INSTRUMENTATION OF TRIBOELECTRIC EFFECTS ON PROJECTILES

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ABSTRACT

Triboelectric phenomena occurs when static electricity accumulates on the surfaces of flying projectiles due to friction of air contaminants on the aerodynamic projectile surfaces. The sequence of events that create this phenomena indicate that as the projectile flies through the denser atmosphere, electric charges are transferred from the surface of the flying projectiles to the dust as a result of the collision with the atmospheric air stream.

In the development of highly static sensitive electronic circuitry used in timing and fuzing, the need to know how the charge builds up has warranted the investigation of the triboelectric affects during flight. This paper will discuss the method of instrumentation used, the pre-flight test results obtained during dynamic wind tunnel tests, and the instrumentation system used to perform the triboelectric measurements.

BACKGROUND OF TRIBOELECTRIC PHENOMENA

In 1988 projectile fuzes experienced in-flight prematures called “Down Range Prematures” (DRPs) which were attributed to a phenomena described as triboelectric phenomena. These DRPs occurred on projectiles that were armed and fuzed with an electronic timer. The electronic components used in these circuits were extremely sensitive to static discharge. The occurrence of flight anomalies initiated a literature search on the triboelectric phenomena. The results of this search indicated that static voltages were building on the projectile surfaces in contact with the air molecules.

Initially it was thought that the static build up was a result of charge transfer from the air molecules to the projectile surfaces. A metal shield “Faraday Cage” was used to encapsulate the electronics. This device prevented the static charges from upsetting the fuze electronics by allowing the electrical charges to concentrate on the outer surface of the shield while the volume inside the metal shield remained electrostatically neutral.

The Faraday Cage resolved most of the “Down Range Prematures” anomalies. However, many unknowns still existed in the minds of the fuze systems engineers. The questions were in the area of the voltage levels that caused the premature detonations. Information was also needed on the arrangement of the charge distributions on the fuze surfaces. The telemetry approach was initiated to provide a versatile information link to study the triboelectric phenomena.

Phase 1 of the triboelectric study generated data which indicated that electrons were being transferred from the projectile surfaces to the air molecules. The data collected at the wind tunnel tests showed that the polarity of the projectile surfaces was positive with respect to the ground plane. This information conflicted with the literature study theory and would be investigated in the next phase.

Parallel with the telemetry system approach, a computer program was under develoment at Arnold Engineering Development Center (AEDC). This computer model was designed to simulate the actual flight conditions and provide the surface static build up for each fuze as a result of the simulated environment. The telemetry data would then be used to validate the results of the computer simulation.

INTRODUCTION

Telemetry instrumentation was needed to measure the high voltages which accumulated on the surfaces of flying projectiles. The high voltages were represented by low level signals linearly proportional to the input. The telemetry instrumentation was designed to perform nonintrusive in-flight measurements and to meet given requirements. The instrumentation was required to measure voltages from 25 volts to 40,000 volts. The input impedance was designed to be very high, typically 1000 megaohms. The input capacitance was designed to be very low, typically 10 pico farads. These two parameters were designed to maintain sufficiently low leakage not to affect the output signal from the instrumentation. The projectile surfaces were electrically connected to the instrumentation using very low dialectric loss wire. The wire maintained its insulating properties up to 40,000 volts. In all testing performed in the laboratory at ARDEC and at the wind tunnel at NASA Lewis Research Center, Ohio, the voltages collected on the projectiles were below the insulating properties of the wire insulation.

Telemetry data was collected for phase 1, at the wind tunnels at NASA. Four fuze models were instrumented and triboelectric data was collected for every simulated environmental condition. The instrumented fuzes were: Fuze A, Fuze B, Fuze C and Fuze D. The data was hard wired from the projectile to the data acquisition system located in the tunnel control room.

