CERN-PS/AC2-KJ26

SOME TENTATIVE DATA FOR A HELIX TYPE LINAC AND TWO DRIFT-TUBE TYPES.

by K. Johnsen and A. Citron.

- - - - - - - - -

In a recent report by one of us (CERN-PS/KJ25) it was shown that it seems possible to focus a helix type linac by employing the AG focusing principle. This means that we shall have to consider the helix in comparison with the types using drift-tubes, in order to find whether one of these should have profound advantages over the other one. To have a basis for a discussion on this we have calculated a very preliminary set of data for a helix type and two for an Alvarez type.

The Helix Type. (Table I)

For the theory of the helix we can refer to K. Johnsen: "On the Theory of the Linear Accelerator", Chr. Michelsens Inst., Beretn. XVI, 3.

The basic choices to be made were wavelength, phase angle and period of focusing system at injection. The choice of wavelength was mainly governed by helix-diameter and helix-pitch considerations. The frequency is doubled once. In a more careful study we shall have to consider possibilities of using a shorter wavelength already from the start.

A rather large phase angle was chosen in order to get a wide trapping region. After the damping has reduced the phase oscillations sufficiently, the phase angle is reduced to 30°.

In choosing the period of the focusing system it was assumed that the lenses ought to be at least twice as long as the diameter of the system which it is going to surround. With the helix diameter we get, this will be about 8-10 cm, and consequently the lens period is chosen as L=0.5 m as a reasonable figure.

The accelerating field at injection is then found from the stability diagram in KJ25. This field is rather low, and in order that the field can be increased as rapidly as possible, the first few sections are rather short. We have further assumed that the maximum accelerating field we can tolerate on the axis is 2.5 MV/m. This may be conservative if we use a travelling wave pattern (external feedback), as the maximum field between the windings is then 6-7 MV/m. However, if we use a standing wave pattern, the maximum field is twice as high, and the figure 2.5 MV/m is high.

The series impedance of the helix structure decreases with increasing particle velocity, and the field therefore also decreases from input to output of a section. After the maximum field of 2.5 MV/m is reached, the steps in energy (number of sections) are mainly governed by the fact that this drop in field strength should not be too large. It is further also governed by the power dissipation in each section, as it was considered desirable that this should be so small that each section can be fed from one valve or two valves in push-pull. These considerations may not be very important, and the possibility of decreasing the number of sections above 4 MeV should be considered. However, the more sectors the accelerator is divided into, the less sensitive it is to phase-velocity errors, frequency errors etc.

The many steps in helix-diameter were obtained because it was thought desirable to stay close to the maximum of the shunt-impedance curve most of the way. However, near the injection a much larger diameter than this consideration would give, was chosen in order to get a reasonable pitch, and loss-considerations are anyway unimportant in this part of the accelerator, as the losses in the first two sections are almost negligible compared with the losses in the whole machine.

These considerations have given three different diameters, with the largest diameter in sections 5 and 6. As the diameter in these sections is rather large, we should consider to decrease it at the expense of the shunt-impedance.

The pitch is now determined by the parameters given above, and calculated from a formula given in the paper to which reference was given at the beginning of this section.

The shunt-impedance and losses have been calculated under the assumption of having only a forward travelling wave. In other words, we assume that we can use an externad feedback, and that the losses in the feedback can be neglected compared with the losses in the helix itself. If a suitable external feedback cannot be made, the helix will be built as a resonator, and for the same acceleration the losses will be twice those given in the table. It should be noted that in the first two sections, the power flow is so low that these sections will probably be run as travelling wave sections with no feedback, the residual power being dissipated in a matching load.

The build-up time is the time it takes for the energy density to build up to $1-e^{-1}$ of its final value, when the waveguide is operated as a resonator. When the data discussed above are known, it can be calculated. We find that sections 5 and 6 have the longest filling time, which again indicates that modification of the diameter of these sections, as suggested before, may prove advantageous.

In the last line of the table are given the magnetic field gradients required to obtain the wanted $\cos\mu_0$. In the three first sections $\cos\mu_0$ and the accelerating field at input end of each section is chosen so that the working point for the synchronous particle is in the top corner of the stability triangle. Later the working point is further down, and as we have then a wide region within which $\cos\mu_0$ may be chosen, the corresponding value for the field gradient is not given. Where, inside this region, $\cos\mu_0$ should be chosen, may be governed by other considerations, such as admittance matching between the linac and the synchrotron.

