OPERATION EXPERIENCE WITH THE CYCLONE-OCTOPUS COMBINATION

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ABSTRACT

Over the last year (till September 1986) the CYCLONE-OCTOPUS combination has been operated almost 85% of the total possible time for nuclear physics, isotope production, radiobiology and neutrontherapy and technological applications.

A new ECR-source for multicharged heavy ions using a Sm-Co permanent magnet octupole (OCTOPUS) was constructed at the C.R.C. in Louvain-la- Neuve during 1985. The source was put into full operation with the cyclotron by the end of October 1985.

A minor problem of short term instability of the beam intensity was solved by changing the main stage microwave feed from radial to axial.

During restart after this modification, a hole was melted, by accident due to a human error, in the octupole envelope, causing a water leak. Except from this, the new source operated continuously and reliably up to now. The performance level, which is comparable now to that of ECREVIS, is still preliminary and should be improved by future development.

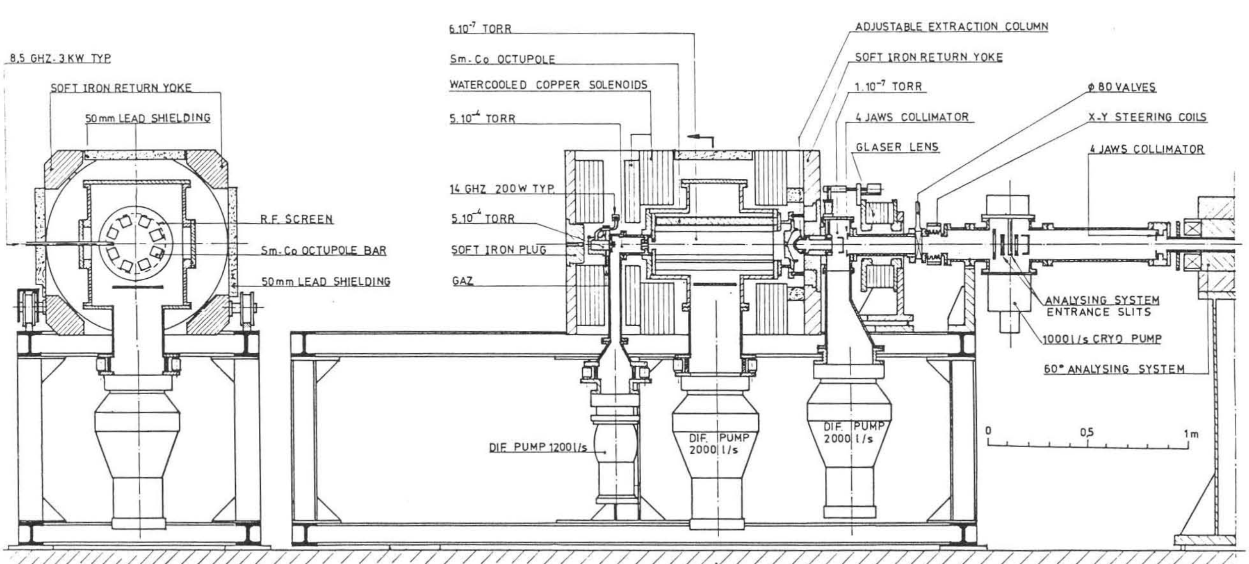
1. GOALS OF THE OCTOPUS PROJECT

In October '84, it was decided to replace the large superconducting E.C.R.I.S. ECREVIS[1,2,3] with a new source of conventional design.

The goals of this replacement were :

- to improve the reliability of the system, eliminating the long down-times associated with cryogenic problems ;
- to get a more economical source operation by the suppression of the liquid helium costs and by a reduced power consumption ;
- to have a smaller plasma volume to reach a higher R.F. power density with the existing klystrons ;
- to test a "shorter" aspect ratio ;
- to have an open octupole, allowing a radial access to the plasma for diagnostic purposes or for the introduction of metal elements ;
- to test an iron yoke, reducing the power needed and the stray field. It would also reduce the sensitivity to outside magnetic perturbations of the plasma centering.

