AN R.F. MODULATED ELECTRON GUN FOR NINA INJECTION EQUIPMENT

by

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1 INTRODUCTION

In the 5 GeV electron synchrotron, NINA, at Daresbury, acceleration is achieved by the use of 5 iris loaded cavities distributed around the ring. These operate at a frequency of 408 MHz. However, the 40 MeV linear accelerator serving as its injector employs a 2856 MHz r.f. system. Both systems are synchronized by operating from a common frequency source, the frequency for the linac being derived via a X7 frequency multiplier.

As originally installed, the linac delivered a 1 μs pulse of electrons bunched at a frequency of 2856 MHz. Seven electron bunches were therefore injected for every full cycle of the synchrotron r.f. cavity voltage, and only one of these bunches can be at the correct stable phase angle, ϕ_s, for beam capture. The bunches adjacent to this correctly injected bunch will exhibit synchrotron oscillations, which will be damped as acceleration proceeds. Those bunches which are far removed from the stable phase angle will exhibit large amplitude oscillations and be lost by collision with the vacuum chamber walls. Typical ratios of current injected to current captured indicated that about 2 or 3 out of 7 bunches could be captured. The current injected but lost due to large synchrotron oscillations increased the beam loading problems which occur at high intensities by causing large transient cavity voltage changes immediately after injection, before being lost.

The system to be described[1] aims to overcome the limitations of current which can be accepted by the synchrotron, by applying r.f. modulation at 408 MHz to the beam before acceleration in the linac. The ideal result of this would be the production of a single bunch of electrons for each NINA r.f. cycle which could always be injected at the stable phase angle. The charge in this bunch would need to be increased over the unmodulated case but, since the injected current would be wholly accepted in NINA, a smaller current is sufficient to produce the same beam in NINA.

It was not found to be practicable to produce a single bunch, but the system was capable of having substantially all the current in two equal bunches, which is very nearly as good. These bunches may best be injected at about ± 25° from ϕ_s and hence small inherent phase oscillations are to be expected. However, complete capture of injected current is experienced up to the point where cavity voltage is seriously perturbed by beam loading.

A particular experimenter, carrying out time-of-flight measurements on K^o mesons, required every other bunch in NINA to be suppressed so as to give 5 ns rather than 2.5 ns between successive bunches. In order to meet this requirement provision was also made for 204 MHz modulation of the gun. The specified output of the linac was to give 350 mA within 1% energy spread and with an emittance < 3.2×10^{-6} metre radians.

2 DESCRIPTION OF GUN

The gun originally designed for the linac was unsuitable for r.f. modulation, so an 80 kV electron gun developed by Vickers Limited[2] and rated to produce currents in excess of 10 A at a pulse length of a few nanoseconds, was evaluated for this purpose and appeared suitable in all respects except for the disadvantage of having an oxide cathode, which might have a rather limited life, and which would require replacement if the machine had to be let up to air.

Figure 1 shows the expected performance of the gun and linac for different operating conditions. At 408 MHz the relative phases of gun and linac can be adjusted to obtain either of the two conditions shown in figs. 1(a) and 1(b). This shows that the ideal single bunch injection condition cannot be realised with this system, but as far as the synchrotron is concerned all the current can be injected at about 25° each side of the synchronous phase angle, or alternatively, 63% of the current can be at the synchronous phase angle and the remainder at 51° from optimum. Both of these conditions give a substantial improvement over the unmodulated case.

The predicted operation at 204 MHz is shown in fig. 1(c). Here it can be seen that five linac bunches will be injected every other cycle of NINA r.f. By suitably adjusting the phase between linac and synchrotron for optimum beam capture, this should give a condition where the beam captured is contained in alternative r.f. buckets, the remaining buckets being left completely empty.

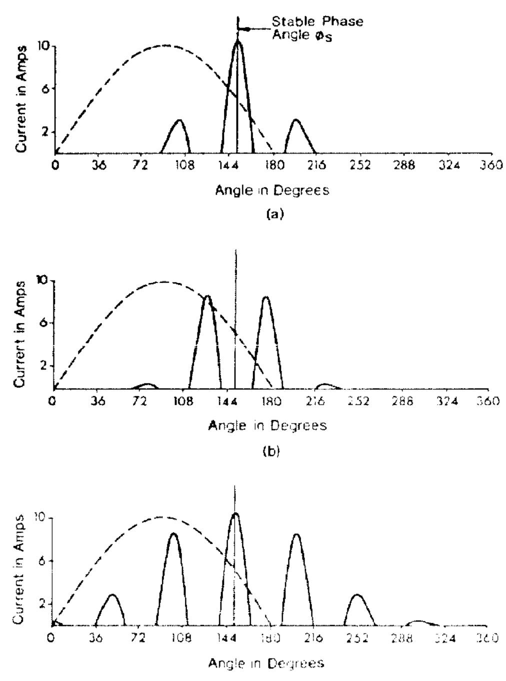

Fig. 1. Injection conditions calculated from gun characteristics.

3 THE R.F. MODULATED GUN SYSTEM

The use of a gun with an oxide cathode demanded a very carefully designed vacuum system to minimise any risk of poisoning, and a remotely controlled all-metal vacuum valve was fitted to isolate the gun in the event of a vacuum failure elsewhere in the system.

The r.f. input circuit for the gun is a co-axial cavity using the 3 $\lambda/4$ mode for 204 MHz operation and the 5 $\lambda/4$ mode for 408 MHz operation. The cavity has the same dimensions as the co-axial part of the gun electrode assembly. A d.c. blocking capacitor for the bias is provided by inserting a mica disc between the rear (grid) flange of the gun and the mating flange of the circuit, and using insulated fixings. The circuit can be tuned and matched for either frequency by a remotely controlled motor drive mechanism. Figure 2 shows a schematic arrangement of tne gun and its input circuit.

