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TITLE RAILGUN POWER SUPPLY SYSTEM UTILIZING TRACTION MOTORS AND VACUUM INTERRUPTERS

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Railgun Power Supply System Utilizing Traction Motors and Vacuum Interrupters*

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Summary

A railgun power supply has been designed that utilizes traction motors, vacuum interrupters and pulse transformers,. An assembly of 28 traction motors, which store approximately 75 MJ, energize the primary windings of three pulse transformers at a peak current of 50 kA. At peak current an array of vacuum interrupters disconnects the transformer primary windings and forces the current to flow in the secondary windings. The secondary windings are connected directly to the railgun and require no opening switches. By staging the vacuum interrupter openings, a 1 MA to 1.3 MA ramped current waveform can be delivered to the railgun.

Introduction

The Lethality Test System (LTS) at the Los Alamos National Laboratory is an electromagnetic launcher system that is presently being constructed to perform impact experiments. This system will be capable of accelerating 20 to 30 g projectiles to 15 km/s in 4 ms. To achieve this velocity the power system must supply a current waveform that rises from approximately 1 MA to 1.3 MA during the acceleraton period. A three - stage, distributed energy storage system has been chosen for the base design. These stages must deliver approximately 30 MJ to the railgun during projectile acceleration.

System Description

A parallel connected assembly of dc traction motors, equipped with appropriate flywheels, was chosen as the primary energy storage system. The discharge current of these motors, when utilized as generators, is increased to the necessary level for railgun operation by means of cryogenic pulse transformers. All current interruption is accomplished on the primary side of the transformers at 50 kA to avoid the necessity for extensive switch development. A commutated vacuum interrupter array provides reliable, low-cost interruption using commercial components.

A simplified schematic of the primary charging circuit is shown in Fig. 1. With switch, S_1, open, traction motors, TM, are accelerated to 2200 rpm in approximately 5 min by power supply, PS. S_1 is then closed, causing a sinusoidal current rise in the transformer primaries, T1 thru T3. When a peak current of 50 kA is reached in 2.6 s, crowbar switches, S_2 thru S_4, close and trap the magnetic energy in the transformer primaries.

Figure 2 illustrates the discharge circuit of a single transformer. Current is initiated in the railgun by the closing of S_5 and the opening of the circuit breaker, CB_1. This forces the primary current into the varistor, R_1 which causes the primary current to decay rapidly. Simultaneously, the magnetic flux, which is coupled to the secondary winding, causes the secondary current to increase. The peak current in the secondary is determined by the turns ratio of the transformer and the amount of coupled flux. T_1 is designed to produce approximately 1 MA with a 20:1 turns ratio. T_2 and T_3 are each designed to produce 300 kA with a 7:1 turns ratio. Because energy is stored in the individual transformers due to the short - circuited primary windings, T_2 and T_3 can be discharged in a staged sequence by opening their respective circuit breakers. The railgun current waveform, which is the summation of the secondary currents switched in proper sequence, is shown in Fig 3. To maintain relatively constant acceleration of the projectile, the current must increase from 1.0 to 1.3 MA to offset the accumulated effects of ablation of the rail electrodes and wall insulators. The projectile velocity as a function of time for this current waveform is shown in Fig 4.[1]

Traction Motors

A parallel connected assembly of 28 dc traction motors was chosen as the most economical means of storing the large amounts of energy required for the LTS. Including flywheels, field and armature power supplies, and controls, the entire traction motor system costs less than one cent per joule. This is approximately one-fifth the cost of commercial homopolar generators.[2] In addition, the motors are rugged, modular, and well characterized.[3] At full speed, the inertial energy of a single motor is 0.85 MJ. Due to the capability of the motor shaft to sustain high torque, substantial flywheels can be added to increase the energy storage of each motor. Each motor - flywheel will store 3.2 MJ at full speed, however, they will be discharged at only 90% of full speed to aid commutation at high currents. A series diode is included in the output leg of each motor to prevent the parallel connected assembly from internally discharging in the event of a single motor failure. A photograph of the motors is shown in Fig 5.

Cryogenic Pulse Transformers

To power a railgun with the traction motor array, the output current pulse must be compressed in time and increased in amplitude. A cryogenic pulse transformer can perform both of these tasks efficiently. In addition, the turns ratio of the three stages can be tailored to suit the current requirements set by the railgun. Although the final design for all three transformers has not been completed, dimensions and efficiencies for a base design are given in Table I. The manufactured costs of the transformers in this system are estimated to be

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2 cents/J, based on the kinetic energy in the traction motors.

