# HIGH VOLTAGE POWER SUPPLIES FOR ION BEAMS ELECTRON COOLERS

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*Abstract*

High voltage power supplies, developed for feeding the electron coolers EC-35 and EC-300, are described in this report. Stabilized voltage power supplies with output voltages 35 kV and 300 kV with the current up to 5mA and stability up to $10^{-5}$ are used for electron cooling of heavy ion beam. Under high potential of these power supplies there are many auxiliary power supplies, feeding the gun, control electrode, suppressor and control electronics. In this report the original decisions underlying in development of power supplies are considered. The electron coolers were developed under the contract between Budker Institute of Nuclear Physics (Novosibirsk, Russia) and Institute of Modern Physics (Lanzhou, China)

## INTRODUCTION

Two electron coolers were created by Budker Institute of Nuclear Physics (Novosibirsk, Russia) for Institute of Modern Physics (Lanzhou, China). The coolers were created within the international project for heavy ions research [1].

These devices allow carrying out the experiments on the internal and external targets. Such experiments require the high quality of ion beams. Electron coolers are used to reach this quality. Since ion beams are cooled by "cool" electron beams, they should correspond to special requirements: 1) electrons speed should be equal to ions speed, 2) transverse impulse must be enough small. Therefore electrons coolers require the high voltage power supplies with high stability. For that purpose two high voltage power supplies were developed and manufactured. One of them is for electron cooler with electron energy up to 35keV, other one is for electron cooler with electron energy up to 300keV. The parameters of power supplies are shown in the Table 1.

Table 1.

| Cooler Parameters\ | Units | 35 keV | 300 keV |
|---|---|---|---|
| Maximal voltage | kV | 35 | 300 |
| Minimal voltage | kV | 2 | 25 |
| Maximal current | mA | 3 | 5 |
| Instability of output voltage | -- | $10^{-5}$ | $10^{-5}$ |
| Maximal ripple level | -- | $10^{-5}$ | $10^{-5}$ |

## PRINCIPAL PART

### *Functional Circuit Diagram of the 35kV Power Supply*

The circuit diagram is presented in Fig.1. Main regulator of power supply is pulse-width modulator (chopper) with internal feedback system for suppressing the ripples of Input Power Line Rectifier. Chopper output voltage comes to transistor inverter, which operates at the frequency 20 kHz. Inverter output voltage comes to step-up transformer, then diode-capacitor voltage multiplier. Inverter frequency is equal to the resonant frequency of "step-up transformer – voltage multiplier" system.

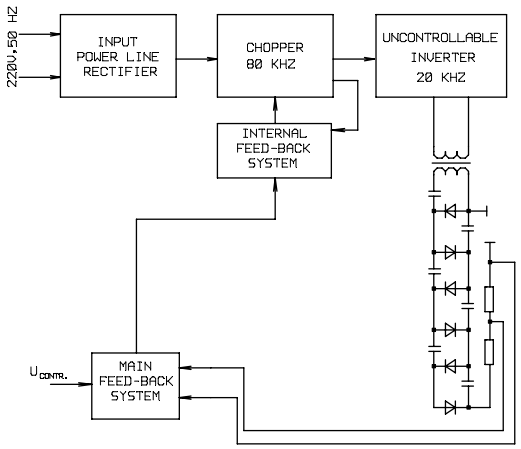


Figure 1: Functional circuit diagram of 35 kV power supply.

Voltage multiplier and step-up transformer are placed in special oil-filled tank. Voltage to be measured comes through resistive divider to Main Feedback System. It is used for chopper output regulation and output voltage stabilization. The power supply is fed by standard power line 220V/50Hz and has computer control by using of internal multi-channel DAC-ADC. Power supply monitoring (circuit breaker status, chopper output voltage measurement, output high voltage measurement) is realized also by this DAC-ADC.

### *High Voltage Rectifier 300kV*

Main and most difficult part of 300kV power supply is high voltage rectifier. Simplified circuit diagram of the rectifier is shown in Fig.2.

High voltage rectifier is sectioned rectifier column with capacitive coupling to primary circuit. Rectifier sections are fed in parallel by their inputs, but they are connected in series by their outputs. Parallel feed of all these sections through the high voltage gaps provides the equal loading all the rectifier diodes. Exciting electrodes 1 and 2 are placed inside the tank 5 along all its height. High frequency voltage comes to these electrodes. The Rectifier sections are placed one over another and behind the electrodes. Every section consists of receiving electrodes 3 and 4, diode bridge rectifier and capacitive filter. In the center of sections there is a hole for the high voltage dividers.

