as follows for optimization:

a) Torsional resonance

If howling sounds with constant frequency (several hundred Hz) are emitted by the motor immediately after switching on, especially when the unit is set for high current limit values, even when potentiometer P5 is set to its left hand stop position, then the servo system is oscillating by torsional resonance of the tacho-generator. Disc rotor motors, which usually coupled to a tacho-generator with relatively large moment of inertia on a thin resilient shaft, are rather prone to this kind of trouble, because the resonance frequency of this mechanical oscillatory assembly may lie in the normal transmission band of the loaded servo amplifier. To suppress this torsional oscillation, the controller bandwidth in the speed control loop must be reduced such that the gain becomes smaller than unity in the vicinity of the resonance frequency. This is the purpose of the capacitor C5.

To make adjustment, connect a decade capacitor box to the otherwise unconnected soldering tie points and increase the capacitance step by step. After every increase, turn the potentiometer P5 to the right until oscillation commences, and then back to the left immediately. Oscillation thereby ceases at some potentiometer setting which is further to the left than the setting at which it commenced, due to the hysteresis of the system. The correct capacitance value has been found when further increase the capacitance just no longer reduces the width of the hysteresis. Any such further increase of the capacitance then merely causes deterioration of the dynamic control behavior (overshoot).

For the further procedure in commencing operation, leave the potentiometer P5 set just below the point at which initiated oscillation stops again.

b) Integrator capacitor C4

In a speed control system, the controlled shaft should respond as stiffly as possible, although brief overshoots are usually acceptable. This requirement is met by ensuring that the integrator capacitor C4 has a value which is no longer then absolutely necessary (e.g. 33nF).

On the other hand, the shaft must not overshoot in response to an overriding position controller, i.e. the integral gain factor must be small. This condition calls for a large value of C4 (e.g.0.22µF). But then the shaft shows large yield for a certain time after every abrupt load change. An optimum performance compromise must here be found with the aid of a decade capacitor box.

One way to obtain good stiffness as well as absence of overshoot in a position step response function, is to use the integral component switch-off feature (terminal Kl.15) <u>during the positioning process</u> (cf. Section 1.5 “integral component switch-off”).

c) DC voltage gain

An exactly defined static stiffness is often desired, particular for operation with an overriding position control loop. The static stiffness can adjusted with R22. Increasing the value of this resistor reduces the stiffness. The stiffness also depends on the setting of the input voltage divider P1 or P2, but not on the gain setting with P5.

4. Service Information

4.1 General Fault Tracing

The following table lists in concise presentation the most commonly encountered types of faults and their possible causes.

Fault Symptoms	**Possible Causes**
Shaft does not move, motor has no holding torque, no indication	Output stage enable (terminal 15) missing, supply voltage (terminal 26 missing, break in armature circuit, nominal current value jumper connection (terminal 7-8) open, +15V power supply defective, fine fuses blown in the controller or driver electronics (see components layout diagrams).
Shaft does not move, but motor has holding torque	Limit switch inputs (terminals 9-10, 11-12) are open circuit, output stage enable (terminal 16) missing (brake present), nominal speed value missing, motor shaft mechanically blocked.
Motor ”accelerates to maximum speed”	Tacho-voltage missing or tachogenerator connected with wrong polarity, break in tachogenerator circuit.
Fault status indication D37, red; relay drops off	Ground short fault, all-round arcing on slipring in motor, motor shaft blocked mechanically, motor heavily overloaded, fault in the electronic circuitry of the unit, defective output stage.
Fault status indication D38, yellow; relay drops off	Ballast resistance value too large, transformer voltage too high, fault in the ballast circuit (threshold value too high).
Fault status indication D37 + D38 (red + yellow); relay drops off	Interior temperature of unit too high, blower fan not operating (only for series 20K units).
No mechanical power, no fault status indication	Pulse current too small.
No mechanical power, I^2t response indication	Friction too great, armature short in motor, motor field excitation too weak, oscillation due to incorrect dynamic adjustment, I^2t current limiter incorrectly adjusted, mains ripple on the input line.
Motor speed too slow	Incorrect tachogenerator matching (P3), input signal attenuated too much (P1, P2), supply voltage too low, load to large.

Fault Symptoms	**Possible Causes**
Non-uniform rotation, armature current undulation too great	Tachogenerator defective, short circuit in armature, ground potential loops.
Unsteady running	Gain too large, undulation on the tacho-voltage too large, stray signal injection or positive feedback due to improper input circuit wiring.
Stationary state unstable	Input circuit wiring not correct.
Ballast resistor becomes too hot	Operating voltage too large, moment of inertia too large for the moving masses, braking cycles too frequent.

4.2 Short Circuit in the Output Stage

A low resistance multimeter suffices to determine whether a short circuit is present in the output stage. With the motor disconnected and without external load connected to the DC intermediate circuit (terminal Kl.36 open circuit), the defective quadrant can be found by the following procedure and associations:

Make measurements only with no power supply voltage connected.

Positive terminal of multimeter	Negative terminal of multimeter	Tested quadrant
38	36	positive-left
39	36	positive-right
37	38	negative-left
37	39	negative-right

The internal battery polarity for the Ohms range, which is opposite to the polarity for voltage measurements in most multimeters, has already been taken into consideration in the above table. After an initial kick of the meter pointer, a very high resistance reading should be obtained for all four measurements. If a low resistance reading is obtained, or if a direct short circuit is found, then a fault is present in one or several output stage transistors or in an inverse current diode.

