HIGHLY STABILIZED ELECTRON ACCELERATORS FOR ELECTRON MICROSCOPY AT EXTRA-HIGH VOLTAGES

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Summary

Interest in higher voltages for electron microscopy was stimulated by the successful operation of the world's most powerful electron microscope operating at a maximum voltage of 1.5 MV. Other installations have since been built covering the voltage range of 500 kV to 1 MV.

A 1 MeV electron accelerator of the new pressurized type design is being constructed. The dc power supply and the accelerator are housed in separate pressure vessels and connected by a shielded high voltage cable.

Projects involving electron accelerators up to 4 MeV are now under consideration.

Electron accelerators of the air-insulated design

The first electron microscope designed to operate at an extra-high voltage was constructed by G. Dupouy at the Institute of Electron Optics, Toulouse, France.[1] The layout and performance of the 1.5 MeV electron accelerator for this microscope was discussed at the First Particle Accelerator Conference in 1965.[2] When built, Dupouy's microscope was 10 times more powerful than existing electron microscopes of standard industrial design and 5 times more powerful than research instruments available at that time. Until the Toulouse electron microscope proved successful, the pessimistic view existed that at voltages above 500 kV contrast would suffer to such an extent that it would be impossible to take micrographs.

The positive results obtained from the 1.5 MeV microscope have encouraged and initiated further projects, such as the 750 keV electron microscope of the Cavendish Laboratory at Cambridge, England (microscope design by Dr. V. E. Cosslett), and the 1 MeV microscope for the Research Center of the United States Steel Corporation at Monroeville, Pennsylvania (microscope supplied by RCA, Camden, New Jersey) scheduled to start operating shortly.

General design considerations

The electron accelerators used for the supply of high energy microscopes must comply with the following requirements:

1. During the exposure time of the micrographs, which may be as long as 3 minutes, the required stability of the accelerating voltage including ripple and noise must be 1 part in 100 000 or better.

Special high filters were designed in order to reduce the voltage ripple to this figure. In view of the very high overall stability, the components in the high voltage regulating loop must have a stability better by a factor of 5 or 10 than the intended final stability of the accelerating voltage. In particular, this holds true for the ohmic-capacitive measuring potentiometer of the accelerating voltage, the reference voltage source and the amplifiers in the regulating circuit.

From experience it is known that due to the stray capacitances of such installations, ripple voltages will occur. Corona discharges, which normally can be tolerated in other less critical applications, must be completely eliminated.

Therefore, the air-insulated electron accelerators were designed with low voltage stress and large clearances.

2. Microdischarges in the accelerating tube i.e. fast fluctuations of even a few volts cannot be tolerated. The accelerating column must be conditioned up to higher voltages than the intended maximum operating voltage.

3. Mechanical vibrations, even of small amplitude, must be eliminated. As a result, no moving or vibrating parts can be included in the accelerator. The same applies to ac transformers where hum and magnetic stray fields are equally un-

desirable.

4. The entire path of the electron beam, between the cathode and the entrance aperture of the electron microscope, has to be shielded against the influence of the magnetic field of the earth which would otherwise strongly deflect the electrons from the axis of the acceleration tube. For this reason, the electrodes must be made of mumetal and the accelerating gaps must be covered by shields of the same material.

5. Electronic equipment, in particular with solid state components for the supply of the electron gun at high voltage potential should be avoided. In such equipment, breakdowns in the accelerator would cause malfunctions.

1 MeV electron accelerator of the air-insulated design

The main parts of a 1 MeV air-insulated accelerator are:

- Electronic supply and regulating system.
- 1 MV dc power supply of the Cockcroft-Walton type with additional filter stack.
- Electron gun, acceleration tube, vacuum equipment and accelerator structure.

Figures 1 and 2 illustrate some of these parts.

The supply and regulating system for the electron accelerator are fully electronic. The medium frequency ac voltage is generated by a RC oscillator and applied to the high voltage transformer of the cascade generator through a modulator, driver chain and power amplifier. The Cockcroft-Walton cascade rectifier consists of 5 stages of 200 kV each and includes one coupling and one smoothing column and 10 high voltage selenium rectifiers. An additional filter stack is connected to the dc capacitors in order to reduce the ripple voltage. The three capacitor columns which support the high voltage terminal of the cascade generator, are mounted on a common base plate.

