Fast Time Response Electromagnetic Disruption Mitigation System

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Predicting and controlling disruptions is an important and urgent issue for the International Thermonuclear Experimental Reactor (ITER). Magnetic confinement devices that rely on substantial amounts of plasma current to sustain the plasma discharge have the potential to disrupt and will require methods to rapidly quench the discharge after an impending disruption is detected. For ITER, the warning time for the onset of some disruptions could be less than 10 ms. In the proposed method, a cylindrical boron nitride projectile containing a radiative payload composed of beryllium or boron nitride particulate matter, and weighing about 11 g is accelerated to velocities on the order of 1-2 km/s in less than 2 ms using a linear rail gun accelerator, and the capsule injected into the tokamak discharge in the 3 to 6 ms time scale. The device referred to as an Electromagnetic Particle Injector (EPI) has the potential to meet the short warning time scales, for which an ITER disruption mitigation system must be built. Because the system is fully electromagnetic it should be well suited for long standby mode operation with high reliability.

I Introduction: The primary advantage of the device referred to as an Electromagnetic Particle Injector (EPI) is its potential to meet the short warning time scales, for which an ITER disruption mitigation system may need to be built. Figure 1a describes the injector operating principle. The projectile is placed between two conducting rails separated by about 1 to 2 cm. The length of the rails would be about 50 -100 cm long. The projectile is placed in front of a conducting spring, as shown in Figure 1b. A capacitor bank is connected to the back end of the rails. Discharging the capacitor bank causes the current to flow along the rails as shown in Figure 1a [1]. The J x B forces resulting from the magnetic field created in the region between the rails, and the current along the spring armature accelerates the projectile. Because of its simplicity and ability to accelerate projectiles to very high velocity (of over 5 km/s) it is being actively researched for mass acceleration purposes. An issue that needs to be resolved for these high duty cycle applications is electrode erosion. However, in a disruption mitigation system, due to the low duty cycle, electrode erosion is not expected to be an issue.

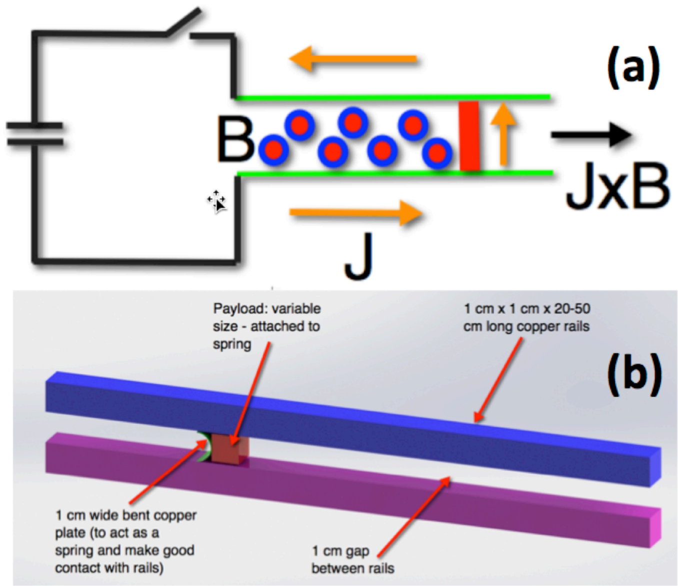

Figure 1 (a) Operating principle of a rail gun accelerator, (b) The metallic spring provides the current path.

Figure 1a shows the direction of the magnetic field generated by currents flowing along the rails. One way to increase the efficiency of the injector is to increase this magnetic flux that penetrates the region between the rails. To improve this field other more complex electrode geometries are also being considered [2]. However, the ITER environment offers another potential advantage to a linear rail gun system as the ambient magnetic fields in ITER could be used to augment the gun-generated magnetic field and further increase the efficiency of the injector. Thus, if the rail gun electrodes were to be aligned with the external magnetic field the efficiency could be further improved. Efficiency increases of a factor of two are possible if the injector could be placed close to the vessel. Another added advantage of the closer installation is that the projectile transit time would be further reduced. Thus, while the large ambient magnetic fields are generally an issue for most systems, it helps the linear rail gun injector improve its performance and reduce the projectile delivery time.

