NUMERICAL MODELLING OF MHD INSTABILITIES IN Z-PINCH HOT SPOT

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Abstract

The focus of the work is on the study of some physical mechanisms connected with Rayleigh-Taylor-type MHD instabilities development. We compare our numerical results with experimental data obtained at High Current Electronics Institute (HCEI, Tomsk) [1]. Dependence of liner stability and radiation output vs. mass of liner, its initial radius, cascade scheme has been investigated in Tomsk. In our paper we try to explain by 1D and 2D MHD modelling the obtained experimental data and to analyze the role of main scales determining the liner implosion: magnetic field penetration into the body of plasma, heat-conductivity, radiation transfer. Some phenomena are investigated: shock wave motion, ionization, axial plasma motion and others. For double gas puff the collision of outer cascade with inner plasma is investigated in detail.

Introduction

Presently an essential efforts went into the description of the problem of the MHD instability of the gas puff implosion. The Rayleigh-Taylor (RT) instabilities are the first obstacle to obtain homogeneous plasma column. The RT instability problem has not been solved up to now. In papers [2, 3] it is supposed that multilayer gas puff has an internal property of suppressing MHD instability.

In this paper the MHD model is used to analyze processes of RT instability. There are several mechanisms which could be studied by MHD and play an essential role in liner implosion: thermal wave from plasma current heating, radiating effects cooling plasma, structure of observed shock wave, etc.

The numerical modelling is carried out by 1D MHD code ERA [4] and 2D MHD code MAG [5]. Radiation effects in MAG code are treated in optically thin plasma approximation (bremsstrahlung loses of energy). ERA allows to take into account radiation transfer in continuum and line spectrum. That permits to specify the results of 2D calculations.

Different Liner Configurations

A series of calculations were carried out for GIT-4 parameters: current with an amplitude of 1.6 MA with front duration of 100 ns [1]. Then current assumed to be constant. Several cases are considered for Argon load:

1. one-cascade puff; $m = 31$ μg/cm (only 1D); $r_0 = 1.4$ cm;
2. one-cascade puff; $m = 61$ (1D) and 50 μg/cm (2D); $r_0 = 1.4$ cm;
3. one-cascade puff; $m = 154$ (1D) and 250 μg/cm (2D); $r_0 = 1.4$ cm;
4. one-cascade puff; $m = 61$ (1D) and 50 μg/cm (2D); $r_0 = 4$ cm;
5. double puff; inner cascade: $m_{in} = 61$ (1D) and 50 μg/cm (2D); $r_{in} = 1.4$ cm; mass between inner and outer cascades $m_{inter} = 20$ (1D) and 9 μg/cm (2D) 1.4 cm $\leq r_{inter} <3.96$ cm (1D) and 3.5 cm (2D); outer cacsade: $m_{out} = 10$ (1D) and 15 μg/cm (2D); $r_{out} = 4$ cm.

K-shell radiation yield obtained by ERA code for these cases is slightly correlated with Oreshkin's results presented in paper [1]: there is a maximum of the yield for single-cascade gas puff with 50 μg/cm and initial radius of 1.4 cm (case 2). It is interesting to note that the effects of temperatures of electrons and ions distinction play an important role for light liner (case 1). 1D and 2D results are summarized in Table 1. In 1D results the heavy liner is compressed very late and due to constant current could not expand. Therefore the 1D results of the case are incorrect.

Table 1: Summarized results for different cases. CR – compressed ratio as it is looked in a pinhole picture (the result has been obtained by corresponding computer code), TOI – time of implosion (ns), TASW – temperature after shock wave (eV), TAMC – temperature at maximum compression (eV), MFDL – magnetic field diffusion length (mm) at the beginning of implosion (for double gas puff second digit is the MFDL in inner cascade)

Case	CR	TOI	TASW	TAMC	MFDL
1	9	110	80	800	1.5
2	14	120	60	1750	2.5
3	10	230	40	1650	5.5
4	8	210	100	600	2
5	15	290	20	2300	3.5 (1.5)

Hot Spot Formation in Light and Heavy Liners

Using 2D code MAG the instability development was studied. For the investigation one need to set the source of nonhomogeneous. It has been supposed that small region (~50% in z-direction and ~5% in r-direction) near upper boundary has smaller density ($\sim 5 \div 10\%$)

The study showed the difference in dynamics of light and heavy liners implosion (see Fig.1). For light liner the surface modes of RT instability are dominated and for heavy one the surface mode is transformed to the instability developing inside plasma (volumetric mode). This phenomena is connected with the penetration of magnetic field which is higher for heavy liner. The heat conductivity is lower due to lower temperature and higher density.

Calculated dynamics of hot spot formation in the case of light liner is quite ordinary (Fig.1, upper two pictures): the shock wave propagates to the axis and heat wave propagates ahead shock wave due to high heat conductivity. As a result small hot spot is formed. This hot spot – hot dense region radiates intensive without significant absorption.

