# SOME WAYS OF RESOLVE OF THE ADS LINACS-DRIVERS TECHNICAL PROBLEMS

A.M. Kozodaev, A.A. Drozdovsky, V.N. Konev, N.V. Lazarev, D.A. Liakin, A.M. Raskopin, V.V. Seliverstov, O.V. Shvedov, V.S. Skachkov, ITEP, Moscow, Russia

*Abstract*

The possible ways of increase of reliability, radiating cleanliness and efficiency of ADS power linacs-drivers are discussed.

## INTRODUCTION

Two threatening problems of nuclear power on today can not be considered as satisfactorily solved. First - accumulation of radioactive waste with half-life of thousand - millions years. The capital decision here can be if not destruction such waste in general, then their transmutation in radionuclides with the rather small period of half-life. Second - maintenance of ultimate high degree of safety NPP (nuclear power plants) and reduce the risk of nuclear failure up to acceptable value of an order $10^{-6}$ events per one year [1].

Both these tasks can be solved with use of accelerator driven system (ADS). Functionally ADS consists of three main blocks – accelerator, target and subcritical assembly. Each of these blocks has a set of rather uneasy physical and technical tasks, for which it is necessary to find the optimum decisions.

## SOME PROBLEMS of LINAC-DRIVERS

The reasonable energy of protons in ADS lays within the limits of 0.6-2 GeV. One decade ago it was considered, that the accelerator with beam current 100-300 mA is required, now it is lowered till 30-50 mA. For experimental systems (XADS), obviously, the current 1-5 mA is sufficient. The test installations can have of considerably smaller energy and currents of the accelerated beam, that is determined by experimental tasks, scheduled on them.

As it is known, reactors «do not love» spontaneous jumps of a neutron flux and thermal regime. And in transmutation ADS at operation of the accelerator on a high-temperature target is allowable to have only a few unprepared stops per year [2]. Therefore problem of reliability of the driver operation takes on a special acuity.

The acceleration of the large currents up to energy ~ 1 GeV is fraught with danger of high activation of the accelerator and impossibility of its hand-operated service if not to accept of effectual measures to reduction of particle losses and downturn of a radiation level.

Huge power of the accelerated beam (50 MW!) on reasons of profitability requires of all possible increase of efficiency and cutting of accelerator cost. Some cost estimations are given in Table 1.

As one can see, of conditional costs of 1 MW of a beam (without the operational charges) are in inverse dependence on size of a current and differ more than on the order. High costs constrain construction of high-intensity accelerators and full-scale ADS, also show necessity of preliminary researches and approbations of the physical and technical decisions on rather inexpensive XADS. Such kind of the facility is being constructed at ITEP now [7]. At the same time the problems of the full-scale high power linac-driver are being researched as well [8].

Table 1: Estimations of some powerful linacs costs

| Project. Beam parameters | Kinds of expenditures | Sum | Ref. |
|---|---|---|---|
| APT 1.7 GeV; 0.1 A | Total accelerator cost | 2235 M$ | [3] |
| | 1 MW of the beam cost | 13 M$ | |
| Abstract evaluation 1 GeV; 20 mA | R&D and construction cost | 300 M€ | [4] |
| | 1 MW of the beam cost | 15 M€ | |
| EURISOL 1 GeV; 5 mA | Components of accelerator cost | 120 M€ | [5] |
| | 1 MW of the beam cost | 24 M€ | |
| SNS 1 GeV; 2 mA | Total accelerator cost | 300 M$ | [6] |
| | 1 MW of the beam cost | 150 M$ | |

## RELIABILITY

*1.* The strict requirements to reliability of accelerators - drivers force to examine all ways of its increase. Use of a proton beam (instead of $H^-$, $d^+$, $H_2^+$, that from some positions has the advantages) reduces requirements to vacuum system, that promotes increase of the mean time between failure of the accelerator as a whole. To the same purpose serves facilitated on 20-30 % the mode of operations of devices and equipment of the accelerator. The formation of elements of magnetic optics on base of rare-earth materials [9], if it allows a level of radiating fields, raises reliability by exception of necessity in the power supplies and cooling of magnetooptics devices and simultaneously allows to create a unchangeable or adjustable magnetic field up to 2.5 T with accuracy of its configuration up to 0.05%.