To take out the output stage heat sink of a series 5K unit, the control electronics must be removed first of all. Then break the connections to the intermediate circuit current bus rails (accessible from the terminals side). After disconnecting the 16-pole tape cable plug on the driver circuit and releasing two screws in the baseplate (accessible from below), the heat sink can be swung aside. The connections to the choke and to the three-phase AC terminals 33-34-35 need not be broken for changing transistors in the output stage.

For series 20K units, the relevant side panel and one plastic component mounting screw each in the perforated panel and in the blower fan panel must be released. The control electronics and the driver electronics must be taken out too (both are plug-in subassemblies). After unsoldering the positive connecting leads which are accessible from above and releasing one screw each in the plastic holding feet, the heat sink can be swung aside so that the transistor connections are the fully accessible.

Both heat sink assemblies in a unit (left and right) are identical. The positive quadrant lies at the top on each heat sink assembly. Only transistors with the same color designation (same current amplification class) may be connected in parallel. Transistors from different manufacturers (recognizable by having physically different cases) should never under any circumstance be connected in parallel. Which one of parallel-connected transistors is defective can easily be determined by removing the collector bolts. When tightening the bolts, proceed uniformly and cautiously, so that the insulating where do not become damaged.

4.3 Replacing the Control Electronics

Occasionally it is necessary to replace the control electronics to remedy a fault. In this case it is essential to match the replacement assembly to the current and voltage capability of the basic unit, because otherwise the latter may suffer damage.

a) Voltage normalization of the commutation current limiter

Adjustment of this normalization is necessary only when the commutation current limiter is used. Adjustment is made with the resistors R112 – R115. Selected metal film resistors with ±1% tolerance must be used. The table at the end of this section specifies the proper values.

b) Overvoltage switching threshold

The diodes D32 and D33 (91Volts) together determine the overvoltage switching threshold, whereby an additional voltage of 15V is effective.

c) Current normalization

The resistors R109, R110 (on soldering tie points) determine the sensitivity for generation of actual armature current signal. Under no circumstances is it permissible to use higher values than those specified below (tolerance ±1%).

d) Excessive current switching threshold

The resistors R120, R121 (on soldering tie points) determine the excessive current switching threshold, one for each side of the output stage (tolerance ±5%).

e) rms current limit value

The resistor R145 determines the ratio of pulses current to rms current, i.e. the current boost factor. Under no circumstances is it permissible to increase its value above the limit values specified in the table.

f) Tables of values for selected components

Nominal Voltage	R112 – R115 ±1%	D32 ±5%
150V	165kOhms	100V
200V	221kOhms	150V

Nominal Current	R109, R110 ±1%	R120, R121 ±5%	R145 ±5%
10A	3.83kOhms	22Ohms	22kOhms
25A	8.87kOhms	470Ohms	33kOhms
35A	13.7kOhms	120Ohms	27kOhms
50A	11.3kOhms	220Ohms	18kOhms
70A	16.5kOhms	100Ohms	18kOhms
100A	25.5kOhms	56Ohms	18kOhms

4.4 Replacing the Driver Electronics (with ballast circuit)

Severe faults in the output stage may lead to consequential damage to the driver electronics. Fault localization in this assembly is usually very tedious, so that replacement of the complete assembly is recommendable. It is thereby quite essential to observe the proper nominal voltage rating (150V or 200V); the difference lies the threshold voltage for the ballast circuit. The voltage determining component is the resistor R33 according to the formula:

$$R33 = \frac{U_s - 8.8V}{4*10^{-4}A}$$

If resistors with ±1% tolerance are used, it is generally not necessary to readjust the threshold voltages.

Nominal Voltage	R33 ±1%	Threshold voltage of the ballast circuit (on/off)
150V	453kOhms	195/185V
200V	590kOhms	250/240V

4.5 Replacement Parts

In order to be able to make immediate repairs in the case of system breakdowns, it is advisable to hold the following replacement parts ready in stock. To repair faults in the electronic circuitry it is usually better practice in the interests of rapid restoration of normal operation, to replace the complete circuit card, whereas replacement of individual transistors in the output stage is readily possible. However, the chief single components of the electronic circuitry are of course available as replacement parts too.

<u>List of recommended stock replacement parts for series 5K units</u>

1 Control electronics, 150V or 200V (specify current rating)
1 Driver power supply with ballast circuit, 150V or 200V
2 Plug-in driver modules
3 Output transistors BUL 5032 (for 25A and 35A units)
2 Driver transistors BUX 48
3 Output transistors BUL 1532 (only for 10A untis)
1 Fast diode DSD 17 (for 10A and 25A)
1 Fast diode DSDI 17 (for 10A and 25A)
1 Fast diode DSD 35 (only for 35A)
1 Fast diode DSDI 35 (only for 35A)
2 Rectifier diodes DS 17
2 Rectifier diodes DSI 17
1 Measuring resistor RH-25 0.01Ohms (0.1Ohms for 10A)
1 Ballast resistor HLZ 275 5.6Ohms
2 Fuse cartridges, 0.1A rapid blow (for control electronics)
2 Fuse cartridges, 1A rapid blow (for driver electronics)
1 Set of integrated circuits for the control electronics
2 Sets of resistors and diodes for all currents an voltages
2 Driver transistors BD 301
2 Driver transistors BDX 34
1 Driver transistor 2N3440 (with U_{CEO} at least 300V)

