RELIABILITY INCREASE WAYS FOR HIGH-POWER LINACS – ADS DRIVERS *

A.M.Kozodaev, N.V.Lazarev, D.A.Liakin, A.M.Raskopin, V.S.Skachkov

ITEP, Moscow, 117259, Russia

Abstract

The reliability problem becomes special significant in a high-power linac, when it is used as the driver of electronuclear facility. In the report the reliability analysis of large linacs, their high power RF and other technological systems is given. Some possible means and engineering solutions suggested for reliability increase of planed super-power accelerators are considered.

1 INTRODUCTION

The study of an opportunity to create electronuclear facilities driven by charged particle accelerators (ADS), is conducted in all developed countries, where the nuclear power plays a considerable role. The proton linac-drivers on energy 0.6-1.7 GeV with an average beam current up to 100 mA (about 100 times more reached up today) are offered and are developed in a whole row of physical centers, some of the proposal projects have their own names: APT, TRASCO, EA, TRISPAL, KOMAC, NSP (+JHP), ESS (SNQ), SNS [1-12]. These designs are given here in decreasing order of beam power from 100 (170) to 1 MW. Joint proposal of ITEP, MRTI, IHEP and others suppose output beam power to be 30 MW [13]. We believe, that the modern technologies approach in order to allow creation of such accelerators. However it remains a necessity to carry out appointed circle of examinations on a row of physical and technological problems. It seems that the most strong R&D works are fulfilled in LANL under linacs for very pride Project APT and much more modest Project SNS.

It is necessary to note huge beam power of the order of tens of a megawatt and more. The sudden spontaneous interruption of such beam power feed on a ADS target causes sharp changes in its thermal regime, that leads to shorten term of its service, if not to the worse consequences. When linac operates in ADS complex with a subcritical reactor the sudden stops would be even less tolerant. In the review [7] it is scored, that at accelerator operation on a high-temperature target in a PWR reactor and in facilities for transmutation it is permissible to have not more than 3 (!) unexpected stops per one year. The reactors, as it is known, too “do not love” spontaneous jumps of a neutron flux and thermal regime. Besides, similar installations have extremely major cost. Full cost of the APT Project, for example, is estimated approximately as 7 B$ US [14]. It is clear from here the special importance of reliable operation of the powerful linac-driver and boosted attention of the developers to this problem [15-18].

*Work supported by Russian Fund of Basic Researches

2 OPERATION EXPERIENCE OF WORKING LINACS

A series of proton (or H^-) linacs with output energy 20-100 MeV works as injectors of large synchrotrons in a mode short (10-15 μs) and rare (1-10 Hz) pulses (I-2, ANL, CERN Linac-1, CERN Linac-2, KEK etc.). Bringing up to date insufficiently reliable linac parts and systems [19, 20], they succeeded in reduction of the total downtime of such machines up to 0.5-1.0 % of the planned operating time per year that can be considered as satisfactory result.

At increase of output energy, duration and pulse-repetition rate, as in a case of FNAL linacs (before upgrade 200 MeV, d.f.=0.2 %) and BNL (200 MeV, d.f.=0.35 %), the shut-down times rises up to 2 and 7 % respectively, and at a fill d.f.=12 % on linac of a meson factory LAMPF with energy 800 MeV and beam power of 800 kW the downtime will increase till 15-20 % that are medial quantities for a 9-year’s period of operation [21]. It is possible to explain it by rising of power capacity of all technological systems, and also magnification of full amount of equipment. The distribution of downtime among technological systems of LAMPF linac have been described [21]. It is important to note, that two systems – the injector and RF system together give about 60 % of downtimes.

3 PHYSICAL AND TECHNICAL SOLUTIONS RAISING RELIABILITY

Made by I.M.Kapchinskiy and V.A.Teplyakov the pioneer proposition of a principle RFQ [22] not only has unclosed an opportunity of acceleration of strong currents at low β, but also has allowed sharply to raise reliability of injectors. Therefore RFQ structure is included practically in all powerful linac designs.

Application of materials with a small capture cross-section (for example, graphite) [11] in a construction of accelerating resonators will allow by an order to reduce a radioactive phone, that immediately will leads to increase of reliability.

Construction of the focusing channel in medium- and high-energy parts of the linac on basis of rare-earth materials [23], if the neutron fluxes do not exceed levels, permissible for them, excludes necessity of the power supplies for lenses that essentially raise operation reliability of the accelerator as a whole.

If it is planned to send the beam on several targets, it is preferable to work in pulse mode [24], when the natural pauses between pulses are used for making and removal of field deflecting a beam. Due to this the threat of throw up powerful beam on a wall during its commutation is removed. Besides, the efficiency of the accelerator can be essentially enlarged.

It is necessary to own up, that acceleration of H^- ions or deuterons will not promote to increase reliability of the super-power driver, for the requirements to a vacuum pumping-out will raise and the radioactive circumstances will become more complicated.

