EXPERIMENTAL STUDY OF CUMULATIVE PHENOMENA IN A PLASMA FOCUS AND IN A LASER PLASMA

V. A. Gribkov, O. N. Krokhin, G. V. Sklizkov, N. V. Filippov, and T. I. Filippova*

High-speed laser interferometry at two wavelengths, high-speed multiframe shadow photography, x-ray and neutron-radiation studies, as well as a probe procedure are used to show that the processes of cumulation in a plasma focus and in a laser plasma of special geometry proceed in two stages — hydrodynamic and kinetic. In the first stage, both in the case of MHD cumulation (plasma focus) and in the case of hydrodynamic cumulation (laser plasma), the main processes are determined by the formation of a cumulative jet. In the second stage, an intense relativistic electron beam is produced in the plasma focus and interacts strongly with the plasma, whereas in the cumulative laser plasma there is observed generation of high-power Langmuir noise that leads to the formation of a group (up to 1% of the total number) of fast electrons having an energy 5-10 times larger than the energy of the bulk of the electrons.

INTRODUCTION

Great interest is attached, in the present-day research on controlled thermonuclear fusion, to the investigation of plasma obtained in installations that make use of the cumulative effect. The gist of this method is that the energy initially accumulated in the large mass of the plasma or in the magnetic field is transferred to a relatively small number of particles. This is usually done by collapsing plasma clusters that are accelerated with a magnetic field or by gas-dynamic motion [1, 2]. A characteristic feature of cumulative processes is usually that an appreciable fraction of the particles of the large plasma mass flows out of the cumulation region, so that a high temperature can be attained in the remaining plasma (see, e.g., [3]).

The cumulative effect can be obtained also by another method, wherein compression without shock waves is produced when a spherical target is exposed to a high-power radiation pulse [4-6] of suitably chosen form. High density and temperature are then reached at the center of the target.

The reason for the interest in the cumulation installations is that the theoretical studies of the last decade have demonstrated the possibility of producing in them controlled thermonuclear fusion in the relatively near future (laser plasma, relativistic electron beam). In addition, a number of experimental setups already in existence and based on the cumulative effect have unprecedented neutron yields (for example, the plasma focus), so that investigations with the aid of these setups yield much valuable information on the behavior of the plasma under conditions close to thermonuclear.

The cumulation effect was discovered in the second half of the past century, when a sharp increase was observed in the piercing ability of shells in the presence of a pit in the explosive

*I. V. Kurchatov Institute of Atomic Energy.

charge. The first theoretical studies were made in the forties by a group of American scientists headed by Taylor [7]. In our country, a theory of cumulation was developed by Lavrent'ev [8]. It was shown in the theoretical papers that when a conical shell with angle 2α is collapsed under the influence of the explosive, a cumulative jet is produced at the apex of the cone, on the cone axis, and this jet propels approximately 10% of the collapsed mass at a velocity given by the equation

$$v_j = \frac{v_0}{\tan(\alpha/2)}, \tag{1}$$

where v_0 is the rate of collapse of the cone elements. It is seen from (1) that the jet velocity is larger the smaller the angle α. The idea of cumulation came subsequently into use in plasma physics. Since modern electric-discharge devices and lasers produce higher collapse velocities than explosives, an appreciably larger velocity of the cumulative jet can be obtained. The greatest progress in this direction was attained by now with installations of the plasma-focus type and in a laser plasma.

The present paper is devoted to an experimental investigation of the physical processes that take place in the course of magnetic cumulation of a plasma (a "plasma-focus" setup) and in the case of gas-dynamic cumulation (laser plasma obtained by using a special target geometry). The principal experimental plasma investigations were made with interferometers, x rays, and probes. Particular attention was paid in the investigations to the final stage of plasma cumulation in which the highest parameters are reached as a rule.

Despite the larger number of experimental and theoretical studies performed to date on magnetic cumulation, on the phenomena accompanying it in general, and on the plasma focus in particular [9-34], there is still no clear idea concerning the operation of this installation. The least understood are precisely the most interesting phenomena that occur in the plasma focus, namely the generation of high-power hard x rays and neutron pulses. The studies of cumulative laser plasma are only in their initial stage, and information contained in the articles published on this subject [36-39] are quite skimpy.

We proceed now to describe a procedure especially developed by us, using high-speed photography in a laser beam, and note that all other diagnostic methods used by us are slight modifications of classical procedures [40, 41].

CHAPTER I

PROCEDURE OF HIGH-SPEED INTERFEROMETRIC INVESTIGATION OF A NONSTATIONARY DENSE PLASMA

1. The Maximum Information Obtained by Optical Laser Research Methods

A question encountered in laser interferometry of fast-moving objects is that of the volume of information obtainable as the result of the experiment.

When an object moving with velocity v is photographed, the blurring of the image in the object plane is $v\tau$, where τ is the exposure time. Accordingly the resolution is $N_1 = (v\tau)^{-1}$. On the other hand in the case of an object that is at rest, the resolution of the interference pattern is determined by the width of the laser line, which is uniquely connected with the exposure time

$$\tau \simeq k/\Delta\nu = k\lambda^2/c\Delta\lambda \tag{2}$$

(k is a coefficient that characterizes the degree of temporal coherence of the laser pulse, and $c = 3 \cdot 10^{10}$ cm/sec is the speed of light).