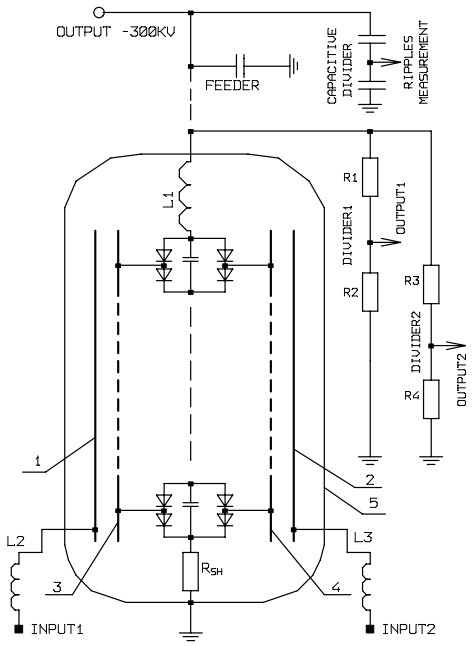


Figure 2: Simplified circuit diagram of high voltage rectifier.

The number of sections depends on required output voltage (300 kV) and voltage on single section (20 kV). To choose smaller voltage is not advisable because of excessive increase of sections number and decrease of capacitive coupling with exciting electrodes. But in case of ultrahigh voltage the choice of high voltage diode becomes more difficult. The distance between the electrodes 1-3 and 2-4 is determined by output voltage of high voltage rectifier and electrical resistibility of insulation. Based on that, the dimensions of the high voltage rectifier, diodes type, insulation gaps, were chosen. The intervals between the plates 1-3 and 2-4 are 60mm. The same distance is between plates 1, 2 and tank wall. The height of the rectifier tank is 1.6m, its diameter is about 1m. The number of sections is 15, with rectified voltage 20 kV per each section. Capacitance between the electrodes 1-3 и 2-4 is about 25pF and it is inserted in series with the load. So the feed of such construction must be realized by AC voltage with enough high frequency (320 kHz were chosen), otherwise voltage drop in this capacitance should be very high. For getting such high voltage on exciting electrodes two series-resonant circuits with frequency 320 kHz are used. Necessary condition of high efficiency and enough high voltage on the electrodes is high quality factor of resonant circuit. The inductances L1 and L2 are air-gap chokes. The capacitors of resonant circuit are capacitances between the electrodes 1-3 and 2-4. The windings of inductances are made by 5 twisted high frequency wires (Litz wires). The Q-factor of resonant circuit is about 150-160. At the output of high voltage rectifier there is air-gap choke L1 used for suppression of the ripples and for electric breakdown protection. The capacitance of a feeder and L1 forms LC-filter with resonant frequency about 10 kHz. The tank is filled by SF6 under redundant excessive pressure 0.7 atm.

## *High Precision Voltage Dividers*

Main elements in stabilization system are two high precision resistive dividers. Main technical problems, which must be solved when developing high voltage dividers, are following:

1) Prevention of leakage current and corona discharge of dividers parts.

2) Absence of over – voltage in the dividers parts in case of dielectric breakdown.

3) Getting the wide (as wide as possible) frequency bandwidth of dividers.

4) Shielding

Taking into account, that construction of high voltage column is multi-section device of voltage combining, one of most preferable variant is creation of a space inside the high voltage rectifier. This space has the form of trunk with screening rings, which are equipotential to high voltage sections of rectifier. Moreover, around the dividers there are so-called balancing rings.

Stray capacitances along balancing rings form the natural capacitive divider. Distributed potential along these rings removes the transverse field between the rings and dividers. Both of dividers are placed along the axis line of rectifying column and are encircled by the line of balancing rings. It results in realization of above-listed requirements.

1) First divider is wide-band; it is included in the feedback loop of the output voltage stabilization. Moreover, it has an electric contact with balancing rings and serves for smoothing electric potential along high voltage column. The resistors of this divider are film resistors, HVRS-43-E type, 200MOhm 10kV, Ohmcraft company. They have grade of accuracy 0.1%, temperature coefficient +25 ppm/°C in the range of temperatures from 0°C up to +125 °C. The number of resistors is 60.

