STATUS REPORT ON THE COLLECTIVE LINEAR ACCELERATOR AT DUBNA

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Investigations connected with the creation of the accelerator working at the collective effects, were developed in Dubna in two main directions:

a) testing of the model of the main principles of this method,
b) creation of separate elements and parts of the future accelerator.

1. Experiments on the Acceleration of α-Particles Using the Model of the Collective Accelerator

The 100 A, 1.5 MeV beam is injected into the ADHESATOR chamber. During initial turns the beam has an elliptical cross-section. The dimensions of the cross-section are 1.6 x 1.2 cm.

Calculations show that allowing for variations in the frequency of betatron oscillations due to the capture of ions from the helium medium in which compression occurs, the ring cross-section measures ≈ 1 mm at the final stage of compression when $P=10^{-7}$mm Hg. These calculations are confirmed by the measurements made of the ring radial cross-section during its ejection from the potential well by the system of thin electrodes.

The ring ejection is performed by shunting one of the semicoils of the external field[1]. By changing the time for switching on the shunting, a necessary gradient of the field decay, when a part of ions is kept in the potential well of the electron ring, is found. A number of ions at the given accelerating gradient agrees with the calculations[2].

It is difficult to measure local gradient values very precisely. Therefore, when the ring was accelerated the mean field gradient in the 40 cm accelerating area was maintained at approximately 8-10 Oe/cm. With this gradient, the acceleration of the ring less than maximum allows to accelerate double-charges α-particles up to 30 MeV. As calculations show[2]; the ratio of the number of accelerated α-particles to those initially trapped in the potential well is 30%.

The accelerated ring, charged with α-particles, strikes the target which is made of copper foil.

The target is located in the region of the strong field decay; a dummy target is placed directly in front of the target and the electron component is precipitated on it. However, due to the irregular precipitation of the electron ring, the energy of α-particles is spread out towards higher energies.

A technique of measuring the induced activity on the copper target was used to monitor the beam of α-particles and to determine its main parameters. This activity is a result of the interaction of accelerated α-particles with ^{63}Cu and ^{65}Cu nuclei.

The main nuclear reactions on copper are as follows:

$^{63}\mathrm{Cu}(\alpha,n)^{66}\mathrm{Ga}$	$T_{1/2}=9.4$ h
$^{63}\mathrm{Cu}(\alpha,2n)^{65}\mathrm{Ga}$	$T_{1/2}=15$ min
$^{65}\mathrm{Cu}(\alpha,n)^{68}\mathrm{Ga}$	$T_{1/2}=70$ min
$^{65}\mathrm{Cu}(\alpha,2n)^{67}\mathrm{Ga}$	$T_{1/2}=78$ h .

^{66}Ga is a very convenient isotope for monitoring gamma radiation as its gamma spectrum contains two intense lines of 511 KeV and 1040 KeV. As the measurements were carried out in 4-5 hours after irradiation, the contribution from the other channel reaction in the 511 KeV line is insignificant due to the short-life of ^{68}Ga and ^{65}Ga [3].

The bremsstrahlung interaction of electrons with ^{63}Cu and ^{65}Cu nuclei forms a secondary reaction on copper. The photonuclear reaction threshold on $^{65}\mathrm{Cu}(\gamma,n)$ is 11 MeV. In order to estimate the effect of the isotope yield from these reactions, the copper target was irradiated by the ring of electrons at maximum compression. There is no activity in the gamma spectrum for this target in the energy ranges which interest us. Thus, by measuring gamma spectra from the copper foil, it is possible to assess the energy and the number of α-particles striking the target.

Estimates were made by the efficiency with which α-particles were recorded using this isotope. It was shown that it is possible to monitor α-particle fluxes with $N_\alpha > 5 \times 10^8$ and $E_\alpha > 10$ MeV.

To determine the parameters of the α-particle beam, targets were placed 40 cm from the medium plane. The target is a composite type comprising five sheets of copper and aluminium foil. The gauges of copper and aluminium foil are 12 mg/cm^2 and 5.4 mg/cm^2, respectively.

Four to five hours after irradiation the activity of the foil was measured using a scintillation spectrometer.

