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FINAL REPORT:

A Research Program in Magnetogasdynamics Utilizing Hypervelocity Coaxial Plasma Generators

NSG 8014

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A Final Report

ABSTRACT:

A broadly-gauged research program in magnetogasdynamics utilizing hypervelocity coaxial plasma generators has been completed with the achievement of its principal objectives. That research was supported under NSG 8014 (and NGR 11-008-002) for a period of three years (at an effective level of one man-year), the last year executed under a "no cost" extension terminating on May 31, 1976. A complete hypervelocity coaxial plasma generator facility has been assembled and tested. Significant progress has been made in the direction of understanding the important processes in the interaction of hypervelocity MGD flow with transverse applied fields. It is now proposed to utilize the accumulated experimental capability and theoretical analysis in application to the analysis and design parameterization of pulsed magnetogasdynamic direct energy convertor configurations.

Review of Research Objectives:

Plasma generators (guns) are compact, highly efficient, controllable sources of hot, relatively dense, high velocity plasma flow. Coaxial plasma generators are able to generate relatively collimated, hypervelocity flow and are particularly attractive sources of flow for basic research in magnetogasdynamics. Significant work had been done by P. N. Espy (N72-20689) and E. L. Shriver (TN D-6687) of NASA, Huntsville in developing and studying such generator configurations. Thus, it was within that context that the following objectives were defined:

a.) The construction and testing of a complete hypervelocity generator facility and the construction and testing of a complete set of plasma flow diagnostics

b.) Measurement of generator system and plasma flow properties and the determination of flow properties' dependence on system parameters

c.) Investigation of the dominant processes in the interaction of the hypervelocity flow with an applied transverse field from both the theoretical and experimental standpoints

d.) Application of that analysis to study plasma-field interaction configurations being considered in magnetogasdynamic (MGD) direct energy convertor research.

A research effort dedicated to the achievement of those objectives was begun on June 1, 1973. Detailed reports on the results at the end of Year One and Year Two of the effort have been submitted for NASA review previous to this report and thus only a summary as of the end of Year Three (under "no cost" extension) will be presented here.

Report on Experimental Effort:

A complete generator facility has been constructed and tested which has the following subsystems:

1.) A coaxial plasma gun and connecting assembly with gun length of 10 cm, outer electrode to inner electrode ratio of 4, characteristic gun inductance of 30 nh, overall assembly+gun+capacitor inductance of 1 μh

2.) A high voltage energy storage system which can store up to 12 kj at 10 kv with a capacitance of 240 μf and a ringing frequency into the gun of 10 kHz. A complete system capable of storing up to 240 kj has recently been acquired as "government furnished equipment" from Marshall Space Flight Center, Huntsville. This facility, however, has not yet been installed at Morehouse.

3.) A vacuum system capable of pumping the vacuum chamber in which the gun is operated (the chamber made of Corning sanitary drain pipe sections) into the 1μHg to 1 Torr range from 1 atm within only a few minutes

4.) A "master sequencer" and trigger system using an Abtronics Model 100 four channel delay generator and a Tobe Deutschmann Model TG-2 high voltage pulse generator (as a capacitor bank trigger)

5.) Electrical monitors (voltage dividers and current loop probes) coupled to a 10 MHz storage oscilloscope, Tektronix Model 564B

The following plasma diagnostics have been assembled and tested (although some of them have as yet not been satisfactorily calibrated for quantitative measurements):

1.) A "time-of-flight" velocity monitor using Tropel 330 light detectors, fiber light guides and a 100 MHz storage oscilloscope

2.) A Mach-Zehnder interferometer as a plasma density monitor composed of a Ealing Corp. steel optical table with isolation pedestals, four prism tables, two beam splitting cubes, two penta prisms, two precision adjustable slits (used as knife-edges), two 50 cm achromatic doublets and a helium-neon alignment laser (Metrologic). The interferometer is set up so that it can be used in the Schlieren mode (as a density gradient monitor) with minor rearrangement and readjustment. A Xenon Corp. flash lamp system is used as a light source.