*2.* But basic way of maintenance of reliability is effective methods of redundancy. In order that the thermal state of target-blanket part of ADS had no time to change, the beam can be absent only 50-70 ms. Fast automatic inclusion of redundant units without any heating and tuning therefore is allowable only. The working reserve can be effective. Let's consider opportunities of such reservation, meaning that the least reliable units are injectors and RF system. It is possible to divide high-power linac into three parts: head or front-end (including injector) with output energy till 12-20 MeV, intermediate on energy of the order 100 MeV (consisting usually from several resonators with drift tubes) and main part, where the beam acquires energy up to 1 GeV. For each part it is possible to offer the own way of reservation.

The head part is expedient to make up in form of two independent parallel channels [10]. Both should work: one - in structure of the driver, another - for the applied purposes (production of emitters for positron-emission tomography, manufacture of radio-nuclides, irradiation of materials and products). In case of failure of acceleration for any reason in main channel the output beam of the second channel automatically is switched during of a few milliseconds for the further acceleration in the structure of the driver.

Each of resonators of an intermediate part should be supplied from several (for example, four) RF channels so that, at least, one of them was superfluous, and the acceleration can be provided at work only of three channels [11]. Then the relative idle time $t_{id}$ of RF system will be determined by possible «shortage of reserve»:

$$t_{id} \approx N(N/M + 1)(t_r/t_{op})^2,$$

where: N - the number of working RF channels, M - reserve channel number, $t_r$ - average restoring time of a single RF channel serviceability, $t_{op}$ - average operating time of single channel to a refusal. At $t_r$ = 2 h, $t_{op}$ = 1500 h and 5 resonators in structure of an intermediate part (N = 15, M = 5) idle times of its RF system will make only $t_{id}$ = 0.01%.

The qualitative new decision for significant increase of reliability of the longest main part of the accelerator (MPA) was offered in [8, 12] and was advanced in [10, 13]. It was proposed to supply elementary accelerating MPA gaps (their number reaches usually 2000–3000) by groups with 1-4 gaps from individual RF generators ranged 50-70 kW, instead of unite till 20 gaps for RF excitation them in resonators from one 1-1.5 MW klystron as it usually made. Thus the failure of one of generators does not result in loss of a beam, as the displacement of particles on momentum will make a small share of separatrix width. In Fig. 1 the evolution of a contour, representing a beam is shown at instant switch off of RF field in one gap in area of energy 600 MeV (a) and at automatic indemnification by increase of amplitude RF field on 10 % in 30 subsequent gaps (b). The direction of evolution of ellipses is specified by arrows. An initial contour and contour after indemnification practically coincide. After returning repaired RF generator into operation the system of auto regulation quickly will

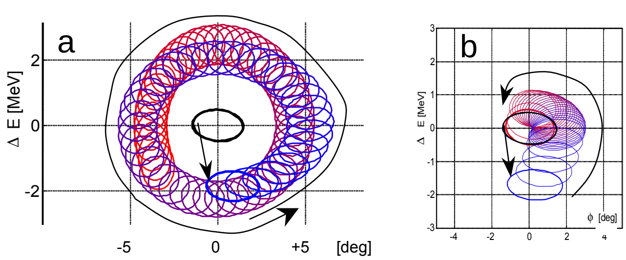


Figure 1: Evolutions of an ellipse representing a beam at switching-off of one accelerating MPA gap without indemnification (a) and with indemnification (b).

restore an initial mode. So the uninterrupted formation of an accelerating field MPA can be organized.

Overall representation of anticipated reliability of the accelerator as a whole is shown in Table 2.

Table 2: Overall summary of anticipated reliability

| | Front-end | Intermediate part | Main part |
|---|---|---|---|
| Output energy | 12-20 MeV | ~ 100 MeV | ~ 1 GeV |
| Reservation method | Redundant working Front-end | Redundancy of RF channels | Inherent property of big quantity of RF channels |
| $t_{id}$ | 0.005 % | 0.01 % | 0 |
| Increase of working RF or other units | 100 % | ~ 35 % | ~ 1 % |
| Comment | Redundant Front-end serves for applied purposes | Redundancy of RF channels is 30% | 3-4 RF channels can be repaired continuously |

## RADIATING CLEANLINESS

The problem, obviously, should be solved by simultaneous optimization of beam dynamics with the purpose of losses reduction and utilization of offered in ITEP [8] ways of reduction of a level of residual radiation by replacement traditional for accelerator channels materials (copper, steel) which are in engagement with a beam on materials with small cross-section of activation and low level of residual activity. From Table 3 it is visible, that at rather small energies the using of graphite as absorbers of particles, dropping out of acceleration, is preferable because it has a small yield of neutrons. Graphite simultaneously allows to lower radiating loadings to a level, at which the application permanent magnet lenses is possible. At large energies the aluminium can be used effective.

