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1-20-94 QSD

UCRL-ID- 115694

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October 20, 1993

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**MICROWAVE MICHELSON INTERFEROMETER SYSTEM
REPORT OF FIRST USE ON A RAILGUN †
GREEN FARM, SAN DIEGO, CA**

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(October 20, 1993)**

I. INTRODUCTION

This report summarizes the successful first attempt to use a Michelson microwave interferometer to measure the position of a projectile throughout its acceleration by a railgun. The test was performed at the DNA Green Farm facility operated by Maxwell Labs Inc. The test was performed using the ARDEC-ACB gun to accelerate a 1.1 kg polycarbonate projectile to about 2.5 km/s. The projectile had an initial injection velocity of about 490 m/s.

II. DESCRIPTION OF SYSTEM

Basically the system is a 1 GHz Michelson Interferometer. Figure 1 is a block diagram of the system. A solid state oscillator provides 100 mW at 1 GHz. 1% of the power is coupled through a 20 db directional coupler to a crystal (Xtal) detector which serves as a monitor to check the oscillator if needed. 99% of the power enters a power divider. Half of the power serves as a phase reference for the interferometer, passes through a 20 db attenuator and enters a power adder. The other half of the power enters a circulator to begin the path as the active (phase shiftable) leg of the interferometer. The power entering circulator port No. 1 emerges out of port No. 2. A coax-to-waveguide/waveguide/waveguide-to-coax apparatus incorporates two sheets of high voltage insulating mylar to provide electrical insulation between the railgun and the microwave system. The waveguide-to-coax section also provides electrical insulation between the rails. The microwave power is feed into the muzzle of the railgun by way of a transmission line which transitions from the 50 ohms of the coax to the ~100 ohms of the railgun. The microwave power then propagates towards the breech of the railgun until it is reflected by the projectile (if its metallic) or the armature (metallic or plasma). The projectile position determines the path length, hence phase of the reflected power. The reflected power then retraces the original path back to the circulator where it enters port No. 2 and emerges from port No. 3. The active arm power proceeds through an attenuator and amplifier combination with a net power gain of 15 db. The active arm, with its projectile position determined phase, enters the power adder along with the reference arm, with its fixed phase. The combined microwave signal passes through a narrow band filter

† Work funded by Don Lavine, Aberdeen Proving Ground in cooperation with DNA and ARDEC.

Work performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under contract No. W-7405-ENG-48.

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to reject any possible high frequency EMI. A crystal detector then detects the algebraically combined phase dependent power.

III. SYSTEM OPERATION

As the phase of the active arm is shifted by the motion of the projectile or armature, the two signals add algebraically thereby providing a cyclic output from the detector (see Figure 2). Each of the voltage peaks corresponds to a zero relative phase shift and the valleys correspond to a 180° relative phase shift. The active phase shifts 2π (360°) radians for each half wavelength of projectile motion. The wavelength at 1 GHz is 0.3 m in free space and about 0.29 m in the ACB-ARDEC gun. A slightly shorter wavelength results from the dielectric effect of the rail spacers on the propagation velocity of the microwaves. Hence each voltage peak (cycle) corresponds to a projectile displacement of 0.147 m in the ABC-ARDEC.

IV. RESULTS OF TEST

Figure 3 shows the microwave output signal digitally recorded during Green Farm test No. 184 on October 7, 1993. The test was a nominal 4 MJ kinetic energy launch of a polycarbonate projectile accelerated by a base push plasma armature. Time 0.0 ms corresponds to the injected entrance of the projectile's base mounted fuse into, and commutation of, the "hot-rails" (electrically charged) at the breech of the ACB-ARDEC gun. The 1.1 kg projectile traveled for about 1.0 ms at an injected velocity of about 490 m/s at which time the capacitor bank discharge sequence began. The initial bank charge energy was 7.4 MJ which provided a peak current of 2.64 MA at 3.05 ms. The projectile emerged from the 7.5 m long railgun at about 5.2 ms. Figure 4 is a position vs time plot extracted from the raw microwave record. A discontinuity at 6.25 m (4.62 ms) is indicated. Rail damage was also observed to have occurred during this test at about the same position. Figure 5A is a velocity vs time plot extracted from the position vs time plot. Clearly some of the data points which indicate spurious velocities are artifacts rather than data. Figure 5B is a revised velocity vs time plot where artifact data has been judiciously removed by use of a filtered Fourier Transform.

The maximum indicated velocity is 2.6 km/s in the 4.2 to 4.6 ms range corresponding to a projectile position of 5.1 to 6.2 m in the barrel. At 4.6 ms the microwave record indicates a decrease in the plasma leading edge velocity and also a sudden discontinuity in the raw microwave record. (There was evidence of post shot rail damage at this position.) Figure 6 is the reconstructed microwave data after filtering of the Fourier Transform to reduce the unwanted artifacts. Figure 7 is a position vs time plot reconstructed from Figure 5B. The Maxwell recorded B-dot data points are also shown in Figure 7.

V. DISCUSSION OF RESULTS

This one test sequence has resolved several issues regarding the potential use of microwaves to measure in-bore railgun projectile position and velocity. Although there is some jitter in the data, the technique has tracked a projectile from breech to muzzle while accelerated by a plasma armature in a large bore, high energy railgun.

VI. CONCLUSIONS

From the test sequence described above, we conclude:

- Microwave technique successfully provides projectile position data!
- Microwave attenuation through barrel is sufficiently low to permit measurement of projectile position from breech to muzzle.
- Microwaves are effectively reflected by non-contacting metal objects (e.g. aluminum foil covered tennis ball with diameter smaller than rail bore.)
- Microwaves are effectively reflected by plasma armature and/or small (3 cm) metal disc mounted on front of projectile (in 9 cm bore gun).
- Microwave system frequency (1GHz) is well above railgun EMI noise spectrum.
- Railgun operates in a single TEM mode without complex waveguide modes causing multiple wave propagation interference.
- Microwave waveguide isolator is an effective means of electrically insulating rails from microwave system and eliminating ground loops.
- Technique can supplement B-dot data for projectile position measurement.
- Technique requires only one data channel to yield numerous data points.

VII. RECOMMENDATIONS

Based on the success of this first test of a microwave interferometer on a railgun, we recommend a continued effort to: 1) improve the signal-to-noise ratio, 2) fold the transmission line away from the projectile flight path while improving the coupling efficiency, 3) development of data reduction software, and 4) the implementation of the refined system on appropriate railgun facilities for routine use.

Figure 1

Figure 2

Figure 3

Figure 4

Figure 5a

Instantaneous Velocity calculated from Fourier Transform Data

Figure 5b

Figure 6

Figure 7

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