INSTRUMENTATION DESIGN

The triboelectric measurements instrumentation consisted of a very high input impedance attenuator and an operational amplifier. The attenuator reduced the signal level from thousands of volts to a low voltage signal compatible with CMOS and TTL circuitry. The voltage output (Vout) was designed to be +/- 10 volts at +/- 30,000 volts input (Vin), respectively. The attenuator reduced the signal level from 30,000 volts to +/- 5 volts. The signal was then fed to the operational amplifier, which introduces a multiplication factor of 2.0. The overall transfer function between the output (Vout) and the input (Vin) is a linear function with a constant factor of 3000. Figure 1 describes the individual contribution of each block diagram to the overall transfer function. To obtain the input voltage sensed at the projectile surfaces, the output signal from the instrumentation was multiplied by a factor of 3000. Figure 2 shows the fabricated hardware used in phase 1 wind tunnel testing.

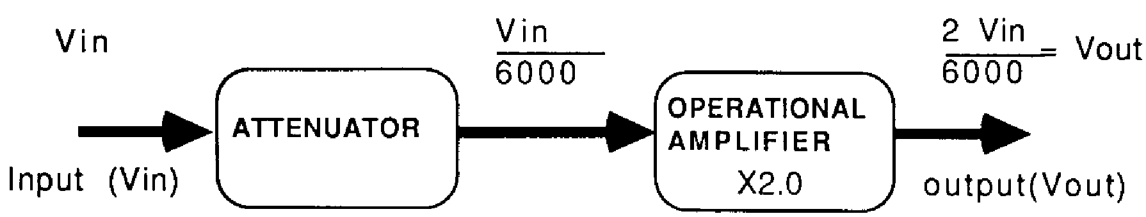

FIGURE 1

The voltage buildup on the projectiles was related to the capacitance between the two surfaces monitored, (Q = CV). The surface charge density, σ, was then obtained by dividing the surface charge, Q, by the area, A, of the surfaces.

$$\sigma = \frac{Q}{A}$$

Q ----- Charge in coulombs

A ----- Area of surface in m^2

σ ----- Surface charge density coulomb / m

The voltage between any two surfaces of the projectiles was obtained by multiplying the surface charge density by the area and dividing by the capacitance constant between the two surfaces.

$$V = \frac{\sigma A}{C}$$

V ------ Voltage in volts

C ------ Capacitance in Farads

In phase 1 of this study, the voltages were measured relative to a ground plane. The ground plane which consisted of a copper board that replaced the existing fuze electronics was located inside the fuzes. The ground plane was connected to the electrical ground of the instrumentation and the data inputs were connected to the surfaces to be monitored. The attenuator was designed to sense the electrostatic field across two surfaces, and output a voltage attenuated by a constant factor of 6000. As discussed in the introduction, the leakage of static charges was minimized by the high impedance and the low capacitance characteristics of the attenuator and the low dialectric loss wire.

In the initial stages of the instrumentation development, three types of insulated wire were tested. The first type was rated at 200 volts dialectric breakdown. The second type was rated at 10,000 volts and the third type was rated at 40,000 volts. During tests performed in the laboratory facilities at ARDEC, the first two types of wire were eliminated, because of dialectric breakdown. These breakdowns were most severe when the static voltge accumulated and discharged at high rates of change. The third type of wire, 40,000 volt insulation value, has been successfully used throughout the laboratory tests at ARDEC and phase 1 tests at NASA.

During phase 1 of the triboelectric measurements program, one of the areas of concern was to perfect the understanding of the distribution of static charges on the surfaces. As described previously, it was decided to electrically ground the instrumentation ground plane to the fuze ground plane. This approach showed that static voltages built up on all external surfaces relative to the fuze ground plane. More data would be required to learn how the electrostatic surfaces behave during actual flight. It must also be studied how the sudden discharges of electrostatic energy upset the fuze electronics, which resulted in the faulty operation during the DRPs.

The capability of making triboelectric measurements via telemetry was developed to provide an opportunity for the fuze systems engineers to study the phenomenon. This study would be expanded in phase 2, to include different possibilities of charge distribution on the surfaces and to study how the dialectric breakdown of the fuze surrounding materials upset the firing circuits in the fuzes.