The accelerator structure is connected to the cascade generator through a high-ohmic damping resistor which is designed to protect the cascade rectifier and the acceleration tube from flashovers. Moreover, this damping resistor, together with the capacitive part of the voltage divider, forms an additional filter.

The accelerating tube consists of porcelain isolators sealed together by metal flanges and double O rings. The accelerating electrodes are made of highly polished mumetal. To further cover the accelerating gaps between the electrodes cylindrical shields of mumetal are provided. Entire mumetal screening is necessary to minimize the effect of the magnetic field of the earth on the electron beam.

The accelerating tube is surrounded by several insulating cylinders, which support the high voltage terminal of the accelerator structure. These insulating cylinders are mounted on a common base-plate, whereas the acceleration tube is free-standing and self-supporting and directly mounted on top of the electron microscope. One of the insulating cylinders contains the ohmic-capacitive voltage divider used in reading the accelerating voltage and controlling the regulating system. Another insulating cylinder contains the insulating shafts of the remote controls for the electron gun. In parallel to the accelerating column in a third insulating cylinder is a bleeder-chain. The fourth insulating cylinder contains a coupling capacitor for the compensation of the residual ripple voltage at the high voltage terminal of the accelerator structure.

The electron gun and its auxiliary equipment is inside the high voltage terminal. The cathode of the gun is of the pinpoint type and energized from a battery. The electron gun accepts 6 cathode cartridges which can be changed by remote control. The anode voltage of the electron gun is obtained from a potentiometer which is connected in series with the bleeder-chain of the accelerating tube. This system makes it possible to keep constant the ratio of the anode voltage to the accelerating voltage. In the injector system, underneath the anode are two pairs of deflecting plates for the X- and Y-deflection of the electron beam. The deflecting bias is obtained from a portion of the anode voltage potentiometer. Insulating shafts, which are driven by servo-motors at ground potential, are designed for the remote control of the equipment at high voltage potential. These remote controls are intended for

- the adjustment of the beam current,
- the fine focusing of the electron beam,

- the X-deflection,
- the Y-deflection,
- the change of the cathode cartridges.

Further remote controls monitor the battery for the beam current and the Wehnelt battery.

An automatic feed-back control is designed to adjust the Wehnelt voltage proportional to the accelerating voltage. This feed-back loop is controlled by the current reading of the bleeder-potentiometer.

Inside the high voltage terminal on a common frame are several meters, read through a television camera at ground potential.

A pumping manifold is connected to the bottom end of the accelerating tube. The vacuum system consists of a 3-stage oil diffusion pump, a refrigerated baffle, a fore-vacuum pump and various valves and vacuum gauges. The vacuum system is designed for automatic operation.

A rotating pick-up electrode is installed in the pumping manifold. This electrode together with an oscilloscope measures the deviation of the beam from the optical axis of the acceleration tube and the beam density profile. It facilitates the adjustment of the electron beam at the entrance aperture of the electron microscope.

The electronic regulating system is connected to the ohmic-capacitive voltage divider, which reads the accelerating voltage. The output signal from the secondary of the voltage divider is compared with the output from an adjustable reference voltage source. Any differences between the secondary voltage of the potentiometer and the reference voltage, i.e. error signals, are amplified by ac and dc amplifiers and passed through a mixer amplifier. In the modulator the amplified error signals are used to modulate the amplitude of the base frequency which is then applied to the grids of the electron tubes in the power amplifier.

A 3-phase bridge circuit using silicon diodes is used as dc power supply for the power amplifier.

In view of the high internal impedance of the 10 kc/s transformer, it became necessary to introduce another feed-back loop into the regulating system. For this purpose the high voltage transformer is equipped with a third winding. It delivers a control voltage which passes through a rectifier and filter circuit to the modulator. This regulating loop corrects the voltage drop of the high voltage transformer.

