SUPER CYCLE SYNCHROTRON-STRETCHER

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Abstract

The method of the duty factor increase of the extracted beams, while keeping the average current value invariable, is presented.

In recent years producing intense and almost continuous GeV energies electron beams for fundamental investigations of electron and photon interactions with hadrons and nuclei at the distances less than one Fermi [1], has become important.

The generation of such beams is realized mainly by two methods. The first method is creation of the multiple-stage 'racetrack microtrons, of SEBAF (USA) or MAMI (FRG) type and the second one is creation of the stretchers of electron beams, pre accelerated either in linacs (such as HP-2000, USSR) or in the electron synchrotron (ELSA, Bonn) [1-5].

Another method of the duty factor increase is suggested in this paper, which seems to be more economic, may become more optimal and more competition able. This method includes reconstruction of the working electron synchrotrons to get the decrease of the duration of acceleration periods and the magnetic fields fall in the synchrotrons for increasing duration of the beam extraction, while keeping invariable the average value of the synchrotron's intensity.

Usually electron synchrotrons operate at 50-60 Hz repetition rate of acceleration cycles. But in case of creating a flat top in the magnetic field for extraction of a monochromatic energy beam the equivalent repetition rate f_e of the acceleration cycles correspondingly decreases and it leads to the decrease of the current average value of the accelerated or extracted beam (I_{ab}). Consequently, for holding I_{ab} value invariable, it is necessary to keep the total time invariable too, $\Sigma(T_f + T_a + T_{ft})$. Then for increasing the flat top duration T_{ft} it is necessary to use all the possibilities for decreasing the sum of intervals of the acceleration time T_a and the magnetic field fall time T_f (fig.1a) to the minimal acceptable values and on account of this decrease only to provide corresponding increase of the flat top duration. That is the essence of the third method of generating almost continuous beams in the so-called super cycle synchrotron-stretcher.

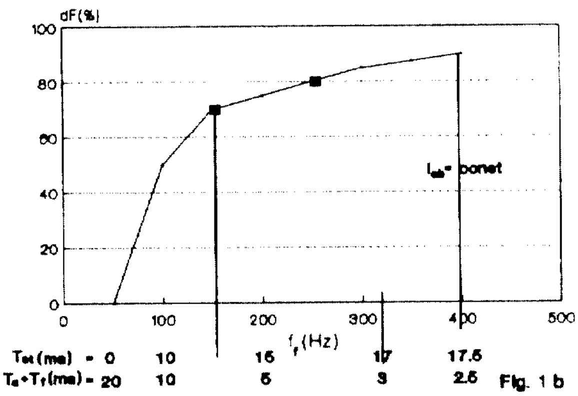

Fig. 1 b

Figure 1b shows duty factor as a function of the value of the total duration of the acceleration period and field fall ($T_a + T_f$) or of the pulse frequency of the electromagnet windings power and the flat top duration (T_{ft}) where duty factor determined by the relation

$$df = \frac{T_{ft}}{T_a + T_f + T_{ft}} 100\ \%$$

characterizes the value of the beam "macroscopic continuity" (without bunching).

As the basic point of the super cycle synchrotron-stretcher is to keep I_{ab} constant, then duty factor value at 50 Hz frequency is considered to be equal to 0 (fig 1b), because the flat top of any duration at this frequency, formed at the magnetic field sinusoid maximum, decreases I_{ab} at once. In figure 2 the curves of I_{ab} decrease and T_{ft} increase for achieving high values equal 50 Hz, are shown for comparison.

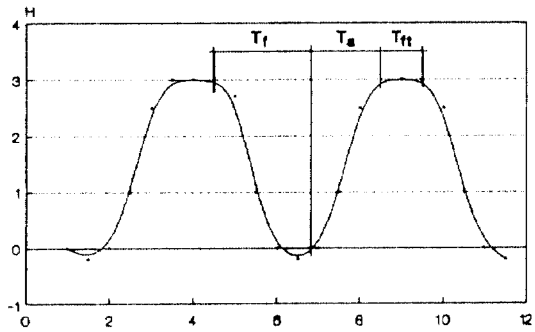

Fig. 1 a

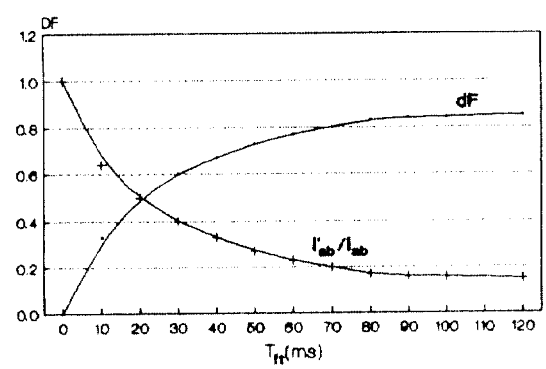

Fig. 2

It is seen from figure 1b that for the optimal values of f_f frequencies we can take values in the range of 150–250 Hz at which duty factor will be in 70–80 % limits. It is proved that these df values are suitable for carrying out the wide range of the fundamental experiments as well as for making the realization of the synchrotron corresponding operation noticeably easy.

