

STATUS OF THE ACCULINNA-2 RIB FRAGMENT SEPARATOR

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Abstract

Operated since 1996, the ACCULINNA RIB fragment separator has provided scientific results recognized by the nuclear physics community. In 2008 it was decided to build a new separator, ACCULINNA-2 which should deliver RIBs produced with 35-60 A MeV primary heavy-ion beams with $3 \leq Z \leq 36$. It is optimized for large RIB intensities and high precision studies of direct reactions populating nuclear systems near and beyond the drip lines through sophisticated correlation experiments [1].

Late 2011, SIGMAPHI got a global contract for optics check, design, fabrication, installation and alignment of the complete ACCULINNA-2. It includes magnets, vacuum and PS for about 40 magnets, from small correctors to 1-6 tons quads, 14 tons dipoles and 6- and 8-poles. We describe the evolution of the project, from functional needs to working system. Thanks to the early involvement of the industrial partner, the collaborative spirit and the freedom of tradeoff between magnet, PS and vacuum chamber, the final product meets all and even exceeds most requirements while meeting industrial needs for standardization.

The next step of the upgrade, a zero-angle spectrometer is also reported.

INTRODUCTION

FLNR JINR ACCULINNA-2 does not compete with large RIB facilities but rather complement them in a **cost effective** solution, delivering **high intensity RIBs** in the **lowest energy range** accessible to in-flight separators shown in Table 1.

Table 1: Characteristics of in-flight separators. $\Delta\Omega$ and $\Delta p/p$ are angular and momentum acceptances, $R_p/\Delta p$ is the first-order momentum resolution for 1mm size object.

	ACC/ACC-2		RIPS/BigRIPS	A1900	FRS/SuperFRS	LISE3
	FLNR	JINR	RIKEN	MSU	GSI	GANIL
$\Delta\Omega$ [msr]	0.9 / 5.8	5.0 / 8.0	8	0.32 / 5.0	1	
$\Delta p/p$ [%]	$\pm 2.5 / \pm 3.0$	$\pm 3.0 / 6.0$	± 5.5	$\pm 2.0 / 5.0$	± 5.0	
$R_p/\Delta p$	1000 / 2000	1500 / 3300	2915	8600 / 3050	2200	
$B\rho$ [Tm]	3.2 / 3.9	5.76 / 9.0	6	18 / 18	3.2 - 4.3	
Length [m]	21 / 38	27 / 77	35	74 / 140	19 (42)	
E [AmeV]	10±40 / 6±60	50±90 / 350	110±160	220±1000 / 1500	40±80	
Additional RIB Filter	No / RF-kicker	RF-kicker / S-form	S-form & RF-kicker	S-form / Preseparator	Wien filter	

As shown in Fig. 1, its structure is very comparable to that of RIPS in RIKEN [2] with a separation accomplished by means of dipole-wedge-dipole selection.

High intensity, DC mode primary beam of U-400M cyclotron hits the solid beryllium, rotated liquid-cooled production target. Normal conducting magnets including 6- and 8-poles are used. The low intensity secondary part of separator is placed outside the accelerator closed area providing good background conditions in the experimental area.

The reader is referred to [3] for the expected beams, sources, instrumentation and planned experimental program and [4] for further reading on the facility.

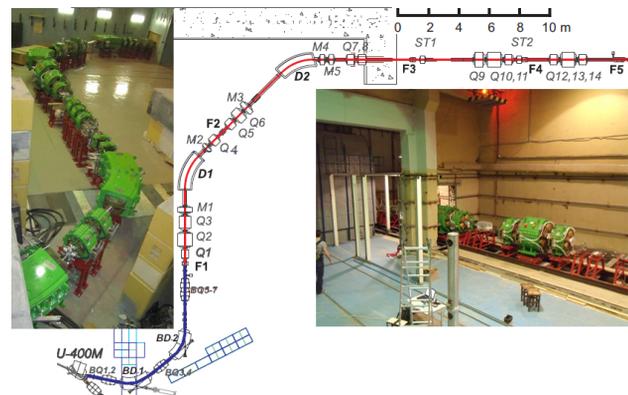


Figure 1: General layout and Room1 magnets, from primary line (blue) dipole BD1 to secondary line (red) quad Q8 (left) and Room2 Q10 to Q14 (right).

OPTIMIZATION

The scope of responsibility for SIGMAPHI was:

1. Optics check and « challenging »
2. All magnets – full electromagnetic calculations, mechanical design and fabrication
3. All power supplies, choice and fabrication
4. All vacuum, pressure calculations, layout, fabrication
5. Installation of all hardware
6. Alignment

Being in control of the 4 first items gives full freedom for an **optimized design** leading to an **energetically efficient and cost effective** facility, a too rare, although very interesting opportunity.

