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PULSED ELECTRON BEAM PRECHARGER

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TABLE OF CONTENTS

	<u>Page</u>
A. INTRODUCTION AND CURRENT STATUS OF THE PROJECT.....	1
B. CONTRACT PROGRESS DURING QUARTER TWO.....	7
1. Task A - Precharger Modification.....	7
a. BG-2c Vacuum Station.....	7
b. MINACC Electron Beam Accelerator.....	14
2. Task B - Installation of Charge vs. Radius Apparatus.....	18
3. Task C - Modification of Pulsed Power Supply.....	21
4. Tasks D-H - Preparations for Experiments.....	26
a. High Concentration Aerosol Generation.....	26
b. Aerosol Dilution and Measurement System.....	28
C. PUBLICATIONS, PRESENTATIONS, AND PARTICIPATIONS.....	31
1. "Use of an Electron Beam for Particle Charging..."	31
2. "Flue Gas Cleanup Technology Utilizing Energetic Electrons".....	39
D. PERSONNEL.....	44

LIST OF FIGURES AND TABLES

- Figure 1 The Two-Stage Laboratory-Scale Electron Beam Precipitator (EBP) Wind Tunnel.
- Figure 2 Location of the Electron Beam Precipitator (EBP) and the Pulse Energized Electron Reactor (PEER) within the 3 MeV Accelerator Vault.
- Figure 3 Top View of the MK. III-B Electron Beam Precharging Module showing the Ionization and Charging Zones.
- Figure 4 Schematic Diagram of the 100 keV Electron Beam Accelerator, or the MINACC.
- Figure 5 MINACC Electron Beam Cathode Filament Current vs. AC Filament Voltage for the new and old Electron Beam Emitter Filaments.
- Figure 6 MINACC Electron Beam Current vs. AC Filament Current for the Cathode Screen and the Window Assembly.
- Figure 7 MINACC Electron Beam Current vs. AC Filament Current for the Cathode Screen and the Window Assembly.
- Figure 8 Top View of the BG-2c Vacuum Station, the 100 keV Electron Beam Accelerator (MINACC), and the E-Beam Precharging Module.
- Figure 9 The FSU Particle Charge vs. Radius (Q/A) Monitoring Apparatus, showing the Laser Beam, the Video Viewing and Monitoring System, and the Particle Charge Measurement Cell.

- Figure 10 Schematic Diagram of the High Voltage Pulse Generating Circuit to be used for E-Beam Pulsed Particle Precharging.
- Figure 11 Circuit Layout of the Micromac (μ Mac) Analog-to-Digital Converter showing the connections to the Precipitator Plate Electrodes and the Host Computer.
- Figure 12 Top View of High Voltage Pulsed Power Supply showing the Rectifier Network, the Capacitor Bank, the Rotating Spark Gap, and various other components.
- Figure 13 Schematic Diagram of the Fluidized Bed/Screw Feeder Aerosol Generator used for High Concentration Resuspension of Bulk Fly Ash and Hydrated Alumina.
- Figure 14 The Climet Optical Particle Size Distribution Measurement System featuring the CI-225 Counting Unit and the CI-210 Multichannel Analyzer.
- Figure 15 The Microprocessor-based Data Acquisition and Analysis System serving the Electron Beam Precipitator.
- Table 1 Hot Cathode Filament Current and Voltage Measurements for the New Electron Emitter Filament.

CONCISE STATEMENT OF WORK PROPOSED

- Task A: Modification of precharger for pulsed and DC energization of anode.
- Task B: Installation of the Q/A measurement system.
- Task C: Modification and installation of pulsed power supply to provide both pulsed and DC energization of the precharger anode.
- Task D: Measurement of the removal efficiency for monodisperse simulated fly ash particles for two energization frequencies and several pulse heights.
- Task E: Measurement of particle charge for monodisperse particles for DC only and DC plus pulsed operation.
- Task F: Optimization of pulse energization schedule for maximum removal efficiency of test aerosol particles.
- Task G: Practical assessment of results for monodisperse test particles.
- Task H: Measurement of the removal efficiency for polydisperse test particles for two energization frequencies and several pulse heights.

