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REPORT ON THE
13th EUROPEAN CYCLOTRON PROGRESS MEETING
MILAN, MAY 6th - 8th, 1976

by

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The 13th European Cyclotron Progress Meeting took place in Milan on May 6th - 8th, 1976. There were about 80 participants from 25 laboratories presenting status reports of cyclotrons and interesting technical developments in 7 sessions, one additional session being devoted to applications.

1. Interesting Points from Status Reports

1.1 Triumf - C. J. Kost

Operation at about 1 μA 10^{-7} torr tank pressure, 70% transmission. 5 μA during a 1-hour test, pulsed external proton beam 48 μA, polarized proton beam 10 nA. Micro duty cycle 11%, ΔE = 1 MeV FWHM at 520 MeV. Beam emittance 0.4 π mm.mrad FWHM, maximum beam split ratio up to 5000/1 between two simultaneous external proton beams.

Schedule 4 x 24 hours per week going to 12 x 24 hours per fortnight.

1.2 Vicksi - W. P. Johnson, A. Susini

Van de Graaff has accelerated 10 μA of Ne^{6+}, beam line to cyclotron complete.

Magnet being remeasured with new, pyrotenax insulated trim coils, will be transferred to Berlin in July 1976. RF resonators constructed at Nucletec have high current pistons using mechanically compressed contact strips, 35 A/cm. Dees and resonators vacuum tested and checked out, transport to Berlin in April-June 1976, Dee voltage in September 1976.

1.3 Harwell VEC - E. J. Jones

Proton energy raised to 58.5 MeV for medical isotope production. Maximum proton beam > 500 μA. Among other beams quoted were:-

Ion	E_{max}/MeV	Current/μA
$^{7}Li^{2+}$	50	2
$^{7}Li^{3+}$	90	1
$^{12}C^{4+}$	115*	10
$^{58}Ni^{6+}$	53*	10 - 30
$^{58}Ni^{8+}$	95*	1
$^{93}Nb^{8+}$	75*	0.1

* Maximum energies calculated from $E_{max} = 86q^2/A$. Very low energy operation for ion-implantation, e.g. 1.2 MeV $^{11}B^{+}$.

^{123}I production using (p, 5n) reaction : 7.5 mC/μAh.

Medical beam line for neutron tests on animals under construction.

Time allocation	:	Metallurgy	: 67%
		Chemistry	: 13%
		Universities, heavy ions	: 20%.

1.4 Louvain-Cyclone - G. Ryckewaerts

The axially mounted source has been replaced by a source on a radial arm, increasing ion extraction efficiency from 20% to 60%. Installation of 20^{o} K cryopanels in the extraction region has improved pumping speed by factor 3 to 9 x 10^{3} l/s and yield of A^{3+} ions by factor 10.

1.5 Orléans - G. Goin

Commissioning completed in March 1976, machine now operates for activation analysis and beam development. Beam-lines being installed.

Performance:-

Protons	: 5 - 38 MeV,	max. external current	100 μA
Deuterons	: 5 - 25 MeV,	" " "	100 μA
α	: 10 - 50 MeV,	" " "	40 μA
$^{3}He^{++}$	: 8 - 64 MeV,	" " "	40 μA

Machine uses single orbit for all energies and particles but operates on 2nd, 3rd or 4th harmonic.

1.6 Ganil - C. Bieth

Ganil will have up to eight RF cavities for its three cyclotrons, three being used for flat-topping. The five principal cavities operate at frequencies between 5.85 and 13.4 MHz.

Wide-band techniques without tuning of pre-amplifiers will be used as far as possible : a transistorized 5 kW wide-band amplifier drives a 100 kW output tetrode of 12 ohm input impedance, this low value being used to avoid parasitic oscillations.

The first design of the RF cavities for the split pole cyclotrons has been model-tested. A Q factor of 5000, 70% of the theoretical value, was measured, but multiple stems and pistons complicate tuning. A new model cavity with bent stems joined by a common short circuit is tuned with panels and is likely to be more reliable.

Studies on RF breakdown as function of surface condition and of mechanical effects due to forces between the panels are in progress.

Peak voltages of 180 kW at 15 MHz are applied between panels, giving rise to currents of 2500 A in the RF contacts. When the present tests are completed a specification for a prototype cavity will be established.

1.7 SIN Ring Cyclotron - M. Olivo

Maximum beam current in 1975 : 60 μA.

Present average current about 20 μA, giving 1800 μA h per week. Improved RF stability by optimising feedback loops of frequency and phase control systems.

Experiments:-
31 High energy physics
10 Biomedical
10 Low energy including isotope production.

About half the experiments require high intensities.

SIN are planning new biomed beam with building west of present experimental hall - see SIN Annual Report 1975, p. B.18.

Observation of phase compression during acceleration due to radial variation of accelerating field which induces axial magnetic field and reduces bunch length from 20^o at injection to 16^o at full radius. Effect predicted theoretically by Joho, Particle Accelerators, 1974, No. 6.