TELEMETRY DATA ACQUISITION SYSTEM

The triboelectric data collected in the wind tunnel required a more sophisticated data acquisition system than the one used in phase 1. In phase 2, a computer system and a new software package was developed to monitor, digitize and permanently store the collected data. The software also includes a mathematical package to perform calculations. The software was also designed with a high degree of versatility to accept a changing set of triboelectric data parameters. The data acquisition system acquired for this program was designed to accommodate data format changes that are expected as the program continues.

WIND TUNNEL TESTING

The wind tunnel was an excellent method of simulating the actual flight conditions in a controlled environment. Humidity, dry air and dust were introduced in the air stream. Three mach numbers were achieved that simulated the projectile velocity in actual flight. Other factors involved in the simulation were the Stagnation Pressure (the ambient pressure), the Stagnation Temperature (the temperature of the moving air around the body), and the Reynold’s Number that is a measure of the viscous friction effects of the environment in which the projectile flies. The Reynold’s Number and the temperature were the key parameters in the first set of wind tunnel tests. Forty-six test runs were conducted in phase 1. Each of the fuze models was subject to a test run with water, dust, dry air and no dust. The flow rate was also varied to obtain standard pressure, high pressure, standard temperature and high temperature. The temperature was varied by heating the air stream. Due to problems experienced with the heaters during the first few runs, all of the needed data, at high temperature, could not be acquired. This malfunction should be resolved in time for phase 2

Economically, the wind tunnel was also an optimum method of simulating the flight conditions. This method allowed the simulation of possibilities and combinations of atmospheric conditions. Some of these conditions have already been studied and no direct connection was found to the triboelectric phenomena. The list of conditions to be tested in phase 2 would more than likely approach half the number of conditions tested in phase 1.

PHASE 1 TRIBOELECTRIC TEST DATA

The data collected in phase 1 was reduced and organized in report format. The data indicated a definite presence of static build up on the surfaces of the projectiles. The fuze models tested in phase 1 were Fuze A, Fuze B, Fuze C, and Fuze D. Fuze D configuration was so large (approximately 24 square inches of area) that it restricted the flow of air in the wind tunnel. Due to this restriction of air flow, the post test data did not show significant build up of charge. A substantial amount of data was collected with the remaining three fuze models. However, it is not the objective of this paper to present a detailed discussion of the results. For additional information regarding a detailed comparison of the data results, the reader should request “The Development of a Test Procedure to Certify Projectile Fuzes to Triboelectric Effects”. This document must be requested through SMCAR-FSN-M, Picatinny Arsenal, N.J. 07806-5000.

Plot #1 contains data collected with Fuze A. The static build up at the brass nose piece indicates a voltage build up of 2250.0 volts. The other two surfaces did not indicate substantial voltage build up. This run was performed with the following conditions:

1. Reynolds Number -- 2,072,252 1/ft
2. Flow Rate -- 23.20 lbs/sec
3. Temperature -- -167 Deg F
4. Dust mixed with the air molecules
5. Mach Number -- 1.968

The data in plot #2 shows voltage build up at the nose piece and at the shell of Fuze B. The voltage measured at the nose piece was approximately 2200.0 volts and the voltage measured at the shell was approximately 4700.0 volts The conditions for this run were:

1. Reynolds Number -- 2,645,491 1/ft
2. Flow Rate -- 38.88 lbs/sec
3. Temperature -- -168 Deg F
4. Dust mixed with air molecules
5. Mach Number -- 1.968

Plot #3 contains data collected with Fuze C. Two surfaces were monitored in this model. The first surface was a plexiglass dome, located in the front of the projectile. The body of the projectile was also monitored. The voltage at the dome first jumped to an approximate value of 3300.0 volts and then jumped to a peak value of 4500.0 volts. This run was performed with the following conditions:

1. Reynolds Number -- 2,645,491 1/ft
2. Flow Rate -- 24.64 lbs/sec
3. Temperature -- -225 Deg/F
4. Dust mixed with air molecules
5. Mach Number -- 2.473

RF TELEMETER FOR TRIBOELECTRIC MEASUREMENTS

The RF telemeter for the triboelectric measurements consists of four main units:

1. Battery power supply
2. The power control circuit
3. Signal conditioning
4. Telemetry transmitter and multiplex (FIG. 2)

The four units are integrated in a rigid self-contained package with its own power supply. The RF communication link consists of a phase modulated transmitter designed and qualified to IRIG standards.

