OPERATIONAL EXPERIENCE WITH THE LOW ENERGY 2% DUTY FACTOR GHENT ELECTRON LINAC

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Abstract

The Ghent low energy 2% duty factor electron linac began regularly scheduled operation in March 1986. A total of 16100 hours beam-time has been accumulated. This linac has an energy range between 1.75 MeV and 15 MeV, a max. pulse repetition frequency of 5000 Hz and a max. pulselength of 10 μsec. The accelerator is capable of delivering electron beam intensities of up to 2 mA(mean) and beam power densities up to 150 kW/cm^2. Safe transport of these low energy beams with high average current and power, to different experimental stations, requires specific beam handling components, control units and automatic feedback systems.
This paper will be divided in two parts. The first part gives a short description of the general set-up, summarizes overall beam performance and describes shortly some specific developments needed to handle the high power beam. The second part is devoted to operational experience and improvements in beam operation.

General set-up

Accelerator

During 1985, a 15 MeV linear electron accelerator was installed at the Nuclear Physics Laboratory of Ghent State University, as a valuable complement to the existing .1% duty factor 90 MeV linac. The overall lay-out of the accelerator facilities, with the 15 MeV linac to the right-hand side, is shown in figure 1.
The 15 MeV accelerator was supplied by CGR-MeV, we designed and build the high power beam transport systems (vacuum chambers, magnets, power supplies, beam monitoring and handling units,...) and peripheral equipment. This accelerator facility is mainly devoted to experiments in the field of photo- and electrofission, radiation dosimetry, accelerator physics and materials research. The existence of this facility, covering the energy range of medical and industrial accelerators, but with (for Belgium) unique performances, opens a wide range of accelerator based services.
Main accelerator specifications are given in table 1..

The accelerator consists of a 40 kV Pierce type electron gun and a prebuncher cavity, two constant-gradient traveling wave sections operating in the TM010 mode at 2999 Mhz and receiving their RF power from one common 4 MW peak, 60 kW average power klystron with a hard-tube modulator.
The SF_6-filled waveguide network includes a specially designed high average, high peak power variable directional coupler for HF-distribution between both sections. At the exit of the first graded v/c buncher section 1.75 MeV electrons can be deflected for low energy experiments with a deflection magnet followed by a variable slit system. The intersection region incorporates also a quadrupole triplet and beam intensity and position measurement units. At the exit of the second constant v/c section we installed 5 transport channels with appropriate high beam power handling and monitoring components.

Beam energy range :	1.75 - 15 MeV
Duty factor :	2%
Max. beam pulselength :	10 μsec
Max. beam pulse repetition rate :	5000 Hz
Peak beam current :	100 mA
Max. average beam current :	2 mA
Max. average beam power :	20 kW
Accelerated current in 1% energy bin :	up to 80% of Imax
Beam emittance :	2.7 π mm mrad
Number of accelerating sections :	2
RF source :	1 klystron TV 2013 B
Electromagnetic frequency :	2999 Mhz
RF power :	1.5 MW peak 30 kW mean
Klystron modulator type :	hard tube

Table 1 : Main accelerator characteristics

High power beam transport system

The design of this transport system was constrained by the necessity to house the accelerator facility in a restricted area of the existing accelerator building, partly occupied by the 90 MeV facility. The construction of the beam handling system was not only determined by optical considerations, but also by the high beam power involved. From the point of view of beam power deposition, average current density is the crucial parameter. The low energy of the machine is not an advantage, because the collision stopping power does not change very much with energy.
The accelerator is capable of delivering electron beams with a mean intensity of 2 mA and a diameter of 4 mm, corresponding to a beam power density of 150 kW/cm^2. This power density is capable of inflicting thermal damage to nearly any unprotected beam line component in time intervals shorter as 1 s. Therefore, apart from the usual protection against failures (power or pump failure, entry of water at water-cooled parts, entry of air if parts are melted through by the beam ...) the system had to be designed to overcome possible involuntary beam slips.

