Concepts of Z-Pinch Controlled Fusion

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Concepts of controlled fusion:

a) low density and long-living plasma (magnetic confinement)
   – tokamaks JET, (TFTR,) ITER, (EU, Japan, Canada, Australia),
   helical systems (Germany, Japan)
   D+T, densities $\sim 10^{20}$ m$^{-3}$, time of confinement $\sim$ s

b) high energy density and short living plasma (inertial confinement) D+D
   - huge lasers (USA-NIF, France, Japan, UK…)
     densities $> 10^{30}$ m$^{-3}$, time of confinement $< 10^{-14}$ s
     direct and indirect drive - symmetry, ultrahigh energy electrons, fast ignition, efficiency
   - or Z-pinches (Russia, USA) +magnetic confinement (kT)
     densities $> 10^{30}$ m$^{-3}$, time of confinement $\sim 10^{-8}$ s,
     indirect drive of soft X-rays
     high energy plasma component and neutron production
Z-pinches concepts

**XUV indirect drive**
Z-device Albuquerque, USA
18 MA / 100 ns, double tungsten liners,
280 TW - 1 MJ soft X-ray energy per 5 ns, 15% efficiency
temperature of radiation ~ 150 eV $\rightarrow$ 250 eV (X1)

**keV range of X-rays, hot spots**
localities with temperature and density of ~ two orders higher than in other pinch plasma
$\rightarrow$ local ignition of a few localities inside of the pinch
Linhart and Bilbao - simulations 10 MA / 10 ns
µm localities, a few % of particles

**100 keV range of ions, neutron yield** - experiments with D plasma focus devices - PF 3 at Kurchatov Institute, PF 1000 at Warsaw
(yield $10^{12}$ - probability $10^{-6}$)
Z-accelerator $10^{9-11}$, MAGPIE $10^9$, S – 300 $10^8$. 
Theory of Z-pinch

total transformation of kinetic energy into heat (Bennett equation)
chain: compressing magnetic energy $\rightarrow$ kinetic energy $\rightarrow$ heating of the pinched plasma $\rightarrow$ radiation and the stationary conditions are described by Bennett equation

hot spots and neutron production $\leftarrow$ increase of resistance $\rightarrow$ high electric field generation $\rightarrow$ acceleration of electrons (X-rays) and ions (neutrons)

acceleration of ions and electrons
- the same mechanism at the same time?
Today problems

XUV - Z Albuquerque, S-300
fast compression without instabilities W-liners
symmetry of radiation and pellet
high current switch – opening switch
direct transformation of kinetic energy into heat ?
financial support

Study of X-rays (hot spots)
higher Z elements radiation in K- and L-lines of Al, Ti, Ar→
density, temperature, B
problems with experiments and theory

High energy ions >100 keV
PF devices more efficient than fast Z-pinch devices
differences – time, volume, plasma density
question of B_z influence [4]
Role of magnetic field at energy transformations
ICDMP – PF 1000 and S-300 experiments

Experiments with thick wire loads (+liners and plasma-sheath)
- depress an instability development
- slow down the velocity of transformations of the plasma configurations

\( B_z \) - spontaneously self-generated at the Z-pinch implosion - consequence of the fluctuations of plasma density, implosion velocity and cylindrical symmetry of magnetic field - random orientation.

Experiments improved the existence and transformation of \( B_z \):
- helical structures in some phases of pinching discharges
- relatively long and stable pinch phase
- pulsation of pinch phase
- ”second pinching” of the pinch phase → hot spots
- confinement or back return of the plasma exploding from the pinch

neutron yield at Al wire in the PF
neutron generation after pinch and X-ray pulse 100 ns

Influence for study of fusion:
Efficient XUV production - depression \( B_z \) (fast Z-pinches, influence of initial phase of wire breakdown and evaporation).

Mechanism of acceleration of electrons and ions
Conclusions

**Intensive research** in the field of Z-pinches
- study of dense plasma at different configurations
- complex diagnostics of single shots

**International collaboration** of scientists in experiments, diagnostics, simulations and theory

**International financial support**

General interest of representatives of human community to **solve the problem of production and consumption of energy**
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