INSTABILITY OF AN INDUCTION PINCH

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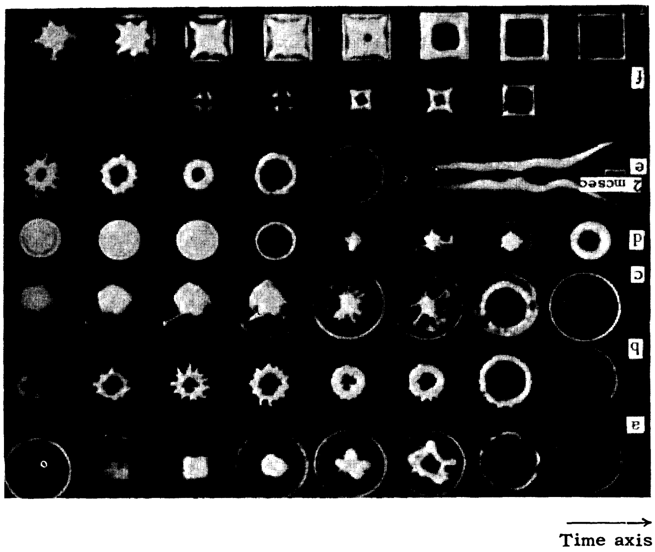
In a paper presented to the Fourth International Conference on Ionization Phenomena in Gases (Upsala, 1959), we considered a new type of instability, observed in pulsed compression of plasma in linear induction (theta) pinches.* The existence of such an instability was inferred from streak photographs of the discharge, taken through a narrow slit from the end of the chamber along the direction of its axis with the slit oriented along a chamber diameter. These photographs have shown that in some cases, following compression, plasma formations are ejected from the pinch surface, sometimes reaching the chamber walls.[1]

Further experiments in which the discharge was photographed with a SFR-2M high-speed camera operating in the "time-magnification" mode, mostly pertaining to the theta pinch, have disclosed a close connection between this effect and the azimuthal inhomogeneity of the radial velocities of the plasma during the compression process. It was found that in view of the presence of such an inhomogeneity, the contracting plasma layer is not cylindrical in form, as was assumed in our paper, as well as in papers by others, but is greatly deformed, assuming sometimes weird shapes. The photographs in these experiments were also taken from the ends of the chamber, sometimes in two modes simultaneously — in the "time-magnification" mode from one end by streak photography (through a narrow slit) from the other. The theta pinch was excited, as usual in an axially symmetrical magnetic field rapidly alternating in time, produced by discharging a capacitor into a single cylindrical turn. To avoid distortion of the photographs by reflection of the axial jets of the plasma at the ends of the chamber, the turn was located in the middle of the chamber, sufficiently far away from its ends.

The figure shows individual examples of the photographs obtained. Photographs a, b, c, d, and e (cylindrical chamber) and f and g (chamber with square cross section) pertain to the "time-magnification" mode. These photographs show the characteristic time variation of the shape of the pinch cross section. It is seen on analogous pictures, taken at a small angle to the camera axis, that the pinch (in any case, during the compression stage) retains the same shape of azimuthal section throughout its length. Picture e was obtained simultaneously with picture f, by streak photography through a narrow slit, and shows an eruption of a plasma formation from the surface of the pinch. Each of these photographs corresponds to a definite half cycle of current in the capacitor circuit. The exposures of the individual frames were 0.5 μsec. The time between neighboring frames was 2μ sec (a four-rowed system of lenses was used; we show here one of four rows of corresponding photographs). According to these pictures, an electrodeless vortical discharge is ignited at the start of the half cycle in the thin layer of gas adjacent to the chamber walls. Even before the plasma layer breaks away from the walls, its glow acquires a certain azimuthal inhomogeneity. During the breakaway and subsequent motion of the plasma, the brighter sections acquire smaller radial accelerations (velocities). As a result, the contracting plasma layer deviates considerably from a cylinder. In the initial stage of contraction, the pinch frequently assumes the shape of a polygon. In cylindrical chambers, the number of sides, their dimensions, and their relative orientations vary from experiment to experiment, or even from half cycle to half cycle of current in the same experiment. The expansion of the pinch after the maximum compression also proceeds with unequal radial velocity. The expansion figures produced are frequently similar to the contraction figures, and are turned by a certain angle in the azimuthal direction (photograph a). This is seen particularly clearly on figure h, where the angle is 45 deg. More complicated figures of motion are also observed. For example, on Figs.