FIG. 1 OCTOPUS SOURCE



2. SCHEDULE OF CONSTRUCTION

The design of OCTOPUS took place from November '84 till April '85. From April to July, the various parts were manufactured in our Institute workshop. In August, the ECREVIS source was stopped, dismantled and stored. The installation of OCTOPUS started in September and was completed in one month.

Since OCTOPUS and ECREVIS shared a lot of common equipment (vacuum system, analysing system, R.F. transmitters, control room etc), it was impossible to test OCTOPUS separately before dismantling ECREVIS.

Only two weeks of beam tests were allowed in October, before the source was put into operation on the cyclotron. This tight schedule was needed to minimize the interruption of E.R.C. source- produced heavy ion beams for the cyclotron.

3. DESIGN OF OCTOPUS

The design of the OCTOPUS source was based on the experience of the ECREVIS source and the E.C.R. ion source of Berkeley. The present design is illustrated in fig. 1 and the main parameters are summarized in Table 1.

Main stage	
length between mirrors	60 cm
diameter	18 cm
type of multipole	octupole (Sm-Co)
easy axis orientation	radial
E.C.R. frequency	8.5 GHz
E.C.R. field	.3028 T
R.F. power maximum	5 kW
R.F. power typical	1.5 ... 2 kW
Typical magnetic field	
axial at mirrors	.4 T
axial + radial at octupole (center of pole)	.46 T
axial + azimutal at octupole (between poles)	.3 86 T
Injector stage	
E.C.R. frequency	14.3 GHz
R.F. power maximum	600 W
R.F. power typical	10 ... 120 W
Magnet power	
maximum	85 kW
typical	60 kW
Weight	
copper coils	1.100 Kg
Sm-Co for octupole	96 Kg
soft iron yoke	2.000 Kg
Typical pressures(in operation)	
injector stage pumping station	1.0 ... 2.0 10^{-5} mBar
main stage	0.7 ... 1.6 10^{-6} mBar
extraction chamber	7.0 10^{-7} mBar

TABLE 1 : OCTOPUS parameters.

4. INITIAL TESTS

The original design of OCTOPUS called for the maximum diameter of the octupole (see figure 2.A.), to increase the pumping speed and the plasma diameter.

However, this gave an E.C.R. resonance surface which was not closed between the Sm-Co bars. Actually, with nominal coil settings, the maximum field between the bars was .2980 T, i.e. lower than the E.C.R. field of .3028 T.

The initial tests showed that such a non closed E.C.R. surface did not work effectively. Therefore a new octupole holder, with a smaller radius and, therefore, a larger field, was built quickly (see figure 2.B.).

After changing the octupole diameter, reasonable values of current were obtained, as illustrated in Table II.

Those currents are given for an extraction voltage of 10 kV. The nominal analysing slit width of 16 mm (used for injection in the cyclotron) combined with divergence slits at the entrance of the analyzing magnet define an emittance of 200 $\times\pi$ mm.mrad. However to increase resolution during source development, smaller slit widths (resp. 8 mm and 4 mm) are used. For comparison one can assume that the beam intensity increases proportionally with the accepted emittance, to some extent.

Beam development on OCTOPUS was then interrupted, and the source was put in full operation for the cyclotron or for low energy atomic physics experiments. Table III shows some beams accelerated by the OCTOPUS-CYCLONE combination. It must be noted that the transmission through the cyclotron has been quite low due to poor vacuum caused by outgassing through the cracks in the lower liner (see par. 8).

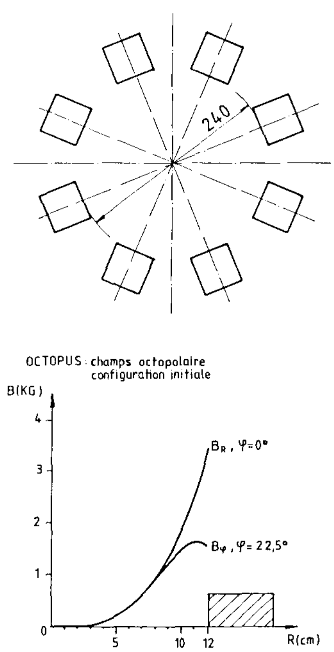


Fig. 2.A. OCTOPUS : octupolar field initial configuration.

