INERTIAL ENERGY STORAGE RESEARCH AT THE UNIVERSITY OF TEXAS AT AUSTIN

by

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ABSTRACT

During the past few years the Energy Storage Group at the University of Texas has been doing research on the design, theory, and application of homopolar machines. Two machines (0.5 MJ and 5.0 MJ) have been built and a third machine is now under construction. This third machine is intended to study the fundamental limitations in fast discharging homopolar machines. Studies have been conducted on other homopolar systems with energy storage of up to 63 GJ.

Experimental research areas discussed include brush testing, electromagnetic bearings, and welding. Theoretical areas include pulse compression and magnetic field mapping (static and transient codes with nonlinear material properties have been written). Other applications of homopolar machines including research, military, and industrial uses have been investigated and are discussed.

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Introduction

As the energy requirements of large fusion experiments approached the tens to hundreds of megajoules range, the need for a simple, reliable, inexpensive replacement for batteries and capacitors to supply this energy became apparent. The type of homopolar machine in which the armature also acts as a flywheel to store the energy appeared to be a viable candidate for these power supplies in many cases [1], [2]. In 1972, the Electrical and Mechanical Engineering Departments at the University of Texas in cooperation with the Fusion Research Center at the University of Texas began to study the limitations and characteristics of this type of machine as a pulsed power supply. Originally these machines were considered only for energy transfer times in the range of several seconds, but as more applications requiring faster transfer times appeared, a study of the fundamental limitations of discharge times was begun. Now, many more applications for large pulsed power supplies that could be serviced by these homopolar devices have been found. Industrial applications that have been identified

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include resistance welding, heat treating and forming of metals, seismic wave generation, down-hole formation fracturing, and of course the pulsed power requirements of the large fusion power reactors. Research applications include lasers, shock tunnel experiments, weapons simulation, and numerous applications requiring the generation of high intensity magnetic fields.

Each rotor of the disk type homopolar machines being studied models as a capacitor. The capacitance of slow discharge machines is usually several kilofarads. This capacitance can be decreased to the range of tens of farads by varying the rotor shape, rotor material, and applied magnetic field intensity. These lower capacitance machines have much faster energy transfer times (possibly down to milliseconds), but the cost per unit energy stored increases significantly.

As this research effort grew, the Energy Storage Group was formed. This group has built two homopolar machines and is now building a third, a fast discharging experimental machine. Other research areas now under investigation by the group include homopolar machine field control for pulse shaping and rotor position control, resistance welding, and brush testing.

One Half Megajoule Homopolar Machine

This machine was initially designed by a group of mechanical engineering students as a senior design project and went through many modifications before becoming a successful machine. One of its major problems was that the rolling element bearings which were used proved unsatisfactory because they were in a very high magnetic field. This problem was solved by replacing these radial bearings with oil lubricated hydrostatic bearings. These hydrostatic bearings appear to be a good choice for most homopolar machines, but since they are fairly difficult to design, the Energy Storage Group has done considerable work on the analysis of their characteristics.

The half megajoule machine had a steel rotor in the shape of a right circular cylinder. It had a capacitance of about 5 kF and an internal resistance of about 400$\mu\Omega$. It has been discharged into a resistive load in about seven seconds with a peak current of about 14 kA

One experiment performed on this machine involved a magnetic thrust bearing [4]. The ferromagnetic rotor was successfully "floated" between the pole pieces of the magnetic yoke by differentially controlling the field coils with a feedback control system.

Five Megajoule Homopolar Machine

This machine has been described in detail elsewhere [5] and is covered here only in summary. Like its smaller predecessor, this machine also has a steel rotor, hydrostatic bearings, and copper-graphite brushes. It has a capacitance of about 5.9 kF with an internal resistance of 19$\mu\Omega$ and an internal inductance of approximately 45nh. It has been discharged from one half speed into a low impedance in about 700 msec with a peak current of 560 kA. This machine is now the power supply for several other experiments including the field coil for the fast discharge machine and for our welding experiments. It has successfully welded pieces of 10 cm diameter thick wall stainless steel pipe using a current of about 150 kA.