1 Driver transistor 2N5416
5 Small signal transistors BC 327-25
5 Small signal transistors BC 337-25
2 Small signal transistors BF 421
2 Small signal transistors BF 420
1 Power transistor IRF 712
1 Power transistor IRF 720
2 Electrolytic capacitor ECE-E 22µF/35V
2 Fast diodes BA 157
5 Transistor insulating washers TO-3

<u>List of recommended stock replacement parts for series 20K units</u>

1 Control electronics, 150V or 200V (specify current rating)
1 Driver circuit with ballast circuit, 150V or 200V
10 Output transistors BUL 5032
1 Fast diode DSD 35
1 Fast diode DSDI 35
2 Rectifier diodes DS 75
2 Rectifier diodes DSI 75
2 Measuring resistor RH-50 0.01Ohms
2 Fuse cartridges, 0.1A rapid blow (for control electronics)
2 Fuse cartridges, 1A rapid blow (for driver electronics)
1 Blower fan, type 7950, for 230V
1 Set of integrated circuits for the control electronics
2 Sets of resistors and diodes for all currents an voltages
2 Driver transistors BD 905
2 Driver transistors BDX 34
1 Driver transistor 2N3440 (with U_{CEO} at least 300V)
1 Driver transistor 2N5416
5 Small signal transistors BC 327-25
5 Small signal transistors BC 337-25
2 Small signal transistors BF 421 (or BF 423 with U_{CEO} 300V)
2 Small signal transistors BF 420 (or BF 422 with U_{CEO} 300V)
1 Power transistor IRF 712
1 Power transistor IRF 720
2 Electrolytic capacitors ECE-E 22µF/35V
2 Fast diodes BA 157
1 Fast diode BYW 98-50
10 Transistors insulating washers TO-3