Experimental conditions

Photograph	Initial voltage, kv	Capacitance, μf	Length of magnet turn, turn, cm	H_z max $\times 10^6$ gauss	No. of current half-cycles	Working gas pressure, mm Hg	Dimensions of discharge chamber, cm	Material of discharge chamber wall
c	30	90	55	12	1	Air 0.1	dia 27. $L = 100$	Porcelain
d	30	90	15	40	1	Nitrogen 0.1	dia 27. $L = 100$	Porcelain
a	30	90	15	40	2	Helium 0.07	dia 27. $L = 100$	Porcelain
b	30	60	22	43	1—2	Helium 0.1	dia 12. $L = 70$	Glass
e	30	180	55	18	1	Helium 0.1	dia 27. $L = 100$	Porcelain
f	30	180	55	18	1	Helium 0.1	dia 27. $L = 100$	Porcelain
g	30	90	15	40	1	Air 0.1	$22 \times 22 \times 50$	Glass
h	30	90	15	40	2	Air 0.1	$22 \times 22 \times 50$	Glass

b and d we see that meridional fin-like plasma jets emerge from the surface of the expanding pinch. Sometimes the fins are wavy, or else, as they approach the chamber walls, they are smoothly deflected in a common direction. In this case the jets acquire a certain rotary momentum relative to the central pinch. The plasma jets are frequently reminiscent of certain types of solar protuberances. In some cases the pinch is compressed in the form of a double layer of plasma (photograph c). Here, following the maximum compression of the central pinch, the plasma jets form "jumpers" with the still contracting outer sheath. We could discuss many other forms of plasma motion, but lack of space forces us to confine ourselves to these examples.

It should be noted that the observed effects vanish when the gas pressure increases. They do not appear, or at any rate are greatly attenuated, when the chamber has a small diameter (about 1 or 2 cm and less). In chambers with a rectangular cross section the shape of the pinch and its relative orientation are always fixed. This makes it possible to investigate the properties of the plasma not only by photography, but also by means of magnetic or electric probes and by other methods.

The main cause of the observed phenomena lies obviously in the magnetohydrodynamic nature of the motion of the plasma in magnetic fields. The azimuthal rotation of the figures of the expanding pinch relative to the contracting figures, indicates that a certain role is played in this process by reflection of shock waves from the magnetic fields enclosed by the plasma. From the character of the spatial variation of the pinch figures it follows that the plasma formations behave in magnetic fields like elastic bodies that are characterized by a "coefficient of elasticity" which is greatly dependent on the direction of the field. Experiment has shown that deformation of the plasma layer is greatly hindered along the field lines but develops readily perpendicular to the field, apparently with minimum energy loss.

Even a qualitative analysis of the presented data shows that the plasma is not in equilibrium when in the stage of maximum compression. Intense damped macroscopic motions, which lead to eruptive instabilities of the pinch, are excited rather weakly in the plasma. These instabilities apparently give rise to the main difficulty when attempts are made to produce a high-temperature plasma with the aid of pulse processes. The eruptive instabilities should be observed not only in linear but also in toroidal chambers, although they are more difficult to photograph in the latter.

In the present communication we give only a brief description of the main outlines of plasma motion in a theta pinch. A more detailed exposition of the results, including those for a linear pinch, and a discussion of the mechanism of the observed phenomena will be presented in a later paper.

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*As is well known, the term linear pinch is used for a plasma column compressed by the magnetic field of its own current. A theta pinch is produced in a vortical discharge in a gas, in an axially-symmetrical magnetic field that builds up rapidly with time.

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[1] Kvartskhava, Kervalidze, and Gvaladze, J. Tech. Phys. (U.S.S.R.) **30**, 297 (1960), Soviet Phys.-Tech. Phys. **5**, 274 (1960).

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