Contribution aux exercices de prospective nationale 2020-2030

Accélérateurs et instrumentation associée

RELIABITY AND EFFICIENCY OF HIGH POWER LINACS -

FIABILITE ET EFFICACITE DES ACCELERATEURS LINEAIRES DE FORTE PUISSANCE

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1. Informations générales

Titre : Reliabity and Efficiency of high power linacs –

Fiabilité et efficacité des accélérateurs linéaires de forte puissance

Acronyme : *(optionnel)*

Résumé

The proposed action aims at developing new and innovative methods to improve High power hadron accelerator RF-tuning, operation and reliability. This is, in particular, a major challenge for the ADS technology. The work prospective (divided in 5 topics) consists in: developing new and innovative technics to apply failures compensation in Superconducting RF (SRF) linear accelerators; developing new tools and reliability models of SRF linacs and compare the model results with data from reliability runs; participate in the prototyping of new generation of RF solid state amplifiers; study accelerators efficiency optimisation in a context of sustainable development.

Préciser le domaine de recherche *(plusieurs choix possibles)*

- ***Physique des accélérateurs (nouveaux concepts machines, optique et dynamique des faisceaux…)***
- *Sources de particules (électrons, positrons, muons, protons, ions lourds stables, ions radioactifs…) et cibles associées*
- *Supraconductivité accélérateur (aimants fort champ, cavités SRF…)*
- *Accélération plasma (électrons, ions…) et interaction lasers/faisceaux*
- ***Technologies RF innovantes (structures haut gradients, alimentations RF…)***
- ***Diagnostics faisceau, instrumentation et contrôle intelligent***
- ***Développement durable de la discipline (infrastructures technologiques, efficacité énergétique, fiabilité…)***
- *Autre R&D spécifique : (préciser)*

Préciser la motivation principale visée par la contribution :

- ***Accélérateurs pour la physique nucléaire***
- *Accélérateurs pour la physique des particules*
- ***Accélérateurs pour les sources de lumière ou de neutrons***
- ***Accélérateurs pour les applications sociétales (santé, énergie, industrie…)***
- *Autre : (préciser)*

2. Description des objectifs scientifiques et techniques

There is presently a growing demand for high-power hadrons accelerators to better support various fields of science like particle physics, nuclear physics, or neutron-based physics. These applications typically ask for beams with very high mean power in the GeV range, which goes significantly beyond the present capability of most of existing facilities.
Reliability is a major challenge within the perspective of improving the performances, and sustainability of these Megawatt class accelerators. To optimise the operational costs of such accelerators the availability requirements are becoming more and more challenging. These requirements are even more stringent in the case of Accelerator Driven systems (ADS). As an example, for the MYRRHA (Multi-purpose Hybrid Research reactor for High-tech Applications) ADS demonstrator, the actual availability limit is set to a maximum of 10 beam interruptions (longer than 3 seconds) over a 3-month operating cycle.
Another example where beam availability has been identified as a critical issue is: Compact Accelerator-driven Neutron Sources (CANS)[*]. Developments of such accelerators are foreseen to replace or overtake nuclear reactors for neutron scattering. The CANS accelerator will have to enable to produce the neutron flux with the same availability than research reactors (such as : Orphee-LLB, ILL).

So, to minimize the overall power consumption and therefore decrease the operating costs the use of Superconducting RF (SRF) technology is becoming mandatory: especially for machines that requires CW (continuous wave) operation or a high duty cycle. The architecture of most of these new machines is therefore based on a SRF linear accelerators (linacs).

Several studies showed that the failure rate of a superconducting linac (composed of many cavities) is dominated by the reliability of the injector and more particularly by the serial RF units. It is therefore necessary to design linacs, with redundant elements, able to survive a certain number of failures without any significant beam interruption.
To improve the reliability of SRF linacs, it is fundamental to include these requirements from the start in the design of the machine. Therefore the action we propose consists in:

- developing new and innovative technics to apply failure mitigations in SRF linacs and evaluate the feasibility of such procedures,
- developing new tools and reliability models to assess weak points in linacs design and construction,
- prototyping new generation of RF solid state amplifier with enhanced reliability capabilities.

