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PULSAR: AN INDUCTIVE PULSE POWER SOURCE*

E. C. CNARE, W. P. BROOKS, and M. COWAN

Sandia Laboratories
Albuquerque, NM 87185

Abstract

The PULSAR concept of inductive pulsed power source uses a flux-compressing metallic or plasma armature rather than a fast opening switch to transfer magnetic flux to a load. The inductive store may be a relatively unsophisticated DC superconducting magnet since no magnetic energy is taken from it, and no large current transients are induced in it. Initial experimental efforts employed either expendable or reusable metallic armatures with a 200 kJ, 450 mm diameter superconducting magnet. Attention is now being focused on the development of much faster plasma armatures for use in larger systems of one and two metres diameter. Techniques used to generate the required high magnetic Reynolds number flow will be described and initial experimental results will be presented.

Introduction

PULSAR is a system which produces pulsed power by magnetic flux compression with metallic or plasma armatures. A superconducting magnet supplies the flux and chemical energy produces high magnetic Reynolds number armatures for the compression. Various forms of PULSAR[1,2] have been proposed for use in coal-fired and inertial fusion power plants as topping stages which have the potential of increasing plant efficiency to greater than 50%. As a prime pulse power source PULSAR becomes more economically attractive the larger the required pulse energy. It becomes competitive at about 10 MJ when its dimensions are the order of a few metres.

The first experimental model of PULSAR generator employed a 0.45 m diameter magnet. When tested with metallic armatures the pulse rise time ranged from 80 μs in the radial mode to 600 μs in the axial mode. Comparison between predictions and experiments showed that PULSAR performance with metallic armatures could be accurately anticipated, however, for some applications there is greater interest in the much faster rise times which can be achieved with plasma armatures. Unfortunately, with plasma armatures it is much more difficult to match theory and experiment. Therefore, to establish dependable scaling laws for plasma armatures an experimental program is being carried out, to extend generator size into the "full scale" region. This will be done with low energy magnets to keep costs down. The program calls for construction of two additional experimental generators, one utilizing a 1 m diameter, 200 kJ magnet and another with a 2 m diameter, 2 MJ magnet. Figure 1 shows the original 0.45 m magnet and the new 1 m magnet which will be involved in generator experiments during the later part of 1979.

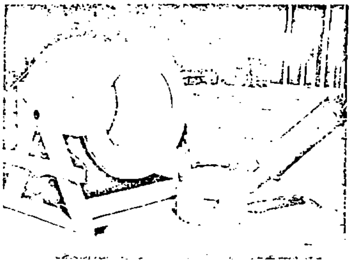

Fig. 1. One m and 0.45 m Superconducting Magnets for PULSAR

This paper will describe a new technique for generating the required high magnetic Reynolds number

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*This work was supported by the U.S. Department of Energy.

plasma armatures which will be used for the larger systems. Results obtained with the new technique in the 0.45 m system will be presented and compared both to those obtained in previous experiments and to predictions of a numerical model.

Plasma Armatures

Previous plasma armature systems[3] consisted of a centrally located, axially initiated explosive charge that was used to radially expand a weakly preionized deuterium gas. The best performance of such a plasma armature produced only about 1/50th the current of a radially expanded metallic armature. In contrast, results of a computer model[4] of the plasma armature predicted about the same peak current as that from a metallic armature due to ohmic heating of the plasma front which "bootstrapped" the conductivity to high values. The suspected reason for the disagreement is that the code does not allow particle exchange between zones so mixing and cooling at the explosive-gas interface is neglected. Because the flow was subsonic, these processes were probably very important, but accounting for them would have required major code changes. This was not warranted since plasma armatures produced by this experimental system were clearly inadequate. Instead, a new experimental approach was developed which more nearly approached the conditions of the optimistic code. A supersonic plasma-producing armature system was developed. Supersonic flow produces a shock with clean "test gas" between the shock front and the explosive-gas contact surface.

The magnetic Reynolds number of the plasma flow is given by

$$R_m = \mu_o \sigma v \ell$$

where μ_o is the magnetic permeability, σ is the plasma conductivity, v is the plasma velocity and ℓ is the plasma flow distance. Since the conductivity is proportional to $T^{3/2}$ and the temperature behind a strong shock is proportional to v^2, the magnetic Reynolds number is proportional to v^4.