Fast non-intercepting beam monitoring and protection units , placed at strategic locations in the transport system, react under faulty conditions. In each unit, the beam current, position and spill are measured continuously. The beam current intensity is measured using ferrite-loaded toroidal coils. The beam envelope and peak current are displayed. To detect beam loss between two subsequent units, pulse integration for accurate charge

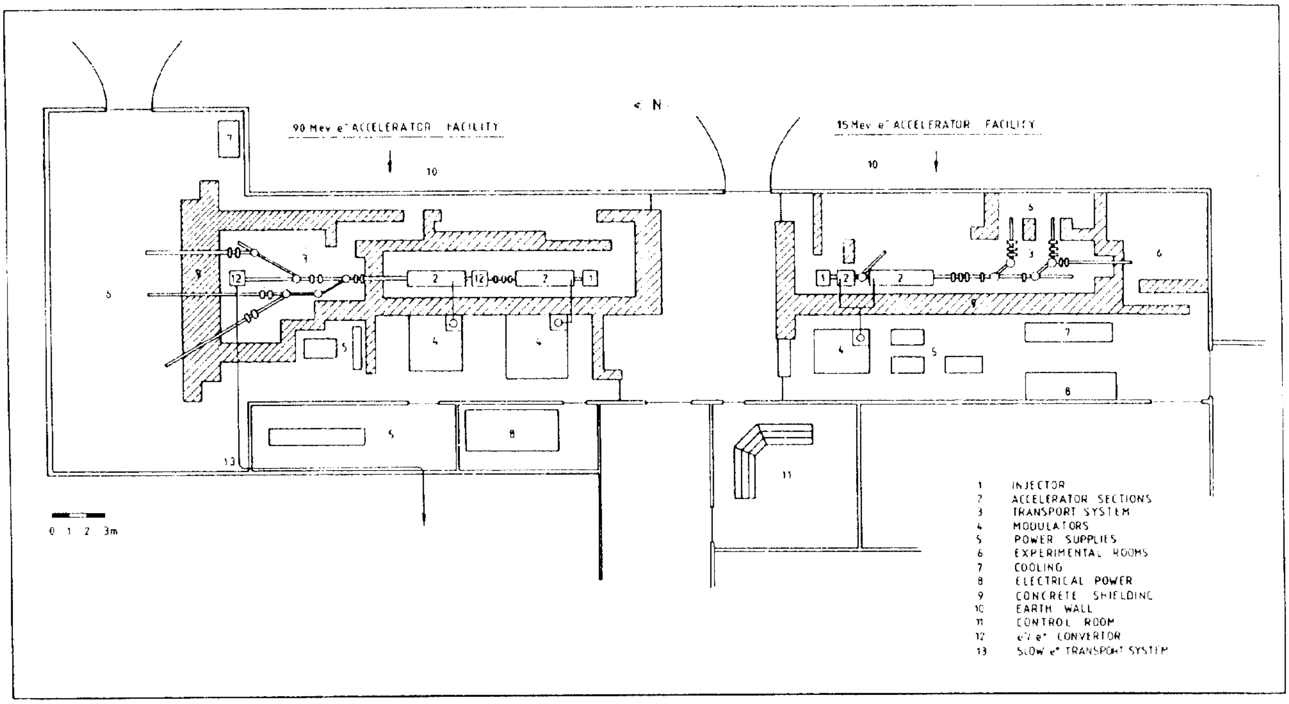

Fig.1. Lay-out of Ghent linear electron accelerators

comparison is performed. Two pairs of low-cost solenoidal pickup coils per unit are used for beam position monitoring. Beam spill is controlled by thin insulated annular secondary emission Al-foils. If one of the sensor signals exceeds a predetermined value, the beam repetition frequency is automatically turned down to 50 pps.

Radiation cooled faraday cups designed to dissipate the energy in a 1 mm diameter 20 kW beam of 10 MeV electrons are used as beam stops, and for some applications, as γ-beam production targets. The electrons are stopped in a cylindrical core of graphite, having a low vapour pressure at high temperatures and low thermal expansion coefficients. The re-entrant conical core hole is chosen to increase the impingement surface of the beam and to suppress the number of backscattered electrons escaping from the cup. The heat is removed by radiation from the outer surface of the core to the surrounding stainless steel water-cooled vacuum enclosure. Thermal and electrical insulation between core and vessel is provided by cylidrical ceramic Al_2O_3 supports. The construction of the energy-analysing slits is based on the same principles. This type of beam stop and slit construction was chosen because it has a low cost, is easy to manufacture, has no movable parts and no high pessure cooling system is needed. An eventual failure does not result in spilling water into the vacuum system.