A. INTRODUCTION AND CURRENT STATUS OF THE PROJECT

Re-commissioning and upgrading several of the important subsystems of the FSU Electron Beam Precipitator (EBP, Figure 1) wind tunnel continued during Quarter Three in preparation for the pulsed electron beam precharger experiments. Work was completed this term on the BG-2c vacuum station, the 100 keV MINACC electron beam accelerator, and the precharger pulsed power supply. The particle charge vs. radius measurement device was installed next to the wind tunnel and preliminary tests were initiated. High concentration aerosol generation was advanced by the addition of a heated gas supply to the apparatus. Dilution of these high aerosol concentrations was necessary in order to measure the particle size and number; a CI-294 dilution system was installed for this purpose. Attempts were begun to shield the Climet CI-225 optical particle counter and the CI-210 multichannel analyzer from the excessive RFI produced by the pulsed power supply. One publication appeared in the IEEE Transactions, and the submission of the 396 page Final Report for the previous DOE contract also occurred during the term. The subsections following the Introduction and Current Status of the Project contain specific details of the work done in each area of the Pulsed Electron Beam Precharger project.

Under Task A (Precharger Modification) an intense source of electrons is provided to the E-beam precharger by a 100 keV MINACC electron beam accelerator constructed at FSU. For the most part, the accelerator has functioned reliably with the notable exception of a problem with frequent beam window blowouts early in the developmental stages. An upgrade to the accelerator housing and beam focusing electrodes was made last term, followed by a series of measurements determining the amount of electron beam actually delivered to the precharger. It was disconcerted that a significant fraction of the beam was lost to the window housing, however, the interval electrode geometry was modified resulting in much improved MINACC performance.

The BG-2c vacuum station is now operating reliably after having survived a near catastrophe due to a cooling water failure. The 4 inch CVC diffusion pump cannot operate properly without sufficient cooling water. Pump overheating and eventual oil "cracking" is the result. The water lines were cleaned of debris, another water flow sensor was installed, the diffusion pump was cleaned and re-wrapped with new soldered copper cooling coils, and a thermostat controlling the diffusion pump heaters was installed.

Ultimately, the BG-2c can provide a vacuum of 3×10^{-6} torr to the accelerator cavity. These low pressures are necessary to prevent electron scattering within the accelerator tube which will result in a less intense, more diffuse beam. A description of the operation of the various pumps, valves, vacuum gauges, and other controls comprising the BG-2c vacuum station dedicated to the 100

The diagram illustrates the layout of the TEST SYSTEM, showing the arrangement of various components and their dimensions. The system is divided into several sections:

- PARTICLE INJECTION SECTION:** This section includes a **Port Window** and a **Pre-Charger Reactor**. The distance between the Port Window and the Pre-Charger Reactor is 3'.
- COLLECTOR:** This section contains a series of **Plates** and **Wires**. The distance between the Pre-Charger Reactor and the Collector is 1'.
- PLAN VIEW:** This view shows the overall layout of the system. The distance between the Collector and the Port Window is 7'6".
- Port Window:** This component is located at the end of the system. The distance between the Collector and the Port Window is 1'.
- Beam Tube:** This component is located at the end of the system. The distance between the Port Window and the Beam Tube is 1'.
- Other Components:** The system also includes a **Fan**, **Filter**, **Outlet Damper**, **Window**, **Ductwork Junctions**, and **Port**.

The dimensions are as follows:

- Distance between Port Window and Pre-Charger Reactor: 3'
- Distance between Pre-Charger Reactor and Collector: 1'
- Distance between Collector and Port Window: 7'6"
- Distance between Port Window and Beam Tube: 1'
- Distance between Beam Tube and Port: 1'9"
- Distance between Port and Window: 2'
- Distance between Window and Outlet Damper: 1'9"
- Distance between Outlet Damper and Fan: 1'9"

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keV MINACC electron beam source is also included in this report.

