Electrofluid Dynamic Generator

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Theme

THIS paper describes an experimental study that was performed to determine the limiting factors on current production in cylindrical channel electrofluid dynamic (EFD) generators. The development of an efficient, high power density, single stage EFD generator depends on the ability to produce high charge density current beams in the conversion section. In this study three factors are discussed and examined experimentally: 1) the use of singly charged aerosol particles instead of ions as carriers of charge, 2) the proper use of shielding electrodes to decouple and reduce the effect of space charge-induced electric fields on current density, and 3) the application of voltage to the shield electrodes to cancel space charge-induced fields at the entrance of the conversion section. The results indicate the importance of space-charge shielding for improving the level of current production and the improvement in total performance when low mobility particles are used as carriers of charge. The experiments also demonstrated that the corona method of charging is an efficient and effective means of producing unipolar charged particles.

The research effort at the Aerospace Research Laboratories (ARL), Wright-Patterson Air Force Base, Ohio, is directed toward the development of a compact, efficient EFD generator in the range of one to one hundred kilowatts for use in remote locations as an alternative to rotating machinery.

Content

EFD power generation is the direct conversion of the kinetic energy of a gas flow into electrical energy by the interaction of unipolar charged particles and an applied electric field. Because of the inherent characteristics of electric fields, the EFD generator is necessarily a high voltage, low current device which is analogous to the Van de Graaff generator. In the high-pressure, injector-powered EFD generator developed at ARL, high pressure air is expanded through a supersonic primary nozzle at the entrance to the channel. Entrained secondary air (working fluid or carrier gas) transports, by viscous interaction, unipolar charged particles from the corona needle at ground potential against the axially applied electric field and deposits the charge at high potential on the collector electrode.

The current, or charge density, in an EFD channel may be severely limited by the effects of 1) high mobility charge carriers and 2) electric field concentrations at the entrance to the channel. When the charges have high mobility, they tend to pile up around the corona electrode canceling the charging field and, as a result, excessively high charging potentials are necessary for a given level of current. And a large proportion of charges carried into the channel drift to the walls of the channel where they build up until arcing occurs. Without a means of adequate shielding, the space-charge in the channel creates a region of high electric field concentration at the entrance to the channel. The combined effect of high charging potentials and space charge fields causes spark discharge at low levels of current at a fraction of the current predicted from theory. Previous studies showed that the presence of a grounded electrode near the entrance of the channel would partially shield the entrance to the channel from the applied and space charge fields downstream. This shielding, however, was not adequate to prevent excessively high fields within several flow diameters of the needle, and current was limited by the dielectric strength of the gas. Numerical solutions on the fields in a cylindrical channel generator indicated that the electric field concentrations could be reduced by increasing the size of the shield electrode and by placing the shield closer to the charge cloud at the entrance to the channel. By using low mobility aerosol particles and by placing several small vane electrodes in the flow near the needle electrode to create the image of a large shielding electrode, the space charge field is partially relieved from the needle and is concentrated on the larger surface of the shielding electrode. A second method of shielding was developed for small channels where the use of small vanes in the flow is impractical. A positive potential is placed on the shield electrode to cause space charge field cancelation downstream of the charging electrodes.

Experimentally, the use of water aerosols, created by condensation in the expanding primary flow, as carriers of charge was compared with unipolar ions by changing the relative humidity of the primary flow as shown in Fig. 1. Under dry flow conditions a high percentage of the needle current is lost to electrodes in the channel, the amount depending largely on the pressure in the channel; ion mobility is pressure dependent. When water is added to the flow, nearly all the needle current is transported to the collector indicating that the charged particles have "zero drift". Figure 2a shows the channel configuration that was used to determine the effect of shielding on the level of current transported from the region of charge production. The conversion section was shortened and the collector was run short-circuited to reduce the influence of potential buildup down-

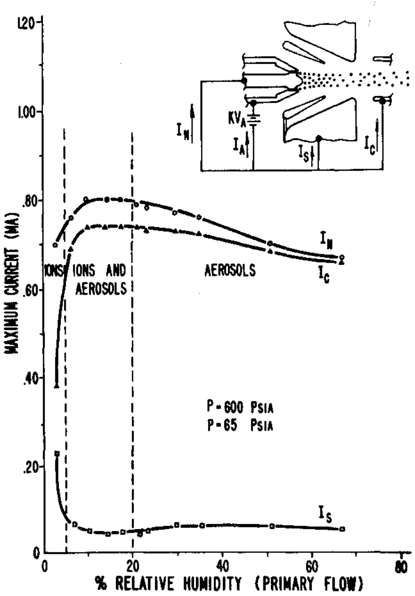

Fig. 1 Effect of flow humidity on current production.

