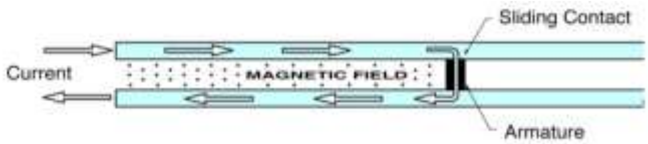
MASTER INTERSHIP PROPOSAL – 2021/2022

Understanding wear modes and modeling of mechanical wear mechanisms in electromagnetic railguns

Context:

The electromagnetic railgun is a hypervelocity launcher where the projectile can reach speeds higher that 2 km/s using an electromagnetic force produced by a high power pulse current of several mega-amperes. Such projectile speeds offer key advantages in terms of range, kinetic energy at impact, and distance to interception in the context of modern missile defense systems [1], see Fig.1.

(a)



(b)

Figure 1 : (a) Railgun NGL60 during a shot of a 60mmx60mm projectile at the French-German research institute of Saint-Louis (ISL) [Delmote et al., 2018] (b) Simple two-rail breech-fed railgun geometry [McNab et al., 2011]

Basically, the railgun is a large electrical loop where the current flows from one rail to the other through the armature which makes the bridge between the two rails [2, 3]. When current flows in the circuit, a magnetic field is established in the space between the rails. This field interacts with the current to produce the Lorentz force, which both accelerates the projectile and produces a mutually repulsive force on the rails, see Fig.1(b). During a shot, the projectile is sliding between two rails and the friction between armature and rails in railgun is under the conditions of high pulse current, ultra-high-speed sliding contact. Under very high-speed velocity, various wear mechanisms (mechanical and/or physico-chemical) can occur and can be at the origin of the degradation of rails which in turn could compromise the use of the experimental facility. Similar wear mechanisms are typical in machining and high-speed machining of metallic materials where the tool/workpiece interface is submitted to large velocities and temperatures [4, 5].
Under certain circumstances, which are expected to be clarified during the internship, some asperities and particles of different sizes stick together with the rails surface. During subsequent shots, the armature thus impacts micro-obstacles of various sizes resulting in formation of gouging (typical tear-drop shaped, see Fig.2).

Figure 2 : Typical gouge on copper rail [McNab et al., 2011]

Project of the internship:

Keywords: Experimental characterization, Numerical simulations of high-speed contact, wear of materials, heat transfer.

The candidate will be exposed to a unique launcher system and will have the opportunity to participate in the development of knowledge used for ISL's electromagnetic launcher. He/she will be part of a collaboration project between ISL and LEM3 which aims at increasing the lifetime of the launcher. The duration of the proposed internship is 6 months and will be divided in three parts:

1/ Literature review:

The first stage of the internship is to conduct a literature survey on wear mechanisms in general and more specifically those related to the electromagnetic railgun. Making the parallel with what is observed during other dynamic processes (e.g. high-speed machining) would be of great interest to broaden the field of interest and take inspiration to develop a wear modeling dedicated to railguns.

2/ Experimental part:

The second stage will focus on the experimental investigation of wear mechanisms occurring in railguns. The experimental part of the study will be done at ISL where railgun shots at various speeds will be performed. The candidate will conduct microscopic analysis, surface profiling investigations and microstructure observations in order to clarify the relationship between experimental conditions and wear mechanisms.

3/ Numerical simulation of high-speed contact:

So far, a strong influence of the surface roughness of the rails on armature wear has been found experimentally. Numerical simulations (conducted using Abaqus) will help to clarify the occurrence of such mechanisms under controlled loading conditions considering for instance asperities vs asperities contact under dynamic loading

The last stage of the internship will focus on numerical simulations of high-speed contact including the role of asperities (sizes and shapes, statistical distribution...), pressure contact, sliding velocities and thermal environment under high speed impact considering armature geometries. Starting from simple model surfaces like cylindrical blocks of asperity tips the model can be tuned towards more realistic surfaces by adapting surface parameters from 3D surface profiling experiments on rails and armatures done with confocal microscopy at ISL.

Profile: Student of Master 2 or engineering school, in physics or mechanics of materials, motivated by experimentation and numerical simulations.

Application: Applications (including a CV and covering letter outlining your motivation for the position) should be sent to Gautier List (gautier.list@univ-lorraine.fr), Slim Bahi (mohamed-slim.bahi@univ-lorraine.fr) and Philippe Delmote (Philippe.Delmote@isl.eu).

Closing date: 31th March 2021

References

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[3] L. Xu, Y. Geng, Applied Mathematical Modelling, 2012
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