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DEVELOPMENT OF A HIGH POWER RF SYSTEM FOR THE DARESBURY SRS

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Abstract

The r.f. system for the high current electron storage ring is illustrated in its present state of development, attention being drawn to modifications and counter measures added to the original design. Some of the characteristics, problems and achievements of the system are discussed. Practical techniques for the diagnosis of system problems are described.

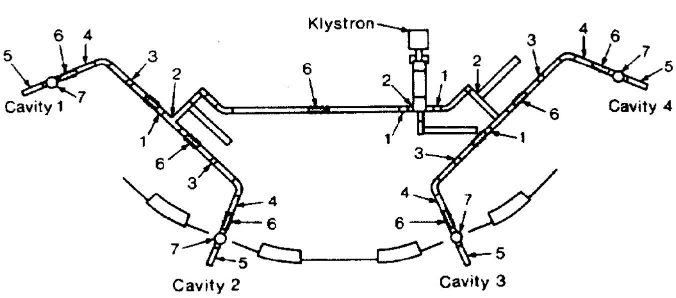
1. Introduction

Unlike other subsystems of a particle accelerator the r.f. system performance is characterised by marked interaction with the particle beam. Thus full development and optimisation is possible only when beam is available.

For the above reason development of accelerator r.f. systems is an extended process aimed at improving the system and at the same time not putting existing operational performance and reliability at risk.

The following paper describes some of this development process carried out on the Daresbury SRS. The work described is essentially of a practical nature and no claims are made for innovative techniques. The writers felt however that a record of their experience would be of interest to other workers embarking on accelerator r.f. system design and commissioning of a similar nature.

2. Arrangement of the Daresbury r.f. System at Commissioning



1. Fixed phase shifter
2. Magic tee and coax load
3. Directional coupler
4. Variable phase shifter
5. Cavity matching unit
6. Flexible waveguide
7. Waveguide to window transition.

Figure 1. Showing composition and layout of SRS r.f. system as at commissioning:

2.1 For economic reasons no ferrite isolator or circulator was included at this stage. The system of magic tees provides 6 dB of reverse power attenuation for the klystron at the fundamental frequency of 500 MHz.

2.2 The settings of the short circuit cavity matching sections and the high power phase shifters have the facility for continuous variation, in track, via the computer control system. During the SRS design stage it was envisaged that the settings of these components would vary under changing beam conditions for optimum results.

2.3 It was intended to start SRS commissioning with cavity higher order mode suppressors fitted to the cavities. These suppressors would be damping monopole antennae specifically tuned to the three major measured mode frequencies of 819, 1076 and 1392 MHz. Higher known modes would be damped by ferrite absorber.
Due to manufacturing problems with ceramics however, all available effort was devoted to overcoming waveguide window problems. As a result the SRS went into service with no cavity damping devices fitted.

3. Performance of the RF System at Commissioning

Before and after commissioning a very problematic fault was present both under beam and no beam conditions.

The symptoms of the fault were as follows:-

3.1 With all four cavities detuned the klystron could be run up to its full power in excess of 250 kW, the power being dissipated in the magic tee loads.

3.2 With the cavities on tune r.f. power in excess of 100 kW caused an audible waveguide breakdown accompanied by a klystron reverse power trip.

Subsequent examination of waveguides showed arc marks resulting from flashover potentials in excess of 200 kV. Arc marks were most prevelent in waveguide to cavity window transitions. The pattern of arc marks gave some indication that r.f. power was being propagated in the TE11 or TE21 mode. Both these modes are beyond waveguide cut off at 500 MHz.

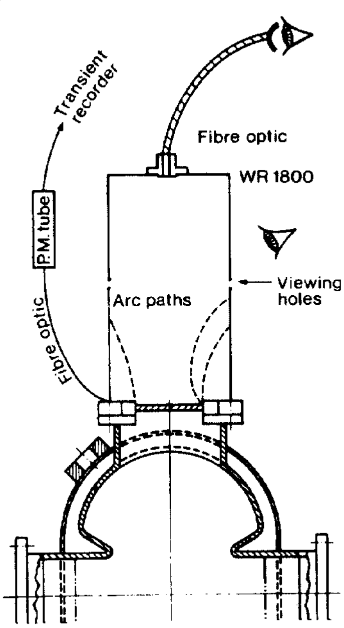


Figure 2. Method of observing and detecting waveguide arcs under no beam conditions.

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The possible existence of appreciable power being transmitted in these modes led to the klystron being suspect for excessive harmonic output. This suspicion was not however confirmed by measurement taken just below breakdown power level. Harmonic levels were however higher than specification. During investigations sparking was actively observed in cavity 3 window transitions (see Fig.2). Two methods were successful. In the first method a 3 cm diameter hole was made centrally in the long wall of the window transition. Sparks were then observed between the transition wall and the window rim, using the naked eye and due care. The second method employed a light fibre device introduced into the roof of the waveguide via a cut-off tubular guide section. Sparking occurred at an individual cavity power of ~ 27 kW. Cavities had been previously rig tested to ~ 50 kW with no breakdown.