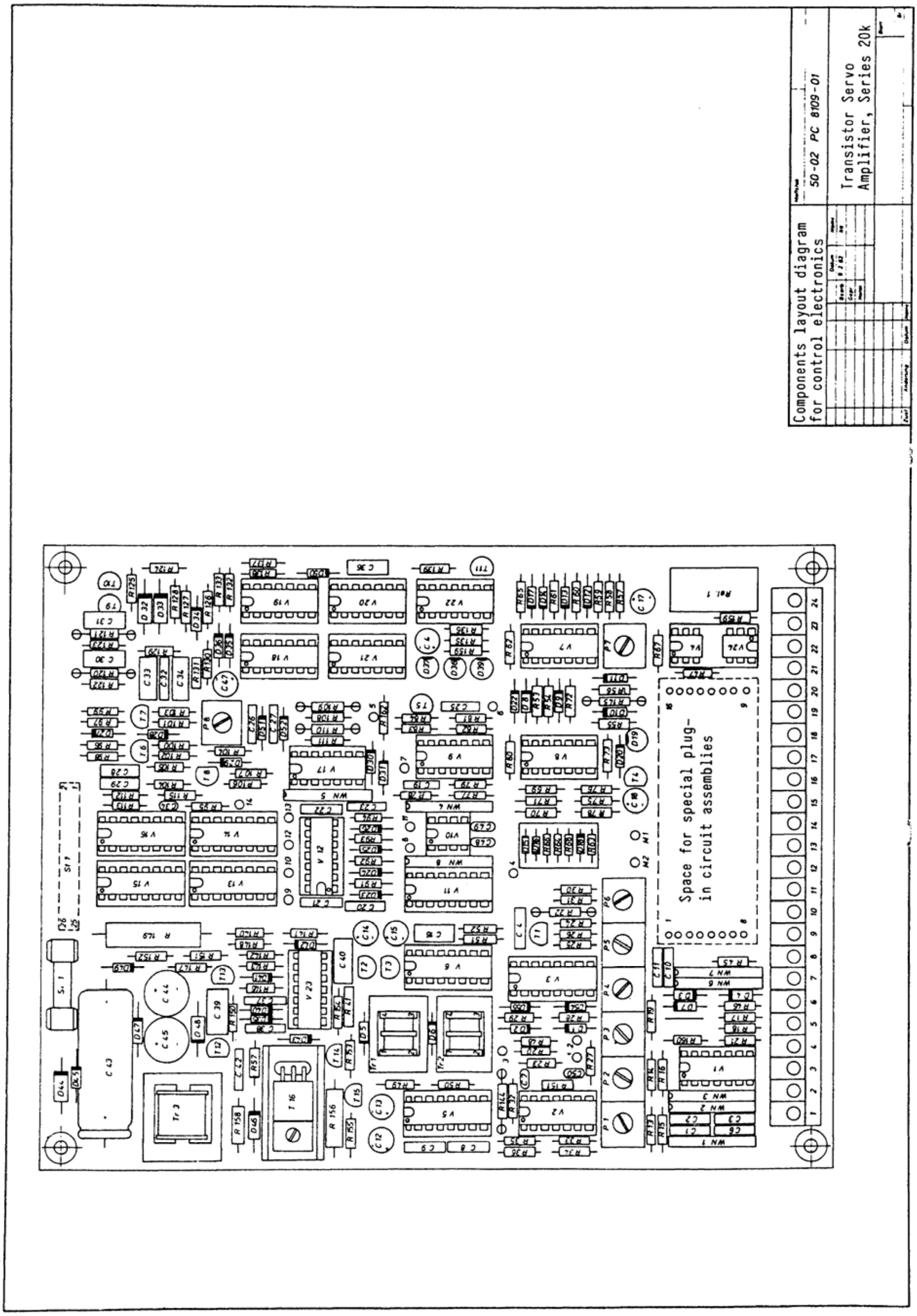

Figure 15: Components layout diagram for control electronics

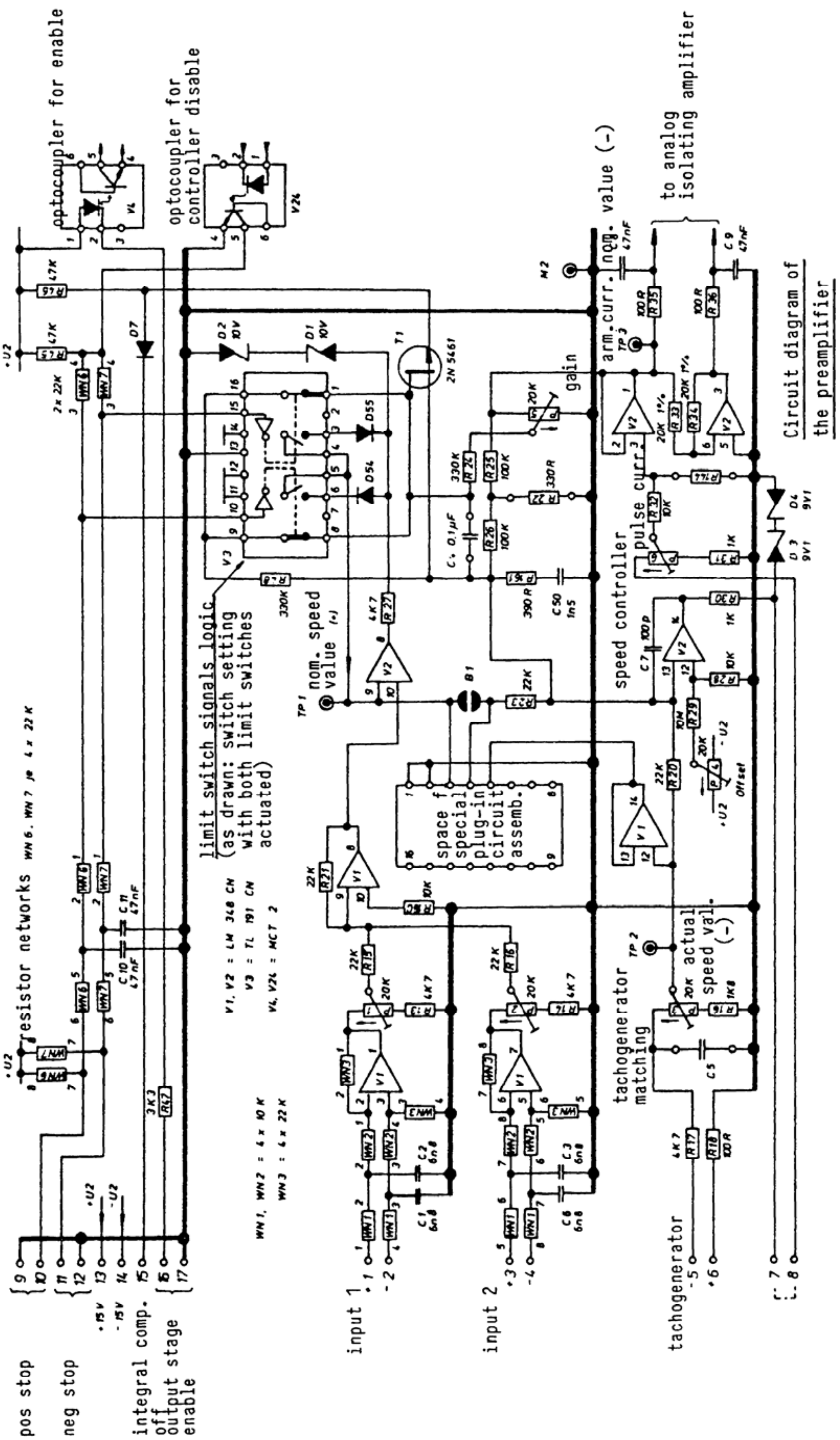

Figure 16: Circuit diagram of the preamplifier