Table 3: Comparative parameters of some materials on residual radiation

| Material | Relative residual radiation in 24 hours after irradiation by protons with energy: | | |
|---|---|---|---|
| | 100 MeV | 500 MeV | 1000 MeV |
| Copper | 1 | 1 | 1 |
| Aluminium | 0.5 | 0.27 | 0.2 |
| Graphite | 0.017 | 0.01 | 0.0088 |
| Boron | 0.008 | 0.007 | 0.0064 |

By this way it is possible to lower a level of residual radiation on 1.5-2 order. Researches that are carried at ITEP give the encouraging results [14] and required to be continue.

## EFFICIENCY

The efficiency of the accelerator to the greatest degree is determined by efficiency of use RF energy in its resonators. At room temperature in a continuous mode RF losses in resonators of the linac on energy 1 GeV will make 35-40 MW. If the beam current is less ~ 35 mA, the main part of RF power spend on heating of resonators. Use of SC resonators in this case is very effective. However they are twice more expensive of usual ones [15], and effectiveness, reliability and safety of SC mode at acceleration of intensive beams on today are insufficiently clear and require further study. At the same time, this direction successfully develops, and the SC resonators are used in all realizing projects of powerful linacs.

By our estimations, the use of SC resonators loses expediency at beam currents more then ~ 80 mA.

The efficiency of the linear accelerator with RT (Room Temperature) resonators can be raised by application of a pulse mode, technique of which is well mastered, and the efficiency grows with reduction of an average beam current. The condition of advantage of a pulse mode can be shown as [16]:

$$\frac{t_P + 4.3\tau}{t_P} \cdot \frac{I}{I_P} < 1 ,$$

where: $t_P$ - duration of a pulse beam current, $\tau$- time constant of the resonator, $I$ - average beam current, $I_P$ - pulse beam current.

The stronger inequality is fulfilled, the more will be power efficiency of a pulse mode. The dependences of complete efficiency (from mains net, with the approached account of an energy consumption by all technological systems of the accelerator) from value of an average current for powerful 1 GeV linac with RT resonators in pulse and CW modes of operation are given in Fig. 2.

From the diagrams it is visible, that the pulse mode in a range of beam currents from small values up to several ten milliamps energetically is more favourable then continuous. The presence of natural pauses between pulses facilitates a task switching of an output beam on some targets. The pulse mode operation economically is advantageous and in time of setting-up works. At the same time, it is required the special consideration of the questions of utilization of high-current beam pulses by target-blanket assemblies, and also increase of particles losses at pulse beam current.

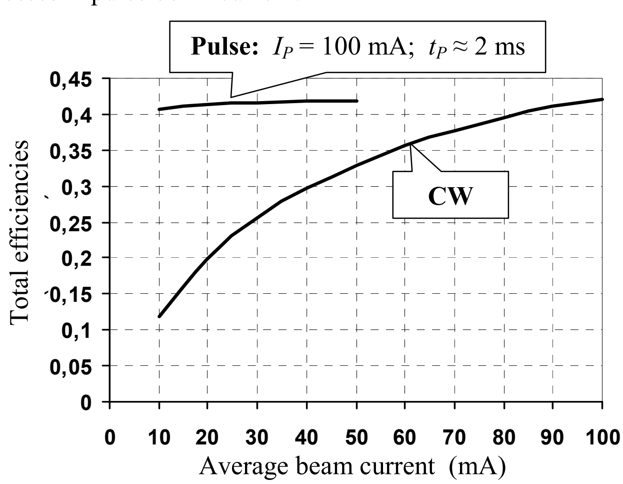


Figure 2: Dependence of complete efficiency of the linac-driver on an average beam current for continuous and pulse modes operation at RT resonators.

## CONCLUSIONS

1. The technical ways of substantial growth of reliability and non-stop operation of powerful linac-drivers of the ADS exist and require the approbation.
2. The significant decrease of radiation level in high-current accelerators can be achieved by introduction of materials with small capture cross-section in all beam channels.
3. The pulse mode of operations of powerful accelerators with RT resonators at the small average beam currents can strong lift the overall efficiency of installation.

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