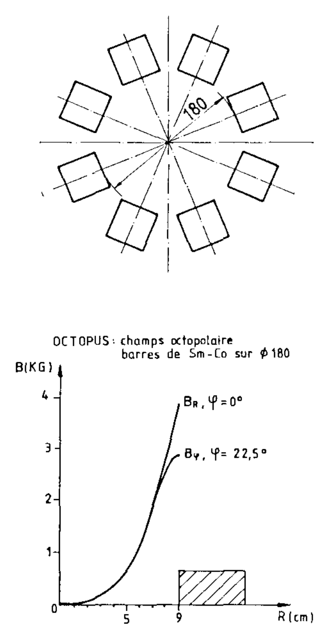


Fig. 2.B. OCTOPUS : octupolar field Sm-Co Ø 180 bars.

Charge state	Nitrogen (1)	Oxygen (1)	Neon (3)	Argon (2)	Krypton (3)
5+	70.	100.	★		
6+	15.	95.	20.		
7+	★	15.	21.		
8+		★	11.	35.	
9+			.4	34.	
10+			★	★	1.3
11+				9.	3.7
12+				3.2	★
13+				0.6	7.1
14+				0.09	★
15+					5.3
16+					4.5
17+					2.7
18+					1.5
19+					★
20+					0.1

★ Mixed beam
(1) in 200 $\times\pi$ mm.mrad horizontally (16 mm slit width)
(2) in 100 $\times\pi$ mm.mrad horizontally (8 mm slit width)
(3) in 50 $\times\pi$ mm.mrad horizontally (4 mm slit width).

TABLE II : Initial beams from OCTOPUS.
(In electrical microamps, at 10 kV source voltage and a vertical acceptance of 200 $\times\pi$ mm.mrad.)

5. STABILITY PROBLEM

Although the beams of OCTOPUS had good long term stability, there were short term instabilities, with time constants of 0.1 ... 5 sec. For some physics experiments, a high stability of the beam intensity is required, and therefore a search was initiated to identify the cause of this instability.

During this search, some source elements were modified unsucessfully :

- a new first stage, made of a quartz dome was tried ;
- the main stage stainless steel end plate on the injection side was replaced by a copper end plate ;
- the stainless steel grid surrounding the main stage octupole was removed.

Finally, following the suggestion of C. Lyneis from Berkeley and T. Antaya from M.S.U., the radial microwave feed was replaced by an axial feed.

In the new configuration, the microwaves for the main stage are introduced in a circular waveguide through the first stage pumping station. The circular waveguide enters the main stage, parallel to the source axis but off center to avoid touching the first stage column. This is illustrated in figure 3.

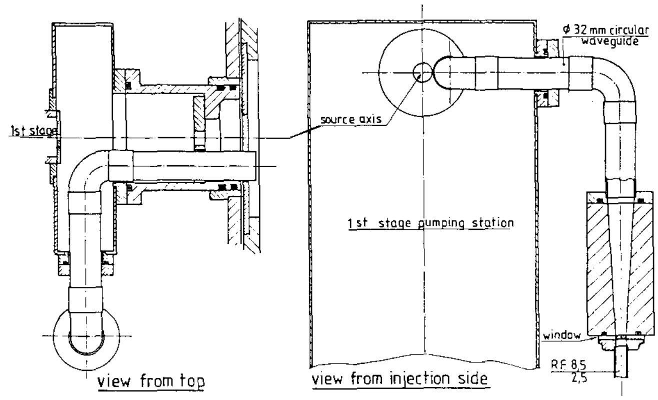


Figure 3 : Axial microwave feed through the first stage into the second giving stable intensity.

This modification completely cured the instability problem. It is therefore likely that a parasitic E.C.R. located at the waveguide entrance in the octupole caused this instability.