The γ-spectrum contains two lines of 511 KeV and 1040 KeV. The half-life of this activity was measured giving a value of $T_{1/2}=9$ h. The energy was defined by measuring the activity in each layer. The maximum yield occurs on sheet 4 of the copper foil which correponds to the energy of (29 ± 6) MeV.

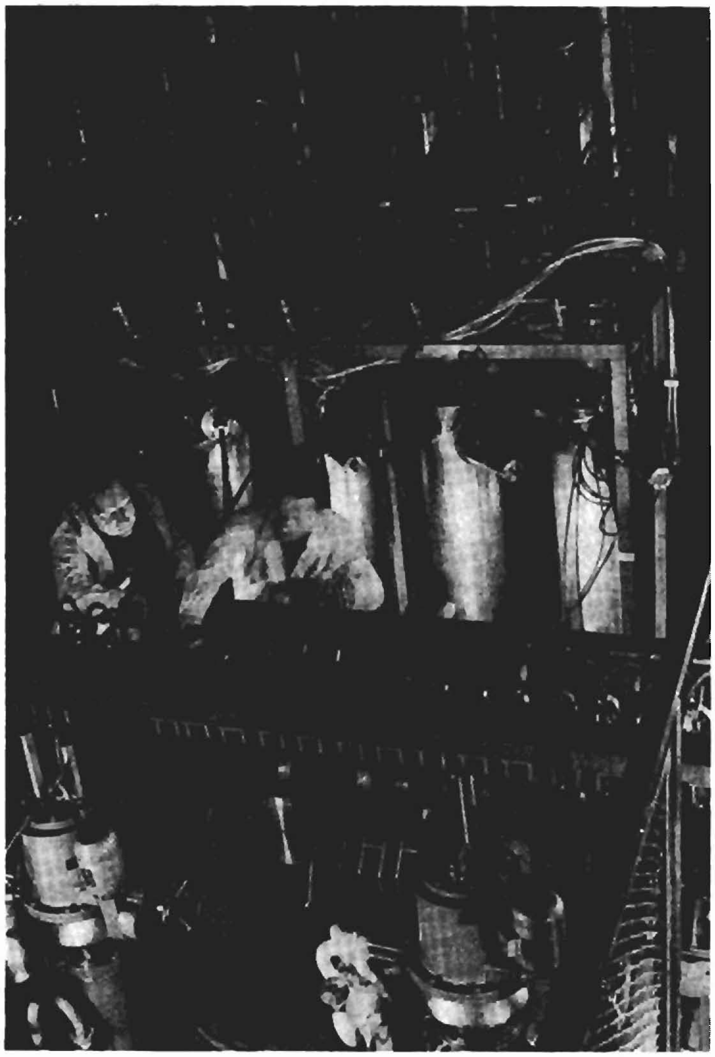

Fig. 1

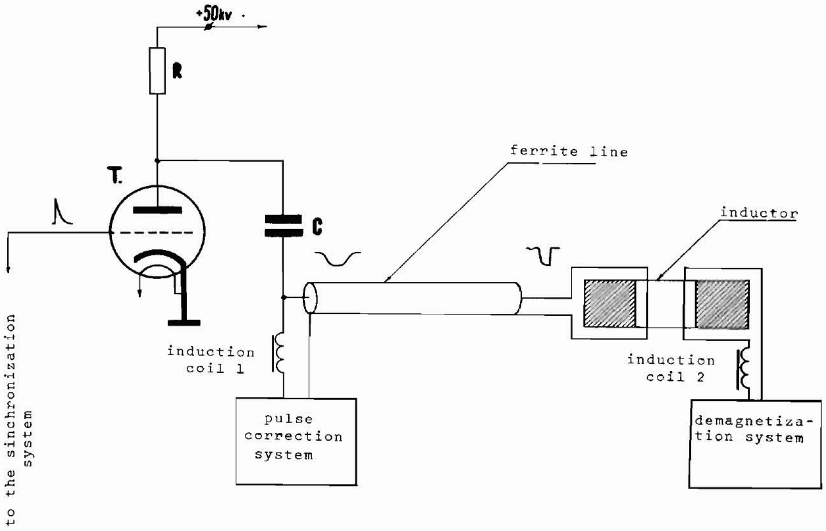

Fig. 2 Principal modular scheme

The error in determining the energy value depends on the error in measuring the thickness of the copper foil, which amounts to 10%, and the inaccuracy in fixing the position of the maximum in the excitation function.