3.) Magnetic field probes for the measurement of induced magnetic fields

Sufficient measurements with the complete system have been taken to show that it is capable of generating a plasma flow-magnetic field regime that is of current interest to basic MGD research: high magnetic Reynolds number, finite interaction parameter and large or small Hall parameter. The following papers have been presented in the three year period on the experimental effort:

Atlanta University Center Chemistry Research Seminar
Atlanta, Georgia
September 21, 1973: "Research in Progress"

Department of Physics Seminar
Talladega College
Talladega, Alabama
January 23, 1974: "Research in Progress"

National Institute of Science
Norfolk State College Meeting
Norfolk, Virginia
April 11, 1975: "A Research Program in Magnetogasdynamics Utilizing Hypervelocity Coaxial Plasma Generators"

Report on Theoretical Effort:

Significant progress has been made in the direction of understanding the important processes in the interaction of hypervelocity MGD flow with transverse applied fields. A thorough review of the relevant theoretical literature has been completed involving a review of more than 100 papers. A careful analysis of the parameter regime optimal for the operation of pulsed MGD direct energy convertors (operating ultimately off of CTR plasmas) has allowed a choice of model defining equations for the interaction (a non-linear system) which includes all of the important processes (Fig. 2). The following mechanisms have been found to be important in controlling the ordered (efficient) conversion of flow kinetic energy into induced magnetic field energy:

a.) Rayleigh-Taylor (interface) instability
b.) Magnetoacoustic instability
c.) Purely growing MHD instabilities (Mawardi, 1962)
d.) Induced vorticity (Witalis, 1968, 1971)

The appropriate configuration of direct conversion (using flows from pulsed CTR reactors or from explosive chemical reactors) has been determined to be diverging, flux compressing cylindrical flow. In this flow regime/configuration a preliminary analysis has been completed of the growth rates for instability mechanisms a.) through d.). While definitive conclusions must await the results of the detailed multi-time scale theoretical analysis currently underway, it is now clear that the optimal operating regime for such convertors is defined as follows:

1.) Supersonic (based on gasdynamic Mach number)
2.) Trans-Alfvenic
3.) Order 1 interaction parameter
4.) High magnetic Reynolds number
5.) Hall parameter
    a.) Low for large system size
    b.) High for small system size

Importantly, it is now clear that such regimes are accessible experimentally by use of the generator facility now operational with minor modification (see for example, Patrick and Brogan, 1958). The axial flow will be directed into a "radial nozzel" (Fig. 3) and thereby converted into diverging, radial flow. A Helmholtz pair will be used to create a transverse (axial) field inducing an azimuthal current via VxB. A bibliography of immediately related literature is provided by Fig. 4.

A paper summarizing the theoretical results to date was presented at a recent meeting of the American Physical Society:

> "Analysis of Hypervelocity Magnetogasdynamic Flow at High Magnetic Reynolds Number", Bulletin of the APS 21, No. 3, 394 (1976)

CONCLUSIONS

Summary of Results of Research Effort:

A research program in magnetogasdynamics that has spanned a period of three years has been completed. In man-years of professional scientific investment this is equivalent to slightly less than one man-year (2x9 mo. @ $\frac{1}{4}$ time + 2x2 mo. @ full-time summer + $\frac{1}{4}$ time for 1 year "no cost"). The high level of activity during this relatively short research time has yielded significant results. A complete hypervelocity coaxial plasma generator facility has been assembled and tested. With the acquisition of a major capacitor bank facility recently from MSFC-NASA, and with the other NASA sponsored research in the Department of Physics, Morehouse College has now legitimate claim to being a regional center for plasma research. In addition, sufficient theoretical machinary has been assembled to significantly extend the current theoretical understanding of a MGD regime of current importance.

Significance of Research:

The parameter regime investigated in this research effort is one very poorly treated in the published literature on magnetogasdynamics. The results then represent a significant contribution to understanding MGD processes in that regime. Perhaps of equal importance in giving significance to this research, the results are potentially applicable to the design of direct energy convertors compatible to flows anticipated from some pulsed thermonuclear fusion reactors currently contemplated.

Projection of Future Research Directions:

The installation of the recently acquired capacitor bank facility will be completed. The plasma generator system will be redesigned so as to produce flows which are radially diverging. The old capacitor bank will be used to power pulsed magnetic field coils of the required cross-sectional area for the testing of designed convertor configurations. A complete parameterization of the power level and efficiency of such convertors will be obtained through an intensive program of measurements.