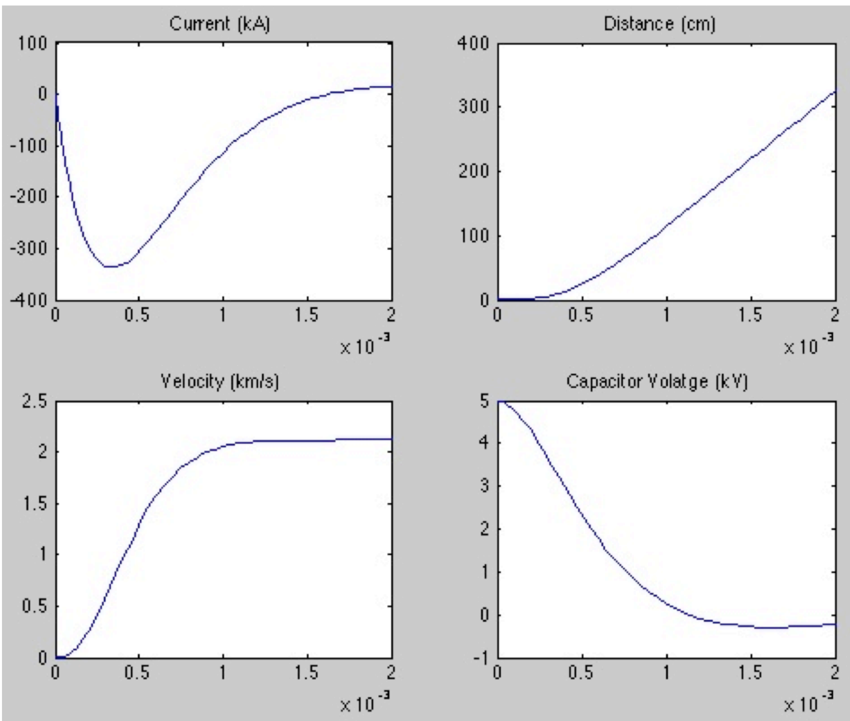

Figure 2: Circuit simulations for an ITER-class injector. The payload mass is 10.6 g. A 50 mF capacitor charged to 5kV powers the accelerator.

Figure 2 shows the results of a circuit simulation calculation in which the rail gun is operated at 5 kV using a 50 mF capacitor bank power supply. The rail gun electrode gap is 1 cm. This results in an inductance per unit length of the rails of 0.69 μH/m. The inductance per unit length is a measure of the magnetic energy stored in the gap between the rails and directly translates to rail gun efficiency. For this case, a 10.6 g projectile is accelerated to 2 km/s in less than 1 ms as shown by the velocity trace. During 1 ms, the projectile travels 1 m, so that the rail gun electrodes need to be 1m long. The current flowing along the rails reaches a peak value of 300 kA and the capacitor voltage is reduced to zero on about the 1 ms time scale.

II Configuration for ITER

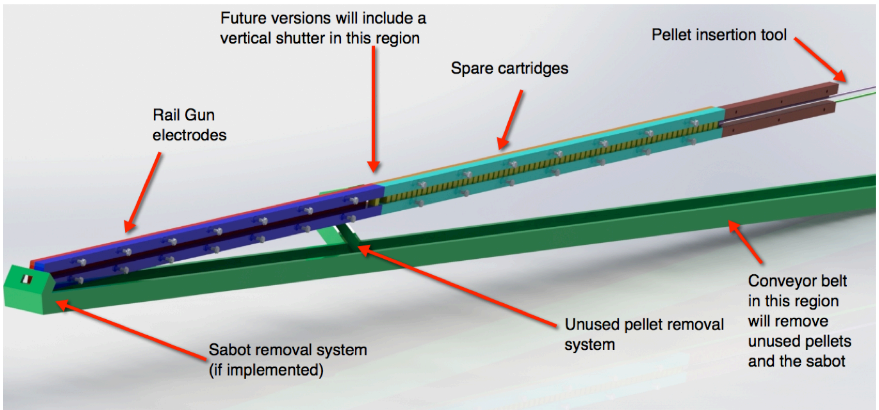

Figure 3: Primary components of the EPI injector. The rectangular aperture in the sabot removal system would be circular for a cylindrical projectile.