The technique we have pursued to obtain higher velocity flow is illustrated in Figure 2. The PULSAR magnet and generator coil are nested at the center of the assembly and two electrically detonated explosive plane wave generators[5] located behind blast shields drive high speed flows which stagnate and expand in the generator coil as shown in the figure. The shields were designed to accommodate straight gas flows through the connecting channels or flows converged from larger diameter explosives into the channels for still higher velocities.[6] In addition, the channels were obtained in 0.60, 0.90, and 1.50 m lengths to determine the effect of channel length on plasma armature quality.

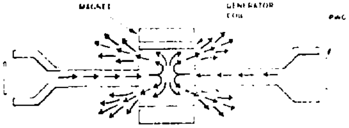

Fig. 2. Schematic for Producing High Speed Plasma Flow

Experimental Results

The experimental setup to test the plasma armature system depicted schematically in Figure 2 is shown in Figure 3. At the time of the test, the LHe dewar is removed from the test area and the super-

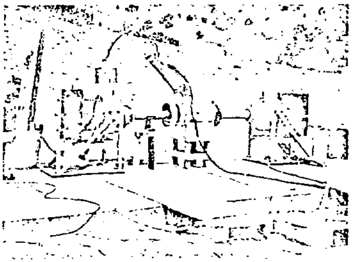

Fig. 3. PULSAR Test Setup for High Speed Plasma Armatures

conducting magnet is operated on its own LHe reservoir. The 10-cm diameter plane wave generators were mounted about even with the open end of the conical blast shields and the low pressure gas channels extend from the explosive to the central expansion chamber. Gas flow velocities in this system were about 20 km/s axial in the channels and 10 to 15 km/s radial in the central chamber. Output current pulses measured in the standard 0.55 μH load for the three channel lengths are graphed in Figure 4 and have been aligned to a common zero time. The magnet current for this test series was 2/3 of maximum so the output can be scaled up by 3/2 for comparisons to previously reported results. The dependence on channel length is seen to be weak with the best of the three tests producing about 8 times more current than the best subsonic plasma armatures and about 1/5th of the code-predicted output.

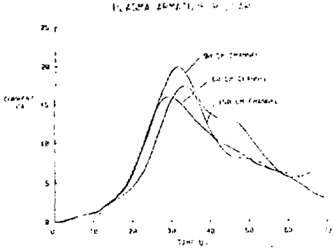

Fig. 4. Plasma Armature PULSAR Output Current Histories

In a test for which the terminals of the generator were shorted, the output current increased about 23%. Assuming similar flux efficiency for the shorted test and tests with the 0.55 μH load, the minimum leakage inductance of the generator was determined to be 2.4 μH. This inductance implies a plasma skin depth of about 3 cm which is consistent with a plasma temperature of a few eV. This is much higher than the temperature expected from shock heating, indicating that some bootstrapping of the plasma conductivity occurred. The energy in the leakage and load inductances exceeded 1200 J but 80% of this was in the leakage inductance. For full-scale PULSAR systems, the ratio of load to leakage inductance energy will greatly favor the load.

Conclusions

A new supersonic plasma armature system produces an order of magnitude better flux compression than the old subsonic one. Experimental results indicate that some bootstrapping of the conductivity by ohmic heating did occur but not as much as a numerical model has predicted. Skin depth in the plasma armature was about 3 cm which for a small system precludes the delivery of a large fraction of the generated electrical energy to an external load. This will not be a problem for full-scale plasma armatures even if plasma properties do not improve.

Acknowledgments

The authors would like to acknowledge the participation of B. W. Duggin in this study for developing the mesh-initiated plane wave generators and for designing the blast shields. The assistance of E. E. Ratliff, R. R. Gallegos, and L. Yellowhorse in fielding the experiments and gathering the data is also greatly appreciated.

References

1. M. Cowan, et al., "Pulsed Energy Conversion with a DC Superconducting Magnet," Cryogenics, December 1976, 699.

2. M. Cowan, et al., "PULSAR - A Flux Compression Topping Stage for Coal-Fired Power Plants," Proc. IECEC 6 (1976) 135.

3. E. C. Cnare, et al., "Pulsed Power Conversion with Inductive Storage," Proc. 7th Sym. Eng. Prob. of Fusion Res. (1977) 1049.

4. T. P. Wright, et al., "Magnetic Flux Compression by Expanding Plasma Armatures," 2nd Int. Conf. on Megagauss Magnetic Field Generation and Related Topics (1979) to be published.

5. R. I. Butler, et al., "Mesh-Initiated Large Area Detonators," Rev. Sci. Inst. V. 47, No. 10 (1979) 1261.

6. M. Cowan and D. A. Freiwald, "Strongly Ionizing High Explosive Shocks," Proc. 7th Int. Shock Tube Symposium (1969) 432.