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STATUS OF EPIC

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Summary

The status of EPIC, a 14 GeV electron-positron storage ring which it is proposed should be built at the Rutherford Laboratory, is given. Changes from the Proposal[2] are described, especially the characteristics of the booster injector and methods of forming bunches in the main ring. The R & D programme on the components for the machine is also outlined.

Introduction

Following the initial design work on the electron-positron and electron-proton storage rings, EPIC[1], a fully costed Proposal[2] for an electron-positron ring at the Rutherford Laboratory has been prepared and was submitted to the UK Science Research Council in November 1974. The design has been made entirely consistent with the future addition of a proton ring. The SRC agreed that there was a strong scientific case for EPIC but could not give approval at least until it was clear that its cost could be fitted within the resources the SRC could provide for nuclear physics in its future plans. The SRC invited the pursuit of possible international involvement in the project and has subsequently approved the continuation of an R & D programme. The Nuclear Physics Board will be presenting to the SRC a programme which includes EPIC and is based on guidelines for its Five-Year Forward Look consistent with the most likely allocation by the SRC for nuclear physics. The basic parameters of EPIC are given in Table 1.

TABLE 1: Parameters of EPIC 14 GeV $e^{\pm}$ colliding beam system

Main ring circumference	(m)	2191.6
Long straight lengths	(m)	133.1
Dipole bending radius	(m)	171.9
Minimum β_v^* value	(m)	0.15
Minimum β_h^* value	(m)	1.5
RMS bunch length	(cm)	1.8
RMS beam width at crossing point	(mm)	0.7
Injection momentum	(GeV/c)	5.3
Number of bunches per beam		2
Number of particles per bunch		$8\ 10^{11}$
Maximum energy loss per turn	(MeV)	19.8
Length of RF structure	(m)	41.6
Peak synchrotron radiation power	(MW)	1.4
Total RF power	(MW)	4.0
Luminosity versus energy	(max)	$\alpha^{\ell}\ E^2$
Tune shift per interaction	(ΔQ)	0.04
Luminosity at 14 GeV	($cm^{-2}\ sec^{-1}/Xn$)	$3\ 10^{31}$

Possibilities for expansion are to increase the RF cavity length to 228.8 m with 8 MW of RF power. An energy of 21.5 GeV can be reached with luminosity of $10^{30}\ cm^{-2}\ s^{-1}$ (see Figure 1) provided that there is no problem with the high synchrotron frequencies which will be reached in the very high electron storage rings (EPIC would have Q_s of 0.09 at 21.5 GeV). Space has been left in the tunnel, straight section length has been inserted and the magnet apertures are sufficient to allow for operation of the electron ring with proton ring for electron-proton collisions. A second electron ring would be a possibility for e^-e^- or e^+e^+ physics.

A description of progress on the programme since the Proposal and since the report by Rees at the IV All-Union National Conference on Particle Accelerators in Moscow in November 1974 is now given.