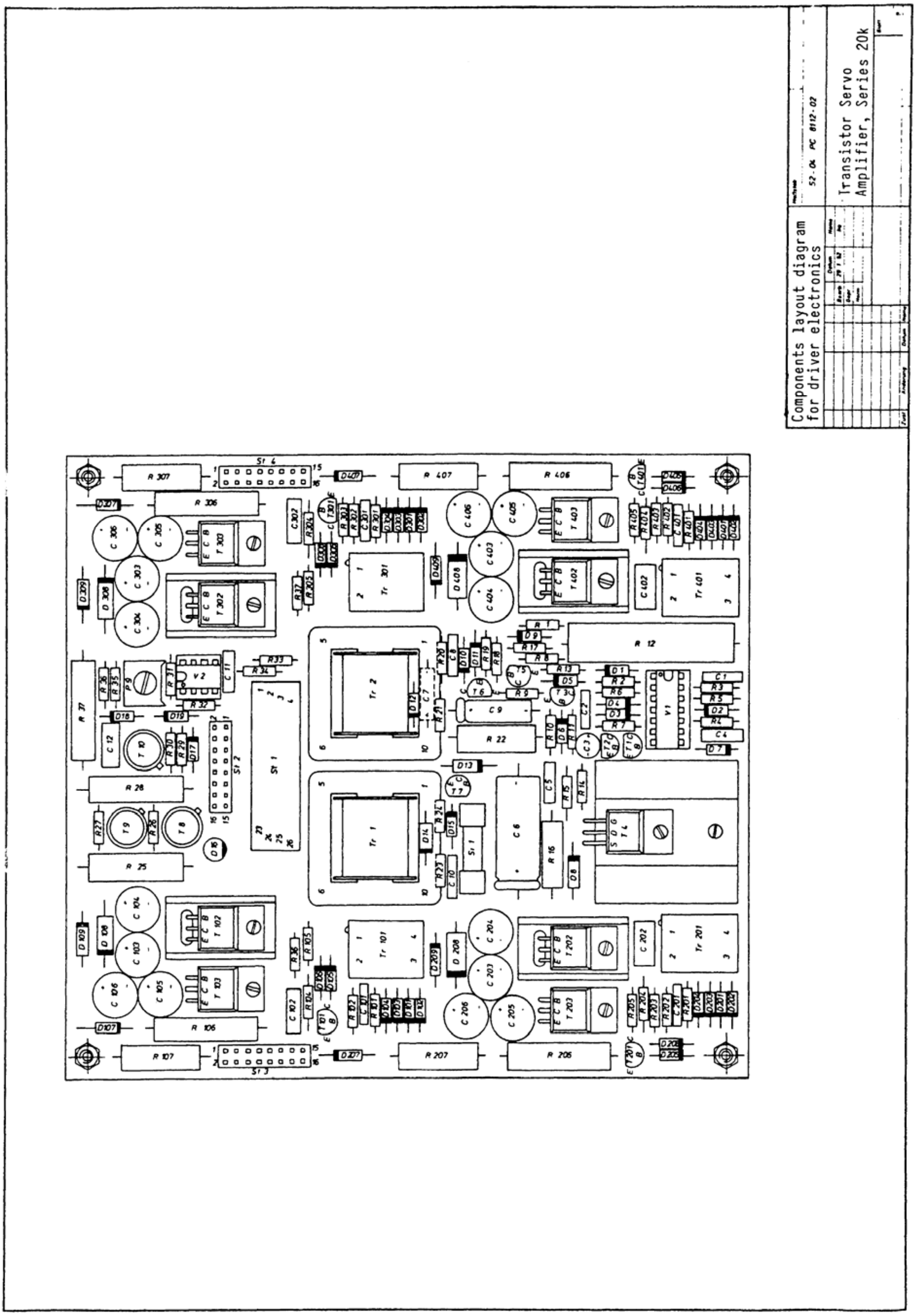

Figure 17: Components layout diagram for driver electronics

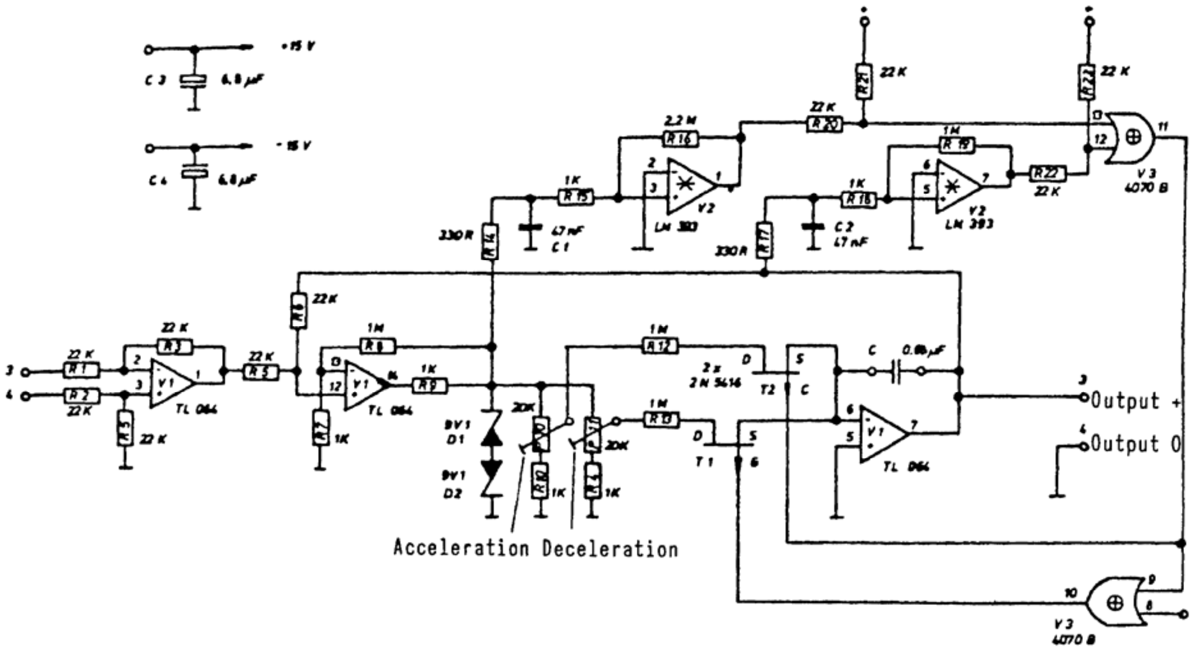

