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THE GANIL BEAM LINES

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Abstract.- The general optical functions of the beam lines are described. The principle of beam lines composed of sections with separated functions was adopted. The main technological characteristics of the equip ments (guiding system, buncher, stripper, beam diagnostics and pumping system) are given.

The GANIL's 250 m long beam lines transport the heavy ions from the injector cyclotron I1 (and later I2) to the two separated-sector cyclotrons SSC1 and SSC2 and from the latter to the experimental area, through an on-line analysing system, the so-called Alpha Spectrometer (on account of its general layout). Generally, SSC1 and SSC2 work together, with a stripper between. But the design of the beam lines also allows the operation of each SSC in solo mode. As far as SSC1 is concerned, this possibility is only used for beam tests in the SSC1 + SSC2 mode, because its injection devices, optimised for working in this mode, provide poor efficiency in the solo mode unless modified.

1. Optical characteristics.- An important requirement for proper acceleration in a multi-stage system of circular accelerators, and hence for delivering a high quality beam on the experimental area, is an adequate beam matching in the six-dimensional phase space at the entrance to each stage. For this purpose it is necessary to have information available about the beam characteristics at the exit of each stage and along the beam handling system : transverse beam center shift, transverse beam dimensions, transverse emittance, energy spread, central phase and time structure.

So the beam lines must not only transport the beam without loss, but also fulfil more sophisticated functions, which are described further on. The beam handling system is composed of sections, each of which ensuring a very precise optical function. The principle of separated functions provides easy and fast tuning. These fundamental ideas were developed as early as 1974.

1.1. Beam line L1 (from I1 and I2 to SSC1)

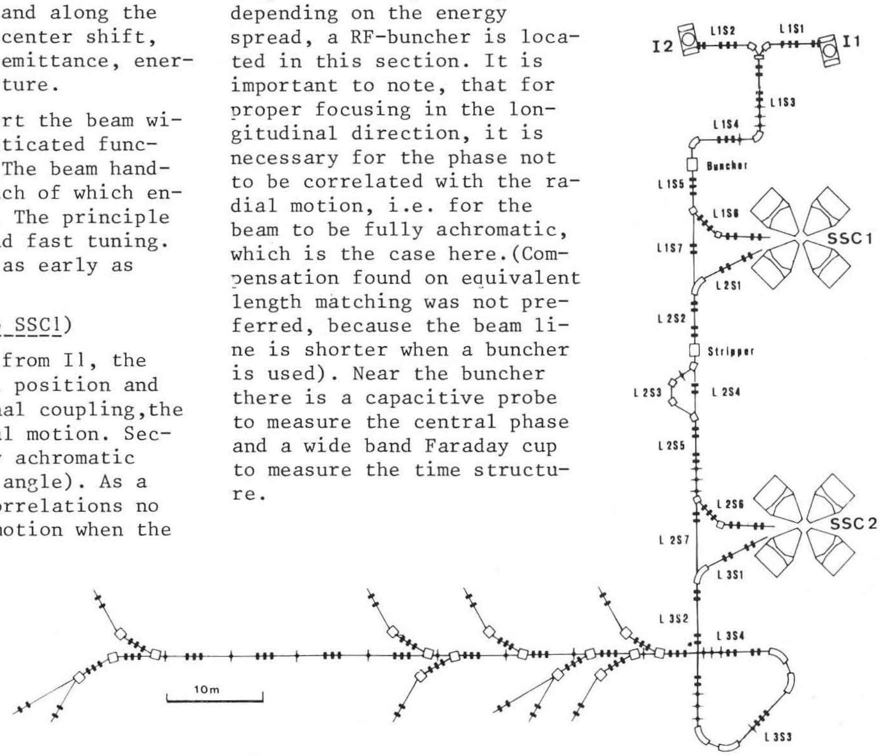
Section L1S1. - When extracted from I1, the beam has chromatic dispersion in radial position and angle. Because of radial and longitudinal coupling,the phase is then correlated with the radial motion. Section L1S1 is matched to deliver a fully achromatic beam (i.e. both in radial position and angle). As a consequence of simplectic relations, correlations no longer exist between phase and radial motion when the beam is fully achromatic.

Section L1S2. - Same function and optical structure as section L1S1, but concerning injector cyclotron I2(not yet built).

Section L1S3. - As the beam is fully achromatic, the func tion of this section is firstly to measure and to limit the transverse emittance,secondly to measure the time structure,and thirdly to match a cross-over at the object point of the analysing magnet of section L1S4. For emittance limitation there are three successive horizontal and vertical slits. A variable magnification system (a quadrupole quadruplet) provides a radial and a vertical cross-over on the central slits. The emittance can be measured either by the three-gradient method, or by scanning the beam with the central slits(§ 2.5). The time structure is measured by a special wide band Faraday cup.

Section L1S4. - The function of this section is to measure and to limit the energy spread of the beam. The first bending magnet is an analysing dipole with uniform field and stigmatic edge focusing. The θ^2 aberration is compensated by curved edge effect. The object point is located on the central slits of section L1S3. A relative energy spread can be filtered down to $\pm 5.10^{-3}$. The complete section is fully achromatic.