Indeed, the usual practice for labs is to have separate contracts for magnets, PS and vacuum, on the basis of *technical* specifications rather than *functional* ones. Every individual supplier is given very little room for change or improvement and must manage to achieve the cost goal

decided in the offer, itself a result of downward pressure on prices from competition.

In the present situation, the overall contract based on functional needs for all subsystems, with room for proposal from mastering root calculations like optics, allows the search for a system that is optimal for customer and supplier, both working as a unique team, a win-win situation that is itself an optimum in human relationships.

The main candidates for optimizing the system are listed below in arbitrary order. The process being iterative in essence, a given candidate may be revisited many times or changed backwards if this provides a better solution.

- Shaping chambers to reduce bores
- Trading gradient for length
- Standardizing magnets (within limits)
- Trading current for turns
- Trading voltage for copper
- Using standard power supplies

The figures of merit are:

- Global power consumption in operation, a figure that will influence the system during its whole life.
- Global costs i.e. design, material and fabrication costs; they are a “one of” and must be optimized as a whole.
- Standardization which not only drives the costs downwards but also highly simplify maintenance.

Of course, at any step of the process, preserving the functional needs is of paramount importance.

Shaping Chambers to Reduce Bore

Figure 2 shows examples of reducing the quadrupole size.

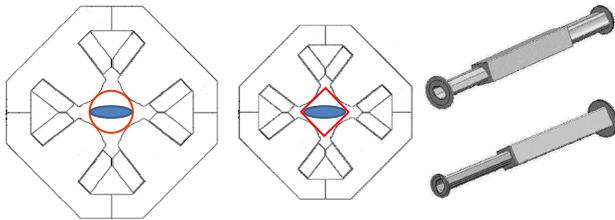


Figure 2: Using square chambers instead of round ones may help reducing the quadrupole size, weight and consumption. Two examples of tailored-to-the-beam chambers in Acculinn-2 are presented on the right.

Trading Coils for PS and Gradient for Length

It is very important for the sake of standardization as well as it is for costs, to work with existing PS as the cost of redesign would be a huge part of the total, especially if every single object must be tailored to needs.

The field in gap of an electromagnet depends on the product of the current in one turn of the coil, times the number of turns, i.e. a parameter of the PS only and a parameter of the coil only. Trading turns for current can then bring the current into the proper range for the PS.

For static fields there is no inductive voltage and Ohm's law applies, with the resistance being proportional

to the conductor length and inversely proportional to the conductor section. To bring the voltage down one must thus increase the conductor section.

The net effect of these 2 trades is an increase in the coil size and weight and the optimum is reached when the global extra cost – not only in money but also in time, loss of standardization ...- of this increase is balanced by the decrease in cost of the PS.

Another possible trade that influences the magnet is the exchange of gradient and magnetic length. To first order, the beam is only sensitive to integrated gradient and, if optics and available space permit, the length can be, within limits, increased to lower the required gradient.

Standardization and Grouping

Standardization groups objects with similar properties. Its advantages are a huge reduction in cost for design, tooling and fabrication and an improved exchangeability and servicing. It has the drawbacks of leading to slightly sub-optimal individual designs and higher material costs. Partial standardization might already help keeping most of the advantages while taming drawbacks.

The 14 secondary quadrupoles offer a good example of partial standardization. The 14 cores are built out of only 3 laminations. Because of very special characteristics, Q1 is unique in its category while the remaining 13 magnets share 2 types of laminations and 2 different lengths, coils and designs for each lamination type as shown in the following Table 2.

Table 2: Grouping the 14 Secondary Quadrupoles

Type	Qty	Quad name	Core	Coil	Design
QM11	1	Q1	A	1	1
QM21	1	Q2	B	1	1
QM22	7	Q4,Q5,Q7,Q8,Q11,Q12,Q14	B	1	1
QM31	1	Q3	C	1	1
QM32	4	Q6,Q9,Q10,Q13	C	1	1
	5	14	3	5	5

The success of the complete optimization process is demonstrated by a 41% reduction of the total power wrt initial specification, of secondary quadrupoles (Fig. 3).

