

APPLICATION OF PULSE POWER TECHNOLOGY TO INDUCTION ACCELERATORS

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Abstract: Induction accelerators have potential as drivers for a variety of applications, from tactical weapons to earth-orbit launchers. This paper describes how pulse-power techniques have been used on several projects at the Center for Electromechanics at The University of Texas in Austin (CEM-UT) to advance induction accelerator state of the art. Use of capacitor energy discharge and power switching are two pulse-power methods described. Also described are fiber optic sensor control and digital feedback.

Introduction

While railguns have become the most mature of the electromagnetic (EM) launch technologies, coaxial induction accelerators can achieve better efficiency and may be configured to operate without contact with the bore. Without electrical contact with the stationary part of the accelerator (stator), induction accelerators avoid the problems railguns encounter when armatures transition from mechanical contact to a plasma.

Past efforts (both at CEM-UT and at other research centers) to develop a hypervelocity inductance accelerator have been unsuccessful. Intuition derived from rotary induction motor theory did not lead to successful designs. However, laboratory tests both at Sandia National Laboratories [1] and at CEM-UT have shown that concepts based on pulse-power technology are progressing more rapidly than those based on polyphase power. The more successful concepts have used technology such as capacitive and inductive storage and high speed switches. Real time diagnostic instrumentation has played an important role in the control of the launcher.

This paper gives examples from several projects showing how pulse-power technology has contributed to advancement of induction launcher design.

Induction Launcher Technology

Induction accelerators are one of the two broad classes of coaxial accelerators. Each class follows the principles of their rotary electrical motor counterpart. The other class, synchronous, requires that flux be maintained

in the moving member (armature) using sliding contacts, permanent magnets, or other means. [2] Induction launcher armatures operate by excluding magnetic flux. This makes the induction launcher mechanically very simple. This simplicity is paid for with the additional operational requirement that current be induced in the armature by way of a rising or falling current in the stator coils. Interesting accelerators have rapidly rising and falling currents. From a power conditioning standpoint, this rising and falling current requirement benefits from pulse-power methods.

Torpedo Launcher Project [3]

Submarine operations, from time to time, require weapons (such as torpedos) and other devices (such as countermeasures) be launched from the hull. The electric launcher studied under this project attempts to improve the compatibility of the launcher with other aspects of submarine operations. Flexibility of operation is one such goal. The launcher uses an 18-in. bore, linear coaxial motor which works on the variable reluctance principle. It works in a similar manner as a common industrial solenoid.

The best power supply for the launcher would have been a very high powered linear electrical amplifier. However, in order to keep the size and complexity of the supply to a minimum, a pulse type switching system was used instead. The very high inductance created by the iron-core design allowed the designers to select the number of solenoid turns so that the launcher works well with existing submarine battery voltage, but also so that current can be handled with a single, silicon control rectifier (SCR). A hockey puck type SCR with 77 mm diameter semiconductor and 3,500 A current capacity was used. The schematic of the power circuitry is shown in figure 1, where L_{power} is the launcher solenoid, V is the ship's battery supply, and S_1 is the turn on switch. A free wheeling diode is provided across the inductor along with a resistor to dissipate the stored magnetic energy remaining in the inductor after the power is switched off.

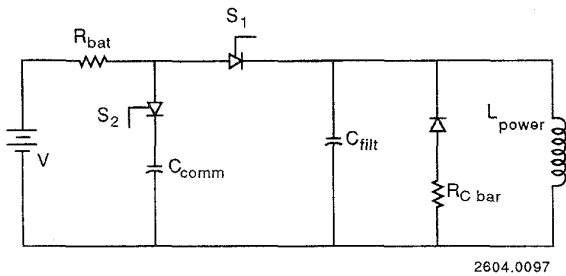


Figure 1. Torpedo launcher schematic

An unusual feature of the design is its commutation circuit. Instead of placing the commutation switch across the ON switch as traditional designs dictate, the commutation switch is placed across the power supply instead. This arrangement improves on the usual practice by providing a more gradual application and removal voltage across the power coil. Snubber circuits are omitted from the schematic for clarity.

This pulse-power method permits application and removal of more than 1 MW of power in a very simple and controlled fashion. When complete, the 3.5 ton prototype motor being constructed under this project will produce a thrust of 90,000 N (20,000 lb) and have a power stroke of 0.5 m (20 in.). An additional 0.25 m of stroke is provided for deceleration of the 0.5 ton armature after the launch is complete. The launcher is nearing completion at this time and being prepared for test.

Direct Current Coaxial Accelerator Project [4]

Part of the direct current coaxial accelerator project (DCA) program calls for the experimental verification of induction launcher theory using a flexible launcher test bed. This test bed has contributed greatly to the technological knowledge base of how and why coaxial induction launchers work. The test bed shown in figure 2 consists of a structure capable of supporting stator coils of various numbers and sizes.