Data was obtained this term from a series of tests designed to relate the cathode filament current to the filament voltage, and the "window", "screen", and "probe" beam currents to each other. These results are presented in tabular and graphic forms, and will allow the accelerator operator to return to pre-determined beam settings easily. Complete characterization of the upgraded MINACC accelerator will aid in the optimization of the electron beam/precharger geometry matching condition which is necessary for effective particle charging.

The primary accomplishments of this contract period under Task B (Installation of Charge vs. Radius Apparatus) are as follows. The control system of the FSU particle charge vs. radius (Q/A) measurement system was modified in preparation for the electron beam particle precharging experiments, and the first two such preliminary Q/A experiments were completed. Installation of a second remotely controlled video observation camera in the 3 MeV accelerator vault provided much greater monitoring capability than before. New personnel were trained in the operation and maintenance of the Q/A system. Finally, a number of graphic figures of the new and upgraded experimental apparatus were produced.

As previously described, the Electron Beam Precipitator (EBP) wind tunnel is situated in an underground vault housing the 3 MeV Van de Graaff electron accelerator (Figure 2). Control of the wind tunnel and the various monitors takes place from an adjacent laboratory approximately 30 linear feet away. System components such as the Q/A apparatus and the two closed circuit TV video monitoring systems were re-wired to allow better remote control operation. In some cases, these functional changes reduced the number of technicians required for each monitoring on data acquisition procedure from two to one. Simplifying the task of running the precharger, precipitator, power supplies, and monitors has been an ongoing goal during this most recent development period.

The chief objective of Task C (Modification of Pulsed Power Supply) is to energize the electron beam precharger anode (Figure 3) with pulsed instead of DC voltage in order to increase the ultimate charging electric field value. The theoretical particle saturation charge increases with increasing electric field, and pulsing the anode will push the maximum electric field to the highest level yet. A rapid energization of electrons and a buildup of ionic space charge will occur during the short pulse. Termination of the pulse prior to the initiation of debilitating sparkover across the precharger electrodes is an important requirement of the power supply. The end result of pulsing the charging electric field will be higher particle charge, which will lead to higher particle collection efficiency.

Pulsed power for the electron beam precharger is provided by

Figure 2 Location of the Electron Beam Precipitator (EBP) and the Pulse Energized Electron Reactor (PEER) within the 3 MeV Accelerator Vault.

Figure 3 Top View of the MK. III-B Electron Beam Precharging Module showing the Ionization and Charging Zones.

a device constructed at FSU for another gas-phase SO_2/NO_x removal process (the PEER streamer corona project). A pulse forming network leads to a rotating spark gap which actually produces the short, very fast rise time pulses needed for superior particle charging. Tests this quarter determined that the rotating spark gap emitted so much RFI that the Climet optical particle counting system, the μMac A/D converter, and the microcomputer data acquisition system temporarily failed to operate. This interference was generated in both the signal lines and in the AC and ground inputs to the instruments. Remedies to this problem were instituted which included filtering the AC lines, shielding the signal cables, and separating the power supply and monitor grounding networks. A grounded Faraday cage surrounding the rotating spark gap is being planned for construction and installation during the next term.

Production of high concentrations of resuspended dust is necessary in order to test pulsed electron beam precharging at realistic particle loading levels. Following extensive redesign and reconstruction of the fluidized bed/screw feeder aerosol generator, testing of this device commenced during this quarter. A problem was encountered both in feeding the dust from the hopper into the fluidized bed, and in the fluidization process itself. Hydrated alumina (Hydral) which is otherwise an ideal monodisperse test aerosol, is very hygroscopic and forms clumps when exposed to humid air. A heated air dehumidification system has been assembled and installed in the compressed gas inlet line; this alleviated most of the dust clumping problem.