FDX

The Fast discharging experimental machine is described in detail in another paper at this conference [6]. This machine has two aluminum rotors and a capacitance of about 17F. It will discharge from one half speed in one millisecond with a peak current of about 1.8 MA. From its full speed of 28,000 RPM it should discharge 340 kj into a useful load in about 3 msec.

Brush Testing

The high sliding velocities and current densities encountered in homopolar machines, require brushes to operate beyond levels normally experienced in conventional electrical machinery. The Energy Storage Group presently has two brush testers in operation. The first has a steel rotor capable of surface speeds of up to 230m/sec and has been used with current densities up to 775 A/cm^2. The second has a copper coated aluminum rotor capable of 460 m/sec and has been used with current densities of 1550 A/cm^2 amps/in^2 in a 60 msec. pulse. The atmosphere in this tester is controllable with respect to gas content, temperature, humidity, and pressure.

Applications in Controlled Thermonuclear Research

The ESG has been involved in several investigations into the applicability of homopolar machines to fusion experiments and proposed reactors. Specifically the devices studied include the toroidal and linear theta-pinch, imploding liners, toroidal Z-pinch, glass lasers, and Tokamaks. Reports have been issued on the studies for the Reference Theta-Pinch Reactor (RTPR) [7], the Texas Experimental Tokamak (TEXT) [8] and the Linear Theta Pinch Hybrid Reactor (LTPHR) [9] and a report is presently being prepared on Experimental Power Reactor (EPR) ohmic heating.

Magnetic Field Plotting

The accurate prediction of the mechanical and electrical behavior of homopolar machines depends on a knowledge of the spatial distribution of currents and magnetic fields during discharge. To this end some effort has been devoted to the development of finite element methods for the calculation of these quantities. Finite element analyses of two dimensional magnetic fields associated with steady direct currents and steady state alternating currents have been widely used in the last six years. These methods are not applicable to the transient regime which is of primary importance in homopolar machines. In fact, the development of the transient analysis, as described in detail in a subsequent paper at this conference [10], is a significant result of the study of homopolar machines by The Energy Storage Group.

The computer program that performs the finite element analysis of both eddy current and field penetration problems, and which is described in [11], is a typical finite element program in that it allows for quite general machine configurations, material properties and boundary conditions. This program has been used to predict the transient current and field distributions of the FDX homopolar machine during discharge and the resulting body force loads have been used as input to a finite element stress analysis of the machine. The details of this analysis are given in [12].

Future Research Areas

The main course of ESG research is and will continue to be the engineering development of homopolar machines as pulsed power supplies; as typified by the continuing improvement of the 5 Mj homopolar motor-generator, development programs investigating new brush materials, the development of FDX, and the design of the TEXT homopolar generators. However additional work is being proposed for the future, primarily in two areas; first the investigation of new applications for homopolar machines and second the development of auxiliary components necessary for the application of homopolar machines.

In the first category investigations are now underway exploring the applicability of homopolar generators as resistance welding power supplies. The extremely high instantaneous power levels available from such generators allow extremely high quality welds to be made with relatively large cross sections with a minimal heat affected zone. Investigations have been proposed concerning the application of homopolar generators as pulsed power supplies for powering laser flash lamps, faraday rotators, high pressure generators, e-beam deflection magnets, and for circuit breaker testing. A U. S. ERDA sponsored joint U.T.-LASL program is currently studying the suitability of homopolar motor-generators as ohmic heating flux reversal elements for large Tokamaks.

In the second area, the low voltage, high current compromise imposed by conventional homopolar machines creates uniquely severe switching requirements for both closing and interrupting switches. A 0.5 MA closing switch has already been built and tested by the ESG and proposals are now being submitted for the development of opening switches

The development of such opening switches would make the use of intermediate, room temperature, inductive energy stores practical to enhance the output voltage of a homopolar machine by orders of magnitude, and hence significantly reduce the energy transfer time into most load circuits.

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