THE DESIGN OF HIGH RELIABLE RF SYSTEM FOR HIGH POWER LINACS *

A.M.Kozodaev, A.A.Kolomiets, N.V.Lazarev, D.A.Liakin,
V.K.Plotnikov, A.M. Raskopin, V.S.Skachkov
Institute for Theoretical and Experimental Physics (ITEP), 117259, Moscow, Russia

Abstract

Possibility of substantial reliability growth of high intensity linear ion accelerators, for solving of a number of nuclear power engineering problems is considered. A way of uninterrupted maintenance accelerating RF field in a Main Part of such Accelerators - MPA, where particles receive the main part of energy is suggested. If each section of MPA contains 1-3 accelerating gaps and is excited from separate RF channel, the failure of one or even several channels will not destroy the resonant acceleration. Besides of that it is easy to compensate the acceleration shortage (on time of channel repair) by small automatic increase of accelerating field strength in the rest operating sections. The great quantity of sections from a disadvantage is transformed into advantage because failure-free MPA operation can be maintained. In the report quantitative estimations for the method suggested and its comparison with variants of RF channel reserve are presented.

1. INTRODUCTION

A high power ion linear accelerator for a nuclear power engineering at a beam current in a range from 10 up to 100 mA and more should have an increased reliability, that is mainly determined by its MPA RF system reliability [1], where particles acquire about 90 % of whole energy. In the offered projects of high-power accelerators the MPA consist of several thousands separate single-gap resonant cells, which are assembled in multigap resonator - section on RF field and channels of RF supply [2-5].

The rise of a reliability is promoted by use of high-performance components, reduced regime of operation, regularity of preventive maintenance, forecasting. However the key approach to solution of the problem is a reserve. We shall estimate its efficiency on an example of the MPA linac, offered by ITEP [5].

Several parameters of the MPA and of its RF system [5] are presented below.

Particle energy at the MPA entrance and exit	100 MeV - 1 GeV
Beam current	100 mA
Cell number (n)	2300
Energy gain on one cell (ΔW_{1C})	390 keV
Cell efficiency	0.72
RF feeders efficiency	0.9
Channel RF power reserve for control	15 %
RF power for one cell	70 kW
Total RF power of all output stages	160 MW

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2. RF SYSTEM WITHOUT RESERVE CHANNELS

At a steady state of long operation in absence of a reserve (Fig.1.1) relative idle time of the whole system-T_D and the average time of its operation to a refusal - T_C is:

$$T_D = t_R/(T_C + t_R); \qquad T_C = t_F/N;$$

where:

t_R - average restoring time of a single RF channel serviceability;

t_F - average operating time of single channel to a refusal;

N - the number of working RF channels (each channel contains the whole equipment, ensuring exciting of RF power, including the rectifier as well as control, interlock and signalling systems) [6].

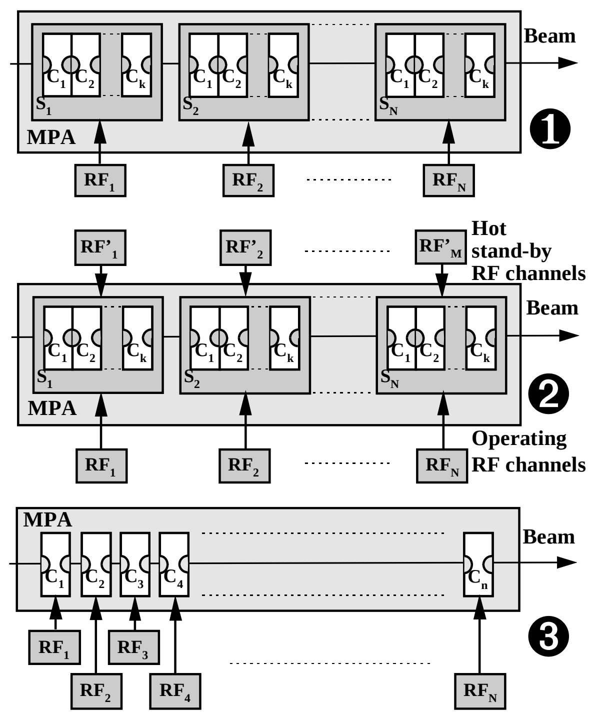

Figure 1. The scheme of MPA RF power supply: 1 - without a reserve, 2 - at hot reservation, 3 - at individual excitation of cells. C - cell, S - section.