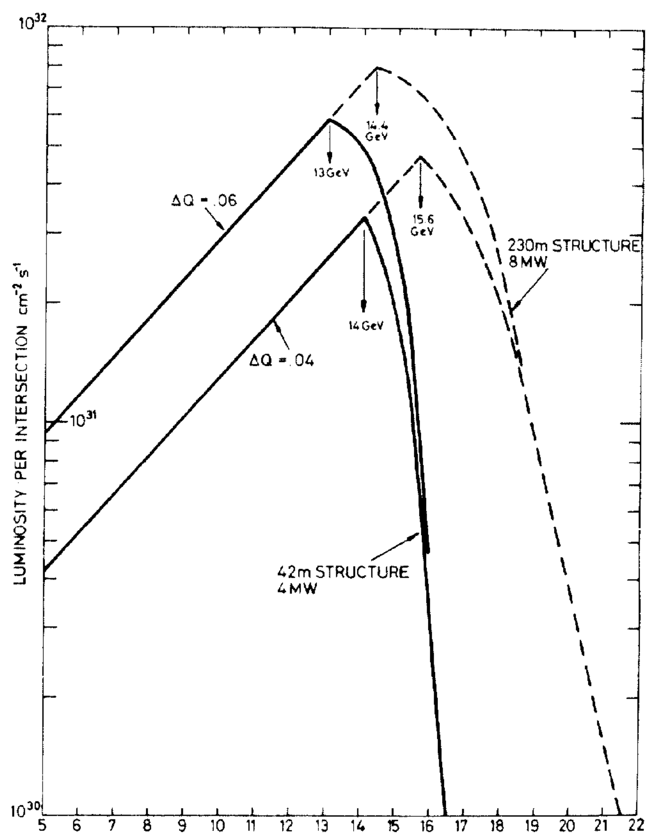

Figure 1: Luminosity vs Energy Characteristics for EPIC

Site

In the Proposal, the siting of the main ring for EPIC was adjacent to the present Nimrod complex of buildings and on the large expanse of agricultural land to the south of the Laboratory. An alternative site has now been investigated which has the main ring surrounding the Laboratory (see Figure 2). Half of the ring building (the half centred on the injection straight) would be tunnelled and the rest constructed by cut-and-fill methods. The quality of the chalk, determined by measurements from boreholes, is extremely good and tunnelling appears to be entirely feasible. Advantages to be obtained from this siting of the main ring are more compactness of the Laboratory and the fact that the land is entirely owned by the SRC or the UK Atomic Energy Authority and is therefore immediately available. The total costs of the tunnels and experimental areas on the two sites are approximately equal.

Work on the site will continue with an accurate dimensional site survey and more boreholes to obtain the necessary information to give to building contractors. Work will also continue on the tunnel design.

Injection

The injection scheme for EPIC, determined by the rate of production of positrons, is based on the following scheme:

- 100 MeV electron linac with gun modulation to give 4A pulses 10 ns long.
- 200 MeV positron linac.
- Energy compression system to give a reduced energy spread.
- Injection into the booster (modified NINA) into 8 buckets of a 58 MHz RF system.
- Acceleration in the booster to 2.2 GeV.
- Flat in the booster waveform for damping.
- Changeover to existing high power 408 MHz RF system.
- Accelerate.
- Inject 8 bunches into one bunch in the main ring by 8-turn injection into transverse phase space.
- Electron and positron bunches are filled on alternate booster cycles.

Some re-appraisals and improvements of the injection scheme have now been made[3] with the followir results:

	Proposal	New design
Booster repetition rate	4 Hz	8 Hz
Positrons per booster fill	$1\text{-}2 \times 10^9$	3.6×10^9
Booster energy	4.8	5.3
Main ring damping time	0.6 s	0.3 s
Time to fill 4 bunches: (1.6×10^{12} e^+ and 1.6×10^{12} e^-) (excl. operational set-up)	$\sim$ 15 min	4.5 min

In the new design 50% injection efficiency into the main ring is assumed.

Alternative injection scheme

Following the idea of Tigner[4] for filling a stora ring from the Cornell synchrotron, an alternative injection scheme for EPIC has been considered[5]. Brief the scheme is to store many bunches (the number being determined by fast kicker technology) in the main ring The many bunches are then accreted into one by taking each main ring bunch, transferring it into the booster where it circulates at approximately fixed energy for the appropriate time so that on re-transfer to the mai ring it is co-incident with the accreting bunch. Obviously, there have to be appropriate relationships between the circumferences of the two rings, the lengtl of the transfer lines, the numbers of bunches in each ring and the RF frequencies in the two rings. The scheme allows the use of a fast cycling synchrotron ($\sim$ 50 Hz) without the requirement for an intermediate storage ring.

For EPIC, within the constraints of keeping the existing NINA RF frequency of 407.88 MHz, changing the main ring circumference by a minimum amount, keeping the main ring RF frequency close to 400 MHz but outside the radio-astronomy band, two possible schemes are given in Table 2.

The length of the transfer lines plus partial arcs of the booster and main ring has to be equal to be an integer times the booster circumference divided by 8 for Scheme 1 or 10 for Scheme 2. For EPIC this would

TABLE 2: Numbers for accretion schemes in EPIC

	Scheme 1	Scheme 2
Number of booster bunches	8	10
Booster harmonic number	$8 \times 41 = 328$	$10 \times 33 = 330$
Main ring harmonic number (h)	$73 \times 40 = 2920$	$91 \times 32 = 2912$
Ratio of main ring to booster circumference	73/8	91/10
Change in main ring circumference from Proposal. $\Delta C/C$	$\frac{41}{42}\cdot\frac{73}{71} - 1 = 0.003689$	$\frac{33}{42}\cdot\frac{91}{71} - 1 = 0.007042$
Main ring RF frequency (MHz)	397.9326	395.5209
h divisible by	8	32
Change in length of superperiod from Proposal (m)	2.021	3.859
Change in booster circumference from Proposal (m)	- 5.904	- 4.434