The hot spot formation for heavy liner is more complicated (Fig.1, middle and lower pictures): because of the magnetic field penetration the strong shock wave runs away from the plasma edge (Fig.1, middle pictures) and then reaches the axis. As a result hot spot is formed (Fig.1, lower pictures) but it is not so hot and dense comparing to the case of light liner. This can be interpreted in the following way. First, only a small part of liner mass is involved into the spot formation, second, shock wave is not so intensive (has lower velocity), third, an axial motion of plasma is significantly higher. Plasma radiates in heavy liner from two regions: 1) hot spot and 2) hot region near plasma edge. The radiation from hot spot is absorbed effectively in cold dense neighbors regions. It could be the possible explanation of decreasing of radiation output in heavy liners. Hot region

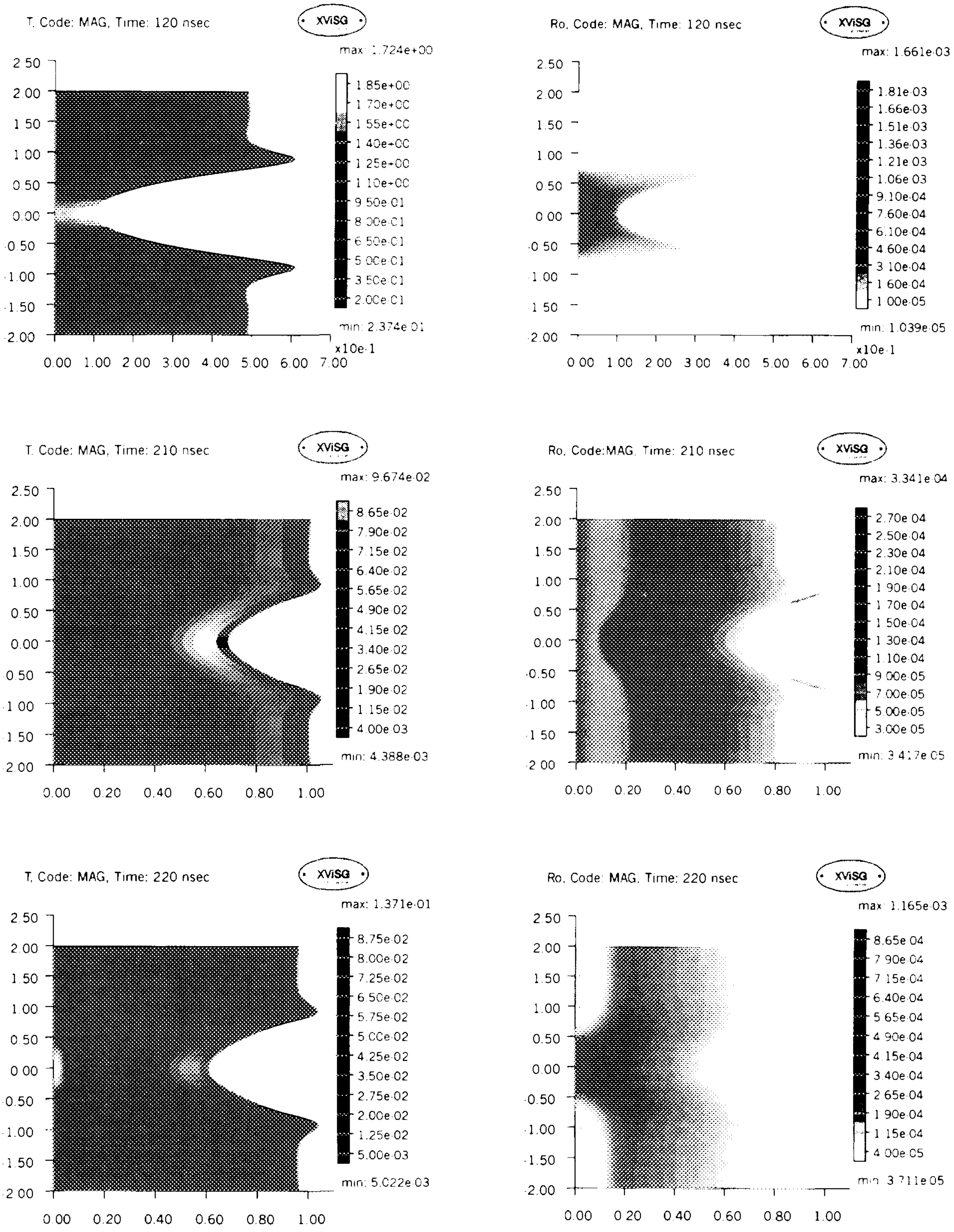

Fig. 1 One-cascade liner.
Left - Temperature (keV), Right - Density (g/cm^3).
Upper - Light Liner (50 μg/cm).
Middle and Lower Heavy Liner (250 μg/cm).

near plasma edge is formed due to Joule heating. Because of low density the radiation yield is not great. The final stage of hot spot formation is connected with two shock waves propagation in opposite direction.

Double Gas Puff Dynamics

The goal of multilayer liner using is instability suppression. It is supposed that a collision between outer accelerated layer and inner one (which is keeping without motion up to the time when magnetic field reaches inner liner due to diffusion) can provide the suppression. The outer liner in Tomsk experiment has lower mass and is a subject of instability. The calculated mechanism of instability suppression during shell collision is the next: the cavity of pertubated outer shell reached inner shell and then the hot region is formed (temperature increases from 98 eV up to 195 eV). Then heat wave is moving fast mainly alone the edge of inner shell and heats the upper edge of inner shell. At the moment the magnetic field continues to press the liner and therefore more uniform (in z-direction) shock wave propagates to the axis.

We estimated only the experimental data of outer-to-inner mass ratio $\eta = m_{outer}/m_{inner} < 0.3$. One need to investigate other range of η.

Spontaneous Magnetic Field Influence

To investigate the effect of spontaneous magnetic field influence on hot spot formation the term $\frac{cm_p}{e} \cdot \frac{A_1}{Z\rho^2} \cdot [\nabla\rho \times \nabla p]$ has been added to the equation of magnetic field diffusion. Results of calculation with and without this term differ slightly. Temperature increases from 1.72 keV to 1.89 keV at maximum compression, but the symmetry of implosion is disrupted. The influence for other data will be studied.

Conclusion

In a future we plan to investigate the role of Hall effect in the frame of Electron MHD, develop 2D radiation transfer code, two-temperature model, develop hybrid code (MHD+PIC) to study the effects of fast particles motion.

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