Let us P_{1max} = 1 MW and t_F = 1000 hours being the maximum technically available RF power of the single channel and time of its operation to a refusal, respec-tively. By such channel it is possible to excite section, containing k = 14 cells. In the other limiting case, when each cell is energized individually (k = 1), channels on power of 70 kW are required, for which we specify t_F = 2000 hours. We evaluate restoring time t_R by the value of 2 hours for channels of any power. Then depending on cell number k per each section the parameters N, P_1 and T_D will have values, shown on Fig.2. It is naturally that the use of RF channels with limiting power (P_1 = 1 MW, k = 14), when the idle times are minimum: T_D = 25 %, T_C ≈ 6 hours, is preferable.

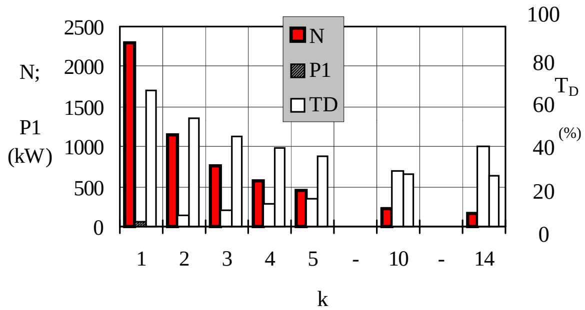

Figure 2. The value N, P_1 and T_D dependence on k, when no reserve channels.

However the result is not satisfactory and the necessity of redundancy is well known. Rather small number of reserve channels (with respect to their total number) improves significantly the situation, but turns out the severe problem of RF power fast switching.

3. "HOT" RF CHANNEL RESERVATION

Tending to full elimination of RF system refusals, we consider the "hot" reservation variant (Fig.1.2), when two channels is simultaneously connected to one section and each of channels having hot filaments is capable to produce full power (redundancy 100 %). In case of working channel failure the ready reserve channel takes immediately a load per self. Leaving in the side all technical complexities of similar switching of power we shall consider such approach being allowable and acceptable. Setting the switching time onto a reserve channel is equal to zero, the relative value of idle times for the whole system will be determined by probable deficit of a reserve [6] and is estimated as follows:

$$T_D \approx N(N/M+1)(t_R/t_F)^2 = 2N(t_R/t_F)^2;$$

where M - reserve channel number (in considered case M = N).

The softer mode is possible at simultaneous operation on each section both working and reserve channels when each of them returns only half power and is ready to return full power at a refusal of the adjacent channel.

The designed values of T_D in these variants are close and are represented on Fig.3. The "Hot" 100 % reservation of RF channels reduces extremely relative value of idle times of the whole system to T_D < 0.5 %, but does not eliminate idle time completely, requires double store installed RF power, double number of channels, operation expenses and power, consumed by filament supply chains.

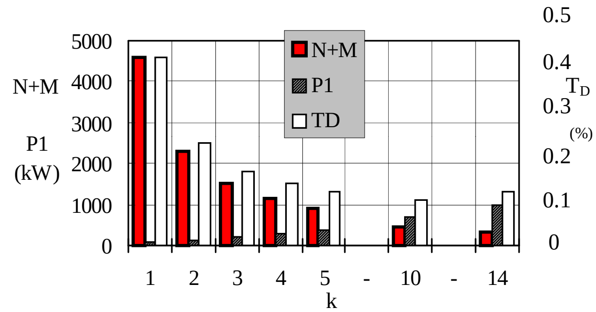

Figure 3. (N+M), P_1, T_D dependence on k at "hot" reservation of channels.

4. USE OF REDUNDANT POSSIBILITIES OF AN ACCELERATING CHANNEL

Qualitatively new approach to the problem of a MPA reliability is opened, if we shall proceed from the support of RF channels serviceability to organization of accelerating process itself. In the case the reliability is determined by redundant possibilities of the whole accelerating channel.

Such approach will be realized, if separate RF channel feeds each cell (Fig.1.3) or section, consisting of a few cells, considering the chain like a unified circuit. When a RF channel failure has occurred all units of the given circuit, cell included, become disable but appropriate automatic increase of accelerating RF field strength or its phase adjustment in several circuits followed by the failed one fill the shortage of energy. After repair the failed channel is put into operation again, and strength or phase of accelerating field in all cells returns in the normal state.