Knowing the energy of α-particles, the integrated flux of incident α-particles can be determined. The calculations give the value $N_\alpha = (1 \pm 0.3) \times 10^9$ of particles per acceleration cycle.

We suppose to perform a further acceleration of the ring loaded with ions in the system of four cavities (Fig. 1). At present we are finishing a preparation work on the formation of the magnetic field.

2. New Electron Accelerator[4)]

The designed high-current induction linear accelerator of the nanosecond range (SILUND) has the following parameters: particle energy E=3.0 MeV, peak current I= =2000 A, pulse length τ = 20 ns, repetition rate f is up to 50 Hz, momentum spread $\Delta E/E \leq 2\%$.

The design of the accelerator with the mentioned parameters was first associated with the problem of the creation of powerful generators of high-voltage rectangular pulses, focusing a beam with large space charge at low energies etc.

A number of questions concerning the SILUND realization is considered below.

2.1. High-Voltage Pulse System

The SILUND high-voltage pulse system consists of 24 generators each containing an energy accumulator, a controlled commutator and a pulse correcting system. Each generator is loaded by 3 inductors which are equivalent to nonlinear inductivity with active losses and a beam. Starting from the beam performances specified,it is necessary to determine the following generator parameters: output voltage 42 kV, current 6 kA and pulse top length 20 ns. The rate of current rise must exceed 10^{12} A/s (pulse rise time 5×10^{-9} s).

The formation of powerful pulses with rise time of 10^{-9} s without additional correction can be realized by applying low-inductivity spark gaps and energy accumulators with distributed parameters. The main disadvantage of these arrangements is the short-life of the spark gap.

Preliminary results showed that powerful hydrogen thyratrons could steadily commutate the current pulses of the 10-12 kA amplitude and 10^{-6} length at a repetition rate up to 50 Hz, however, the maximum rate of current rise being much lower than the required one.

The rate of current rise can be increased due to an additional correction of the leading edge of a pulse. To make a correction, the phenomenon of shortening the leading edge of a pulse which occurs when the latter is propagated in a nonlinear medium, for example, in a co-axial line loaded with ferrite. The following correcting line parameters were chosen experimentally:length 75 cm, co-axial diameter ratio 1.8.

To reduce the number of generators, it is necessary that the power commutated by the thyratron should be completely dissipated in the load, that is the internal impedance of the forming arrangement should be much smaller than the beam equivalent resistance. This can be done by using,as an energy accumulator,a block of high-frequency capacitors the total capacitance of which is easily calculated from energy considerations. In our case it was found to be $(3.0 \div 3.5) \times 10^4$ pF.

The schematic diagram of the generator (pulse modulator) is given in Fig. 2. The pulse length is formed automatically by means of nonlinear load properties and the top correction is performed by a suitable choice of the value and a sign of the initial ferrite magnetization in the correcting line.

2.2. Inductor

The element which creates the electrical field necessary for particle acceleration, inductor, is a one-to-one pulse transformer with toroid ferromagnetic core. Pulses from the generator described above are given to the primary single-turn winding of the inductor.

The ferrite was chosen as an inductor core material. Because of large electrical resistance,the skin-effect in ferrites is negligible so that the dynamic characteristics of ferrite little differ from the static ones. For commercial ferrites the induction increment value ΔB,which defines the inductor core cross-section,was measured to be about 6000 Gs. Then for U=42 kV and τ =20 ns the necessary core cross-section must be 14 cm^2. If the ferrite ring thickness is assumed to be 4 cm and the interior diameter 11 cm, which is due to the choice of the acceleration tube diameter and the radial focusing coil size, then the exterior ring diameter is 18 cm.

The inductor magnetizing current can approximately be estimated on the basis of the specified pulse parameters and the average differential magnetic permeability and in our case is found to be 300÷350 A. The maximum accelerating field gradient on the accelerator axis is 10 kV/cm.