Besides, it seems to be expedient at first to get experimental frequency increase up to 75 or 100 Hz with corresponding decrease of the end acceleration energy to 4.5–3.0 GeV at the Yerevan synchrotron. With that it is possible to increase df up to 33–50 %, as is seen in figure 1b. Obtaining such synchrotron operation is not difficult, as in this case, first, it is possible to use the existing electromagnet windings and RF system without any changes, second, the achieved injection energy 75 MeV will be enough for getting acceleration with small increase of the magnetic field dynamic disturbances and currents of the electromagnet capacity leakages, third, the necessary changes in the electromagnet power system for getting acceleration are very insignificant, as changes are required only to the capacitor banks connections of the resonance circuit. In future, at increasing the flat top duration up to 10–13 msec and other favorable conditions (beam damping) such synchrotron operation can be used for a long time till making new block windings or creation a new magnetic system with separate functions for further increase of f_f frequency. Let's consider the essential technical difficulties, which may appear with further increase of the electromagnet power pulse frequency in the 100–250 Hz range.

The main obstacle while solving this problem is thought to be the increase of magnetic field dynamic disturbances in the injection field, excited on the surfaces of the electromagnet poles and on the metal coat of the vacuum chamber, as well as the increase of the capacity parasitic currents leakages. The latter seems to be more essential for the Yerevan synchrotron, as cabling of the power system there is considered not to be good and, in addition, current capacity leakages maximum is within the injection fields region. At the same time the maximum of the dynamic disturbances is in the average fields area and it looks promising, since to eliminate their influence is more difficult than to reduce capacity leakages, which can be eliminated by a replacement of the cables by buses and by putting capacitor banks nearer the magnet blocks. However, methods of correction of the disturbances caused by the capacity current leakages are well developed, which can't be said about dynamic distortion correction.

In this connection it is necessary to carry out experimental researches of dynamic disturbances in the injection fields with increase of the electromagnet power frequency. It may be realized at Yerevan Physics Institute by creating a magnetic measurement stand, consisting of spare packets of electromagnet with cable winding and of thyristor power source with controlled frequency in the 50–500 Hz range.

Magnet characteristic researches may be done by means of the permalloy probes without additional power supply. It is sufficient to carry out the measurements on the magnetic field different levels by the relative method, which can be ensured by electromagnet power constant component changing.

The dependence of the magnet total losses on the power frequency is well obeyed to empirical expression P = A (1.3 +1.6). Assuming, dynamic currents almost obey this expression and measured values of the nonlinear distortions caused in electromagnet gaps by eddy currents equal 0.01% as a basis[6], it is possible to show that with the power frequency increase by a factor of 5 these distortions will not exceed 0.13%, which is less than allowed values and so it is quite acceptable.

No insuperable difficulties or limits for realization of the corresponding changes in the synchrotron magnet power supply system are seen yet, including the current distribution in the winding cross section and power expenditures with account of keeping duty cycle invariable, although technical difficulties may occur.

However we hope that choice of the optimal scheme will be realized in the near future, since there are a lot of various schemes on the flat top generation in the magnetic field in literature and, besides, the specialists of Yerevan Physics Institute have a big experience in this area. The final selection of the scheme may be done after finding the maximum voltage value in the main block windings, which depends on the type of isolation. It is supposed to choose preliminary voltage U_{max} not more than 15 kV. Most probable, capacitor banks will be installed on the high-voltage cables and parasitic current leakages.

With increasing frequency up to 250 Hz other technical difficulties seem to be overcome. Thus, the estimation made for RF system shows the following.

Synchrotron magnetic field changes according to the law

$$H(t) = \frac{H_{max}}{2} (1 - \cos t) = H_{max} \sin^2 \frac{\omega t}{2}$$

where $\omega = 2 f_f = \frac{2}{T}$

T – is the period of magnetic field intensity changing without flat top.

