Performance and Modification of the MEA R.F. Drive System

F.B. Kroes, T.G.B.W Sluyk, B. Heutenik, NIKHEF, P.O. Box 4395,
1009 AJ Amsterdam, The Netherlands

Abstract

The twelve modulator-klystron units serving the 500 MeV linear electron accelerator (MEA) (ref. 1) will be modified to convert the accelerator into a 900 MeV, 0.2% d.f. injector for the pulse stretcher project, presently under construction (ref. 2). The new klystrons needed for this purpose have to be provided with higher input R.F. peak power, which implies modification of the present R.F. drive system. This modification also involves the inclusion of fast R.F. PIN diode switches in the R.F. drive system of each klystron to enable spreading of the R.F. timing of the twelve stations. This is essential -given the much shorter pulses requested for injection into the pulse stretcher - to suppress the transient beam loading effect- Design consideration for the modification of the MEA R.F. drive system and initial tests will be presented.

1. Introduction

The present 500 MeV electron accelerator delivers 2% d.f. beams at a maximum energy of 600 MeV to the experimental area, where an elaborate nuclear physics programme involving single arm (e,e') and coincidence (e,e'X) experiments is carried out. In order to extent this programme in the future, the d.f. and the max. energy of the beam will be raised to 90% and 900 MeV respectively. To this purpose a pulse-stretcher ring is under construction for which the accelerator (MEA) will serve as a 900 MeV, 0.2% d.f. injector.

Due to the d.f. decrease of the accelerator itself the peak current to be accelerated has to increase from 10 mA to 80 mA to extract acceptable average currents from the pulse-stretcher.

As is discussed elsewhere in this conference (ref. 3) the modulator-klystron units, which provide the R.F. peak power for the accelerator, have to be modified.

The present 2%, 4MW klystrons (VA 938D) will be replaced by 0.2%, 10 MW tubes (TH 2129). Table 1 lists the main R.F. specifications of these two klystron types

Table 1 Main klystron specifications

			Present VA 938D	Future TH 2129
Peak power	input	W	70	100
	output	MW	4	10[a]
Pulse width		µs	40	4
Repetition rate		Hz	500	500
Average input power		W	7	0.7

a) The TH 2129 is capable of delivering 15 MW peak power

Obviously the present R.F. drive systems have to be modified rather drastically to accommodate the newly to install klystron. In addition, related with the much shorter pulse width, provisions have to be made to compensate for transient beam loading. Namely, the current content of the beam pulse during the 1.3 µs fill time of the accelerator sections represents a considerable fraction of the total current in the 2.1 µs beam pulse requested for (three turn) injection in the pulse stretcher.

Compensation of this transient beam loading will be established by spreading starting times of the R.F. pulse for each klystron. This feature requires the introduction of a high peak power PIN diode pulse shaper. In the following section we will briefly discuss the lay-out and performance of the present R.F. drive line system. The design considerations and some initial test of the newly to install R.F. drive system will be given in section 3.

2. Present R.F. drive line system

The lay-out of the R.F. drive line providing the 12 klystrons with R.F. input power is shown in fig. 1.

The R.F.. c.w. signal from the 2856 Mc synthesizer is AM modulated to a pulse width ranging from 0.1 to 40 µs and then amplified in two steps to 300 W, which power is driving the first klystron.

The main part of the 2 MW output power from this klystron is used for feeding the buncher and first section of the accelerator. By means of a 18 dB coupler in conjunction with an attenuator, 15 kW of this power is fed into the 200 m. long ultra-stable rectangular wave guide installed in parallel with the accelerator itself. For each of the remaining klystrons 350 W drive power is coupled out from this drive-line. The coupling ratio of these couplers are ranging from -17dB at the second klystron to -10dB at the last klystron. For optimum performance of the accelerator special care has been taken to keep the droop and ripple of the video pulse of the transmitter of the first klystron within 0.2% over at least 35 µs Furthermore the wave-guide drive line is temperature -and absolute pressure controlled (± 0.03° C, resp. ± 1.5 Torr) resulting in a R.F. phase stability within one electrical degree. The drive-line envelope and support are shown in fig. 2. Each klystron has its own R.F. drive system containing a solid state attenuator (SSA) and a digital phase shifter (DPS) which are electronically controlled.