A detailed theoretical analysis will be completed investigating possible flow destabilizing mechanisms and means by which they might be suppressed. Analysis of the conversion process of flow directed kinetic energy into output electrical energy in the convertor will be carried through to the point of providing power level and efficiency predictions for the experimental effort.

Electrical System Plan

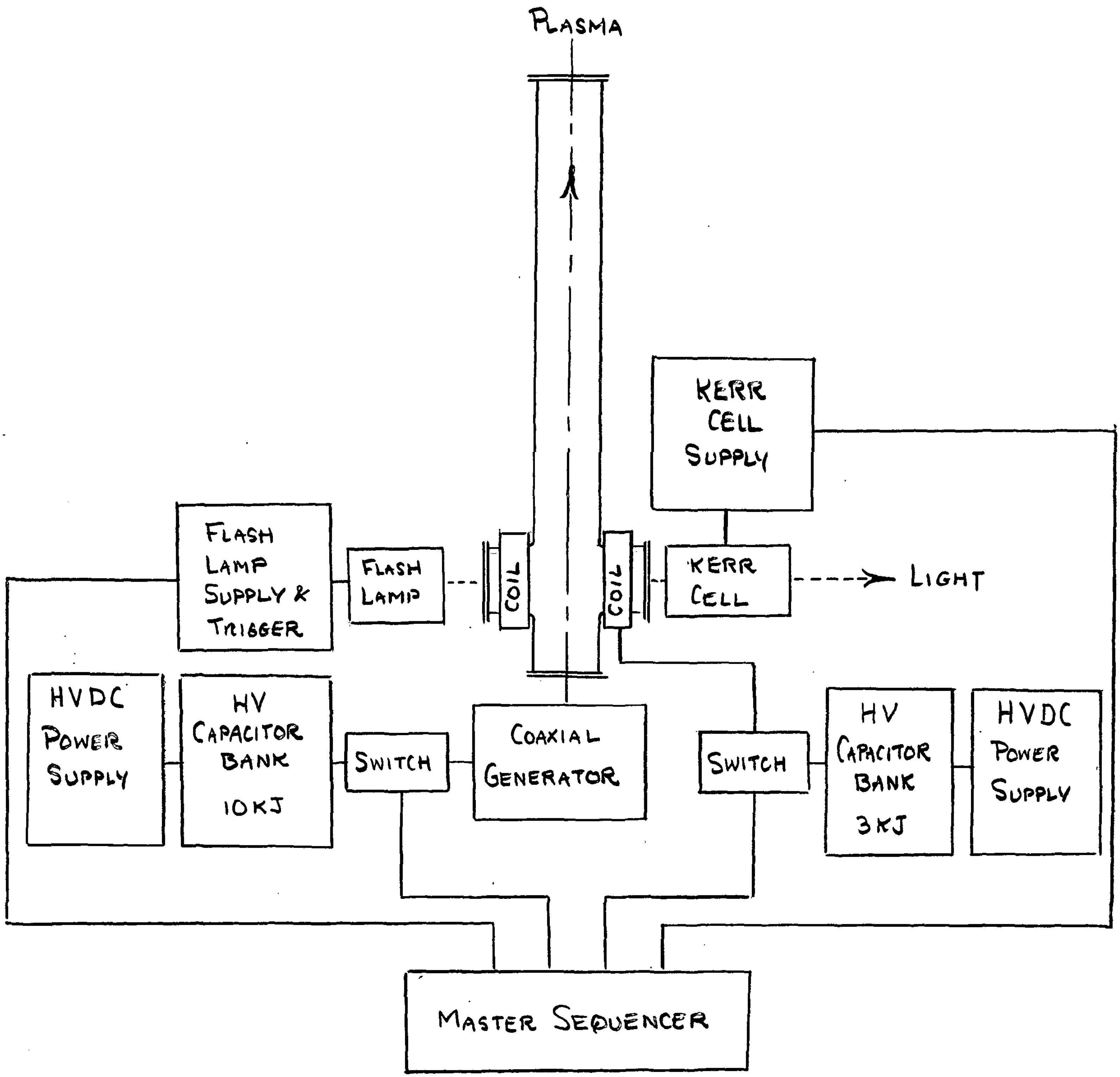


Fig. 1

High Hall Parameter: β_H

$$\frac{\partial}{\partial t}\rho + \nabla\cdot(\rho\bar{v}) = 0$$

$$\rho\frac{D}{Dt}\bar{v} = -\nabla p + \bar{J}\times\bar{B}$$

$$p\rho^{-5/3} = \text{CONSTANT}$$