In spite of the fact that two filter circuits are used to reduce the ripple voltage, it is necessary to apply an additional compensating voltage to the high voltage terminal of the accelerator structure for smoothing the accelerating voltage still further. The compensating voltage is obtained from the measuring winding of the high voltage transformer. Thus, the compensating voltage is automatically adjusted in proportion to the ac input voltage of the cascade rectifier. The compensating voltage from the transformer is applied to the high voltage terminal through the coupling capacitor which is contained in one of the insulating supports of the accelerator structure.

The electronic supply and regulating system, as well as the controls for the accelerator are built into 19 inch standard racks.

Automatic interlocks and protective devices are designed for the protection of the entire installation in case of over-voltages, over-currents, flashovers, and failures in the vacuum system.

1 MeV electron accelerator of the pressurized design

In view of the increasing interest in these special electron accelerators, a new pressurized 1 MeV model is now being designed. In this new design the high voltage dc power supply and the accelerator are enclosed in separate aluminum tanks filled with pressurized sulphur hexafluoride gas. The two units are connected by a shielded 1 MV cable.

The 1 MV dc power supply is basically the same as in the air-insulated type. The Cockcroft-Walton generator including the high voltage transformer and the filter stack are assembled in a pressure vessel which can be installed either horizontally or vertically.

The pressure tank of the accelerator is designed for vertical installation. Components used in this design are of reduced size due to the pressurized atmosphere.

The metal enclosures of the two units provide perfect screening against ac voltages, and the capacitance of the shielded high voltage cable has an additional filtering effect. It is assumed, therefore, that the coupling capacitor for ripple compensation will be eliminated.

Both in the case of the dc power supply and the accelerator, the high voltage cable enters the installation through a flange in the lower part of the pressure vessel. This design offers the advantage that the upper part of the pressure tank can easily be removed without dismantling the cable termination.

The use of pressurized gas reduces the overall dimensions of the installation. With respect to the electronic supply and regulating system, no modifications are necessary.

Future trends

Electron microscopes up to 1 MeV will shortly become commercially available. However, future trends point toward still higher energies. At some research laboratories, projects for the construction of installations with operating voltages as high as 5 MV are under consideration.

Figure 3 shows the simplified layout of a 3 MeV electron accelerator with a maximum operating voltage of 4 MV; the 4 MV value includes the safety margin necessary for conditioning the accelerating tube. The design is the result of a research and development project.

The accelerator and the dc power supply are enclosed in a common pressure vessel. Because of the dangerous influence of magnetic and electric alternating fields, the symmetrical cascade generator is located in the upper part of the pressure tank. The accelerator is equipped with two beam tubes, one intended for the supply of the electron beam to the microscope, and the other for the regulation of the accelerating voltage in combination with an analyzing magnet. A second independent voltage measuring device is provided in the form of an ohmic-capacitive voltage divider made of wire-wound precision resistors. The two acceleration tubes and the voltage divider are mounted in the lower part of the pressure vessel. The electron guns are located inside the cylindrical center terminal of the installation.

The cascade generator is suspended from the cover plate of the upper part of the pressure tank so that it can easily be separated from the accelerator part.

The electronic supply and regulating system are identical to those of the 1 MeV accelerator with the exception of the power amplifier which has to be designed to handle higher power requirements.

References

1. G. Dupouy et F. Perrier: Microscope Electronique à Très Haute Tension, Annales de Physique, No. 5 - 6, 1963.
2. G. Reinhold, R. Minkner and H. Adler: Electron Accelerators for electron microscopy in the 1 MeV range. IEEE Transactions on Nuclear Science, June 1965, Vol. NS-12, No. 3.