Section L1S5. - To compensate the phase spread depending on the energy spread, a RF-buncher is located in this section. It is important to note, that for proper focusing in the longitudinal direction, it is necessary for the phase not to be correlated with the radial motion, i.e. for the beam to be fully achromatic, which is the case here.(Compensation found on equivalent length matching was not preferred, because the beam line is shorter when a buncher is used). Near the buncher there is a capacitive probe to measure the central phase and a wide band Faraday cup to measure the time structure.



Section L1S6. - This section provides at the entrance of SSC1, fistly transverse betatronic matching, secondly chromatic matching both in radial position and angle, and, as a consequence of both the simplectic relations and chromatic matching, proper matching of the phase with respect to the radial motion, i.e. proper matching to the isochronous phase motion inside SSC1. Note that by assuming that the beam direction is section L1S6 is the opposite one, sections L1S1 and L1S6 have the same function.

1.2. Beam line L2 (from SSC1 to SSC2)

Section L2S1. - Same function as section L1S1.

Section L2S2. - The stripper must be located in a fully achromatic section. This is the case here. In order to minimize the increase in transverse emittance due to the angular straggling introduced by the stripper target, a variable magnification system gives a radial and a vertical cross-over on the target. Longitudinal focusing on the target to minimize the increase in longitudinal emittance due to the energy straggling can be performed over a small range by a proper phase compression technique in SSC1. A wide band Faraday cup is located near the stripper to measure the time structure.

Section L2S3. - The function of this section is to separate the charge states, by using the first dipole of a fully achromatic system of four wedge bending magnets. For financial reasons however, this section will not be built now and will be by-passed by section L2S4, which transports the beam to the next section. In this case, the off-charge states will gradually be lost along sections L2S4, L2S5 and L2S6. As a result it will be more difficult to tune these three sections. On the other hand, the equivalent length of section L2S4 is shorter than that one of section L2S3.

Section L2S5. - This section, where the beam is fully achromatic, has similar functions (transverse beam emittance measurement and limitation) and optical structure as section L1S3. In addition, space is saved to insert a buncher later on, if necessary, the phase being not correlated with radial motion.

Section L2S6. - Same function and optical structure as section L1S6.

1.3. Beam line L3 (from SSC2 to entrance of the experimental area)

Section L3S1. - Same function and optical structure as section L2S1.

Section L3S2. - Same function and similar optical structure as section L1S3.

Section L3S3 (Alpha Spectrometer). - The function of this section is the same as that of section L1S4 : energy spread measurement and limitation. The optical structure is a symmetric one : our wedged bending magnets with uniform field and a symmetric quadrupole triplet centered between the second and the third bending magnet. Two sextupole magnets, one between the first and the second bending magnet, the other between the third and the fourth one provide second-order aberration compensation. The analysing sub-unit is constituted by the two first bending magnets. An energy spread can be filtered down to ± 5.10^{-4}. The complete section is fully achromatic.

Section L3S4. - This section, similar to section L1S3, consists of a variable magnification system and a triple radial and vertical slit system. The function of this section is to limit the transverse emittance and to give a radial and a vertical cross-over on the central slits, where the object point of the beam handling system of the experimental area is situated. By matching homothetic conditions, the matching of the beam lines of the experimental area can be held independent of the special accelerator settings.

1.4. The beam handling system of the experimental area

The beam handling system of the experimental area is composed of a straight central beam line on which deviations are grafted, deflecting the beam in the caves , where the experimental devices are installed.

The basic cell of the central beam line is composed of a symmetric quadrupole triplet centered into a straight section. The object point 0 of the first cell is located onto the central slits of section L3S4, where the beam is fully achromatic.

Each deviation is basically a symmetric one, composed of two identical 30° wedge bending magnets, with a symmetric quadrupole triplet between them, which can be matched so that the deviation is fully achromatic. The beam can be time-shared into two caves by exciting the bending magnets of the up-stream deviation in operation with a pulsed power supply. In a few caves ,the beam can be deflected toward a second experimental device by exciting only the first bending magnet of the deviation. In this case, only the achromatic position can be matched, unless another bending magnet is added. Note however, that in every case, chromatic characteristics can be matched.

As regards the cell of the central beam line, two focusing modes are typically used : Firstly, entrance and exit are the radial and vertical focal points. Secondly the exit is the radial and vertical image of the entrance. Let us consider the section of the central beam line between point 0 and the deviation in operation : If the number of cells is even, the first focusing mode is used. (Two cells constitute in this case a double telescopic system, whose transform matrix is the negative unity matrix). If this number is odd, the second mode is used for the first or the last cell and the first mode for the other ones. In the case of time-sharing, the same rule applies for the section of the central beam line between the first and the second deviation in operation.

1.5. Main parameters of the beam lines

		L1	L2 before stripper	L2 after stripper	L3 and down-stream
Maximum stiffness	Tm	0.825	2.88	0.825	2.88
Maximum beam power	kW	0.3	1.2	1.2 (a)	5.
Radial acceptance	mm mrd	40π	15π	18π	5π (b) 8π (c)
Vertical acceptance	mm mrd	40π	15π	18π	8π
Relative energy spread acceptance	10^{-3}	±10	±5	±5	±2

(a) 0.6 kW for the selected charge state to be accelerated in SSC2.
(b) with $\pm 5\cdot 10^{-4}$ relative energy spread (filtered by the Alpha Spect.)
(c) with $\pm 2\cdot 10^{-3}$ relative energy spread.