A line containing the maximum possible energy spread in the bunch, has also been included in the table, mainly because there has been raised doubt that the potential well at the injection end of the linac was deep enough to accommodate the likely energy spread from a pre-accelerator. However, even if this energy spread should be up to 10 kV, which is unlikely, it is still small compared to the energy spread in the bunch, and ver y few particles will be lost due to such an energy spread.

The Drift-Tube . (Table II)

Two drift-tube accelerators were considered, one (A) run at 1.5 m wavelength as the original Alvarez one, the other (B) at 1.0 m.

Parameters for A were obtained by scaling up the Alvarez machine to a total energy gain of 49.5 (from 0.5 to 50) MeV instead of 28 (4 to 32) MeV. The power loss and the shunt impedance per unit length and the phase angle were taken from the Alvarez machine, which leads to the same field strengths and the same energy gain of 2.3 MeV/m. These quantities are not supposed to change much along the machine. The total length and the total power consumption is obtained from the Alvarez machine by scaling up linearly with energy.

The other dimensions are found by putting limitations on the drift-tube aperture. 5 cm at the output end and 2.5 cm at the output of the low energy section(s) were arbitrarily chosen as plausible lower limits; a ratio of 0.84 of drift-tube aperture to period length was taken as an upper limit, which is slightly lower than the maximum of this ratio occurring in the Alvarez structure (0.89). The ratio of gap width to period was varied from 0.20 to 0.30 along the machine in a similar way as done by Alvarez to get similar field distributions. With these requirements it proves possible to obtain the acceleration wanted in two sectors of different cavity diameter. The build-up time follows from the Q-value, which in turn depends mostly on the cavity diameter. A line showing maximum energy spread in the bunch is also included in this table.

Accelerator B has a wavelength of 1 m. The total length is chosen the same as for A; the other dimensions go down roughly as 1/1.5, and the number of gaps goes up correspondingly. The dimensions are found from the same requirements as for A; here we need three sections to comply with them. In fact, in the first section the two limitations on drift-tube aperture approach each other, so that a smaller wavelength could not be considered for this part of the accelerator. The total power consumption is lower than with A due to the skin effect, so is the build-up time due to the smaller cavity diameter. The economy in energy per pulse is a factor 2.2 with respect to A.

Advantages of A are:
1. the fact that accelerators have been operated at this wavelength,
2. the possibility of increasing drift-tube apertures without having to introduce frequency jumps,
3. the wider tolerances in tuning due to the smaller electrical length (Factor 2.2).

Advantages of B are:
1. less bulky construction,
2. lower energy consumption due to smaller power losses and lower build-up time.

Comparison between the two Types.

The main differences between these two types of linac structure, of which data are given in Table I and Table II, are found in

- i) Cross-sectional dimensions.
- ii) Build-up time.
- iii) Q-factor.
- iv) Kind of focusing system.
- v) Number of individual sections.

In the tables there also appear other differences, such as phase-angle and wavelength, but these differences are less fundamental, and partly due to rather arbitrary differences in choices at the beginning of these calculations.

The difference in i) is about one order of magnitude when we consider the accelerating system alone. However, as the helix requires four-pole magnets as focusing lenses, the difference is less when the whole accelerator is considered. Still it looks as if the helix will be less bulky.

The differences in ii) and iii) are both more than one order of magnitude and may be quite important. How important a short filling time is, depends on the behaviour of the HF-valves. The mean power is in any case very low and will not limit the output power from the valves in either of these cases. It is not quite clear how much the output from a valve can be increased when the pulse length is decreased. This must be considered in more detail.

The modulating system, however, will be simpler and cheaper for the short pulse length.

A low Q, as long as the low Q does not result in a low shunt-impedance, is an advantage, as everything is less sensitive when the Q is low.

In the tables we have assumed grid focusing for the drift-tube type, whereas that cannot be used for the helix, and magnetic AG focusing has been assumed in that case. The AG focusing seems to be the most flexible one, but it may not be the cheapest one to make. In comparing the two types of focusing, the loss in intensity due to the grids should also be kept in mind. In the Alvarez machine the grid loss reduces the beam intensity by a factor of about 3.

The helix type with AG focusing will have to be built in more sections than the drift-tube type with grid focusing, although it may be possible to reduce the munber from what is given in the table. However, a large number of sections may not be a drawback. Even if a drift-tube type is finally chosen, we may decide to split it up in more individual sections.

