High Power Electron Accelerator for Flue-gas Treatment

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Abstract

In the paper the present state of work on high-power electron accelerator for flue-gas treatment, which has been started in the Soltan Institute for Nuclear Studies at Swierk in Poland, is described.

1. INTRODUCTION

Electron beam treatment of flue gases is considered as a promising purification method and in the recent years worldwide research and development is taking place[1],[2],[3],[4],[5].

The emission of SO_2 and NO_x in Poland exceeds 4.5 and 0.45 milions tons per year respectively causing serious enviromental problems.Through national projects and IAEA projects POL/8/007 it has been established that this amount of emissions may be partially reduced by irradiating the stack gases with electrons from low energy high-power electron accelerators.With the contribution of such institutions as IAEA,Ebara Enviromental Corporation, Badenwerk AG,Kernforshungszentrum,the Polish Pilot Plant for the electron beam cleaning of flue gases has been built at EPS Kaweczyn in Warsaw. The main objectives of research carried out at the pilot plant are following:

-testing all parts of the installation under industrial conditions
-optimization of the process parameters
-preparation of the brief foredesign and design of the industrial scale facility.

Two ELV-3A russian accelerators installed on the bypass of main stream possess the power 50 kW each and they enable purification of about 10% of total gas amount [6]. The broad industrial implementation of the electron-beam purification technology in Poland may be possible on the basis of accelerators with much higher power in the range 400 kW-1000 kW.

In the Soltan Institute for Nuclear Studies at Swierk the preparatory work and construction of prototype of high power electron accelerator have been started in 1989. In 1990 Soltan Institute sent the request for assistance under IAEA Technical Cooperation Programme and the technical aid was granted(POL/8/008),however up to now the Agency is looking for a sponsor. In the 1992 the work is continued in the frame of Research Project "The prototype of 800 keV/0.4-1 MW electron accelerator for SO_2 and NO_x removal from flue gases" sponsored by State Commitee for Scientific Research.

2. DESCRIPTION OF THE ACCELERATOR

2.1 General assumptions

Basing on the technology requirements the following assumptions were elaboreted:
-electron beam energy 800 keV
-electron beam power 400-1000 kW
-the high efficiency coefficient
-the reliability and simplicity of the operation
-the long time of uninterrupted operation
-the protection against the serious damage of accelerator for example as a result of window foil failure or breakdown process in the accelerating tube
-easy to-do and renewal and repair of subunits

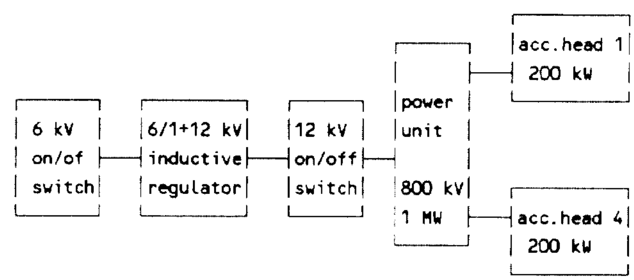

Fig.1 Block diagram of the accelerator

2.2 Power supply unit

The energizing from 6 kV mains is especially convenient in case when the accelerator is installed within the electric power station where such network is usually available. The voltage regulator and stabiliser is meant as the halted three-phase motor with the rotor position shifted and fixed by means of another motor through the self-locking worm-gear. The maximum output power is calculated as the 1.2 MW,efficiency about 0.97. The minimum time of output voltage growth from 1 to 12 kV is chosen as the 90 seconds. The 12 kV on/off circuits are designed to minimize the transient states especially hazardous when the H.V. unit is switched off without the load. The unit is designed as the 30 steps voltage multiplier with magnetic coupling fed from 3-phase, 12 kV line. The magnetic core is grounded; as the insulator a SF_6 gas compressed to 8 at.(0.8 MPa) will be used.

The power feeding of the electron gun heater will be taken from additional 220 V, 1 kW winding operating at the 800 kV potential. The unit will be equipped with two or four H.V. cable or enclosered conductor output connectors, each one supplying one accelerating head. The 800 kV output power is designed to reach the value of 1 MW. The unit will have the shape of cylinder 4.7 m height and 2.8 m in diameter. The total weight is about 18 tons.

2.3 The accelerating head

The electron gun operates at 800 kV potential. The cathode is made of lantanum hexaboride 8 mm in diameter. The pastille is heated indirectly by a heater made of pirolitic graphite. The accelerating tube consists of 32 insulating rings made of ceramic or glass about 200 mm internal diameter and 25 mm hight and electrodes made of steinless steel. The electrodes have such shape to completely shield the insulating rings from the electron beam. The electrodes are polarized with the use of resistor divider. After the acceleration, the electron beam will be magnetically focused and swept accordingly to the window shape. The window will have a rectangular shape: 2 m x 0.2 m with water cooled central support bracket or 3 m x 0.1 m in size. The foil fastening frame is water-cooled also. The foil is cooled by intense air stream.
The maximum current per one head is assumed to be 0.25 A.