TABLE I
Cryogenic Transformer Parameters

Outside diameter (m)	2.27
Height (m)	1.12
Primary turns	80
Secondary turns	4
Resistance of primary at 77K (mΩ)	1.8
Primary current (kA)	50
Secondary current (kA)	950
Energy loss during 2.6 charge (MJ)	7.0
Energy stored in primary, Ep (MJ)	18.1
Energy available from secondary, E_s (MJ)	16.4
Motor kinetic energy, E_k (MJ)	25.3
Efficiency, E_s/E_k (%)	65

Vacuum Interrupters

Interruption of the current in the primary winding of the pulse transformer is necessary to establish full current in the secondary. Current interruption will be accomplished with a two stage circuit. The first stage consists of a commutated vacuum interrupter array that forces the primary current into a parallel second stage. The second stage is passive and consists of an assembly of zinc oxide varistors. A simplified schematic of this circuit is shown in Fig 6. The varistors ultimately force the current in the primary winding to zero in a voltage - controlled fashion. They also absorb the energy associated with stray leakage flux in the transformer and railgun.

Each vacuum interrupter array consists of two parallel - connected, three - phase circuit breakers. One of these three - phase circuit breakers is shown in Fig 7. The individual phases of each circuit breaker are connected in series. When the array is commutated by the 75 kJ capacitor bank, the 50 kA primary current is forced into the varistor. The varistor is designed to limit the voltage to 50 kV at this current. Each vacuum interrupter, therefore, has to withstand 16.6 kV after interrupting 25 kA. This is well within the ability of such devices as shown by earlier tests done for fusion experiments.[4],[5]

The varistor assembly consists of six parallel columns of seven series-connected disks.[6] These disks each measure 75 mm o.d. by 22 mm thick and are capable of absorbing over 20 kJ each. The excellent nonlinear properties of these devices force the primary current to zero much faster than an ordinary resistor would. They can also be easily rearranged to vary the characteristics of the array.

Conclusions

A pulsed power system has been designed to provide energy to the LTS railgun. This system relies heavily on commercially available components, such as traction motors, varistors, and vacuum interrupters. The output stages store over 50 MJ (electric) from a 75 MJ (kinetic) traction motor array. When installed, this system will deliver approximately 30 MJ to the railgun at current levels in excess of 1 MA.

Acknowledgements

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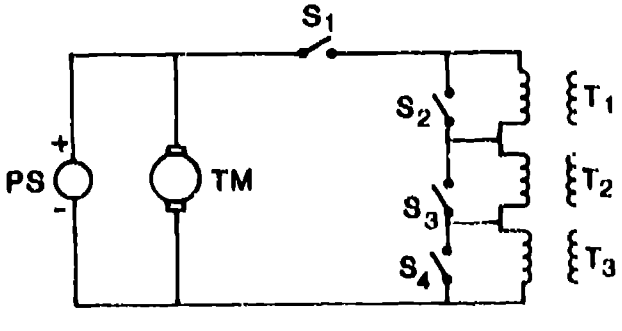

Fig. 1 Primary charging circuit.

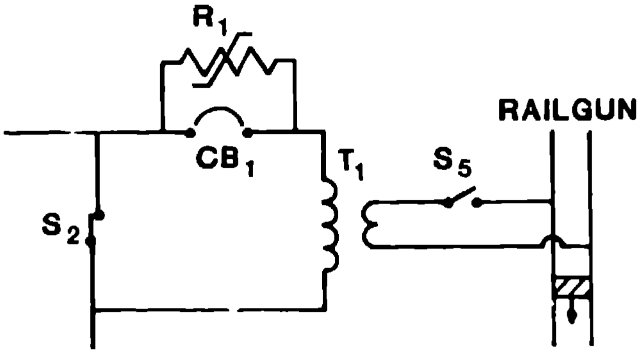

Fig. 2 Single discharge circuit.