An optical particle counting apparatus which is now almost ten years old provides data on wind tunnel aerosol concentration and size distribution for the electron beam precharging experiments. The monitor array consists of two Climet CI-225 sampling units, two CI-294 aerosol dilution systems, and a CI-210 multichannel analyzer which receives and coordinates signals from the CI-225 units. Diluting the sampled aerosol by a factor of 100:1 enables the Climet CI-225 to operate at much higher than normal particle concentration levels - including those typically generated in the wind tunnel by the fluidized bed/screw feeder. While installing and checking these monitors for proper operation, it was discovered that one CI-225 counting unit would not calibrate properly, and the other unit would not pressure-balance when used in concert with the CI-294 dilution system. Manual calibration procedures were instigated which allowed one of the CI-225 units to be mated to a CI-294 using a somewhat revised flow pathway.

B. CONTRACT PROGRESS DURING QUARTER THREE

1. Task A: Precharger Modification

a. MINACC Electron Beam Accelerator

The 100 keV maximum energy electron beam accelerator (the MINACC) delivers an intense electron beam to the precharger for E-beam particle charging studies (Figure 4). This beam source was constructed at FSU using parts on-hand, and was recently (Quarter 2) disassembled and upgraded to improve its performance. Preliminary tests were run on the refurbished accelerator upon its completion. Beam current measurements were made of the total beam output through the thin window ("probe current") the beam fraction lost to the cathode screen electrode ("screen current"), and the beam fraction lost to the window and the window frame ("window current"). The working electron beam energy was 90 keV, while the beam current output to the probe was found to be from 0.5 μA to 10 μA .

During these preliminary runs conducted during the previous term, problems with excessive window current readings were encountered while running the electron beam accelerator. The majority of the electron beam should, by design, pass through the window and out into the precharger without impacting upon the window housing. Approximately one-third of the total current was being lost to the window housing because of electron scattering within the accelerator. After thoroughly checking all of the accelerator wiring connections and beam current measurement leads, a slight modification was made to the internal electrode geometry in the vicinity of the cathode filament. The MINACC was then cleaned, reassembled, and reinstalled in the precharging module. This modification should improve the focusing of the beam within the flight tube, and thus reduce the window current.

At the beginning of the present term, the electron beam was tested extensively. In the course of this testing, data was tabulated relating the electron emitter current (produced by the hot filament cathode) to the filament voltage (Table 1), and also the filament current to the window, screen, and probe electron beam currents. This table was developed for future use in establishing the proper accelerator operating point for each experimental condition during precharger operation. Figure 5 is a plot of filament current vs. filament voltage for the new cathode filament as well as an older version. The newer filament is physically smaller and better represents a point source of electrons, but it has a higher resistive value which requires greater voltage for the same current production.

It should be noted that the probe which is used to measure the electron beam entering the precharger must be removed prior to precharger operation. The probe completely blocks the electron

Figure 4 Schematic Diagram of the 100 keV Electron Beam Accelerator, or the MINACC.

TABLE 1.

Hot Cathode Filament Current and Voltage Measurements
for the new Electron Emitter Filament

Filament Current (mA)	Filament Voltage (VAC)
180	2.59
190	2.80
200	3.00
210	3.27
220	3.53
230	3.79
240	4.11
250	4.33
260	4.67
270	4.99
280	5.33
290	5.62
300	5.94
310	6.26
370	6.55

Figure 5 MINACC Electron Beam Cathode Filament Current vs. AC Filament Voltage for the new and old Electron Beam Emitter Filaments.

beam from entering the precharger, preventing the ionization process from occurring. Calibration curves are therefore necessary in order to relate window and screen current to probe current. Examples of these calibration curves are shown in Figures 6 and 7. In addition, the tests performed this term served to condition the accelerator housing by allowing sufficient time for outgassing, and also to familiarize the operator with the behavior of the electron beam and the MINACC itself.

Figure 6 MINACC Electron Beam Current vs. AC Filament Current for the Cathode Screen and the Window Assembly.

