to avoid the effects of simple and parametric resonances 
\( Q_r = 1 \), the amplitudes of the first and second 
harmonics in the magnetic field configuration are reduced 
by means of symmetrically located cylinders of small 
diameter (8 mm). All measurements of magnetic-field 
intensity were carried out with an accuracy of \( \pm 1.5 \text{ oe} \) 
with a nuclear magnetometer \([2]\). The magnetic field 
is stabilized by means of a nuclear stabilizer \([3]\).

A quarter-wave resonant system with 1 dee is used 
for ion acceleration. The resonance system is supplied 
by an externally excited generator, which provides ac 
voltages up to 40 kv.

Deuterons have been accelerated to 12 Mev and 
\( \alpha \) particles to 24Mev, with a minimum accelerating 
voltage of 8 kv at the dee. The energy of the accelerated 
particles at the terminal radius (52 cm) is measured by 
two methods: measurement of the mean radius of 
curvature of the orbit through the use of three probes, 
and measurement of the range of the accelerated 
deuterons in aluminum foil.

In order to avoid effects due to any noticeable ac-
tivity in the construction elements of the chamber, all 
the measurements were carried out with the intensity of 
the internal beam kept below 1 \( \mu \)a.

In Fig. 1 are shown autoradiographs of the deuteron 
beam at various radii. The acceleration chamber of 
the cyclotron is shown in Fig. 2.

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**INDUCTION ACCELERATION OF A BEAM OF CHARGED PARTICLES**

G. A. Askar'yan

Attempts to obtain an intense gaseous discharge 
usually lead to the formation of a plasma current in 
which the electrons have a relatively small ordered 
velocity but a large amount of stored energy because of 
the self-magnetic field. In the present note we present 
a brief analysis of certain processes by means of which 
it should be possible to accelerate some of the charged 
particles or to produce high pulsed-current densities.

We assume that there is a sharp reduction in the di-
rected velocities or the number of electrons of the 
intense current as a result of some dissipative process 
(elastic and inelastic collisions with molecules and ions, 
electron capture, change of conductivity because of a 
localized change in the electron temperature, application 
of magnetic fields, etc.). This reduction produces an 
induction field which accelerates the other particles 
of the plasma. A rapid reduction in the velocities of 
peripheral electrons can take place, for example, upon 
contact of a moving circular discharge with a surface or 
with a wave front of cold dense gas. The interaction with 
the surface leads to the ejection of vapors from the surface 
of the material into the plasma. In order to reduce the 
amount of such vapor which enters the region occupied 
by the remaining plasma, it is feasible set up in the cur-
rent a velocity component along the surface (for example 
due to the forward motion of a contracting or 
expanding loop). Because of the rapid tangential motion 
of the loop it can escape from the region of exploded 
material vapors; thus it is possible to choose the veloc-
ities in such a way as to control the reduction of current 
and the accumulation of new molecules in a given zone 
of the discharge.

The ionization of the molecules of the shock from 
of the material vapors may not lead to shunting of the 
current if the layer in which electron multiplication 
takes place is small; this multiplication is a consequence 
of the small velocities of the electrons and the increased 
density of the gas, which hinders an increase in the 
energy of the electrons in this region of the discharge. 
For acceleration of the electrons which are formed or 
scattered it is necessary to have a cyclical field which 
also accelerates the other particles. The production of 
this induction field is due to the fact that each *micro-
*This work was completed at the end of 1957.
pressures and temperatures may exceed the quasi-static and/or an external magnetic field. A "skin" distribution with an inherent varying magnetic flux the containment which is strong enough to make the remaining charges heating of the remaining plasma. Because of the short ~ccompanied by an increase in the current density in the total magnetic flux through the circuit varies slowly, the peripheral reduction of the conductivity will be accompanied by an increase in the current density in the remaining part of the discharge and an increase in the energy evolved. The sharp increase in the current density leads to an increase in the peripheral intensity of the magnetic field which surrounds the current and intensifies the contraction of the current causing intense heating of the remaining plasma. Because of the short duration of the contraction process the achievable pulse pressures and temperatures may exceed the quasi-static values (p\text{stat} \sim \frac{I^2}{a^2}, where \(a\) is the effective dimension of the cross section of the remaining part of the turn and \(I\) is the current strength). At very high current densities, created by a peripheral field \( B \geq 3 \cdot 10^6\) oersteds, it is possible for the current to isolate itself because the self-magnetic field repels the diamagnetic molecules of the surrounding medium.

If the conductivity of the plasma is not too large, a reduction in the current can lead to an induction field which is strong enough to make the remaining charges pass through the region of strong momentum loss and energy loss into a region of small loss which is important for further acceleration. In such a gaseous betatron with an inherent varying magnetic flux the containment of electrons in circular orbits and "vertical" stability may be provided by the Coulomb forces which arise in the disturbance of the quasi-neutral state, or by a combination of the Coulomb forces and the self-magnetic field and/or an external magnetic field. A "skin" distribution of current improves the conditions for separation of the ejected and remaining particle currents. Furthermore, if electrons are accelerated in portions of the discharge, the "material" molecules will have much less effect on these than on the unaccelerated electrons because of the rapid variation in the cross section of the interaction. Both of these circumstances relax their requirements on the density gradients of the material vapor produced by the reduction in current.

It is easy to show that a sharp reduction of current can provide the desired field intensity. \(E_{\text{ind}} \approx \frac{I_{\text{eff}}}{L} \tau\), where \(\tau\) is the time required for a sharp reduction of the current in the circuit. For example, with \(L_{\text{eff}} \approx 5 \cdot 10^{-9}\) h/cm, \(I_0 \approx 30\) ka, and \(\tau < 10^{-6}\) sec, we find \(E_{\text{ind}} > 100\) volt/cm, which exceeds the critical field required for acceleration of electrons in a plasma (typical initial electron energies of the order of several electron volts and ion densities of \(n \leq 10^{14}\) ion/cm\(^3\)).

These estimates show that with a sharp reduction in current it is possible to set up conditions which provide continuous acceleration of part of the electrons. The limiting energy required by each of the remaining electrons is \(\epsilon_{\text{max}} \approx (e/c) L_{\text{eff}}\). For example, for the indicated values of the current and inductance we have \(\epsilon_{\text{max}} \approx 5\) Mev, i.e., one would expect an enhancement of the hard radiation.

The induction acceleration processes being considered here can also take place in the radial oscillations of an intense discharge; these oscillations lead to cooling of the plasma and the reduction of its conductivity due to expansion or contact with the walls. The strong induction field (of the order of tens of kv/cm, as observed by oscillograms showing current discontinuities of the order of \(10^{12}\) amp/sec) results in continuous accelerations of electrons and ions in a plasma and the appearance of neutron radiation and \(\gamma\) rays [5]. The probability of continuous acceleration of ions is increased as a consequence of the fact that these processes occur in the reduction of the plasma density in the expansion stage in contrast with processes associated with stretching instabilities or with induction redistribution of current and the production of a peripheral conductivity by the self-magnetic field, which increases in contraction). Stretching causes the production of distorted regions, which also may cause the current to make contact with the walls. We may note in passing, that the second appearance of current close to the axis of discharge may be due to the induction transfer of current and not to the second contraction of the entire plasma.

It is of interest to study the cosmic versions of the induction acceleration processes being considered here in the currents which circulate in the plasmas of stars and in plasma jets which are projected into cosmic space. These phenomena may be mechanisms for the acceleration of cosmic particles.

LITERATURE CITED


†Various methods of accelerating electrons in a plasma have been considered, for example, in [1-4].