Figure 18: Circuit diagram of ramp generator

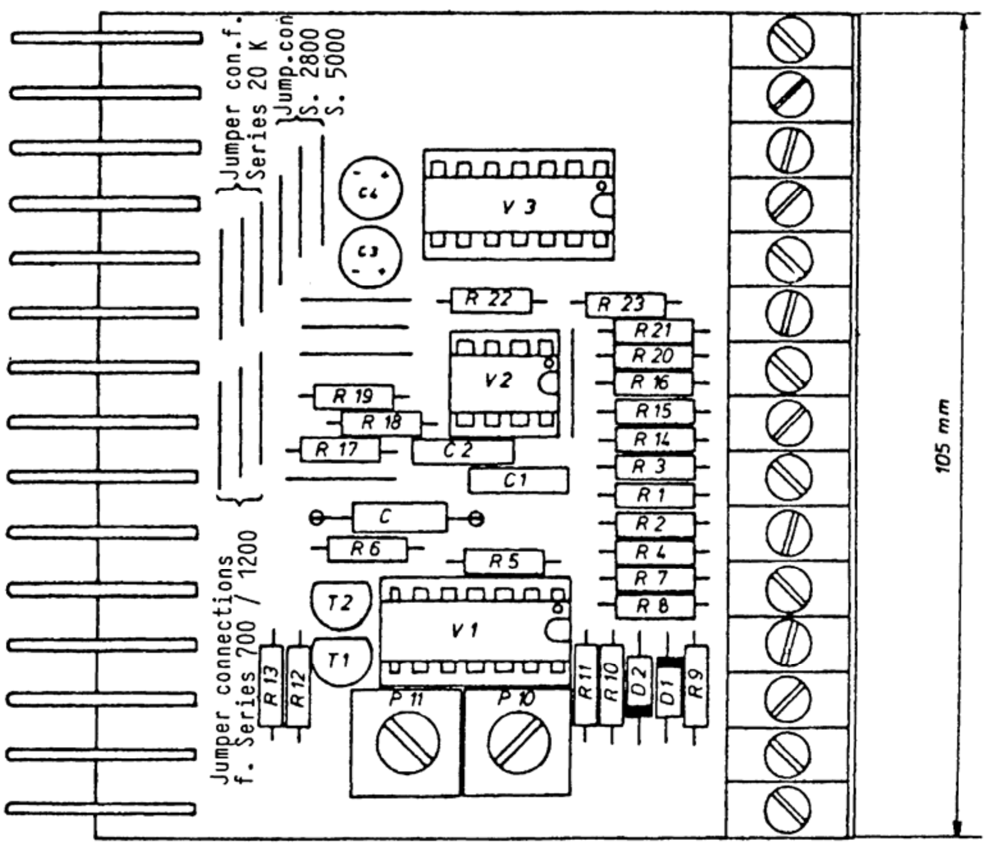

Figure 19: Components layout diagram of ramp generator

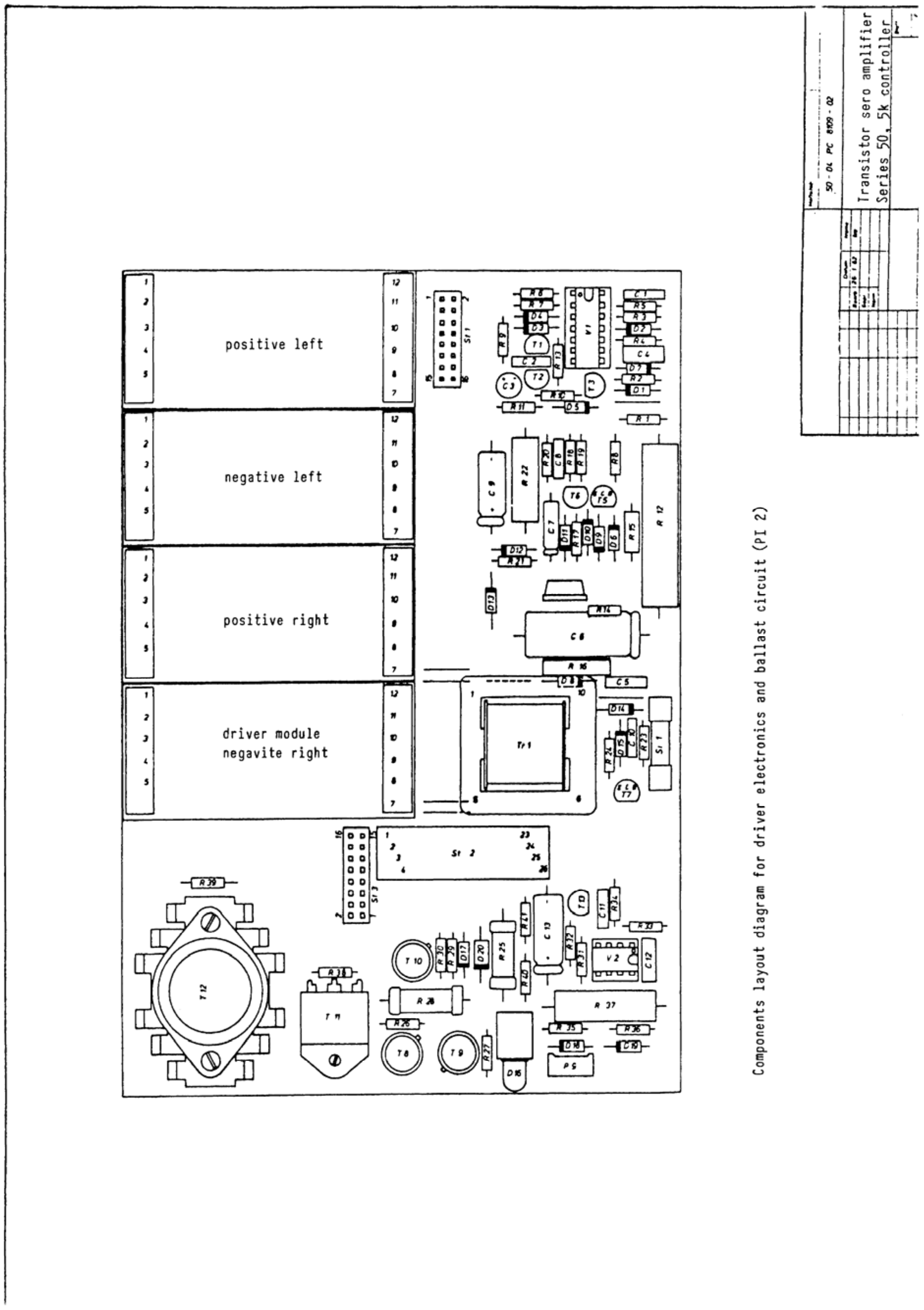