1.8 Liège - D. Lamotte

4-sector cyclotron, Université de Liège

Particles	Energy Range (MeV)
p	6 - 20
d	3 - 11.5
α	6 - 22

in operation since February 1976. External beams under construction.

1.9 Karlsruhe - H. Schweickert

New axial injection system for heavy and polarized ions has given 50 nA of polarized deuterons, 5 nA of $^{6}Li^{3+}$. New correction coils permit field corrections for acceleration of $^{3}He^{++}$ and $^{7}Li^{3+}$ although machine was designed for e/m = 0.5. Hope to accelerate $^{3}H^{+}$ by end 1977.

Cyclotron operates 6200 hours per year, 40% nuclear physics, 40% applied physics research. ^{123}I production yields 10 mC/μA h from 96% enriched $^{124}TeO_2$ target.

1.10 Orsay SC - P. Debray, E. Martin

Magnet shimming for 200 MeV operation is completed. Correcting coils for operation at 170 MeV installed.

RF system completed and tested with Dee in air.

Ion source system : assembly in progress.

Electro-magnetic extraction channel similar to Nevis model using twelve separate conductors including a 2.5 mm septum. Field reduction is ΔB = - 2580 Gauss, radially focusing gradient of 290 Gauss/cm at 7500 A, 17 v.

Automatic control of machine parameters using IBM 1130 computer. Programme execution by micro-processers linked to IBM by CAMAC interfaces.

2. New Projects & Developments

2.1 Milan Superconducting Cyclotron Project

Reports presented by:-

F. Resmini - Status
G. Bellomo - Beam Injection
C. Pagani - RF System
E. Fabrici - Extraction
E. Acerbi - Magnetic Field

The superconducting cyclotron is intended as a booster to the 16-18 MeV tandem accelerator under construction at Legnaro.

Parameters of the present design:-

Number of sectors	3
Spiral angle (deg)	55
Maximum orbit radius (m)	0.8
Energy constant (MeV)	540
Energy variation	1 - 4
Energy gain	10 - 20
<B> Max (T)	4.1
RF range for 3rd harmonic acceleration (MHz)	21 - 63
Dees	3
Magnet weight (tons)	450
Coils (Ampère turns)	6×10^6
Current (A)	2030
Maximum gap (cm)	70
Minimum gap (cm)	7
Trim coils	13
Trim coil power (kW)	200
Radius of stripping foil (cm)	18 - 25

As in other designs only the superconducting coils are at low temperature and field flutter is achieved by saturated iron sectors. Trim coils replace the trim rods used in other designs. Injection is via a focusing channel placed at about 1.30 m radius, strippers are positioned according to injection momentum. Extraction is effected by an electrostatic septum, 120/140 kV cm^{-1}, followed by a magnetic channel which corrects the field gradient. Turn separation at extraction 3-4 mm.

Estimated cost of project : ~ 4 M$.

Status : Design study funded, 1/6 scale model magnet under construction.

2.2 Energy Boosting by the Use of Internal Strippers - E. J. Jones, Harwell

This is a variant of the "harmonic acceleration" scheme proposed for ORIC at the Washington Particle Accelerator Conference 1975 (see MSC-M-2, 1975, p. 3) but here intermediate extraction is avoided by placing strippers at suitable points in the machine and re-accelerating the stripped ions on a lower harmonic. Example : $^{58}Ni^{6+}$ stripped at 46 MeV to Ni^{9+} by a gas stripper. The Ni^{9+} ions spiral towards centre and are converted to Ni^{18+} by a foil stripper. Simultaneous acceleration of Ni^{6+} and Ni^{18+} on 3rd and 1st harmonics. Peak energy of ^{18+}Ni : 450 MeV.

Tests with gas-stripper, surrounded by refrigerated baffles, give localized pressure bump of 10^4 and strip

22 MeV $^{12}C^{2+}$ to 13% C^{3+}, 4% C^{4+}

46 MeV $^{58}Ni^{6+}$ to 9% Ni^{9+}

Foil stripper yields 10% Ni^{18+}. Process could yield 10-100 nA Ni^{18+} beam.

2.3 Studies & Technical Progress

W. M. Schulte (Eindhoven) presented a theoretical study of the radial-longitudinal coupling effect observed at injection in sector focused cyclotrons. For this analysis he uses the "Central Position Phase", i.e. the direction of radius vector from the orbit centre to the particle. CPP = 0 when radius vector is parallel to, but not necessarily coincident with, the Dee gap. The CPP is a canonical variable and permits construction of a Hamiltonian for the phase motion.

He showed that radial-longitudinal coupling can be eliminated by a 3rd harmonic RF or a 2nd harmonic in the magnetic field.

G. Hinderer (Hahn-Meitner Inst.) investigated radial-longitudinal coupling at injection in Vicksi and proposed a purely magnetic system to suppress the effect.

G. C. L. Van Heusden (Eindhoven) showed that vertical apertures can be used as phase selecting slits owing to the phase dependence of axial focusing. Phase selection by vertical slits permits single-turn extraction in Eindhoven cyclotron.