$$\nabla\times\bar{B} = \mu_0\bar{J}$$

$$\nabla\times\bar{E} = -\frac{\partial}{\partial t}\bar{B}$$

$$\bar{E} + \bar{v}\times\bar{B} = \beta_H\,\frac{\bar{J}\times\bar{B}}{\sigma B}$$

Low Hall Parameter:

$$\frac{\partial}{\partial t}\rho + \nabla\cdot(\rho\bar{v}) = 0$$

$$\rho\frac{D}{Dt}\bar{v} = -\nabla p + \bar{J}\times\bar{B}$$

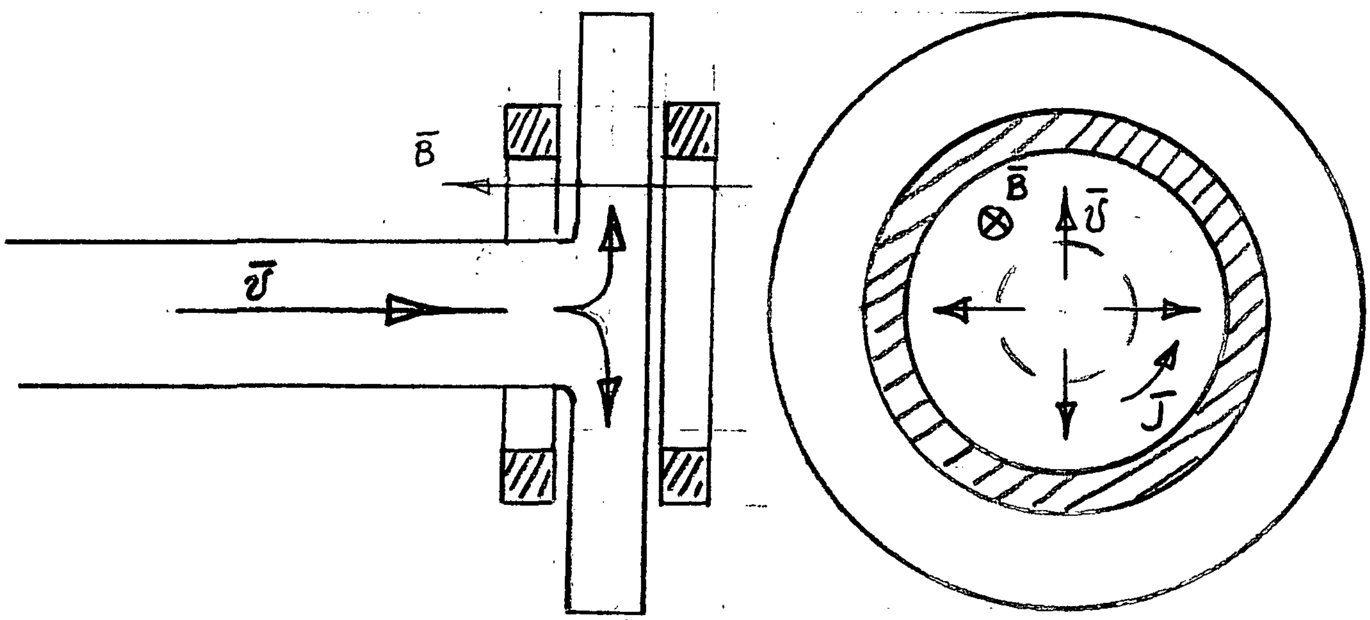
$$p\rho^{-5/3} = \text{CONSTANT}$$

$$\nabla\times\bar{B} = \mu_0\bar{J}$$

$$\nabla\times\bar{E} = -\frac{\partial}{\partial t}\bar{B}$$

$$\bar{E} + \bar{v}\times\bar{B} = \bar{0}$$

Fig. 2



Side View

End View

Fig. 3

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Fig. 4