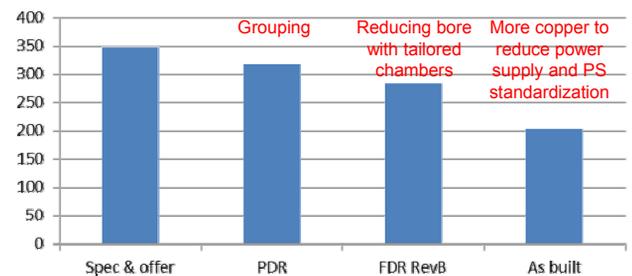


Figure 3: Result of optimization on power consumption of secondary quadrupoles at 4 stages of the process. The main driving term is indicated on top of each step bar but is not the sole responsible for the achieved result.

INSTALLATION AND ALIGNMENT



Figure 4: UL Primary beamline, UR 2 quads, 2 6-poles and 1 8-pole in secondary beamline, LL Installation of D1 secondary dipole on its stand, LR End of primary and secondary beamlines with vacuum elements assembled.

In room 2, the existing floor has a maximum resistance of 1 t/m² and must be reinforced to accommodate the local forces exerted by the 2 groups of large quads, as shown in Fig. 5. Figure 4 shows different magnets in rooms 1 and Fig. 6, shows the power supplies.

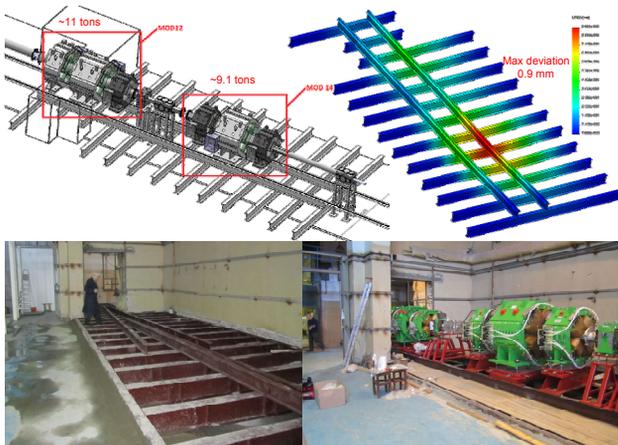


Figure 5: UP beam structure and deformation DOWN floor reinforcement and installed magnets.



Figure 6: The power supply cabinets.

Alignment is performed with a Leica AT401 laser tracker. An accuracy of ± 0.1 mm is achieved (see Fig. 7).

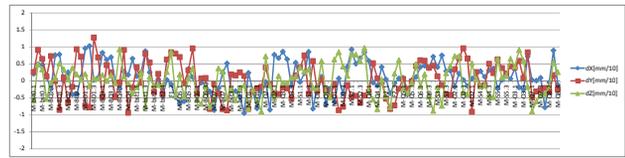


Figure 7: Positioning error (tenths of mm, ± 2 full scale) in the 3 coordinates for all objects of Acculina-2.

ZERO DEGREE DIPOLE

Heavy decay products of the studied exotic nuclei -and decay protons emitted by proton-unstable nuclei- are bent by the well mapped magnetic field. The hit positions of RIB nuclei at F5 are known with 1mm accuracy and one should measure the transverse coordinates passed by the searched heavy decay products and protons after they exit the dipole in at least two planes: 0.5m and 1~2 m from the dipole exit. The nuclei (and protons) are detected by some position-sensitive detectors like MWPC. A TOF detector installed 1~2 m away from the dipole exit provides velocity measurement and, from the measured momentum known from the path in dipole, mass number estimate (Fig. 8).

For neutron-unstable exotic nuclei, the dipole only bends heavy decay products. Neutrons go straight on, passing through the open space allowed by the vacuum chamber and are detected by a plastic-scintillation array installed 2~3 m away from F5.

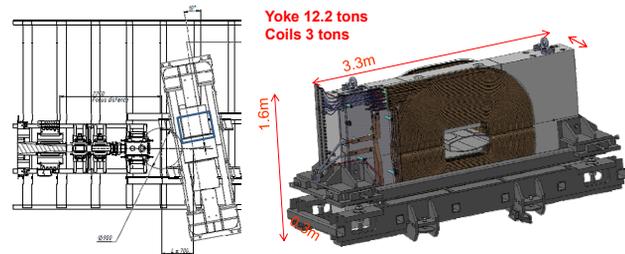


Figure 8: 0° dipole location and mechanical design.

CONCLUSIONS

ACCULINNA-2 is fully installed and commissioned, on time and on budget. First runs should start by end 2015. A global contract for all hardware has opened the possibility for thorough optimization and drastic improvements of the long term operation costs.

The zero-angle dipole is currently under study and production should start soon.

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