Figure 20: Components layout diagram for electronics and ballast circuit

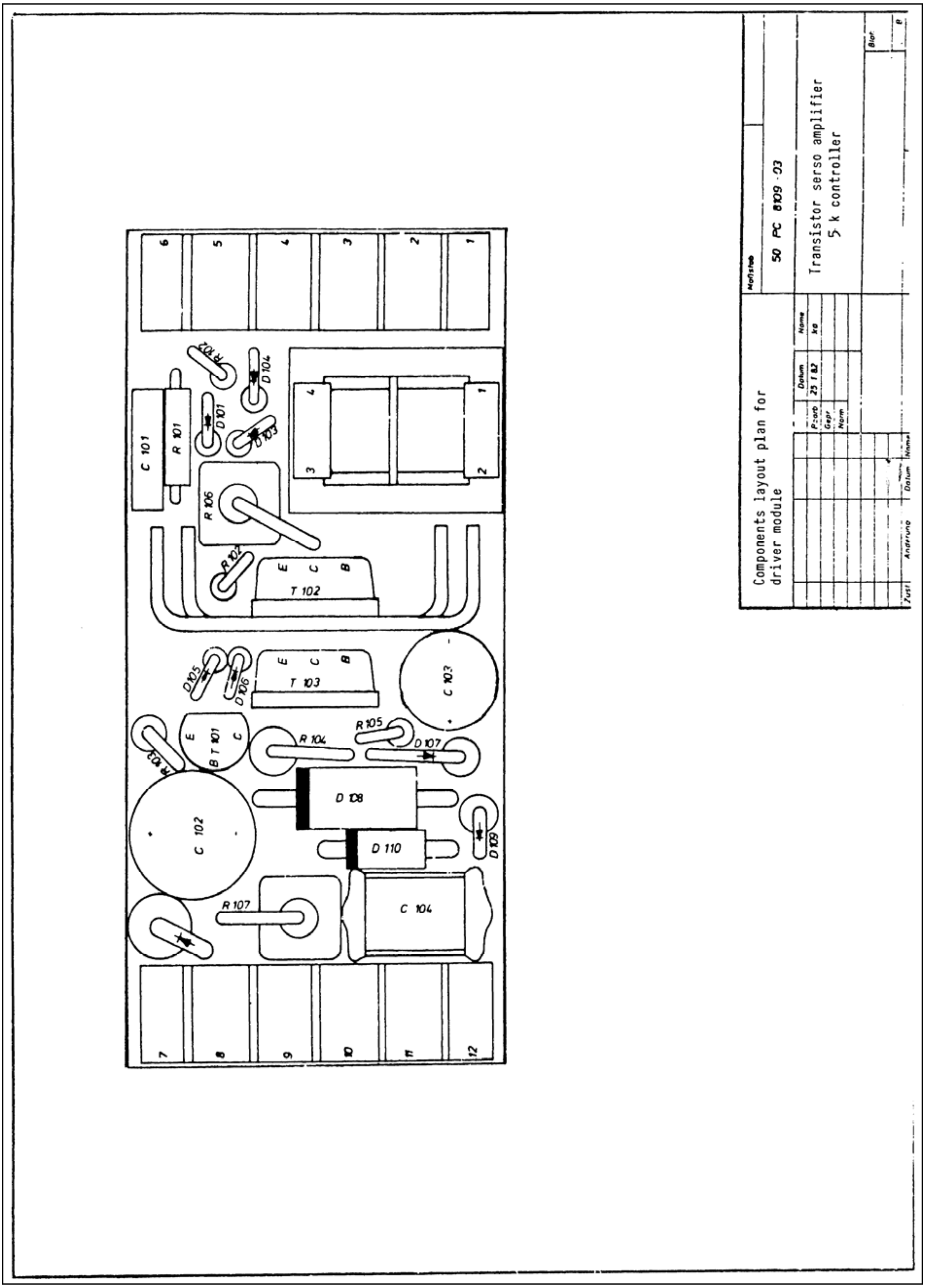

Figure 21: Components layout for driver module

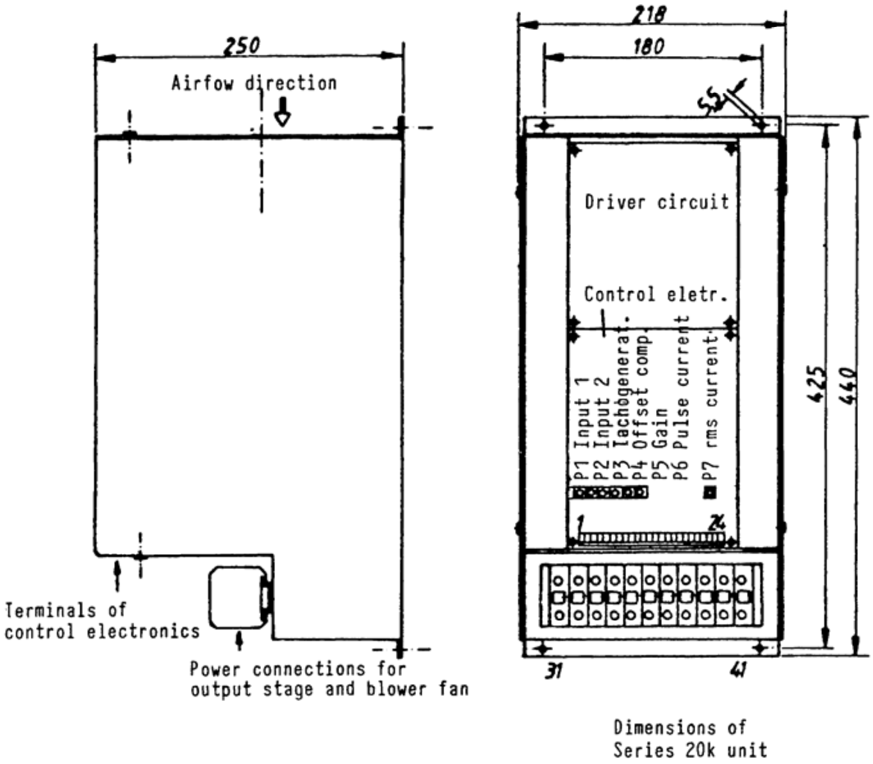