The battery power supply unit was designed to provide dual polarity voltages necessary for the triboelectric instrumentation signal conditioning. It provided +/- 15 volts to the signal conditioning unit and +28 volts to the RF circuitry. The DC power was supplied from a stack of rechargeable batteries, assembled to survive the set-back forces during gun environment.

The power control circuit was a unique combination of optically isolated input transistor logic with very low power CMOS technology. The ciruitry was integrated in the telemeter to operate it from a remote location. This capability substantially improved the DC power management on board the projectile. It allowed the instrumentation to be turned off while charging the batteries. As the projectile was ready to be fired, the instrumentation was turned on and the telemeter was operating at full battery power.

The signal conditioning consists of the same circuitry designed for phase 1. This unit contains an attenuator and an operational amplifier which was designed in phase 1 to be integrated with the RF circuit at a later date.

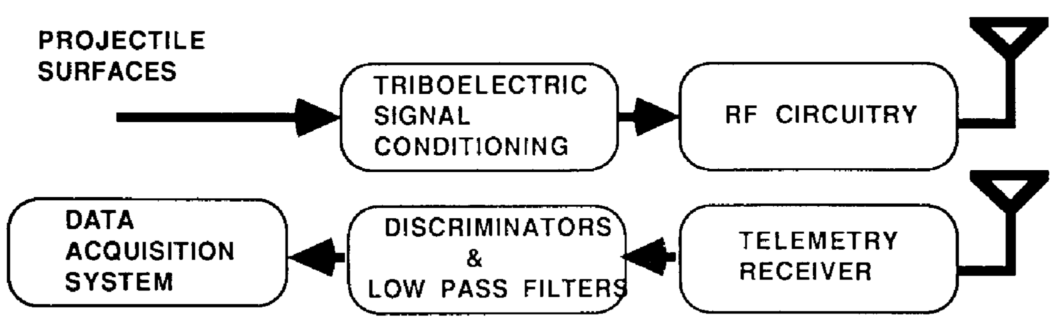

FIG.2 TRIBOELECTRIC MEASUREMENTS VIA TELEMETRY

CONCLUSIONS

Phase 1 of the triboelectric measurements program has been completed with the wind tunnel tests at NASA Lewis Research in Cleveland, Ohio. In this phase, forty six different tests were conducted to simulate most of the environmental conditions encountered at the proving grounds. These atmospheric conditions include humidity, heat, dry air and dust contamination. At the completion of these tests, approximately half of the original conditions were eliminated because they do not seem to contribute to the triboelectric build up problem. Phase 2 will investigate and study the remaining conditions. The objective for this phase is to down select a set of atmospheric conditions which contribute heavily to the static build up.

Parallel with the telemetry program, a computer model for the triboelectric program is under development. The computer model is being developed to provide the systems engineers with the capability to simulate the flight conditions and study the triboelectric build up phenomenon on the fuzes at the system design level. The telemetry data plays an enormous role in providing the electrical characteristics for the fuze materials and the atmosphere surrounding the fuze. These characteristics are used as input conditions to the computer model.

REFERENCES

1. Weston Francis Sears, Electricity and Magnetism, Addison-Wesley Pub. Co. Reading, Mass., Chap 8, pp16, 1951.

2. Herman S. Richard, "The Development of a Test Procedure to Certify Projectile Fuzes to Triboelectric Effects". SMCAR-FSN-M, Picatinny Arsenal, NJ 07806-5000.