Paschen Considerations for High Altitude Airships

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Recently, there have been several proposals submitted to funding agencies for long-lived high altitude (about 70,000 feet) airships for communications, surveillance, etc. In order for these airships to remain at altitude, high power, high efficiency, lightweight solar arrays must be used, and high efficiency power management and distribution systems must be employed. The needs for high power and high efficiency imply high voltage systems. However, the air pressure at these extreme altitudes is such that electrical power systems will be near the Paschen discharge minimum over a wide range of electrode separations. In this paper, preliminary calculations are made for acceptable high voltage design practices under ambient, hydrogen and helium gas atmospheres.

Introduction

Breakdown of the neutral gas under high electric fields (Paschen discharge) is a major concern for the High Altitude Airship (HAA) concept, especially as high efficiency requires the use of high voltage PMAD systems. The difficulty is that concepts for high altitude airships that have been proposed are for altitudes near 70,000 feet (about 21000 meters), where the pressure-distance product is very near the Paschen minimum for many gases for a wide range of electrode separations. In addition, the great size and low weight of the HAA implies that power transmission must be at high voltages, to minimize cable mass. Typical values discussed for HAA power management and distribution (PMAD) systems are about 300 V or above. Thus, high voltage electronics and PMAD systems are particularly susceptible to Paschen discharge at these altitudes.

Assumptions

In the following analysis, we will use the Paschen discharge curves for parallel plate electrodes at a temperature of 23 C and a frequency of 400 Hz, which were provided to one of the authors by William Dunbar (2000) before his death, and are reproduced here as Figure 1. The edited original discharge curves were submitted to MSFC as part of a possible MSFC and NASA standard in Dunbar et al (2000). Dunbar was widely considered to be the world's foremost authority on Paschen discharge. Even though these curves are RMS voltages for a 400 Hz power system, switching transients in a DC system will lead to approximately these values in a realistic HAA PMAD system, we believe. Also, although the temperatures HAAs will experience at 70,000 feet altitude are likely to be much lower than 23 C, the Paschen curves are not highly dependent on temperature.

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Helium

The atmospheric pressure at an altitude of 70,000 feet is about 40 millibars, or about 30 torr (U.S. Standard Atmosphere, 1976). According to Figure 1, helium (the assumed HAA lifting gas) has a Paschen minimum (for parallel plates) at 130 V and 5 torr-cm. At 30 torr, this corresponds to a separation of 1.7 mm. Thus, any voltage difference between electrical components of greater than 130 V will break down helium over a 1.7 mm distance. This is quite similar to distances between traces and wires on printed circuit boards and electronic components.

If the power system uses a voltage of 300 V, helium is seen to breakdown at all pressure-distance products from 1.0 torr-cm to 70 torr-cm. This implies breakdown distances from less than 1 mm all the way to 23 mm (about 1 inch), covering a wide range of electronic component separations. Thus, it will be important for all high voltage PMAD components that are likely to be in a helium atmosphere, or near spots of possible helium leakage, to be potted or pressurized to prevent Paschen discharge. It is also important for the potting compound used to be able to maintain a conformal seal, for high voltage failures on flight experiments such as SAMPIE (Ferguson and Hillard, 1997) have been due to gas entrained by potting compound that pulled loose from the components' surfaces.

Hydrogen

It is also possible that the HAA lifting gas may be hydrogen. It should be noted that the ambient air pressure at 70,000 feet is insufficient for the air to support rapid hydrogen combustion, so the danger from fire breaking out after a discharge is minimal. However, important electronic components could still be damaged by large Paschen discharges, so arcing should still be prevented. From Figure 1, we can see that for hydrogen (H_2), the Paschen minimum is at 210 V and 1.4 torr-cm. At the ambient pressure at 70,000 ft altitude, and an assumed voltage of 300 V, breakdown is likely to occur for pressure-distance products from 0.68 to 4.5 torr-cm, corresponding to electrode separations of from 0.22 mm to 1.5 mm.

If the hydrogen is at higher pressures (if the components are in a pressurized envelope, for instance) the separations under which breakdown will occur will be accordingly smaller. As these separations are similar to distances between traces on electronic circuit boards, it is recommended that high voltage components in a hydrogen environment for HAAs be encapsulated. The same warnings about encapsulation apply for a hydrogen atmosphere as for one of helium.

Air

At 70,000 feet, the composition of the atmosphere is essentially the same as at sea level (U.S. Standard Atmosphere, 1976). The Paschen breakdown curve for air is somewhat different than that for helium. According to Figure 1, it has a minimum of about 240 V at 0.6 torr-cm. This corresponds to a component separation of 0.2 mm. It is unlikely that components 240 V different in potential will be intentionally separated by only 0.2 mm of air. However, the breakdown curve for air is at 300 V or less from 0.15 torr-cm all the way up to 2 torr-cm, corresponding to component separations of 0.05 mm all the way to 0.7 mm. It will be important for high voltage DC components that are likely to be in unpressurized air for separations to be kept above the 0.7 mm distance. High voltage DC PMAD components that are not likely to be in a helium environment need not be potted or pressurized if they do not have component separations of less than about 1 mm.

AC Systems

The AC Paschen curve is dependent on frequency as well as voltage (Dunbar, 1988), and typically Paschen minimum voltages are less than for DC systems, so high voltage AC HAA components should be protected by potting or pressurization. In the event that neither of these techniques is available or practical, maintaining an atmosphere of sulfur hexafluoride around the components will prevent breakdown.

The Importance of Testing

It is important that all high voltage components be tested against Paschen discharge in vacuum chambers at a range of pressures and gas compositions similar to those found at the airship altitudes. They should be tested at voltage, and if they are AC components, at their design AC frequency. The Glenn Research Center can provide analysis and testing under simulated high altitude conditions. The testing will be performed in the new N-PI facility, a national facility for plasma interactions, whose development was supported by the national Space Environmental Effects program, managed by MSFC. Analysis may be performed by Drs. Dale Ferguson and G. Barry Hillard, the SAMPIE Principal Investigator and Project Scientist, respectively, authors of the present paper.

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Figure 1. Parallel Plate Paschen Discharge Curves for Gases at a frequency of 400 Hz