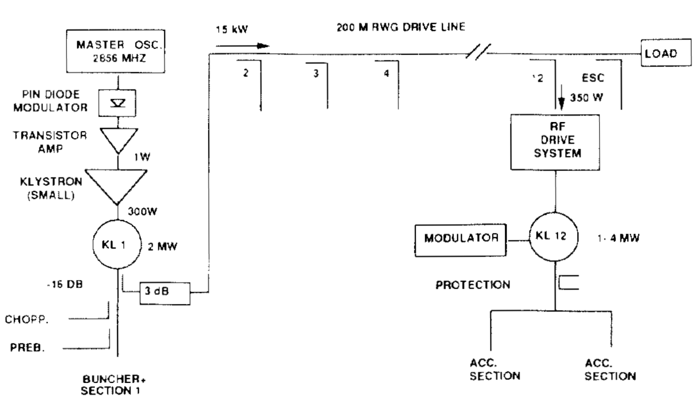

fig.1 Layout of the accelerator RF system

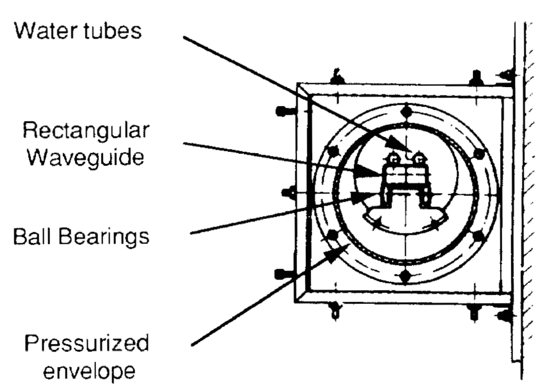

fig.2 Driveline envelope and support

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The Solid State Attenuator (SSA)

The inhouse developed SSA controls on a pulse to pulse basis the klystron drive power -which ranges from 25 to 100 W- for operation at 1, 2 and 4 MW R.F. output peak power levels.

The SSA sets 200 µs in advance the correct R.F. input power before the next pulse is fired.

The device has a flat attenuation response (< 1dB) during the pulse. Its phase remains during the 40 µs pulse constant within 1 degree. Also the long-term stability of the phase is excellent. Although rather insensitive to temperature changes temperature control at 45° C is applied for long-term stability.The SSA can handle 350 W R.F. peak power for 40 µs pulse length.

Some main specifications are given in Table 2

Table 2 Solid State Attenuator (SSA) specifications

range for flat pulse attenuation	10	dB
insertion loss	2.5	dB
phase vs temp	1	degree / °C
input power at 50µs / 4000µs	350	W
speed	10	µs
off-state isolation	-35	dB
input and output reflection	-25	dB
output variation during pulse at various attenuator settings	.5	dB

The printed circuit lay-out of the SSA is shown in fig. 3.

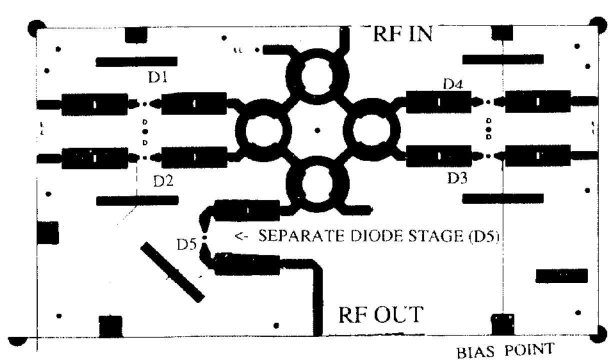

fig.3 Attenuator PCB layout

The Digital Phase Shifter (DPS)

The DPS installed in the MEA klystron drive systems is commercially available. Table 3 presents its mains specifications.

The device is a non-reciprocal latching waveguide ferrite phase shifter. It has 32 phase states (360 deg. 5 bits) from 0 to 348.75 degrees in 11.25 degree steps with low insertion loss (typically 0.9 dB). The accuracy is about 2 degrees. The possible switching speed is 2500 events per second. The phase/temperature sensitivity was measured to be 1 degree -phase / °C. Therefore the device is kept at a constant temperature of 45 °C.

Table 3. Digital Phase Shifter (DPS) specifications

insertion loss	1	dB
phase vs temp	2	degree / °C
input power at 50 µs / 400 µs	350	W (peak)
speed	200	µs
insertion loss variation due to phase stepping	0.3	dB

Computer interfacing and protection electronics

Computer interfacing as well as control of the SSA and DPS units is carried out by elaborate control and protection electronics. The protection circuit takes care of monitoring and interfacing signals such as from different cooling- and vacuum circuits of relevant accelerator components and from standing wave ratio monitors.