Differentiating (2) with $E = 300\, H(t)\, \rho$ we shall define energy gain on a turn without taking into account the synchrotron radiation losses

$$\Delta \varepsilon_a = \frac{w\, T_s\, E_{max}\ (\mathrm{GeV})}{T} \sin \frac{2\pi}{T} t$$

where T – is the duration of one turn.

The necessary total acceleration rate with synchrotron radiation losses – ΔE_{rad} which must be provided by RF system on the turn, will be defined from the expression:

$$\Delta\varepsilon_{nec} = \frac{\pi T_s E_{max}}{T} \sin \frac{2\pi}{T} t + \frac{88.5 * 10^{-6}}{\rho(m)} E^4_{max} \sin \frac{8\pi t}{T}$$

It is suitable to express $\Delta \varepsilon_{nec}$ in the fractions of the known $\Delta \varepsilon_{rad}$ value, which must be provided by the existing RF system with 50 Hz frequency in the $E_{max} = 6$ GeV level, i. e. at the magnetic field sinusoid maximum or on the part of the flat top, when there is no energy gain and there is only loss compensation for the radiation.

Thus

$$\Delta \varepsilon_{nec} = k \; \Delta \varepsilon_{rad} = k \, \frac{88.5 * 10^{-6}}{\rho} \, E^4_{max}$$

where k - is the proportionality factor.

Putting the expression (5) into (4) and dividing two parts of the equation (4) by $\frac{88.5 * 10^{-6}}{\rho} E^4_{max}$ we shall have:

$$k = A(t) \sin \frac{2\pi}{T} t + \sin \frac{8\pi t}{T}$$

where $$A(t) = \frac{T_s \; \rho \; \pi \; * \; 10^{-6}}{T \; E_{max} \; * \; 88.5}$$

Investigating the expression (6) for extremum, it is not difficult to make sure that k has maximum in the interval $\frac{T}{4} < t \frac{T}{2}$, which is illustrated by the curves in fig. 3.

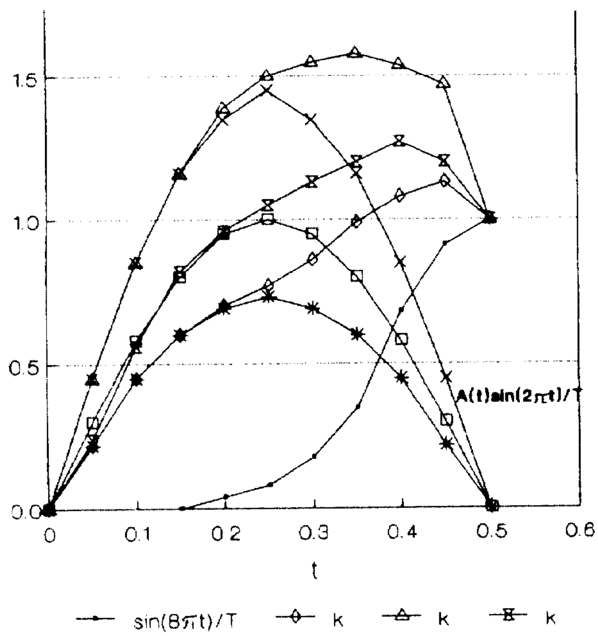

Fig. 3

The dependence of k on T is shown in figure 4, it is seen there that already at T >= 4 ms (f_f <= 250 Hz) maximum acceleration rate does not exceed 10% of the maximum $\Delta\varepsilon_{rad}$ value and that is within the possibilities of the RF system at the acceleration rate. Besides, it is obvious that there are no additional requirements to the old RF system or to the new one, described in paper [7] at the corresponding operation of super cycle synchrotron-stretcher.

So, the considered method of the beam stretching in the Yerevan synchrotron is worth of close studying and assistance, since it can fully be realized by the the Yerevan synchrotron staff only.

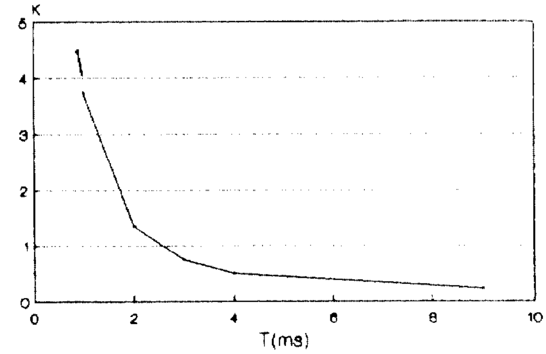

Fig. 4

In conclusion, the authors take this opportunity of expressing their gratitude to A. Ts. Amatuni for encouragement and very suitable comments and to R. O. Avakian, H. H.Vartapetian, E. M. Laziev for active discussions.

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