Y. Jongen (Louvain) has analyzed Heat Transfer in a deflector septum on the basis of a simplified model. A septum with an axial slit of decreasing aperture was shown to have a more even distribution of thermal load than a solid septum, in which all energy deposition by incident particles is concentrated at the entrance. A suitably shaped slit does not affect the extraction efficiency.

C. Hoekstra (Amsterdam) reported on a fast emittance measuring device used to scan the phase planes for 25 MeV α particles by modulating magnetic quadrupole fields between a system of defining slits. Emittance measurements are performed automatically in less than a minute and are used for machine tuning by operators.

A. G. Drentje (Groningen), describing the commissioning of a Q-3D type spectrograph constructed by Scanditronix, showed that focal plane correction can be achieved by changing the edge field of a dipole magnet with a "snake" - a packet of flexible iron strips which is locally compressed to varying degrees to achieve the desired field corrections.

B. Berkes (SIN) reported on the advantages of side coils and shims over pole face windings or shims; they can be placed outside the vacuum and do not reduce the main gap height.

Tran-Duc Tien (CGR - Mev) described a pneumatically-operated cylindrical RF contact ring in which a set of Cu-Be strips joining two end flanges are bowed outwards by pulling the flanges together pneumatically.

M. Fruneau (Grenoble) reported on increasing the yield of the cyclotron by pulsing the RF to match the 25% duty cycle of the PIG source. 75 kV can be used in place of 50 kV CW and extracted beams of C^{4+} and O^{5+} are increased by a factor of about 2.5.

Scanditronix reported on machinable ceramics, manufactured by Coors, USA, with qualities close the alumina.

SIN, Louvain, Harwell claimed improved high voltage behaviour of cavities and avoidance of conductive deposit on insulators by use of cryopanels.

3. Applications

3.1 Medical Applications

R. M. Jean (CGR) reviewed medical applications of cyclotrons, putting the principal emphasis on neutron-therapy for malignant tumours. By raising the energy of the deuterons used to produce neutrons via the $^{9}Be(d,n)^{10}B$ reaction neutron yields increase rapidly and the surface-to-depth ratio of doses is improved by nucleon-cascade effects.

Proton-surgery can be combined with conventional surgery by removing surface tissues and replacing them after irradiation. By this method radiation damage to healthy tissue is minimized.

3.2 Trace Analysis in Pure Metals

J. L. Debrun (Orléans) surveyed the use of cyclotrons for the analysis of trace elements in pure metals and semiconductors. Trace elements of particular interest are C, O, N.

Their determination by chemical methods is rendered uncertain by surface absorption. Activation-analysis of material etched after irradiation avoids surface effects. Using reactions such as

$$^{12}C\ (d,p)\ ^{13}C$$

$$^{14}N\ (d,p)\ ^{15}N$$

$$^{14}N\ (p,\alpha)\ ^{11}C$$

etc.

permits detection of impurities to some parts in 10^9.

3.3 Isotope Production

Among the many examples of isotope production ^{123}I aroused particular interest.

Laboratory	Reaction	Energy (MeV)	Yield (μmC/μAh)
Harwell VEC	$^{128}Te\ (p,5n)$	58	7.5
Karlsruhe	$^{124}Te\ (p,2n)$		10
Jülich	$^{124}Te\ (p,n)$		5

Weinreich (Jülich) quoted other examples of isotopes of medical or biological interest produced by JULIC, such as ^{37}Cl, ^{38}S, ^{48}Cr, ^{76}Br and ^{77}Br.

A knowledge of the cross-section as function of energy permits in some cases an enhancement of the desired reaction relative to competing processes.

4. The Milan Cyclotron

The Milan Cyclotron is a 45 MeV, 3-sector proton accelerator. For detailed data see F. T. Howard, Cyclotrons - 1975, AVF and FM, published by SIN. The machine normally operates with H^- ions, extraction being performed by 10-50 μg/cm^2 Al or 200 μg/cm^2 C foils. By varying their radius the extraction energy can be varied between 18 and 45 MeV. Beam current about 20 μA H^-, up to 100 μA P. Operation 5 x 24 hours/week.

Ion Source : Livingston hot cathrode, Ta filament, 500 A heating current, 1.5 A arc, lifetime 120 hours. Floating anticathode.

RF : 170^o Dee, first harmonic operation at 21 MHz, V_D = 56 kV, power 50 kW. 3 push-pull stages. Ripple-stabilization, loading the RF resonators by a 2 kW tube in feedback system, about 3 x 10^{-6} torr.

External Beams :

(1) Low resolution beam for isotope production.

(2) High resolution ($\Delta p/p \sim 3 \times 10^{-4}$) obtained via double focusing magnet into a 1 mm slit.

Experiments : Isotope production, especially ^{123}I, fission studies, trace elements by activation analysis, in-beam γ-ray spectroscopy on heavily deformed nuclei (p; pα) experiments.