If these signals give cause for disconnecting the R.F. power this can be achieved within 7µs (beam pulses may be as large as 40µs!) in two steps. First the SSA is set to maximum attenuation (20 dB). Because of the high gain of the klystron, the power has to be further reduced by 30 dB, for which purpose a separate diode is incorporated in the circuitry of the SSA (see fig. 3 , diode 5).

3. Modification of the R.F. drive system requested for the pulse-stretcher mode of operation

Apart from the higher peak R.F. drive power level required (see table 1) the main modification is to enable the compensation of the transient beam loading (ref. 4). It is essential to achieve this compensation because due to the much shorter beam pulse (2.15µs) the effect of transient beam loading during the 1.3µs filling time of the accelerator sections is dominantly present. As has been shown in ref. 5 compensation can be established by spreading the starting time of the individual klystron r.f pulses. In order to control the timing trigger of the individual R.F. drive system units relative to each other, fast R.F. PIN diode switches are incorporated in the R.F. drive systems as indicated in the block diagram presented in fig. 4.

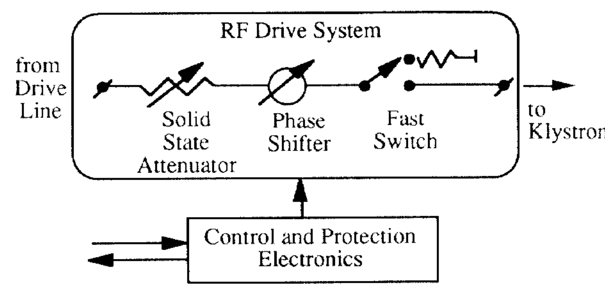

fig.4 : Block diagram of R.F. Drive System

Fast R.F. PIN diode switch

For the transient beamloading compensation project a fast R.F. PIN diode switch is developed. The main specifications are given in table 4.

The first switch is tested in the prototype R.F. drive system under continuous operation conditions. The fast R.F. PIN switch makes it possible to give each of the twelve stations its own R.F. pulse start. The employed fast switch is able to do "hot" switching which means: switch on in the presence of RF-drive power from the Drive-Line (> 150 W, 50µs). The obtained speed is faster than 100ns (rise time). Some protection circuits are build in the R.F. drive system. These are used to prevent the trailing edge of the PIN switch to occur during the R.F. pulse. This gives reduced power dissipation in the switching diodes and failsafe operation.

Table 4. Specifications of the Fast R.F. Switch

insertion loss		1	dB
phase vs temp		0.5	degree / °C
input power	at 50µs / 400µs	150	W (peak)
	at 2µs / 3 ms	250	W (peak)
speed 10-90%		100	ns

Test measurements

For the purpose of the future modification of the R.F. drive systems for the newly to install klystrons a prototype R.F. drive system including the fast R.F. PIN diode switch has been build.

Test measurements with this system have been carried out. Some results will be discussed now.

Figure 5 shows the flatness of the R.F. output of the Drive System for several settings of attenuation. A flat pulse is needed for a low spread in electron energy. The power variation is further reduced by the klystron which works in saturated mode. Since the beam starts at a later point in time than the R.F. pulse, the level is stabilised to within 0.1 dB.

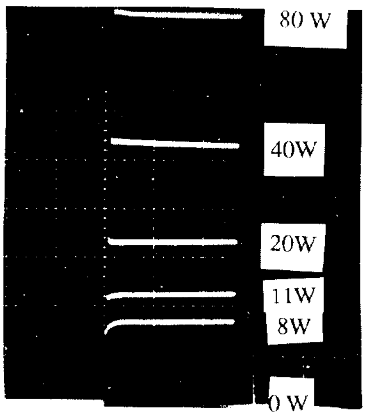

fig.5 R.F. drivesystem output flatness for several attenuation settings. (time 20µs/div)

At the same time an excellent phase flatness of 0.2° is achieved. Figure 6 shows the delayed switching response of the build in Fast Switch.(see spreading time technique) The starting point can be set at any point within the pulse. The falling edge of the Fast Switch is always delayed until after the R.F. driveline pulse to lower the switching power in its diodes.

