Symmetry Issues in Cylindrical Implosions Driven by a Rotating Beam

A. R. Piriz[1], M.Temporal[1], J.J. Lopez Cela[1], N. A. .Tahir[2], and D. H. H. Hoffmann[3,4]
[1]Univ. Castilla-La Mancha; [2]Univ. Frankfurt; [3]GSI-Darmstadt; [4]TU-Darmstadt

Several plasma physics experiments that will be carried out at the GSI future synchrotron facility, SIS100 would require heating of an annular region of a cylindrical target[1]. A very challenging problem in these experiments will be the creation of such an annular heated region. One possibility to achieve this is to use a high frequency rf-wobbler that will rotate the beam with a very high rotation frequency (of the order of a GHz). One important problem in this respect is to assess the minimum rotation frequency of the wobbler that is required to achieve a high irradiation symmetry at the target (of the order of 99%).

A simple estimation of the required rotation frequency has already been performed[2]. In this previous model we assumed an ideal beam focal spot which was a sector of corona (with a constant angular aperture) and with a uniform energy distribution. The temporal profile of the beam power was also considered to be constant throughout the pulse duration, τ_p. In this case the time, t_T required for an increase in the absorber pressure by an amount Δp in an area that is equal to the focal spot area A_{fs} turns out to be proportional to the rotation period T. Since T is also the time needed to increase the pressure in the entire annular absorber region (with an area A_a) by the same amount Δp, we have, $t_T/T = A_{fs}/A_a$ and the relative asymmetry turns out to be $\Delta p/p = N^{-1}$. In this case p is the mean absorber pressure and $N = \nu\tau_p$ is the number of revolutions during the pulse duration with a rotation frequency ν.

This simple picture illustrates the basic features that determine the irradiation asymmetry. However in order to assess the issues more precisely we need to consider a more realistic picture of the problem that includes the circular shape of the focal spot, the energy distribution in the focal spot, and the time dependence of the beam power. The first two effects can be taken into account very accurately by noting that the heating time, t_T at a given angular position will in general, depend on the radial position. This is because t_T is just the transit time of a given point on the beam focal spot across a chosen angular position. The pressure distribution in the annular absorber is calculated by integration over the angular aperture $\theta(r)$, as below:

$$\Delta p(r) \propto \int_{-\theta(r)}^{\theta(r)} P[r'(r,\theta)]\, d\theta \qquad (1)$$

Where $P(r')$ gives the spatial distribution of the energy on the beam focal spot.

The time dependence of the power pulse can be taken into account in an approximate manner by considering a sufficiently large number of revolutions N. In such a case any arbitrary power pulse can be replaced by a sequence of box pulses with different intensities but with same duration (equal to the rotation period T). It can be easily shown that the absolute asymmetry at any given time can be calculated by integrating the power pulse over a time interval equal to the transit time of the focal spot at a given angular position.

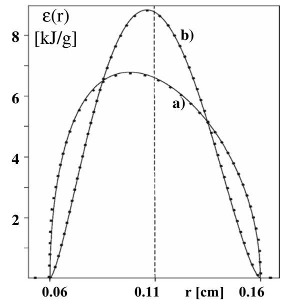

Figure 1: Specific energy distribution at t = τ_p for E_0 = 5 kJ/g and τ_p = 20 ns. a)for a uniform beam focal spot and b)for a parabolic distribution in the beam focal spot. Solid line analytic solution, dotted line simulations.

$$\Delta p(r,t) = \frac{P_0}{A_{fs}} \frac{(\gamma-1)}{2\theta(r)} \int_{-\theta(r)}^{\theta(r)} f[r'(r,\theta)]\, d\theta \int_{t_1}^{t_2} g(t)\, dt \qquad (2)$$

Where $P(r,\theta,t) = P_0 f(r')g(t)$ is the beam power and γ is the absorber enthalpy. Also $t_{1,2} = t - [t_{Tm} \mp t_T(r)]/2$.

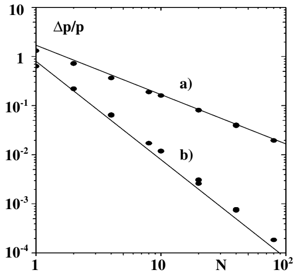

Figure 2: Relative asymmetry, $\Delta p/p$ in the driving pressure at t = τ_p and r = r_m for different values of τ_p, ν and E_0, a) for a box pulse, b) for a parabolic pulse

Fig.1 shows the spatial distribution of the absorbed energy for a uniform as well as a parabolic distribution of the energy in the beam focal spot. Solid lines represent the analytic results while the dots represents the numerical simulations which have been done using a 2D hydrodynamic code, CAVEAT.

Fig.2 shows the relative asymmetry in the driving pressure given by Eq.(2). It is seen that the analytic and simulation results agree very well. Both show that for a box pulse $\Delta p/p \propto N^{-1}$ while for a parabolic pulse on has $\Delta p/p \propto N^{-2}$.

References

[1] Tahir, N.A.; *et al.*: Phys. Rev. E 63 (p. 016402), 2001.

[2] Piriz, A. R.; *et al.*: Phys. Rev. E 66 (p. 056403), 2002.