Operational experience and improvements in beam operation

During the first period of operation the performance of the accelerator has met largely the requirements of the experimental program.
Production and transport of the high intensity beams, with good definition in energy and a narrow spectrum, together with a high degree of long-run stability was the major challenge. Electrical insulation of energy-analysing slit jaws proved to be very useful in optimising machine settings.

Automatic control of beam losses with the fast non-intercepting beam monitoring and protection units had a large effect on reliability, although at the beginning a compromise had to be found for the differential current interlock levels. In view of the compactness of the beam transport system, all sensors were in vacuum mounted, but showed unsatisfactory long-term resistance to the beam halo, containing only a small fraction of the total intensity. We decided to place the monitoring units outside the vacuum system around ceramic beam pipe joints, in a shielded enclosure.

The high power beam handling system performed very well. However long runs at high beam power levels have, at the beginning, been hampered by a slow vacuum degradation. Mass spectrometry indicated a slow increase in hydrocarbon contamination. By outgassing the radiation cooled graphite beam stops and slits in a vacuumfurnace at 2000°C during 48 hours, this problem could be solved, allowing now, during long runs, a vacuum of 10^{-9} Torr in the accelerator sections.

Although, the facility was designed with special attention to the intrinsic stability of each part, addition of supplementary regulation systems was necessary, to improve pulse-to-pulse stability, to compensate for slow energy drifts and to achieve increasingly narrow energy spectra (associated with increased energy analysed beam intensities on target).

We designed a system for pulse-to-pulse stabilisation of accelerating HF power by fast feedback-control of the hard tube driver pulse amplitude (feedback-system [1] in fig.2). Pulse-to-pulse jitter of the accelerated and energy-analysed electron beam intensity amplitude at high repetition frequency levels was substantially reduced.

Energy stability during long runs at high power levels was good, but regular minor adjustments of machine parameters were necessary. HF power repartition between both sections was the most sensitive parameter to compensate these slow energy drifts. We installed an automatic - analysed beam intensity versus magnetic field of the variable RF power coupler - feedback system ([2] in fig.2).

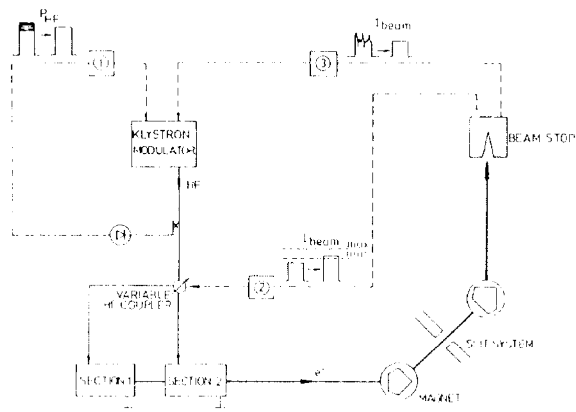

Fig.2. Feed-back systems :

- Pulse-to-pulse stabilisation of H.F. power(1)
- Compensation of slow energy drifts(2)
- Energy spectrum optimisation(3)

Over the whole energy range of the machine, the beam intensity on target during the 10 μsec pulse, is desired to be delivered as uniform as possible versus time. An irregular time structure of the beam on target is not well appreciated by the experimental physicists. We developed an on-line HF power pulse shaping system to optimise the time structure of the energy-analysed beam pulse and the energy spectrum. We exploited one of the advantages of a hard tube klystron modulator. The hard tube driver pulse, 12 μsec long, is divided in 18 slices of .66 μsec. The amplitude of each slice is regulated individually to reduce the amplitude of the oscillations on the top of the analysed target beam pulse and to optimise pulse flatness (feedback-system [3] in fig.2).

Conclusion

Regular operation of the high intensity linac and beam transport system, has given the opportunity to test reliability and to improve performances steadily. With the exception of two holes burned in a magnet chamber, in the very beginning, breakdowns of the machine components occured very seldom.
The 15 MeV accelerator is now routinely in use, running stable and autonomous during runs of 100 hours/week, at full power with beam intensities of up to 1.5 mA (energy spread 1%) on target. Manual operator interventions are exceptional.