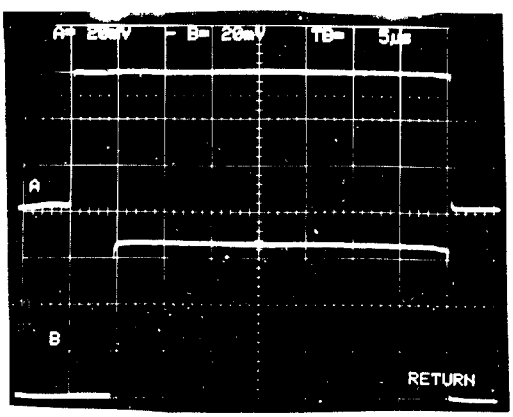

fig.6 Delayerd switching of the R.F. Switch using a long pulse. (timescale: 5µs/div, vertical: relative R.F. power)
A= input drivesystem , B= output drivesystem

Spreading time technique

The prototype of the modified R.F. drive system has been incorporated in one of the stations along the accelerator (number 10).

In order to carry out preliminary tests of the spread R.F. timing mechanism and its influence on the energy spread of the beam the following test has been carried out.

Only the first two modulator-klystron stations (in the following mentioned as injector station) and station Nr. 10 have been used for acceleration. The energy of the beam after the injector station is about 50 MeV and further increased by station 10 to about 97 MeV. The peak current was 5 mA and the beam pulse width 2.0µs. The beam loading term of the accelerator is 2.8 MeV/mA, the fill time of the acceleration structures is 1.3µs. Three experiments are carried out under the following starting time conditions.

Firstly, keeping the starting times of the R.F. pulses from the injector station and station 10 the same, the beam pulse was triggered > 1.3µs later. (exp. 1). This is the usual condition of the present (long R.F. pulse) mode of operation.

Secondly (exp. 2) the starting time of the R.F. pulses of both the injector station and station 10 were simultaneously delayed such that it occurred within 1.3µs before the start of the beam pulse. Finally (exp. 3) the starting R.F. time of station 10 was further delayed relative to that of the pulse from the injector station but still occurring within 1.3µs before the start of the beam pulse. The control accuracy of the different triggers has been 0.1 µs.

In order to study the influence of these spreading time conditions on the beam energy spread, the beam energy and the lowest and highest energy involved in the accelerator beam pulse have been measured with the tune-up line beyond the accelerator. A secondary emission monitor, serving as an energy spectrum analyser is incorporated in the tune-up line. Those measurements give for the three spreading time conditions mentioned above the following results:

Table 5. Results of the tests with spreaded R.F. timing.

		Exp. 1	Exp. 2	Exp.3
Beam Energy (steady state)	MeV	97.1	97.1	97.1
Highest energy detected	MeV	112.9	105.2	99.4
Lowest energy detected	MeV	98.3	98.3	98.3

The energy spread in the first experiment , 14.6 MeV, corresponds with the accelerator beam loading term (2.8 MeV/mA). It is apparent that the spreading time experiment shows a dramatic improvement of the energy spectrum of the 2µs beam pulse. The results are convincingly enough to expect that -by incorporating the fast PIN diode switch techniques in all stations - high energy beams (more active accelerator stations) will show an energy spectrum well within the 1% acceptance of the energy spectrum compressor (see ref. 6) to be installed beyond the accelerator.

Acknowledgement

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References

1) P.J.T. Bruinsma, F.B. Kroes et al. , " The 500 MeV, 2.5% duty factor linear electron accelerator (MEA) ", IEEE Trans. on Nucl. Sci. NS-30 (1983) 3599.
2) -R. Maas et al., " The Amsterdam Pulse Stretcher", IEEE Trans. on Nucl. Sci. NS-32 (1985) 2706
-G.Luijckx, et al. , " The Amsterdam Pulse Stretcher Project (APS)", This conference.
3) F.B. Kroes, E. Heine, " Modification of MEA modulator klystron units enabling short pulse injection into a pulse-strectcher ring", This conference.
4) Linear accelerators (ed. Lapostolle, Septier (1970): J.Haimson "High duty factor electron linear accelerators"
5) B. Aune et al. , "Transient beamloading calculations and experiment at the SACLAY electron linac" , IEEE Trans. n Nucl. Sci NS-30(1983) 2995
6) J.G. Noomen et al.," An energy compression system for the Amsterdam Pulse Stretcher ", This conference.