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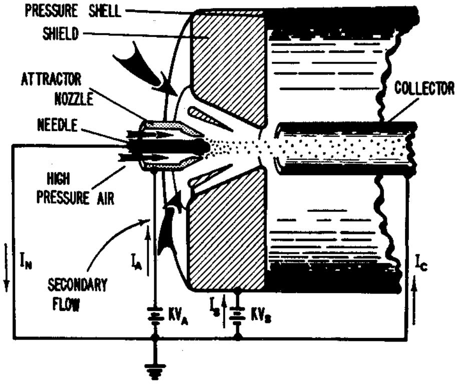

Fig. 2a Schematic of the cylindrical channel with shield geometry No. 1.

stream of the main shield electrode. The shield was segmented to allow closer placement of the shield to the charge cloud without disturbing the flow. Figure 2b shows the second shield electrode reported in this study. The segmented vanes were placed adjacent to the charge cloud and near the attractor to reduce the electric field due to space charge on the needle and attractor. Figure 3 compares the current produced by each configuration for a given charging potential. Placement of shielding electrodes adjacent to the charge cloud within one primary flow diameter allowed an increase in current production (60% for the cases shown).

In smaller channels, it may be impractical to use segmented electrodes extending into the secondary flow. However, by controlling the voltage on the shield electrodes, the centerline voltage in the channel can be reduced; the space-charge-induced fields are cancelled by an opposing electric field between the positive shield and the grounded needle. Figure 4 illustrates how the application of voltage on the shield electrodes can improve current production. At each attractor voltage setting, the shield potential was adjusted to give maximum current. Lower shield voltages resulted in lower current values; higher voltages caused excessive current loss to the shield electrodes.

The experiments indicated that, to a great extent, one may substitute high positive potential on the shield electrodes surrounding the channel for a grounded electrode structure inside the flow near the entrance to the channel. Both methods alleviate the high field stress that occurs in the pesence of space charge. By scaling the pressure, it was found that shielding was effective at all channel pressures up to 10 atm, although to a lesser extent at higher pressures. At all pressure levels, current

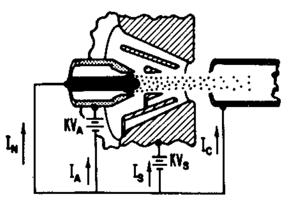

Fig. 2b Schematic of the segmented shield electrode (shield geometry No. 2).

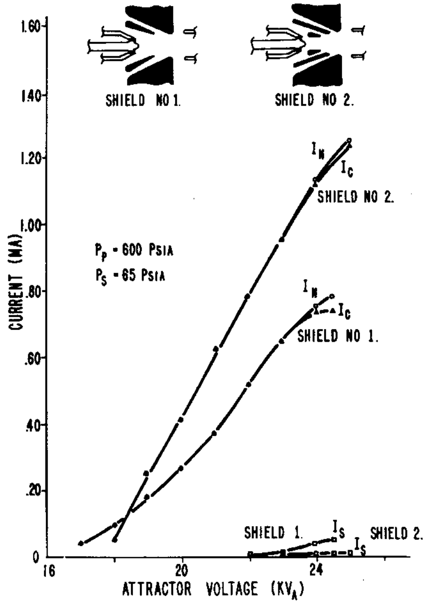

Fig. 3 Comparison of two shield electrode configurations.

production was nearly double the best values previously obtained. At 10 atm, 2.04 ma were produced and 2.02 ma were collected. The results achieved were nearly the maximum to be expected in channels of this size because of limitations due to inhomogeneous field effects. Further improvements may be realized by reducing the channel size as indicated by the Law of Similitudes of electric fields.

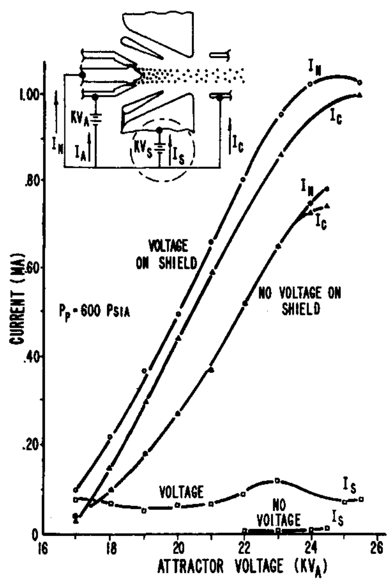

Fig.4 Effect of shield potential on current production.