Power for the test bed consists of stand alone, capacitor modules, one for each stator coil. Each power module has an ignitron connect switch and free wheel switch. The capacitors store 25 kJ when charged to 10 or 20 kV, depending on the capacitance selected. The ignitrons are size D. Buswork for the modules were designed to give low inductance to ensure fast and efficient energy transfer. Coaxial leads connect the modules to the stator coil loads. The test bed power modules are controlled from a shield screen room using digital control circuits. Instrumentation is provided using digitizers controlled

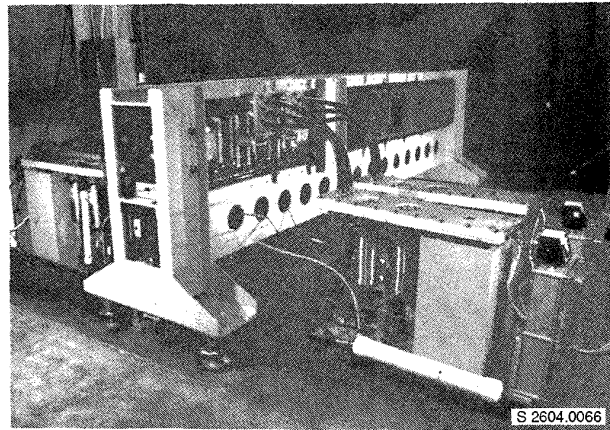


Figure 2. DC coaxial test bed

with a PC computer connected by a GPIB link. Optical velocity gates have been placed between each stator stage. Signals from these gates provide velocity data between stages. They also provide the potential, when fully implemented, of adjusting stator coil firing timing while on the fly. Each portable power module has a firing circuit, charge, and discharge relays.

One of the most troublesome aspects of laboratory work with EM launchers, in general, and coaxial induction launchers, in particular, is interference with control circuitry cause by stray magnetic fields. This is especially bad when attempting to control experiments with low level signals characteristic of computers. To avoid this problem, the DCA test bed with all control originating from the screen room is transmitted to the power modules via a fiber-optic link. This method has proved invaluable in helping to prevent false triggers caused by stray EM fields. The modules have proved very effective in transferring energy to the launcher coils with an efficiency of about 80%.

Induction Launcher Armatures [5]

A troublesome aspect of induction launcher armature design is skin effect. In order to achieve interesting performance from an induction launcher, rapidly rising fields are required inside stator coils. The low resistance shorted coil of the armature attempts to exclude this rising field. This causes large field density gradients on the surface of the armature coil. In armatures with solid conductors, the large gradient induces very large currents in the outer surface of the conductor. Overheated conductors results in many cases.

The heating caused by the skin effect is reduced with the well known method of transposition of conductor. Instead of using solid conductors, armature coils are built with litz wire consisting of numerous conductor strands. Each litz strand is insulated from its neighbor and is twisted so that each strand is represented in all parts of the conductor cross section at some location on the coil. In this manner, each strand sees a very nearly equal induced current. Ohmic heating is spread throughout the armature coil. Hot spots on the surface and especially on the trailing edge of the armature are avoided.

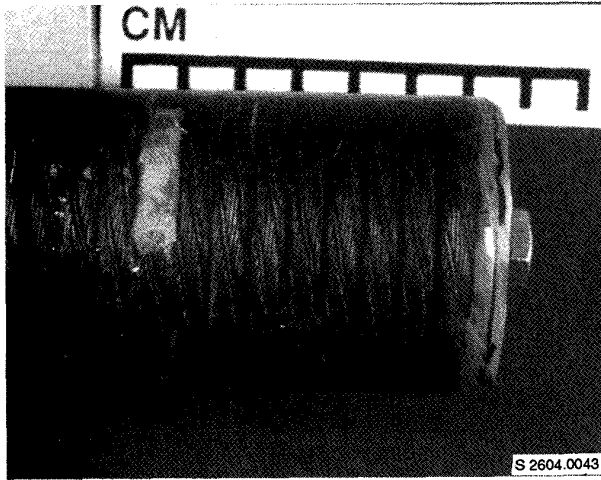


Figure 3. Transposed armature

This well known pulse-power technique greatly improves the performance of inductance launchers. Litz wire is only partially a conductor with the remainder of its volume being insulator and space. As a result, the reduction in the armature heating by using transposed conductors is partially offset by an increase in armature resistance. Using transposed conductors is almost always beneficial.

Figure 3 shows one of several transposed armatures built and tested at CEM-UT. These armatures have survived pressures in excess of 30 T and accelerations in excess of 100,000 g's. The 30-T field compares well with the maximum allowable fields in solid turns predicted by Adrianov. [6]

Conclusions

Pulse-power technology has contributed greatly to the development in induction accelerators. The very rapid rising fields in these devices require careful attention to potential problems, such as skin effect and EM interference. The contribution of the pulse-power community toward a rapidly developing induction launcher field is gratefully recognized.

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