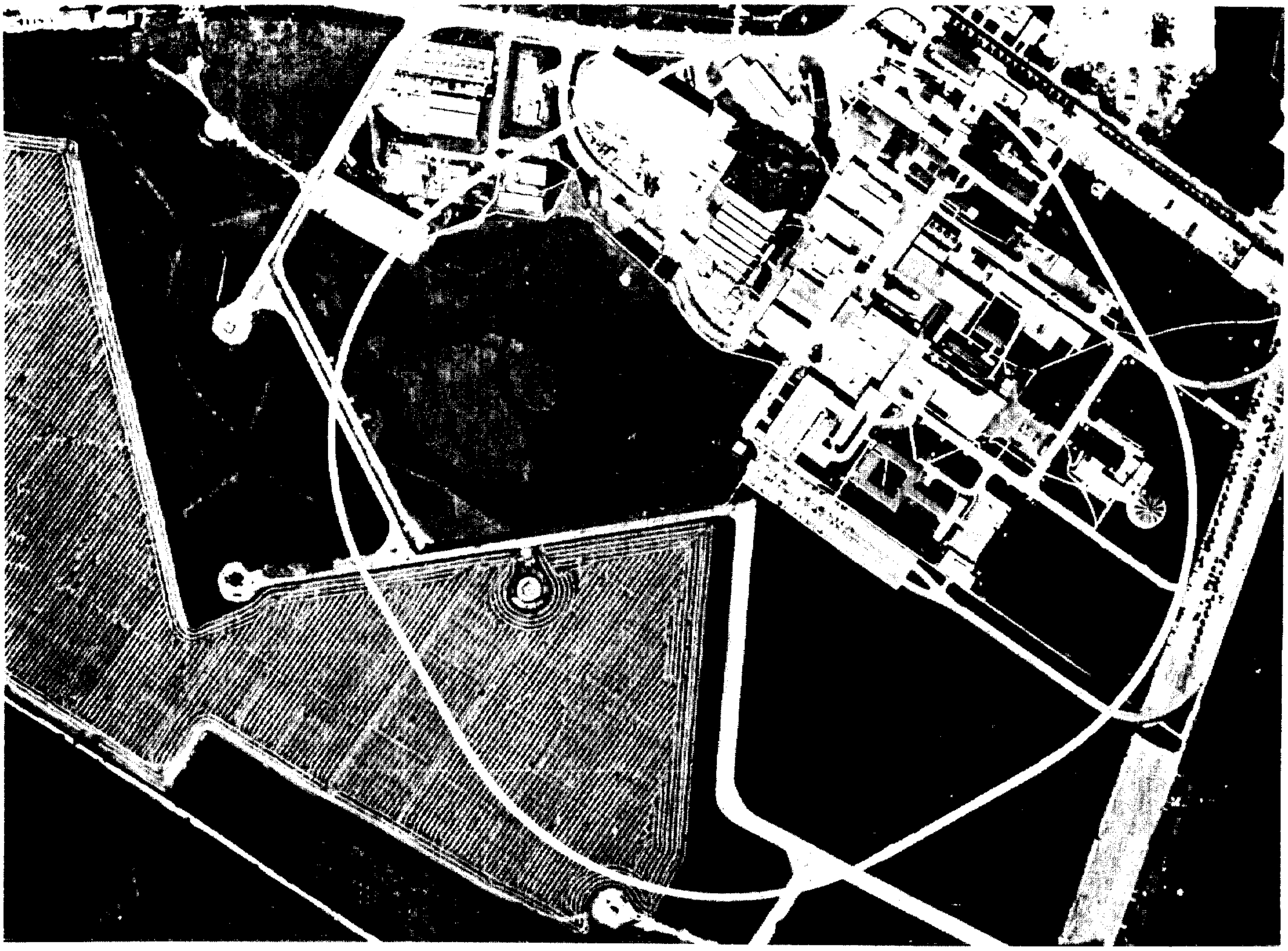

Figure 2: Alternative Siting for EPIC

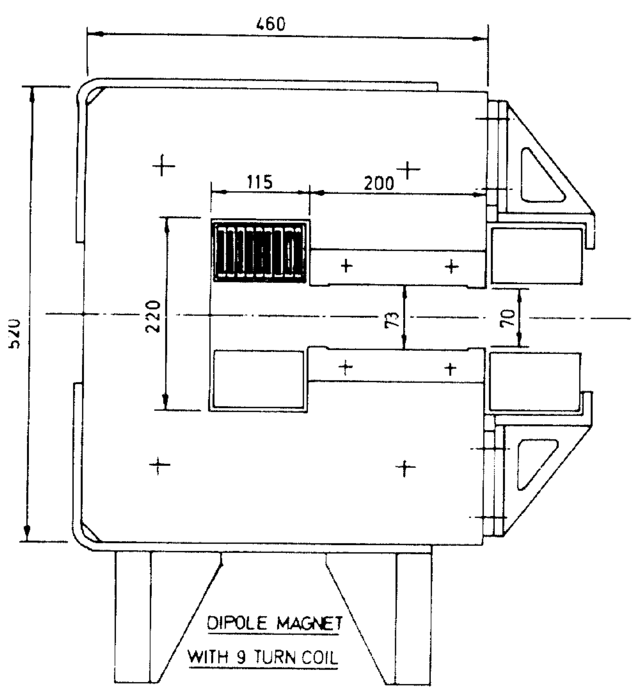

Figure 3: Model Dipole

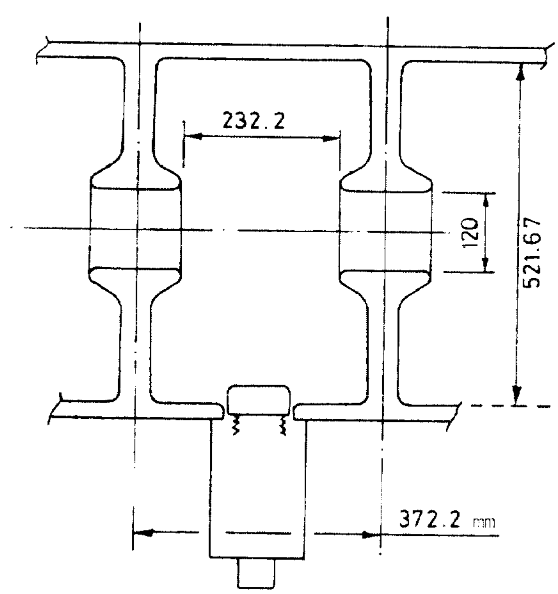

Figure 4: RF Cavity Cell

require transfer line lengths in units of approximately 15 m.

The maximum time for which any bunch would be required to circulate in the booster would be 73 μs so that the energy variation in the booster would be less than 1 part in 10^4.

Advantages for EPIC would be that the existing NINA 53 Hz power supply could be used and the 58 MHz RF system would not be required in the booster. Still to be checked is the beam size in the booster after acceleration to 5.3 GeV and the matching in the longitudinal plane on transfer from the main ring to the booster. Multi-bunch instabilities in the main ring have also to be considered.

A gun modulator system will be made and tried on the NINA injector to test the actual system for producing the 4A 10 ns long pulses required for either injection scheme.

Main ring system

A full-size model dipole has been ordered. A cross-section is shown in Figure 3. Sufficient laminations will be available to make a complete 4.5 m long yoke in either car-body steel or steel heat-treated for optimum magnetic properties. The intention is to make a comparison of the two types of steel to determine whether the cheaper car-body steel can be used to make magnets as described in the Proposal. The coil of the model will be manufactured in the form of a 9-turn single layer copper coil, the current for 0.27 T being 875 A. The computed field shape and pole profile will also be checked by measurements on this model.

Equipment is being set up for the experimental investigation of cleaning techniques for the aluminium vacuum vessels. This work is aimed at determining whether it is necessary to leave space for bake-out of the vessels in the magnet system (± 5 mm was allowed in the apertures of the magnets in the Proposal). Full-length (approx. 10 m) lengths of vessel and the necessary pumping equipment will enable evaluation of the full-scale pumping system.

Radiofrequency cavities