4 FACILITATED MODE OF OPERATIONS

Facilitated (on 20-40 %) the mode of device and equipment operation, on the one hand, conducts to of installation price growth, and on another, - in the much greater degree increases service life of equipment, that raises reliability of all installation and reduces the operational expenses.

5 RESERVATION OF CRITICAL ELEMENTS

As a rule, powerful linacs include an injector, an initial part (it is usually RFQ structure, in which particles are accelerated up to energy not more than 5-7 MeV), intermediate part, where the energy reaches several tens or about 100 MeV, and MP – main part (chain of any variant of RF resonators with up to 20 accelerating gaps in everyone), where the particles energy reaches 1-1.7 GeV. On our estimations [18], RF system of the MP, constructed on the basis of klystrons with power 1-1.5 MW without reserve channels, up to 20 % of time can be in a non-working state. The RF system stops will happen every 6 hours in average. Naturally, such “fragmentary” mode of the driver operation is unacceptable and reservation is needed.

The reserve equipment can be in a cold, stand-by or working state. The cold reservation in our case in unacceptable, as it demands not less than 0.5-1 hours for restitution of linac operation. The stand-by 100-percentage reservation, for example, in MP RF system can reduce relative downtime of system down to 0.5 %, however it do not eliminate them entirely, but for all of them twice increases number of RF channels.

The working reserve can be the most effective. So, it is expedient to have a head part of the powerful accelerator (up to energy 12-20 MeV), including injector, initial part and beginning of an intermediate part, as two independent tracts (Fig.1). Besides both should be in working state: one – as a part of the driver, another – for the applied purposes (production of emitters for a positron-emission tomography, manufacture of radionuclides, irradiation of materials etc.). In case of failure of acceleration in the first of them (for any reason) the beam of the second tract is immediately switched on to maintain continuous operation of the huge facility. The switching of the beam can be accomplished during of a few milliseconds that will not change a thermal mode of T/B, which permits the beam removal on time up to 50 ms.

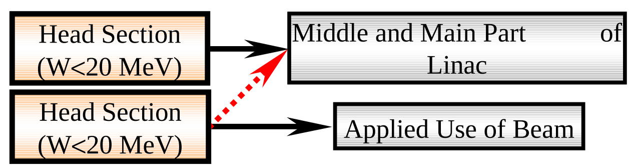

Figure 1: Applied use of a reserve working head part of the linac.

More fruitful idea “of a working reserve”, providing redundancy of installed power of RF channels (Fig.2) is represented. Estimations of the variant with excitation of an intermediate part [8], consisting of 5 cylindrical resonators with drift tubes, have shown, that each resonator is fed by 4 RF channels (instead of required three ones), so at a failure of one of them all necessary power immediately will be donated by 3 stayed normal operational channels, the relative downtime of a whole RF system will be determined only by probable shortage of a reserve and only 0.003 %, that is practically equivalent to absence of downtime at all.

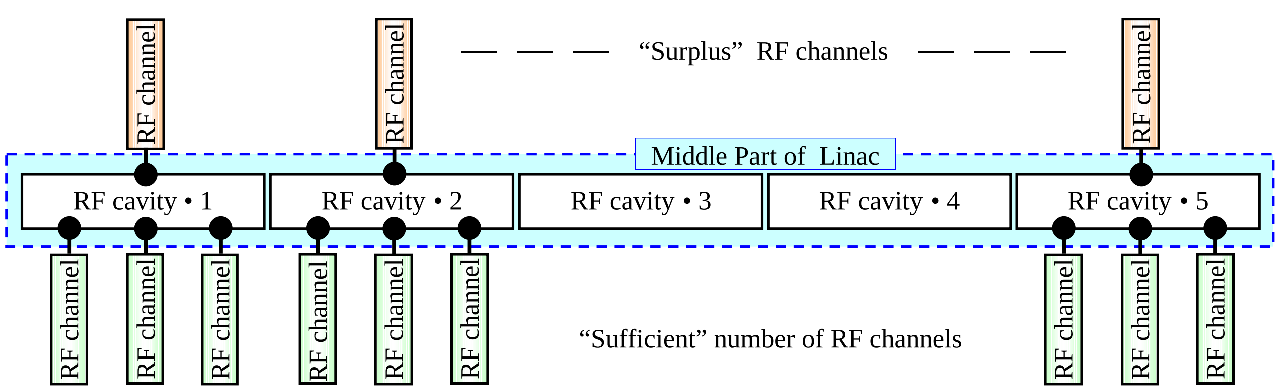

Figure 2: The scheme “of a working reserve” in RF system of an intermediate part of the linac.

On such a way the developers of the APT accelerator go [25], when to ensure design reliability 95 % of RF system they have decided for NC structures (up to energy 217 MeV) to install one additional generator to 3-7 working on one resonator.