2) Second resistive divider is used for high precision measurement of high voltage.

The micro – wire resistors of C5-23-M1-1 type 200MOhm 30 kV meet all the requirements. Temperature coefficient not more than +/-5ppm/°C. Number of resistors is 10. Total value of temperature

coefficient was minimized by special selection of the resistors with temperature coefficient of different character.

Schematic diagram of high voltage rectifier section is shown on Fig.3.

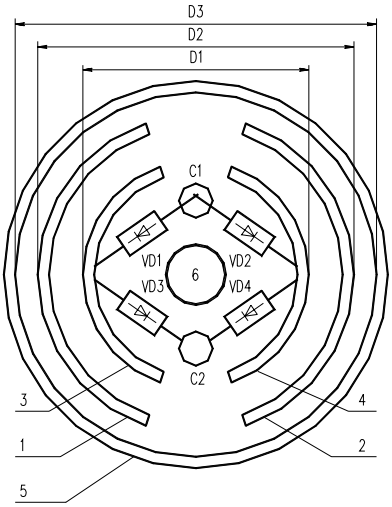


Figure 3: Schematic diagram of rectifier section.

VD1-VD4 – high voltage diodes of rectifier section. The hole 6 – «trunk» with precision dividers. C1, C2 – capacitance of section filter. 5 – tank wall; 1 and 2 – exciting electrodes; 3 and 4 – receiving electrodes.

### *Capacitive Voltage Divider*

Capacitive voltage divider is used for high voltage ripples measurement. Divider are form ed by construction capacitances between metal tube of feeder and hollow cylinder, inserted in feeder (high voltage capacitance), and cylinder surface and grounded body of feeder (low voltage capacity). The value of high voltage capacity is about 23pF. Division factor is approximately 1200. This divider permits to measure the voltage ripples in the frequency range from 10 Hz and higher. Measured voltage from this divider is used to increase stability of feedback loop and to measure the ripples. Following power supply circuit were developed to feed high voltage rectifier.

### *Functional Circuit Diagram of 300kV Power Supply*

Functional circuit diagram is shown in Fig.4. Main functional parts of power supply are: DC-converter VCH-300 (modernized) [2] with galvanic insulated output, high frequency inverter 320 kHz, high voltage rectifier, three high voltage measuring devices (capacitive and two resistive), voltage stabilization system. VCH-300 has the internal feedback loop for suppressing ripples of power line (50, 100, 150, 300 Hz).

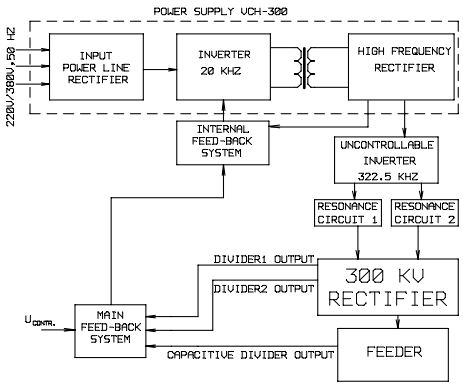


Figure 4: Functional circuit diagram of 300 kV power supply.

Voltage from high frequency rectifier comes to high frequency inverter, operating on a frequency 320 kHz. Inverter has two outputs, loading to two equal resonant circuits. Voltage from resonant circuits comes to high voltage rectifier. Resonant circuits, connected in series with high voltage rectifier, have the resonant frequency about 320 kHz. High frequency inverter is adjusted on this frequency. As stated above, high voltage rectifier has two resistive dividers and one capacitive divider. The measurement of all the voltages comes to main feedback system, which controls VCH-300 converter.

## CONCLUSION

Two power supplies with output voltages 35kV and 300 kV and output currents 3mA and 5mA are developed and manufactured. The 35 kV power supply works in electron cooler in the accelerator of IMP (Lanzhou, China). The 300 kV power supply was tested in the same accelerator.

## REFERENCES

[1] Parkhomchuk V.V., Bocharov V.N., Bubley A.V., Veremeenko V.F. “Electron cooler project for IMP (Lanzhou, China)” XVII Conference for particle accelerators, Protvino, 17-20 October 2000, p. 133-136

[2] Antonov V.V., Veremeenko V.F., Ermolov E.V. “Developing high-precision power supply with IGBT-modules.” XVII Conference for particle accelerators, Protvino, 17-20 October 2000, p. 16-18