6. OCTUPOLE ACCIDENT

When the source was restarted with the new R.F. feed, an accident was caused by an human error. A large R.F. power was fed into the source while a big air bubble was still in the top bar of the octupole. As a result, the stainless steel wall melted, causing a large water leak. The problem was repaired in a few days, but the welding has left a significant protrusion on this bar.

As a result, since this time, ions from Iron, Nickel and Chromium show up in the spectrum when the source is operated at high R.F. powers, degrading the C.S.D. for light ions.

Therefore, during this autumn's general maintenance (October '86) the octupole is being replaced by one of improved design allowing :

- better cooling
- isolated Sm-Co from the cooling water by a second scaled stainless steel jacket.

7. FUTURE DEVELOPMENTS

The source has been used extensively in its present status allowing very little time for development. Obviously the present performance is still preliminary and further development is required. For the near future there are plans to :

- test a decapole or even a dodecapole
- modify the extraction optics to reduce important beam losses occurring now between the source and the emittance defining slits of the analysing system
- test an oven for the production of metallic ions.

Table III Beams accelerated by the OCTOPUS-CYCLONE combination.

Particule	Charge state	E fin MeV	Beam currents (in electrical microamps)				
			Analysed after source	Transported to cyclotron	Internal beam(1)		Final target
					R = 20 cm	R = 92 cm	
Oxygen	6+	225	63.0	40.0	10.0	8.30	6.0
	7+	306	8.0	5.8	1.45	0.73	0.52
Neon	7+	245	30.0	20	5.4	3.9	2.8
	8+	320	11	7	2.3	1.4	1.0
Argon	8+	160	60	35	5.8	3.7	2.4
	9+	200	7.5	4	1.8	1.3	0.7
	11+	315	9	6.5	1.3	0.60	0.300
	12+	378	1.5	1.0	0.21	0.11	0.070
	13+	470	-	-	-	-	0.010
Krypton	17+	378	7.0*	4.0*	0.9*	0.215	0.145
Xenon	23+	400	2.3*	1.7*	0.13*	0.035	0.020

⋆ mixed beams
(1) low transmission in the cyclotron due to poor vacuum - see text.

8. CYCLONE-OPERATION

In 1986, the CYCLONE-OCTOPUS combination has been intensively used until the maintenance starting on September, 6.
Table IV summarizes the different uses of the accelerator.

	Hours	%
Nuclear Physics	2271	45.0
with light ions ($A \leq 4$):1.186 hrs		
with heavy ions ($A \succ 4$):1.085 hrs		
Biomedical Applications		
- isotope production for P.E.T. camera	521	10.3
- neutrontherapy, radio-biology and dosimetry	1155	23.0
Isotope production (others)	402	8.0
Technological applications	73	1.4
Beam developments	165	3.3
Maintenance	205	4.1
Unscheduled shutdown	248	4.9
	5040	100.0

TABLE IV.

Use of CYCLONE-OCTOPUS from Jan. 1, 1986 till September 6, 1986.
Maximum possible time = 5.976 hours
Total operation time = 5.040 hours or 84.3% of max.

A problem has occurred on the lower copper liner covering the pole : cracks have developed under one of the DEES where RF-currents are most intense. These have been repaired temporarily and during this maintenance the liner will be replaced with a new one.

9. CONCLUSION

With the exception of the above mentioned incidents, CYCLONE and OCTOPUS have been performing reliably.

The goals of OCTOPUS : reliability and economy of operation have certainly been met. Up to now, the currents obtained have been comparable to, but not superior to the currents obtained with ECREVIS or the Berkeley source.

However, it should be stressed that these results are preliminary and that significant progress could be made if more time for source development were available.

10. ACKNOWLEDGEMENTS

As for all developments of this size, the paternity of OCTOPUS is shared by all members of the Centre de Recherches du Cyclotron.

Frequent discussions with other members of the E.C.R. community, and specially C. Lyneis in Berkeley, were specially useful in developping this new source.

11. REFERENCES

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