2003-234-N0 -- ANALYSIS AND DEVELOPMENT OF LIQUID METAL TARGETS FOR RIA

Principal Investigators: A. Hassanein, Energy Technology
I. Konkashbaev, Energy Technology

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Purpose: The purpose of this project is to investigate the behavior of a thin liquid metal film under pulsed heat load. Thin liquid lithium film flow is being considered as a stripper for the Rare Isotope Accelerator (RIA) ion beam to obtain higher Z ion projectiles for effective interaction with target materials to produce rare isotopes. Projectile ions can be produced for all charge states (Z = 1-92). The power of the ion beam is high in this case (up to 0.4 MW), and the deposited energy in this heated spot should be removed from the beam footprint by the flowing liquid with a velocity U of tens of m/s. Stability of the thin film with a depth of only a few μm has certain features that are determined by the high speed of the resulting surface capillary waves V_k that is comparable and higher than U. Thus perturbations can propagate upstream. The second problem is the pulsed heat load with high frequency that results in excitation of volumetric sound waves with rather high magnitude of hundreds of atm. Consequences are: a) possible film fracture, particularly if the liquid contains impurities, b) excitation of capillary waves due to coupling sound and capillary waves, and c) pressure disturbances coming to the nozzle exit or at the location of liquid film generation.

All these phenomena can result in serious film surface perturbations that result in film destruction or, for example, in expansion of beam phase space, i.e., “halo” with losses of beam particles. A comprehensive model of thin film dynamics under pulsed heat load is being developed in this project and is expected to serve as the foundation for future experiments in modeling the thin film flow under pulsed heat load. After validation by comparison with modeling experiments it is possible to use this model and corresponding 3-D numerical HEIGHTS package for the actual design of RIA strippers.

Approach: The aim of this proposal is the development of a comprehensive theoretical model of the thin film flow under pulsed heat load and implementing such a model in the 3-D computational HEIGHTS package. These thin liquid lithium films are regarded as strippers for the RIA ion beam to obtain higher Z ion projectile for subsequent interaction with target materials to produce rare isotopes. One of the main concerns is film destruction due to beam penetration. Another concern is beam-particle loss during passage across strippers due to a) straggling and b) variations of the film thickness. Investigation of the second problem is the focus of this project. Such thickness variations can result in capillary waves due to excitation by imperfections of the inlet nozzle, striking of the liquid flow on the receiver, and coupling between sound

waves and capillary waves of tens of m/s velocity. Stability of the thin film with depth of a few μm has certain characteristics that are determined by the high speed of surface capillary waves $V_\lambda(\lambda=10\ \mu m) = 25$ m/s $\geq U$, thus perturbations arising downstream (at the heated zone and at the exit) can move upstream and disturb the film surface.

This project will lead to a new level of understanding of thin planar film flow under pulsed high heat load that was not studied before either theoretically or experimentally. All previous detail investigations regarded only cylindrical jets without consideration of sound wave excitation and their coupling with capillary waves.

Our ultimate goal is to develop and integrate models to study thin flow dynamics and the influence on ion-beam losses. The elaborated model should be validated by experiments, for example, with Li flow under pulsed beam load. Then, a 3-D model will be implemented in the HEIGHTS package and can be used for design of powerful accelerators and other colliders that use liquid metal targets under pulsed heat loads.

This integrated model can study in detail:

- Excitation and dynamics of high magnitude of hundred atm, high frequency of MHz, and small wavelength of 10^{-3}-10^{-1} cm sound waves,
- Coupling of these waves with capillary waves with comparable frequency and wavelength,
- Dynamics of perturbations of excited waves at the inlet and outlet jet/film location, and
- Calculation of beam expansion due to induced variation of film thickness.

Technical progress and Results: We made calculations of beam target/stripper interactions and developed hydrodynamic code for compressible liquid to take into account propagation of sound (pressure) waves. It was shown that conventional codes such as SRIM-TRIM cannot be used for beam-stripper interaction because stripper thickness should be equal (slightly more) to the path length necessary to strip required amount of electrons, $\Delta Z \approx 30$ for the first stripper. Thus, it is necessary to calculate energy losses together with ionization dynamics because stopping power depends on ion charge as Z^2 and therefore, the resulting accuracy of current stopping power calculations is only within a factor of 2 of measured values. Existing codes such as ETACHA and GLOBAL for calculating stopping power together with ionization give results with accuracy of about $\eta \approx 30\%$ in terms of output charge: $\eta = \delta Z/\Delta Z$, $\delta Z \approx 10$, the deviation of calculated Z from exact value. Therefore, the calculation of energy losses or beam deposition into liquid metal flow spot was taken as an input parameter and the calculations were made for some range of stopping power from a minimum value corresponding to the incoming ion charge to maximum value corresponding to output ion charge. It was shown by using HEIGHTS-RIA package that a pulsed heat load with repetition of f_{beam}= 50 MHz results in excitation of sound waves having two characteristic frequencies corresponding to beam frequency f and pressure relaxation with corresponding time of sound waves traveling across beam footprint f_{spot}= 2.5 MHz. The magnitude of these waves, about $\Delta P \approx 200$ atm, is determined by the input thermal

pressure jump per pulse, $P_{jump} \approx$ 50 atm, and ratio $\xi = f_{beam}/f_{spot}$: $\Delta P = \alpha P_{jump} \xi$, α=0.16. These pressure waves and their interactions can disturb and even destroy the film integrity. This problem must, therefore, be investigated in more detail.

Future work will focus on developing a multi-dimensional hydrodynamic package for compressible liquid with high frequency pulsed energy deposition to create self-consistent model to describe all physical phenomena taking place. This HEIGHTS-RIA package will be validated by comparison with both a simplified analytical solution with detail theoretical considerations and planned experiments.

Specific Accomplishments: Preliminary computer package HEIGHTS-RIA to study powerful and pulsed beam interaction with flowing liquid metal targets.