Figure 3 shows the primary components of the injector that could be installed behind the ITER port plug, as shown in Figure 4. A bulletized cylindrical projectile would travel along a curved guide tube before entering the ITER vessel. The curved guide tube also avoids direct line of sight to the vessel. Positioning the injector behind the port plug is to allow easier maintenance and to keep the components below 150C. As shown in Figure 3, attached to the back of the electrodes would be the cartridge loading assembly. The pellet insertion tool would position a cartridge just inside the electrode region for injection. A cylindrical projectile would exit through a circular hole in the sabot removal system. The metallic spring that acts on the projectile would be captured. A conveyor belt assembly positioned below the electrode assembly would be used to remove the sabot spring as well as unused projectiles.

Development Plan: Calculations show that a 20 mF capacitor bank charged to 1.5 kV can accelerate a 1.8 g projectile to 0.4 km/s in 0.5 ms. The rail gun electrode length would be 20 cm, similar to the configuration shown in Figure 1b. The peak circuit current would be 80 kA. These are the parameters planned for an initial test of the concept to validate the velocity parameters. Because of its compact size, it could then be used on NSTX-U for a

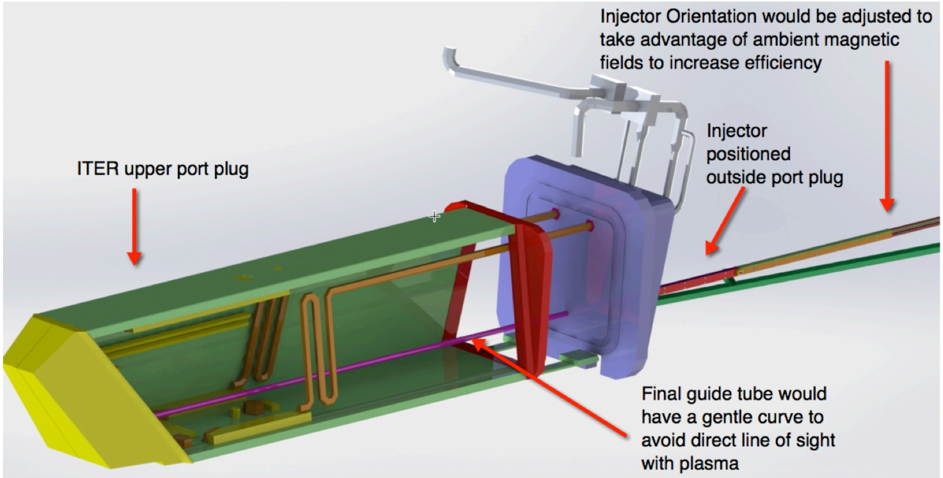

Figure 4: Conceptual installation concept on ITER. The Electromagnetic Particle Injector (EPI) would be positioned behind the ITER port plug.

demonstration of the ability of an EPI system for rapid macro-particle delivery and its ability to thermally quench a disruption.

III Conclusions

An electromagnetic particle injector based on a linear rail gun concept has the potential for rapid response, and ability to accelerate the payload capsule to 1-2 km/s in less than a few ms, which is adequate to meet the < 10 ms response time needed for a ITER disruption mitigation system. Scoping studies suggest that such a system could be installed behind the ITER port plug, allowing easy access to the injector for maintenance. As a next step it is planned to build a small prototype for verification of velocity parameters. Such a system could then be tested on NSTX-U to qualify its ability to rapidly quench a disrupting plasma.

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