The main advantage of the drift-tube type is that it has beeen proved to work and that, by choosing that type and also taking into account the experience gained with this type in USA, we are quite safe. With the helix there are unsolved mechanical problems. They may not be more serious than the corresponding problems faced by Alvarez and his team when they started on the drift-tube type, but as no helix has been built up to now, we shall have to solve these problems ourselves. The main problems will then probably arise in connection with the support of the helix, and a solution must be found that does not introduce too large additional losses at the same time as it must give the required rigidity and precision. Various suggestions have been made, but we shall not discuss them here.

As a whole, we do not think that the time has yet come when we are quite in a position to decide between the two types discussed here.

- - - - - - - - -

Geneva, 2nd March, 1954.

TABLE I

Some Tentative Data for a Helix Type Linac

		section 1	section 2	section 3	section 4	section 5	section 6	section 7	section 8	section 9	total
article energy	MeV	0.5-1	1-2	2-4	4-8	8-15.5	15.5-24	24-32.5	32.5-41.2	41.2-50	50
mpl. of acc. field	MV/m	0.31-0.27	087-0.65	2.46-1.7	2.5-1.74	2.5-1.75	2.5-1.95	2.5-2.1	2.5-2.2	2.5-2.3	
hase angle		60°	60°	60°	30°	30°	30°	30°	30°	30°	
ection length	m	3.6	2.7	2.0	2.2	4.3	4.3	4.3	4.3	4.3	32
avelength	m	3	3	3	3	3	3	1.5	1.5	1.5	
elix diameter	cm	3.5	3.5	3.5	5	7	7	5	5	5	
elix pitch	cm	0.3-0.38	038-0.49	0.49-063	1.0-1.28	2.0-2.6	2.6-2.9	2.25-2.53	253-2.72	2.72-2.9	
ower flux	MW	0.018	0.212	2.96	8.54	23.5	48.6	25.1	33.9	44.4	
hunt impedance	M Ω/m	83-90	90-80	80-60	57-43	40-29	29-24	34-30	30-27	27-25	
osses due to accelerating wave	MW	0.004	0.02	0.12	0.2	0.56	0.80	0.70	0.83	0.96	4.2
(approximately)		1500	1700	1800	2600	3600	3800	3700	3800	3900	
uild-up time	μS	2.2-2.5	2.5-2.8	2.8-3	3.9-4.3	5.5-5.9	5.9-6.2	2.9-3	3-3.1	3.1-3.3	
ossible energy spread in the bunch	MeV	0.08-0.12	023-0.33	0.64-0.90	0.40-0.57	0.68-0.94	1.12-1.34	1.05-1.25	1.35-1.46	1.55-1.71	
ens system period	m	0.5	0.5	0.5	0.5	2	2	2	2	2	
agnetic field gradient in lenses ith no field free section	Gauss/cm	470	670	930	740	> 300					

Table II

Parameters for two possible Alvarez Type Linear Accelerators

		Accelerator A 2 sections			Accelerator B 3 sections			
		1	2	total	1	2	3	total
Wavelength	m	1.5			1.0			
Shunt impedance	MΩ/m	34			38			
Phase angle		30°			30°			
Voltage gain/unit length	MeV/m	2.3			2.3			
Energy range	MeV	0.5 - 4.9 - 50			0.5 - 0.8 - 6.5 - 50			
Section length	MeV	1.89	19.3	21.2	0.13	2.44	18.6	21.2
Cavity diameter	cm	123.1	101.9		82.0	80.1	64.3	
Period length	input cm	4.89	15.11		3.26	4.05	11.54	
	output cm	15.11	47.1		4.05	11.54	31.4	
Drift tube aperture	input cm	4.11	12.74		2.73	3.40	9.69	
	output cm	3.08	5.00		2.50	2.50	5.00	
Gapwidth	input cm	0.98	3.78		0.65	0.81	2.89	
	output cm	3.78	14.1		0.81	2.89	9.42	
Number of drift tubes		19	62	81	3	31	87	121
Power consumption	MW	0.39	4.02	4.4	0.025	0.46	3.47	3.9
Q (approximately)		137000	113000		111000	107000	87000	
Build up time t	μsec	109	90		59	57	46	
Energy/pulse (2t)	J	85	790	875	3	52	318	373
Possible energy spread in bunch	input	0.05	0.31		0.04	0.06	0.30	
	output MeV	0.31	1.82		0.06	0.30	1.48	