2. Technological characteristics of the main equipments

The beam line equipments are driven and controled from the main control room by a MITRA 125 computer via CAMAC link. Generally most of the electronics are installed outside the radiation area.

2.1. Bending magnets

The bending magnets are conventional ones, with uniform field and wedge focusing.
The maximum field is :

1.1 T for 0.825 Tm maximum stiffness in L1 and from the stripper to SSC2 ;
1.44 T for 2.88 Tm maximum stiffness in the beam lines of the experimental area ;
1.6 T for 2.88 Tm maximum stiffness in the remainding beam lines.

2.2. Quadrupole magnets

The characteristics of the seven types of quadrupole lenses are :

type	aperture	length	max. grad.	
1	55 mm	150 mm	20 T/m	
2	70	300	13	
3	70	300	21	same yoke as type 2
4	80	300	8	
5	80	300	20	same yoke as type 4
6	100	300	8	
7	140	300	6	

2.3. Buncher

The buncher installed on L1 is a quarter wavelength cavity, with two gaps. The frequency can be adjusted between 6 and 14 MHz with two movable capacitive panels. For an RF-power of 8 to 12 kW the voltage per gap is 30 to 70 kV. The amplitude stability is ± 1 % ; the phase stability is ± 0.5 %.

2.4. Stripper

Between SSC1 and SSC2 there is a carbon foil stripper (20 $\mu g/cm^3$). To allow fine adjustment of the energy of the beam injected in SSC2, the drum containing 50 foils can be polarized up to ± 120 kV.

2.5. Diagnostics

Beam profile monitors. - The beam profile monitors are multivire chambers (47 horizontal and 47 vertical, 20 µm thick and 0.5, 1 or 1.5 mm spaced gilded tungsten wires), found upon secondary-electron emission. They are generally located in front of each bending magnet, quadrupole doublet, triplet or quadruplet, slits, and at some critical points like buncher and stripper, in order to measure the beam center shift, the beam profile and the relative beam intensity.

Faraday cups. - Two types of Faraday cups are installed : Common ones to measure the absolute beam intensity (for example to calibrate the beam profile monitors) and wide band coaxial Faraday cups to measure the time structure of the beam.

Capacitive phase probes. - For RF -cavity tuning and locking, the central beam phase is measured by non interceptive capacitive probes. In L1 absolute energy measurements can be performed by two capacitive probes.

Slits. - Each slit device is equipped with two jaws which can be positioned separately. Their position is measured by absolute encoders. The jaws are insulated from the ground. The slit device designed for emittance measurements is slightly different : one of the jaws is equipped with a 0.1 mm wide slit through it ; by moving it, the beam can be scanned ; the profile of the beam passing through the thin slit is measured by the next conventional profile monitor. Note that the thin slit is far enough from the edge of the jaw, to ensure that the normal operating mode of the slit device is not disturbed.

2.6. Pumping system

To enable action to be taken rapidly, valves divide the beam lines in the accelerator area into separate vacuum sections : seven sections in L1, six in L2 and three in L3. Each section is pumped with a 450 l/s cryogenic pump and a 450 l/s turbomolecular one, mounted on diagnostic boxes, where the most outgassing materials are situated. Note some exceptions however : firstly, the sections containing the triple slit devices and the associated profile monitors, each equipped with a 1500 l/s cryogenic pump and a 450 l/s turbomolecular one. Secondly, the buncher equipped with a 1500 l/s cryogenic pump and a 600 l/s turbomolecular one. The expected residual gas pressure, ensuring a 90 % transmission rate in each beam line, is 5.10^{-8} torr in L1 and 10^{-7} torr in L2 and L3. Rough vacuum is obtained by 15 or 30 m^3/h forepumps (one per two or three sections) except in the buncher, where a 100 m^3/h forepump is necessary.

As regards the beam handling system of the experimental area, valves are only installed in the caves , to separate the permanently installed beam line equipments from the temporary experimental devices. A residual gas pressure of 10^{-7} torr is obtained with cryogenic and turbomolecular pumps.

Pumps, valves and pressure gauges are driven and controlled by programmable controllers.

3. Present situation - The beam line from the injector cyclotron I1 to the buncher was just begun to run. The remainder of L1 is reaching completion. As far as L2 and L3 are concerned, nearly all the equipments has been delivered, whereas the equipments for the beam lines of the experimental area are in the process of being ordered.

The results of the first tests with an Ar^{4+} beam are summarized below :

energy	10 MeV
intensity	3.10^{12} p.p.s.
radial emittance (97 % of the beam)	50π mm mrd
vertical emittance (97 % of the beam)	30π mm mrd
relative energy spread (97 % of the beam)	$\pm$ $3.1.10^{-3}$
bunch length at output of I1 (97 % of the beam)	$\pm$ 7°