The process of cleaning arc marks from window transitions, phase shifters and magic tees resulted in these items being checked out for physical defects. As no visible arcing had occurred adjacent to the klystron, the doorknob coax to waveguide transition had not been checked exhaustively. In the course of a full scale waveguide strip down exercise, a minute soot mark was noticed at one end of a matching bar, fixed across the doorknob unit waveguide. On removal of this bar extensive concealed arcing became apparent.

Replacement of the offending matching bar with an improved component removed all incidences of arcing, anywhere in the system, under no beam conditions.

It would appear that the threshold of arcing for the matching bar was ~ 100 kW. Harmonics, generated by the arc or the mismatched klystron above this 100 KW level found resonances in the waveguide with associated flashovers.

On the credit side this fault did draw attention to a fact not before treated with sufficient respect. Waveguide components only fulfill their expected purpose when operated at the frequency and mode for which they were designed. In particular magic tees at other than their designed frequency, do not guarantee isolation for the klystron or between cavities.

The fault outlined above, of simple cause and cure but for a time difficult diagnosis, limited SRS performance to 130 mA at 1.8 GeV. On rectification of the fault the SRS rapidly attained 300 mA at 2 GeV. The machine r.f. reliability was however not adequate and erratic due to reverse power trips, both during ramping and stored beam. Sporadic arcing was still occurring particularly on the region of windows. In these instances the klystron was exonerated from blame in respect of its steady state harmonic output at full power.

Cavities at this time were being operated at a fixed coupling factor of 2.0. During investigations the short circuit cavity matchers were extended to an alternative position giving the same coupling factor. An immediate great improvement in reliability resulted enabling beams of 2 GeV 250-300 mA to be used regularly for their useful lifetime.

It was subsequently demonstrated on a number of occasions that quite small changes in matcher positions would provoke outbreaks of waveguide arcing, cavities 2 and 3 being particularly prone.

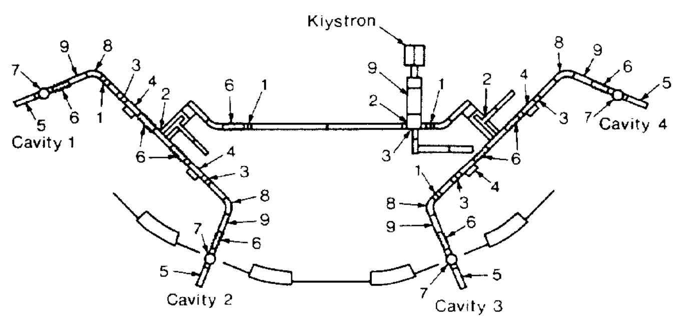
4. Present State of Development

As a result of experience gained in commissioning and measurements described in associated papers[1,2] the following conclusions have been reached or confirmed:-

4.1 The waveguide system is a complex of high Q resonances and intercouplings at many frequencies the situation being modified by adjustment of cavity tuners, cavity matchers, high power phase shifters and beam intensity.

4.2 The use of large diameter ceramic windows to couple the cavities to the waveguide allows simple adjustment of the cavity coupling factor over a wide range. These windows however also provide substantial wideband coupling out for frequencies present in the beam spectrum, with the attendant problem of excitation of waveguide resonances. A beneficial effect of the windows coupling characteristic is that energy is extracted from cavity higher order mode resonances thereby providing a degree of damping.

The conclusions 4.1 and 4.2 have led to a number of anti resonance measures being introduced with beneficial results, ie increased beam current, freedom from reverse power trips and waveguide arc damage.



1. Fixed phase shifter
2. Magic tee and coax load
3. Directional coupler
4. Variable phase shifter
5. Cavity matching unit
6. Flexible waveguide
7. Waveguide to window transition
8. Camera port bend
9. Slotted waveguide

Figure 3. Showing composition and layout of SRS r.f. system as at 1st February 1983.

Layout of the present system is shown in Fig.3 for comparison with Fig.1. The measures adopted, each of which individually produced an improvement, are as follows:-

4.3 Redistribution of waveguide components so that items producing field distortions were not contiguous. For example magic tee and iris plate phase shifters were separated by plain guide where possible.

4.4 Lengths of stainless steel guide were introduced into cavity feeder legs to damp Q.

4.5 Subsequently the guides of 4.4 were slotted 1 cm × 70 cm centrally along the long wall. The object being to radiate power being propagated in modes other than the TE10. By use of monitoring antennae the slots have been shown to radiate components of the beam spectrum 700 MHz and above including cavity mode components. During resonance incidents considerable power is radiated.
Waveguide arcs have been detected by means of microphones and photo cells.
For personnel safety and interference reasons the slots have been covered with absorbing material.