6 OPPORTUNITY OF NON-FAILURE OPERATION OF RF SYSTEM

If MP is constructed on the basis of one- or few-gaps resonators [3,11,18,26], the one of them failure or tract of its RF supply will not lead to losses of the beam, but only to its some shift on a phase plane (Fig.3a). A detuning of the failure resonator and correction both of amplitude and the phase of RF fields in remaining ones can be carried out during a small (<1 ms) time and will completely restore parameters of an output beam.

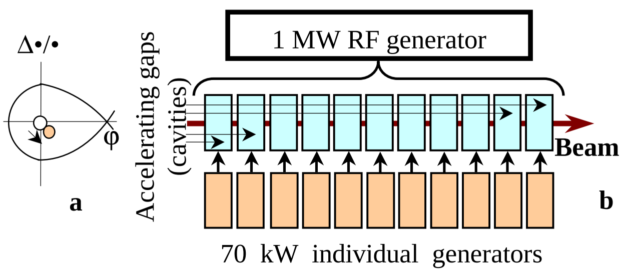

Figure 3: Ensuring of an uninterrupted mode of acceleration in MP due to reserve opportunities of an accelerating tract.

Fig. 3b shows the considered solution of the example with a group of MP resonators [11]. The protons should be accelerated from energy 0.1 up to 1.0 Gev at a beam current of 100 mA and instead of excitation every 10-15 gaps from one 1 MW RF power generator it is offered to use one-gap resonators supplied with individual 70 kW RF generators. At failure even in the beginning of MP, where the energy of protons is close to 100 MeV, the momentum of particles on an input of resonator following the faulty one (on time of automatic tuning of fields in next operating resonators) will be less then nominal only on 0.2-0.3 %, that at approximate of total a separatrix spread of ±1.2 % should not cause essential difficulties. From Table 1 it is visible, that the non-failure operation is achieved at automatic inappreciable magnification of a field in operating resonators. Thus, the great number of separate resonators and low-power RF sources from a deficiency is turned into advantage.

Transition to one- or few-gaps resonators with individual supply leads to cost increase [25]. However magnification of beam availability, the accelerator length decreasing due to independent phasing of resonators and use of standard 50-70 kW TV klystrons instead of specially developed huge and very expensive klystrons on power of 1-1.5 MW can compensate expenditure. It must be noted, that powerful semiconductor RF CW generators with almost unlimited service life are prepared for issue.

Table 1: An example of uninterrupted mode of acceleration in MP due to reserve opportunities of an accelerating tract.

Number of one-gap resonators	2300
Number of RF channels	2300
Average time between failures of RF channels	0.87 h
Number of channels which are continuously taking place under repair	3-4
Necessary energy increase on the whole accelerating tract	0.18 %
Relative downtime	0

It is planning to spread the idea of using the reserve opportunities of an accelerating tract to more powerful RF channels (1 MW), supplying 5-gaps resonators in MP (from 217 MeV up to 1030 MeV) of the APT linac [25].

7 CONCLUSION

The problem of reliability of the powerful ADS linac-driver is a key alongside with a problem of its cost and safety. There is a row of possible solutions, capable to increase essentially the linac-driver system reliability. The tempting proposition of uninterrupted maintenance of an accelerating field in MP of powerful linac requires the further study for finding the most optimal solution.

REFERENCES

[1] G.P.Lawrence, LINAC-98, p.26.
[2] J.L.Anderson et al., ADTTA-99, p.643.
[3] C.Pagani et al. LINAC-98, p.1013.
[4] C.Pagani, PAC-99, p.1126.
[5] C.Rubbia et al., CERN/LHC/96-11/(EET),1996.
[6] A.G.Ruggiero, PAC-97, p.1114.
[7] J.-M.Lagniel, EPAC-98, p.93.
[8] J.-M.Lagniel, LINAC-98, p.706.
[9] B.H.Choi et al., ADTTA-99, p.200.
[10] B.P.Murin et al., ibid, p.764.
[11] V.A.Andreev et al., ADTTA-96, p.241.
[12] L.V.Kravchuk, P.N.Ostroumov, PAC-99, p.3282.
[13] O.V.Shvedov et al., Preprint ITEP-35-99.
[14] APT (Proposal), DOE/S-0074, 1990, p.23.
[15] C.M.Piaszczyk, LINAC-98, p.439.
[16] M.T.Lynch et al., ibid, p.446.
[17] P.J.Tallerico et al., ibid, p.580.
[18] A.M.Kozodaev et al., PAC-97, p.1245.
[19] H.Haseroth, LINAC-84, p.3.
[20] N.V.Lazarev, LINAC-96, p.542.
[21] O.van Dyck, ADTTA-94, p.575.
[22] I.M.Kapchinski and V.A.Teplyakov, "Pribori i Technika Experimenta", 1970, No.4, p.17.
[23] V.S.Skachkov et al., XVI Conf. on Acc., Protvino, 1998, V.2, p.96.
[24] A.M.Kozodaev et al., ADTTA-96, p.1054.
[25] D.Rees, PAC-97, p.2889.
[26] C.Zettler, LINAC-84, p.480.