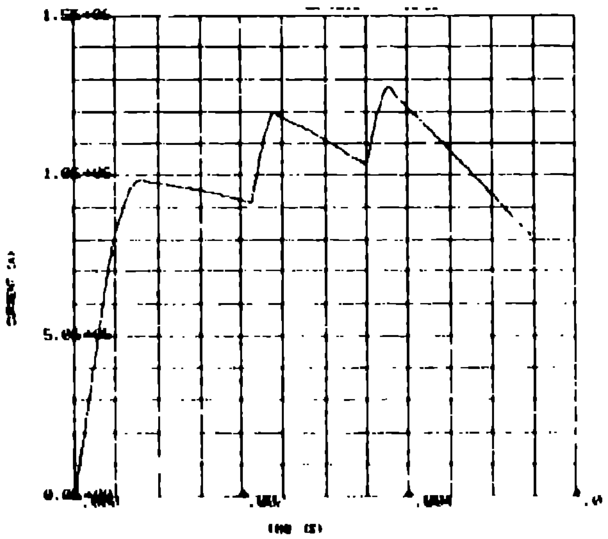

Fig. 3 Railgun current waveform.

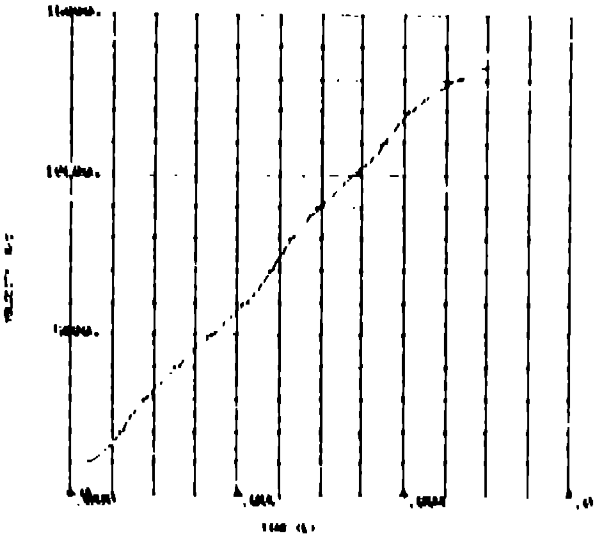

Fig. 4 Projectile velocity vs time.

Fig. 5 Traction motor array.

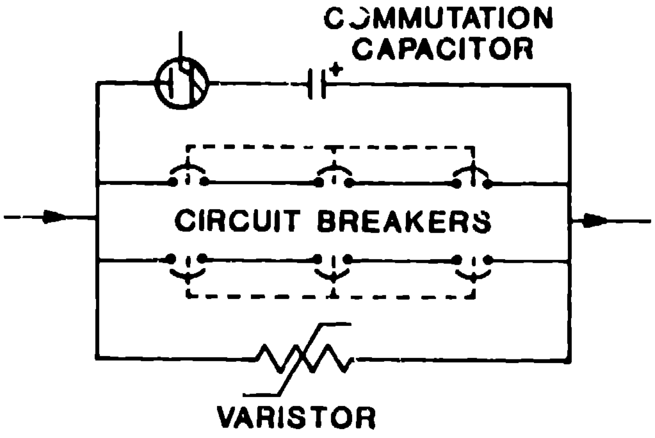

Fig. 6 Simplified switching circuit.

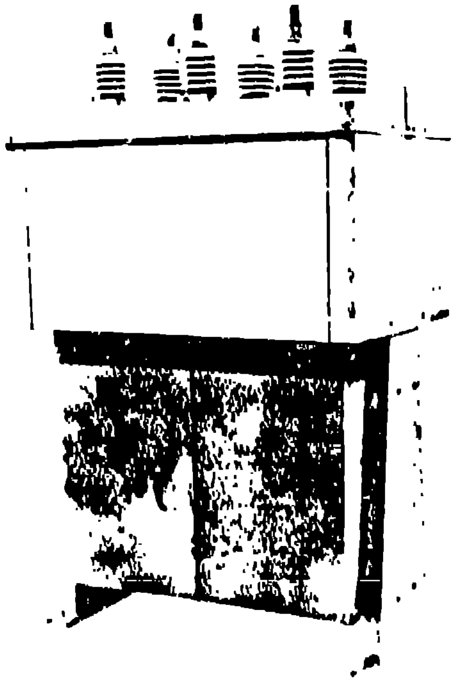

Fig. 7 Three-phase vacuum circuit breaker.

(Photo courtesy of Westinghouse)