4.6 The waveguide components have further been reorganised so that the slotted guides are situated as close to the cavities as possible.

A cut-off tube waveguide aperture has been fitted in the waveguide bends adjacent to the slotted guides and the cavity transition. The tube can carry a data recording 35 mm camera for photographing and logging spark incidents.

4.7 An aluminium slotted guide section has been inserted following the klystron and preceeding the first magic tee.

The spectrum analyser recording (Fig.4) of slot radiation clearly shows that ~ 1070 MHz components generated by the beam are being transmitted back to the klystron.

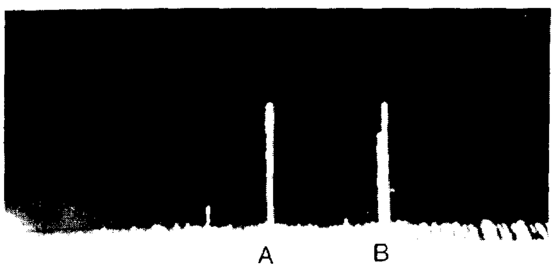


Figure 4. Spectrum analyser recording from an uncalibrated antenna monitoring the slotted waveguide at the klystron. Beam 600 MeV, stacking limiting at 80 mA due to an instability induced by turning off the octupole magnets and causing a large horizontal blow up.

Centre frequency 1000 MHz Scan 30 MHz/div A klystron 1000 MHz harmonic B two cavities resonating ~ 1070 MHz

5. Future Work

As a result of development during the first ten months of operational life the SRS produces reliable long life beams of 300 mA at 2 GeV. Resonance incidents mainly now occur during abnormal operating conditions, intentional or accidental.

It is intended to further desensitise the system by exploring the following

5.1 The fitting of stainless steel faces to the shorting buckets of the cavity matchers, to further damp resonances, which are at their most troublesome at the cavity windows.

5.2 Fitting of absorber antennae in the cavities to damp higher order modes.

5.3 Mode suppression reflection and damping by the use of wire screens or fin line partitions in the waveguides in accordance with established techniques.

5.4 A single 300 kW ferrite isolator is scheduled for installation following the klystron, in mid-1983. This device will enable a far wider range of adjustments of the cavity and waveguide component to be tolerated.

It is also expected that phase and amplitude modulation of the klystron caused by reverse power variations will be much reduced. It is this effect which is thought to be responsible for phase oscillations seen on the cavity volts at low power levels.

6. Beam Development Factors

A factor which has obvious connections with the amplitude of beam driven r.f. resonances is the structure of the electron beam fill spectrum as shown in Fig.5. A fill amplitude oscillogram at the same time shows uneven filling of the r.f. buckets. The uneven fill, is aggravated if beam dropouts ("glitches") are allowed to occur during stacking.

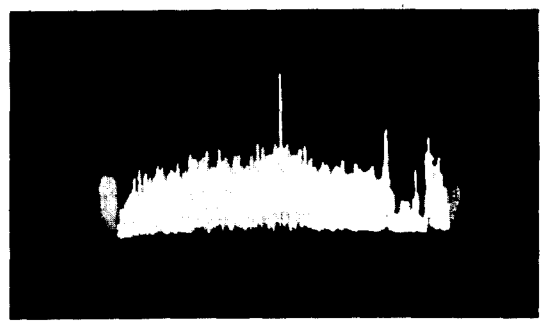


Figure 5. Spectrum analyser plot from the storage ring diagnostic strip with 2 GeV 220 mA beam stored centre frequency 500 MHz Scan 0-1000 MHz peak response 60 dB.

On rarer occasions smooth fills have been obtained. In this case a beam spectrum is obtained showing only fundamental and orbit sideband components see Fig.6. The conditions for consistently obtaining these smooth fills, once mastered, will greatly improve the situation with regard to driving destructive resonances.

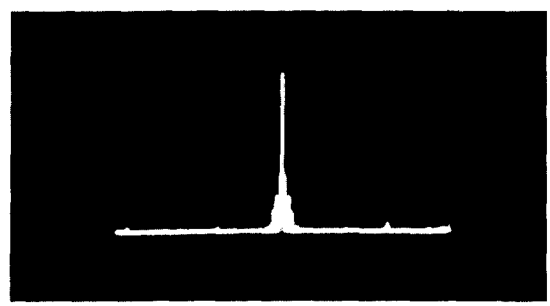


Figure 6. Spectrum analyser plot from storage ring diagnostic strip. 2 GeV 250 mA beam stored centre frequency 500 MHz. Scan 0-1000 MHz peak response 60 dB.

References

1. D.M. Dykes, Paper presented at this Conference. Measurement of the SRS Cavities Higher Order Mode Resonances using Electron Beam Excitation.

2. D.M. Dykes, A. Jackson, B. Taylor, Paper presented at this Conference. Breakdown and Resonance Behaviour of the SRS Waveguide.