An r.f. isolating transformer is required to feed the r.f. pulse for the gun grid from the amplifier, which is at earth potential, to the gun input cavity which is subjected to the -80 kV gun h.t. pulse. This transformer consists of two identical "baluns" mounted 1 cm apart in an oil tank and arranged to overlap to give coupling. The baluns are resonated by means of sliding short circuits which can tune to both operating frequencies, and again the tuning can be set remotely.

Two independent r.f. amplifier chains are employed, with a 204 MHz oscillator phase locked to the main NINA 408 MHz frequency source. PIN diode modulators produce r.f. pulses 1 μs wide and transistors are used to amplify them to 40 watts, after which two valve stages provide the total required power of 4 kW. Changing of the operating frequency is fully automatic and takes two minutes, which is the time for the isolating transformer to drive over its full tuning range. Adjustment of the r.f. power level is usually necessary after changing frequency to enable the same beam current to be obtained without change of bias voltage, so that the linac current servo and energy servo, which control by means of the gun bias, can regain control.

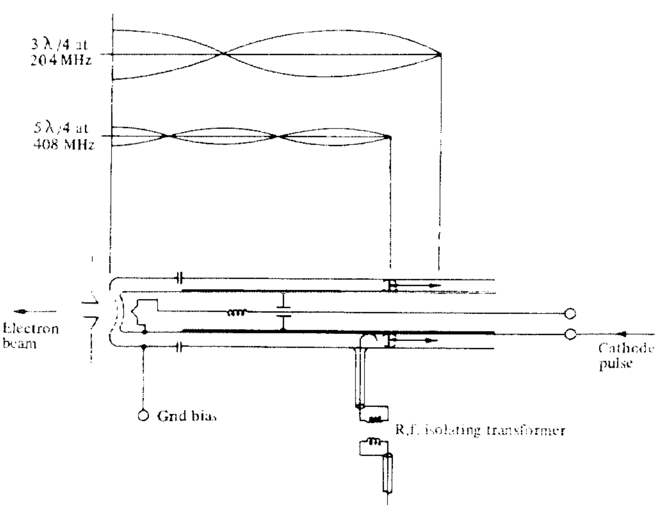

Fig. 2. Schematic arrangement of r.f. modulated gun.

4 EXPERIMENTAL RESULTS

1. 408 MHz Modulation - Measurement of Specified Performance

In order to show that the injector met the specified performance it was necessary to measure the current available from the linac which fell inside a 1% energy band and within the required emittance. For operational reasons it was not possible to set up special apparatus for measurement of spectrum and emittance, so that it was necessary to devise means whereby the normal system could be used to assess these parameters. The energy spread requirement was assessed using an adjustable collimator at a point in the flight path from the linac to the synchrotron where there is a focus in the horizontal plane, but appreciable movement of the beam with energy. The slit was set to pass a beam of zero emittance and 1% energy spread and the percentage of linac current transmitted was measured thus giving an underestimate of the total current within 1% energy spread. After optimization of the linac, then for 5 A peak current from the gun, 1.4 A were injected into the linac of which 0.88 A was accelerated. The current through the 1% slits was 0.40 A.

The emittance of the beam was assessed by measuring the aperture it occupied in the vertical plane in the synchrotron in the absence of any restrictive aperture in this plane. The emittance matching of the synchrotron has been shown to be good. The results showed that all the current fell within the specified emittance.

Observation of the accelerated current in the synchrotron as a function of injection phase confirmed that, after appropriate adjustment of the gun cavity phase relative to the injector, practically all the current was carried in two bunches.

2. 408 MHz Modulation - Effect on Synchrotron

The object of using a modulated gun was to increase the percentage of injected beam captured in the synchrotron. Under optimum conditions it is now possible to capture all the beam up to about 30 mA peak injected (apart from the loss due to inflector turn off time). Beyond this point the transient effects of beam loading on the cavity fields is increasingly evident, giving rise to coherent synchrotron oscillations which limit capture. Experiments are still proceeding to overcome these effects using a phase jump, combined with a suitable amplitude jump in the r.f. power supplied to the cavities to overcome these difficulties.

3. 204 MHz Modulation - Suppression of Alternate Bunches

In the $K^{o}p$ charge exchange experiment the velocity of the K_L^o mesons are measured by recording the time of arrival of K^+ mesons relative to a signal derived from a cavity in NINA which is excited at 204 MHz by the circulating beam. Observation of this arrival time showed peaks separated by 4.9 ns, and complete suppression of alternate bunches in NINA.

4. Cathode Lives

The original aim of a cathode life in excess of the normal NINA running cycle of approximately 800 hours was achieved initially, although some deterioration was observed towards the end of the cycle. Subsequent cathodes have shown a steady improvement as the system cleaned up and better vacuum conditions were achieved, and the last one was changed due to reduced emission after 5000 hours.

It can be concluded that oxide cathodes can work satisfactorily and give good lives in accelerator duty provided that the vacuum system is carefully designed. Further development is in progress to evaluate the performance of a dispenser type cathode, which is expected to yield a further improvement in life, and also to survive if the gun has to be let up to atmospheric pressure.

REFERENCES

1. D.E. Poole et al. DNPL report, to be published.

2. J. Willard. IEEE Trans. Nucl. Sc. June 1967, p.87