The cavity system given in the Proposal was a scaled-up version of the Los Alamos resonant side-coupled cavity system. A simplification in construction and hence a reduction in cost can be obtained by making a simplified cell-structure at the cost of a reduction in shunt impedance (the EPIC Proposal had 4 MW of installed RF power for 1.4 MW of synchrotron radiation and there is some extra power available). The basic cell-structure is shown in Figure 4. Inter-cell coupling will be obtained either using slots or some form of resonant coupling probably in the form of a resonant line. To test these ideas a full-sized 2-cell model is being made which has ports to permit trials of resonant line coupling.

Trials are in hand of brazing and electron beam welding of copper, from which the final cavities will be made, not only from the mechanical viewpoint but also to check the cleanliness of the various techniques from the vacuum aspect.

Machine theory

Some of the theoretical topics covered since the Proposal are being presented at this Conference. These include a study of chromaticity correction using sextupoles[6 7]. The sextupoles introduce resonance forcing terms of second order in combination with α_p and third, fourth and higher order effects. An arrangement of sextupoles has been found in which the second order terms do not appear to be too serious and the third order terms are reduced to small values. Conditions have been found for which the maximum beam size ($\pm 10\sigma_x$, $\pm 10\sigma_y$) is well within the stable region for particles tracked for 100 turns.

Beam loading effects have also been studied[8 9]. The extra power required as a result of the excitation of higher order modes is not as high as allowed for in the Proposal provided that the bunch length does not decrease from its natural size. A total power of 3.2 MW should suffice for the parameters given in the Proposal (compared with 4 MW assumed).

A study[10] of beam-beam effects in which the allowable ΔQ shift in EPIC has been computed for on and off-momentum particles has indicated that the allowable ΔQ shift is very dependent on the configurati and strengths of the sextupole corrections. ΔQ shifts of 0.04 can be achieved in EPIC. More work needs to be done on this topic.

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