One can estimate efficiency of an offered way. During serviceability restoring of the first RF channel failed t_R yet N' channels leave out of operation:

$$N' = t_R / T_C = t_R \cdot N / t_F \ .$$

Thus, during time t_R in common N'+1 channels will be under repair. At keeping of the time allotted to the channel restoring the average frequency of repaired channels placing in service will be equal to average frequency of the RF system refusals occurred.

Consequently,

$$\Delta N = 1 + t_R \cdot N / t_F$$

channels or

$$\Delta n = \Delta N \cdot k$$

accelerating gaps will be continuously out of operation, in average, and the relative value of an additional energy gain

$$w = \Delta N / (N - \Delta N)$$

should be provided by gaps staying in operation.

Because the most relative energy gain per one section $\Delta W_{1S}/W$ takes place in the beginning of MPA, where the least value W= 100 MeV is, just here the section refusal can cause the greatest response in the beam longitudinal motion. Therefore, especially precise operation of the compensation shortage energy system is required. In this place the particle momentum spread is estimated by the value of $\Delta p/p$ = (1-1.2) % or absolute energy spread makes ΔW = (2-2.4) MeV.

The section refusal will effect on the beam dynamics to a lesser extent, and requirement to the electronic system of amplitude and phase tuning will be softer, at the condition

$$\Delta W_{1S} << \Delta W, \text{ that is } \Delta W_{1C} \cdot k << \Delta W.$$

Variants with k =1-3 cells per section can satisfy this condition, though our example [5], in which $\Delta W_{1S} = \Delta W_{1C}$ = 390 keV, is oriented on k = 1 cavity. The failure-free (on RF field) acceleration regime of MPA operation [5] is presented in Table 1.

Table 1. MPA parameters for failure-free ($T_D = 0$) acceleration, suggested here.

Cell number per section k	1
Section number S	2300
RF channel number N	2300
Power per one RF channel P (kW)	70
Average time between consequent refusals of channels T (h)	0.87
Number of channels repaired continuously N	3 - 4
Energy increasing required for compensation w (%)	0.18

Taking into account sluggishness of cavities and feedback channels, the time required for adjustment of field parameters in working sections can be estimated by the value of 30-50 µs. During this time particle energy at the section entrance followed by the failed one will be 0.4 % less than nominal, and momentum - 0.2 %. That is why at a separatrix width of ± 1.2 % there is no any substantial difficulties. Simultaneous failure of two adjacent channels can take place extremely seldom (once per many years at continuous operation) and is not disastrous (during 30-50 µs the particle momentum will be shifted on 1/3 of a separatrix width).

If a particle is given an energy shortage, for example, in the first 100 cells after failed, the field strength in them should be increased by 1% of nominal. At so small increase there is no necessity to make special reserves in electric strength of cells and RF power generators, and can be covered by usual technological tolerances. Therefore the function of a field parameter adjustment can be assigned to the standard control system, which should be intended for fast amplitude and phase adjustment in wide range, under the influence of the beam current instability as well as of a channel parameter or power supply line changes.

5. CONCLUSIONS

1. If the RF channel reservation gives only reduction, though rather significant, of idle time of a high current accelerator, use of the whole accelerating MPA channel possibility allows to achieve failure-free its operation.
2. Integrating on 1-3 cell in section powered from one RF channel, it is possible to compensate failure of several channels by small increase of regime strength in the rest channels during all the time for channels under repair restoring.
3. Regime strength changes required are not out of usual technological tolerances (<1%) and add increase of RF channel power is not necessary.
4. In the ITEP scheme MPA proposal there is no accelerator shut-down when small number of accelerating cells fail. Cell refusal is compensated by the rest working cells and repair can be set aside for a long time to the schedule shut-down.
5. Note that cavities failed are excited by the beam resulting particle energy losses. However tested solution of fast electronic cavity tuning change [7] can be useful to displace cavity own resonant frequency out of the probable band of such excitement for all repair time.
6. Detailed analysis of cell and section technique (as well as RF channel scheme, probable solutions of self-balancing system and RF equipment choice and common economics factors) influence upon beam dynamics should be fulfilled to chose the final solution on failure-free MPA RF power supply scheme for considered high current accelerator.

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