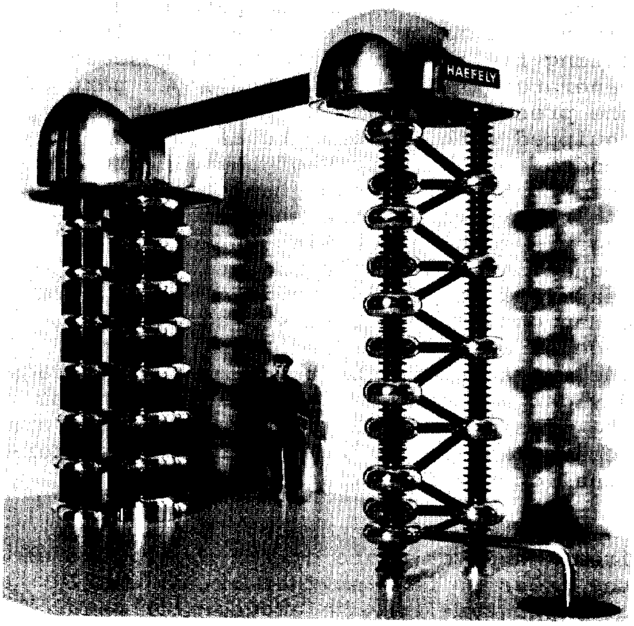

Fig. 1. Model of a 1 MeV electron accelerator of the air-insulated design.

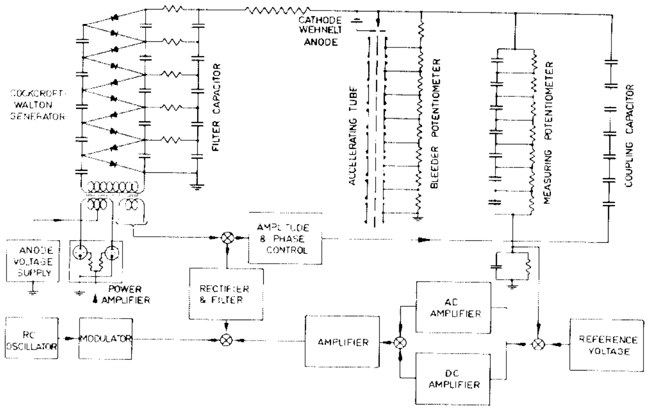

Fig. 2. Simplified block diagram of a highly stabilized 1 MeV electron accelerator.

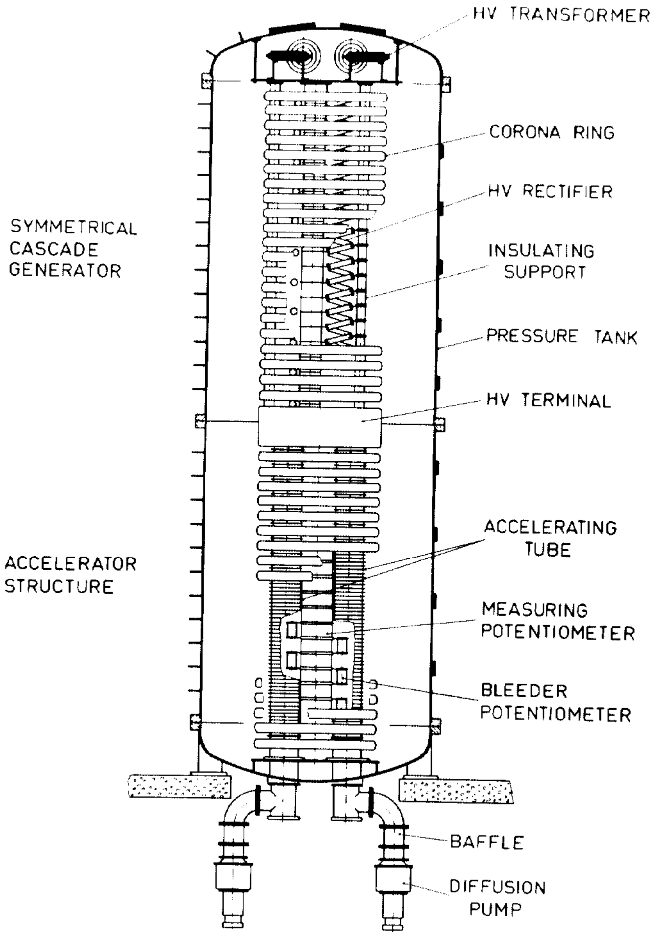

Fig. 3. Layout of a 3 MeV electron accelerator for electron microscopy.