The primary inductor winding consists of three symmetrical turns encircling the core. The ends of the turns are connected with high-voltage cable plugs which are screwed in radial holes of inductor metal framework. A magnetic field coil, which will

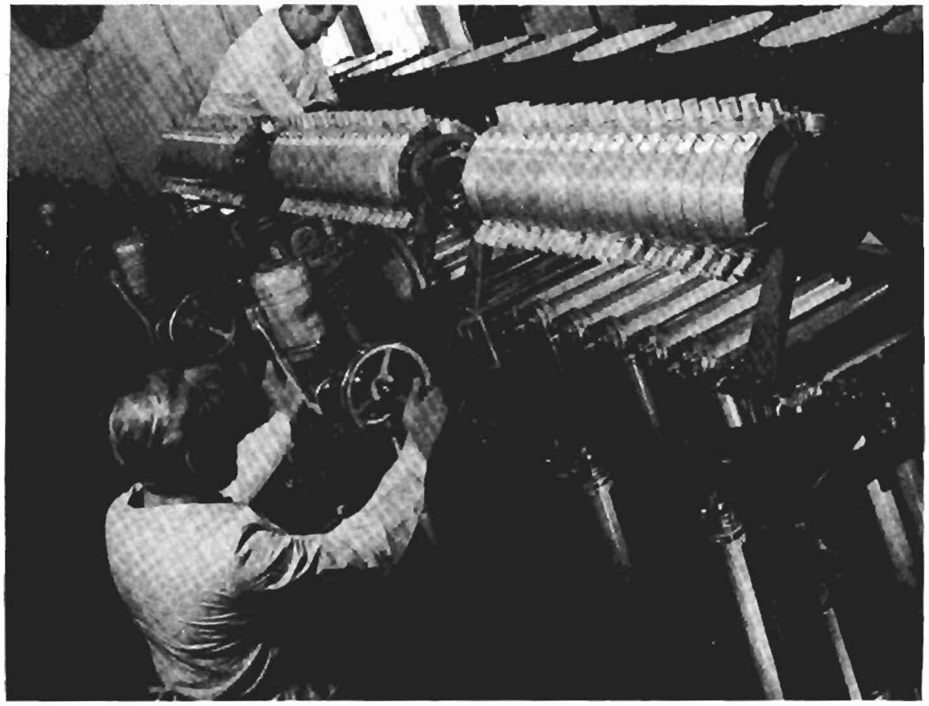

Fig. 3

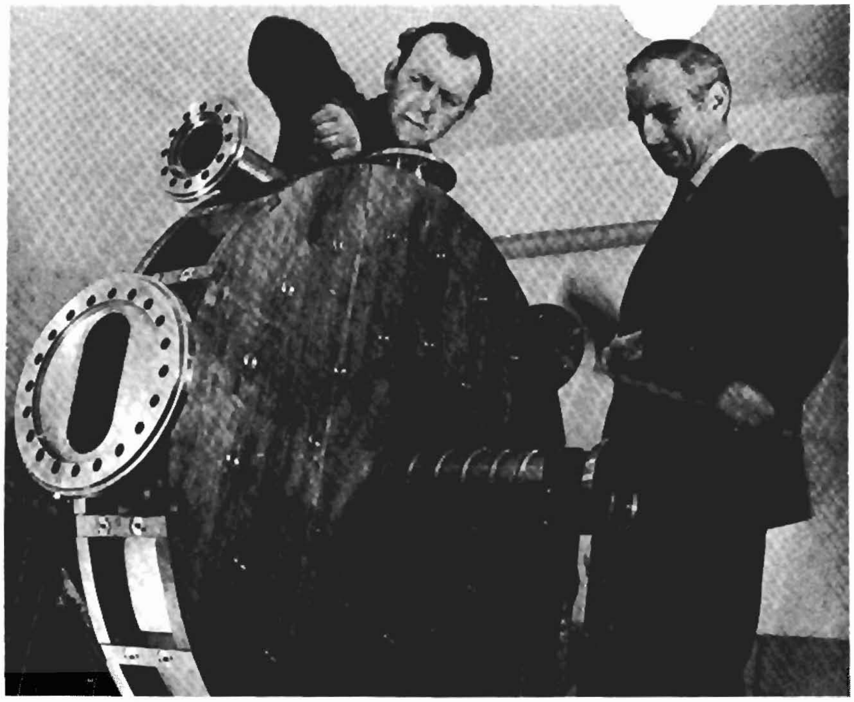

Fig. 4

be discussed below, is co-axial to the internal core diameter. The turn-exciting core and the focusing coil are fastened in a framework by mean of epoxide potting. Individual inductors are mounted in sections. The accelerating section consists of 18 inductors and under operation conditions must provide an increase of the beam energy by 0.75 MeV.