To this purpose, the proposed action could be composed of 5 connected R&D Topics following the structure of an European project coordinated by TIARA submitted to the Horizon 2020 call INFRAINNOV-04-2020 (described in section 3).

[*] See contribution “Compact Accelerator Neutron Source”, *M. Baylac et al.*, submitted to the Prospectives Nationales 2020-2030 in the accelerator field (GT-07).

1 - Beam dynamics studies and algorithm developments (with machine learning method) for fast fault-recovery.

The goal will be to develop beam dynamics and control tools to simplify linac tuning and improve the operational reliability. This will be done by the development of dedicated algorithms for the automatic set-points reconfiguration for cavity failure compensation.

The MYRRHA linac design and the ESS linac will be used as references to test these innovative methods. To this purpose the use of neural networks based algorithms, will also be studied.

→IN2P3 will lead this work. It is planned to be supported through different research contracts (see section 3).

2- Modelling of the RF behavior of a cavity and its feedback control loops to assess the LLRF and tuning performances required and the technological feasibility of fast cavity retuning. The work will consist in improving an existing model developed with Matlab Simulink. A particular effort will be made to improve the modelling of the LLRF electronics and the mechanical tuning system.

→IN2P3 will lead this work. This work is planned to be supported through different research contract (see section 3).

3- Development of reliability model of an SRF linac

The goal will be to develop a realistic availability model of linacs with the Isograph® and AvailSim codes. Specific modules for RF compensation will be developed for AvailSim. The model will be used to evaluate the injector reliability - for example the MYRRHA injector currently under construction and tests at SCK•CEN and also LINAC 4 at CERN - and model results will be compared to experimental data. The number of cavity failures to be expect during the SRF linac operation will be assessed, as well as the effectiveness of the failure mitigation strategy. The impact of component redundancy will also be evaluated.

→IN2P3 will bring its expertise to this work that will be coordinated by CERN. It is planned to be achieved within the Frame of a European Project (Horizon 2020 call INFRAINNOV-04-2020) coordinated by TIARA (see section 3).

4- Construction of a prototype Solid State 352 MHz RF power

The proposed action is to support these developments by developing a dedicated test bench to achieve reliability runs for accelerated testing with some SSA modules. The final goal will be to obtain experimental reliability statistics to “feed” the model developed in topic 3 . The test results will also be used to identify any potential technical improvements.

→IN2P3 will bring its expertise to this work that will be coordinated by IBA company and SCK•CEN . It is planned to be achieved within the Frame of a European Project (Horizon 2020 call INFRAINNOV-04-2020) coordinated by TIARA (see section 3).

5- Accelerators Efficiency within a sustainable development perspective

This work prospect aims at creating a working group to evaluate the criterion that defines accelerator efficiency: wall plug power consumption *vs* power transmitted to the beam, or beam time on target *vs* cost, etc. A generic compact high power linac (50 to 100 mA , 20 to 100 MeV) could be used as reference for the study. This work would address the issue of determining what are the main criterions that lead to choose a linac architecture (normal or superconducting) and how they

interrelate: duty cycle, beam power, construction cost, operation cost, etc. The evaluation of “lost” or “non-used” power can also be studied and the research of sustainable solution to increase accelerators energetic efficiency could also be addressed, as in the ESS example recycling part of the heat generated by the linac klystrons. This study will also rely on the results obtained in the 4 previous topics. The impact of reliability developments (failure-compensation) and technological choices (redundancy) should also be evaluated. This work aims at bringing a feedback on choices made for existing projects and to provide a guideline for future accelerators developments.

A linac designed for a CANS can provide a basic scenario for this studies: this work is related to the topic “Compact Accelerator Neutron Source” submitted to the Prospectives Nationales 2020-2030 in the accelerator field (GT-07).

→ For this work it is proposed to first start with the setup of an IN2P3 working group and then to extend it to collaborations according to projects needs and working perspectives.