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Figure 22: Dimensions of Series 20K unit

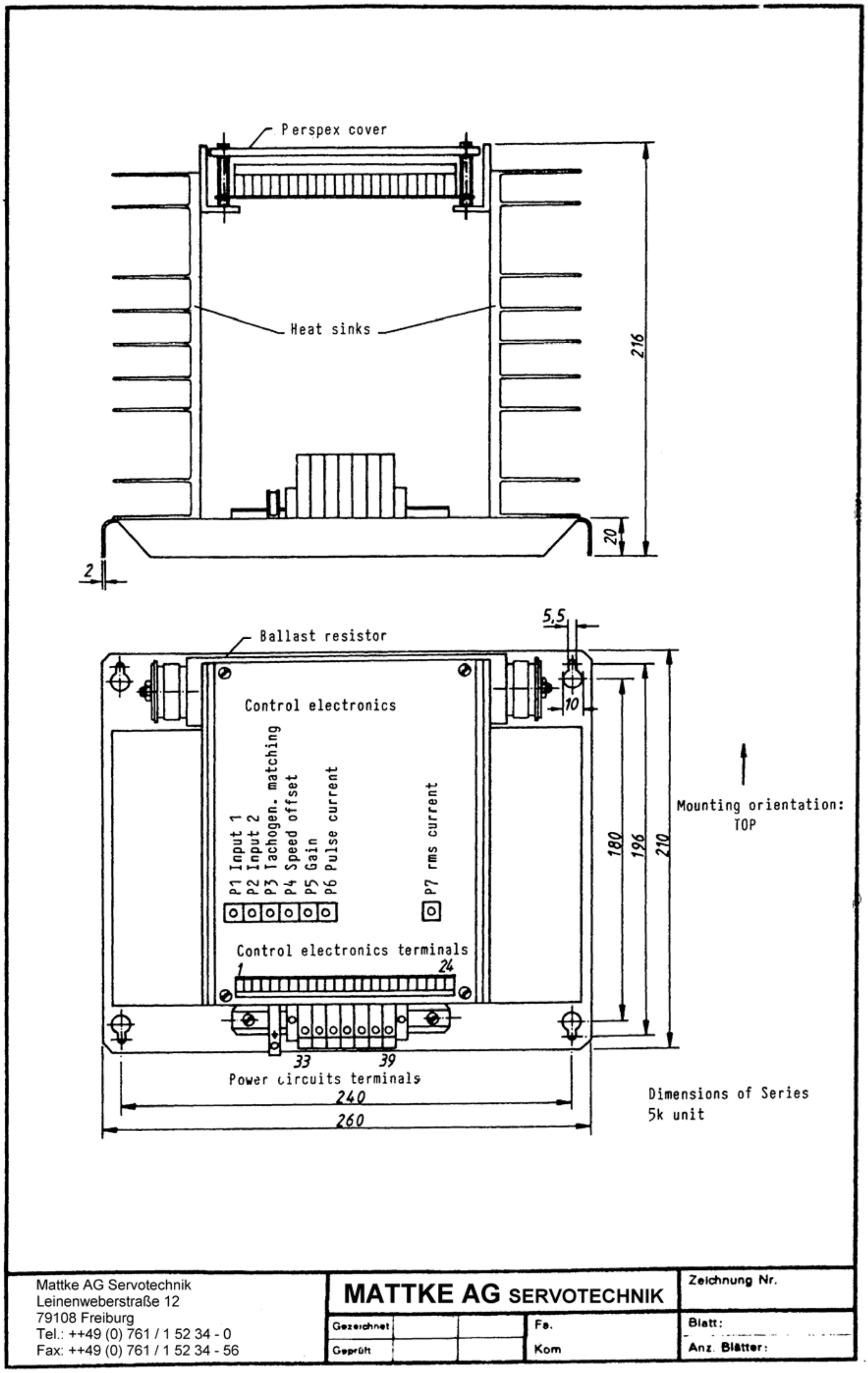

Figure 23: Dimensions of Series 5K