2.3. Focusing System

For focusing intensive low-energy beams of charged particles, it is most advisable to use a solenoidal magnetic field. The calculations show that in order to compensate the Coulomb repulsion in an 0.5 MeV electron beam of 2000 A current and 2 cm diameter, it is necessary to create an axial magnetic field of central strength 2×10^3Gs. To create such a field in the long solenoid we must have 1600 At/cm. Since the radial size of the focusing coil should not exceed 10 mm (due to the smallness of the interior core diameter) a pulsed supply of coils should be provided to ensure normal thermal conditions.

The focusing single-layer coils, each of them containing 8 turns of 80 mm diameter, are supplied in series. At a repetition rate of 50 Hz a forced coil cooling is used.

By the present time the SILUND section which gives a 0.6 MeV beam of 1600 A current and 20 ns duration has been put into operation. A test putting into operation of all the accelerator has also been performed (Fig. 3).

3. Works on Improvement of Ring Formation Systems

Three versions of a new compressor which differ by the vacuum chamber design are being studied. Vacuum and magnetic tests are being performed on one of the versions manufactured from thin stainless steel and reinforced by plastic (Fig. 4). The other ones are being prepared.

4. Superconducting Accelerating Section

During three years the Dubna group has been carrying out experiments on this section. Specific conditions of cavities operation in this section (the presence of

Fig. 5

the 20 kGs magnetic field) forces us to use II type superconductors. A great deal of work has been made on the study of the behaviour of superconductors in magnetic fields. These studies have resulted in the design of the section, one of the elements of which is shown in Fig. 5. At present we begin mounting the section and cryogenic equipment for r.f. and magnetic tests. It is supposed to finish the main mounting work by late 1971.

References

1. V.I. Veksler, V.P. Sarantsev et al. JINR P9-3440, Dubna 1968.
2. I.N. Ivanov et al. JINR P9-5535, Dubna 1970.
3. Table of Isotops, 1968.
4. V.D. Gitt et al. JINR P9-5601, Dubna 1971.

DISCUSSION

A. U. LUCCIO: From your slide, the new compressor appeared to be much flatter than the old one. Since the material and geometry of the walls could affect the stability of the ring and your previous rings appeared to be stable, why did you change the geometry of your new compressor?

V. P. SARANTSEV: We want to obtain, in the new compressor, rings with the number of electrons from 5×10^{13} to 10^{14}. In the compressor, two fundamental phenomena may occur: negative-mass instability and radiative losses due to the chamber's proper modes. To avoid these instabilities, it is necessary to have a small surface resistivity of the chamber wall, $R_W \simeq 0$, and a chamber quality factor, $Q \simeq 1$. If one can fulfil the condition $R_W \preccurlyeq 1$, $Q \preccurlyeq 10$, then these instabilities cannot appear.

C. NIELSEN: How do you achieve $R \preccurlyeq 1\Omega$ and $Q \preccurlyeq 10$ in the new compressor?

V. P. SARANTSEV: For the first condition, we use very thin stainless steel walls. The second condition can be fulfilled either by the chamber dimensions or by introducing reactive elements.

H. HAHN: Did I understand correctly that you plan to use a superconducting linac or, at least, superconducting cavities?

V. P. SARANTSEV: In the next few months, we shall begin to accelerate rings with a system of conventional cavities. As far as the superconducting ones are concerned, we think that we can test them in the next year.

H. SCHOPPER: Do you have any indication of how many captured ions were accelerated?

V. P. SARANTSEV: After the compression, we compute the number of ions to be about 10^{10}; after acceleration we measured 10^{9}. In this experiment, the gradient of the magnetic field was set according to the calculation.