3. Développements associés, calendrier et budget indicatifs

Continuity to previous projects

❖ The action will enable to continue the work undertaken in the Work package 2 of the **MYRTE** (Multi-Purpose Hybrid Research Reactor for High-Tech Applications) **project (2015-2019).** MYRTE is a Co-funded project by **the European Atomic Energy Community's (EURATOM) H2020 Programme** under grant agreement n°662186 (MYRTE project).
MYRTE website**:** http://myrte.sckcen.be/.

❖The work of MYRTE WP2 was defined according to the **MAX** (MYRRA Accelerator eXperiment R&D programme) project (2011-2014). MAX was supported by the **EAEC/EURATOM FP7 Programme** under grant agreement n°269565.
MAX website: http://ipnwww.in2p3.fr/MAX/.

❖ This work prospect aims at continuing the R&D effort undertaken in the **EUCARD-2** project and in the task 6.3 (Reliability and Availability of Particle Accelerators) of the **ARIES** project.

Future projects and working frame

❖ The first 4 topics presented in the previous section are part of an action proposal for the Horizon 2020 call INFRAINNOV-04-2020 for Innovation Pilot projects. The project submission will be coordinated by the TIARA Collaboration Council (Test Infrastructure and Accelerator Research Area, www.eu-tiara.org). The project duration will be 4 years : 2021-2025.

Our proposed action (led by LPSC) is called **REFILL** (***Re****liability and fast* ***Fail****ure compensation methods in RF superconducting* ***L****inacs*). It is currently under evaluation by the TIARA council. It will involve 6 partners :

_ *CNRS : with LPSC and IPNO*
_ *CERN, Europe*
_ *CEA Saclay, France*
_ *ESS, Sweden*
_ *SCK•CEN, Belgium*
_ *IBA (Ion Beam application), Belgium, Industry: for SSA developments*

❖ The proposed work is supported (especially for Topics 1 & 2) by a R&D collaboration agreement contract between IN2P3 and SCK•CEN for the developments and the construction of the MYRRHA accelerator. This collaboration agreement is planned to be extended to ~2025.

Schedule and deliverables for the planned REFILL action (Topics 1 to 4)

Project kick-off : beginning of 2021.

	Deliverable description	Month
1	Project quality plan including measure of success	3
2	Project presentation and detailed working plan for each topic	3
3	Mid-Term report (Achievements on 4 topics)	24
4	Deliverable on beam dynamics studies (Topic 1)	48

5	Deliverable on Cavity and control systems modelling (Topic 2)	36
6	Deliverable on Reliability model (Topic 3)	48
7	Deliverable On Solid state power amplifier prototyping (Topic 4)	48

Tentative budget (period 2020-2025)

Type		Cost (k€)
Human Ressources	Permanent staff : 30 p.m	165
	Post-doc : 4 years	265
	1 phd. (?)	180
Travels		25
Material and other costs : software, licence, coordination actions,…		40
TOTAL		**675**

4. Impact

This action aims at developing new and innovative methods to improve accelerators tuning, operation reliability and efficiency. This is, in particular, a major challenge for the ADS technology, which is one envisaged solution to address the issue of industrial nuclear radioactive waste management: one of the critical problems society faces today, and also in the future, in the context of energy production. Moreover in the present context of global warming, and in a sustainable development context of the field, one should study ways to minimize energy waste and maximize the total efficiency of accelerators.

This action will also enable to support the ongoing work (especially for ESS and MYRRHA) on unique an original methods for fast failure compensations that could be beneficial for the entire accelerator community to improve the tuning and the control of high power linacs.

It is pointed out that reliability and efficiency are a key parameters that has to be considered in the early steps of an accelerator design. Therefore the aim of the action is also to bring experts from different fields - involved in several accelerator projects across Europe - to work together on these issues and to better understand how it impacts the design process of an accelerator: from the theoretical beam dynamics studies to industrial developments.

To this purpose a particular accent will be put on industrial R&D for a new generation of RF solid state amplifiers, with enhanced efficiency and reliability, for pulsed or CW particle accelerators. A collaboration with the IBA Company is already on going on this topic. However, collaboration with other companies (such as Thales electron devices) must also be considered.

References

We provide here a non-exhaustive list of references that present work on which our action will be based on.

Beam Dynamics, Linac design, tuning and retuning

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Reliability

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