3. THE PRESENT STATE OF WORK

In 1991 the works on technical documentation of power supply unit 800 kV/1 MW have been continued in cooperation with High Voltage Apparatus and Switch Gear Factory "ZWAR". The technical documentation of the models has been made:
- model of insulating elements of high voltage coils
- model of magnetic core
- model of three-coils coupling section

Tests and measurements on these models were performed including insulating strength, pressure strength, thermal strength and level of partial discharges in SF6 gas. On the base of these models the technical project of power supply unit 800 kV/1 MW has been completed. Moreover the preliminary project of H.V. outlet by means of enclosured conductor has been proposed. The test stand for checking some parts of accelerating head has been constructed. It permits to carry on such experiments as:
- the long time testing of electron gun
- the electric strength checking of tube elements
- the experimental verification of the computer model of the space charge influence on the electron beam spreading.

The computer programs calculating electron trajectories within electron gun, accelerating structure and free space were worked out taking into account space charge effects.

4. THE ELECTRON BEAM CALCULATIONS

Exact electron trajectories may be obtained by solving the relativistic ray equation, which in cylindrical geometry takes the form [7]:

$$r'' = \frac{1 + r'^2}{2\cdot U}\cdot\left[\frac{\delta U}{\delta r} - r'\cdot\frac{\delta U}{\delta z}\right] \qquad (1)$$

where $U = eV/mc^2 + (eV/mc^2)^2$
and $V = V(r,z)$ is the electrostatic potential.

After some transormations eq. (1) becomes

$$r'' = \frac{(1 + 2\cdot V/mc^2)}{(1 + V/mc^2)}\cdot\frac{(1+r'^2)}{(2\cdot V)}\cdot\left[\frac{\delta V}{\delta r} - r'\cdot\frac{\delta V}{\delta z}\right] \qquad (2)$$

In general, when space charge effects are important, the potential distribution depends on the motion, density and distribution of the individual particles. The exact calculations requires iterative procedure by solving the Poisson equation, calculating trajectories in total beam and repeating two last steps with the newly calculated charge density distribution until a dynamic equilibrum is reached; such procedure is described in [8]. We can also determine the particle trajectories by numerical solving of equations of motion with space charge with the use of BEAMTRACE-like code described in [9]. However, in some particular cases simpler approach may be practical, in which we have no need to solve Poisson equation in each step, but only once Laplace equation. The structure under disscusion, showed in fig.2., may be divided in three main areas: electron gun, accelerating structure and free field region.

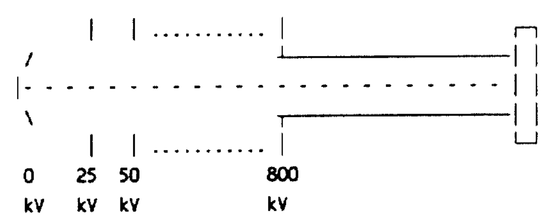

Fig.2 The electron optics structure

The idea is to assess space charge effect in each region and involve some approximations. Two main effects caused by space charge are [10]:
- depression of the potential caused by negative charge
- spreading of the beam due to repulsive forces

The magnitude of space-charge effect may be roughly assessed by simple formula [11]:

$$\delta V = I/(4\cdot\pi\cdot\sqrt{(e/m)}\cdot\sqrt{V}) \qquad (3)$$

where δV is potential drop from the axis to the beam edge. As electron gun area,cathode(0 kV) - second electrode(50 kV) region was taken in consideration. It is obvious that the electron gun area requires the specific treatment [12] and many computer programs are developed for calculations of guns as EGUN [13],[14], EGN2 [15], EBQ[16] or the program outlined in [17]. In accelerating structure beginning from the second electrode (50 kV), however, we can do some approximations because from the formula (3) we see that for I=0.25 A and V=50 kV the value δV = 17 V what gives error $\delta V/V$ = 0.04%. To confirm the rough assesment the calculations of potential field in electron gun area was performed with and without space charge. The comparing the results confirmed that the influence of space charge on V and $\delta V/\delta z$ is very small near the 50 kV electrode and conclusion is to neglect influence and to take space charge term from Poisson equation in differential form:

$$\operatorname{div}\bar{E} = \frac{1}{r}\cdot\frac{\delta(rEr)}{\delta r} + \frac{\delta Ez}{\delta z} = \sigma/\epsilon \qquad (4)$$

where:

σ is the charge density

Er and Ez are r- and z-component of electric field $\bar{E}$

After some transformations we obtain:

$$\frac{\delta V}{\delta r} = -\frac{1}{r}\int_0^r r\cdot\frac{\delta^2 V}{\delta z^2}\,dr - \frac{1}{r}\int_0^r r\cdot(\sigma/\epsilon)\,dr \qquad (5)$$

Now the right side of eq.(5) is inserted in eq.(2). In this form we can use the method to calculate the beam with an arbitrary space-charge distribution: uniform or Gaussian distribution.

5. REMARK

The staff realizing mentioned prototype has an experience acquired during the designing,assembling and operating of EAK 400/100 (400 kV,100 mA) electron accelerator at Swierk. Bearing in the mind serious technical difficulties which can be met increasing the beam power from 40 kW to 400-1000 kW we would like to establish direct contact with other companies for common activity and possible future cooperation in the field of ecological accelerators.

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