Figure 7 MINACC Electron Beam Current vs. AC Filament Current for the Cathode Screen and the Window Assembly.

b. BG-2c Vacuum Station

The BG-2c vacuum station (Figure 8) is a dedicated system designed to maintain the 100 keV electron beam at sufficiently high vacuum for efficient operation. At its present state of development, the BG-2c consists of a 4 inch CVC diffusion pump with baffle, two Sargent Welch #1402 mechanical pumps, a CVC pneumatic test valve which isolates the diffusion pump from the accelerator cavity, a CVC GPT-450 vacuum gauge controller including two gauge sensing tubes, and a relay-based electronic logic system which controls the various valves in the system automatically (Figure 1). The system is built on the chassis of an old Veeco Mass Spectrometer Vacuum Leak Detector which earlier had been decommissioned. Basic operation of the system is as follows (reference Figure 8):

Step 1. Beginning at atmospheric pressure, the roughing and fore mechanical pumps are turned on. The fore pump evacuates the diffusion pump outlet until the pressure in the diffusion pump is around 20 mtorr. Meanwhile, the roughing pump evacuates the accelerator and the connecting cavity above the test valve. This condition is known as the "Rough" mode.

Step 2. When the pressure at the outlet of the diffusion pump reaches 20 mtorr, the system is put in "Diff-Protect" mode. In this state, the roughing pump continues pumping against the accelerator cavity and the fore pump against the diffusion pump, however, the oil heaters in the diffusion pump are now turned on. During the start-up period, the GPT-450 vacuum gauge controller protects the diffusion pump fluid from excessive pressure. As the diffusion pump heats up, the pressure inside it rises rapidly due to the outgassing of the pump oil. When this pressure reaches approximately 30 mtorr, the GPT-450 gauge controller causes the diffusion pump heaters to be turned off, thus allowing the fore pump to bring the pressure back down to a level low enough to prevent damage to the diffusion pump fluid. If everything is working properly at this point, the fore pump will again lower the pressure in the diffusion pump sufficiently to cause it to be turned on again. Thus, the diffusion pump heaters are turned on and off in decreasingly shorter cycles until the vacuum system stabilizes at an outlet pressure of around 10 mtorr with the heaters operating at full power. At this point, the diffusion pump is ready to pump against the accelerator cavity.

Step 3. When the diffusion pump pressure has stabilized, and when the pressure in the accelerator cavity has been lowered by the roughing pump to between 10 and 15 mtorr, the vacuum system is ready to proceed to "Hi-Vac" mode. In this mode of operation, the pneumatic test valve separating the top of the diffusion pump from the accelerator cavity is opened and another solenoid valve simultaneously isolates the roughing pump from the cavity. When the diffusion pump has reduced the pressure in the accelerator

Figure 8 Top View of the BG-2c Vacuum Station, the 100 keV Electron Beam Accelerator (MINACC), and the E-Beam

cavity to less than 1 mtorr, a cold cathode Penning Tube vacuum gauge is activated by the operator to monitor the lower pressure ranges. Also, in this mode of operation, the GPT-450 vacuum gauge controller protects the diffusion pump from a blowout of the accelerator window by actively monitoring the pressure at the Penning Tube. When the pressure in the accelerator cavity rises above a preset trip point, the GPT-450 causes the relay logic system to close the test valve, thus physically isolating the diffusion pump from the accelerator cavity. Atmospheric pressure air causes the hot silicone diffusion pump oil to "crack", rendering it ineffective for producing high vacuum.

Step 4. In the event of a window blowout, the test valve is immediately closed as described above. In this state the accelerator is at atmospheric pressure, and the window can be repaired and the accelerator inspected for other damage without danger to the diffusion pump. Returning the system to the Hi-Vac mode from this state requires only that the accelerator cavity be pumped down again using the roughing pump to a pressure of between 10 and 15 mtorr.

When the BG-2c vacuum station has been pumping on the 100 keV accelerator for at least one week, it can produce an ultimate vacuum in the accelerator cavity of approximately 3 μ torr (3×10^{-6} Torr). This is considered quite good for a system of this type without a liquid nitrogen cold-trap, and is sufficient for the production of a 90 keV beam of electrons with minimal beam scatter inside the accelerator.

In addition to the protection mechanisms described above, during this term, an electrically actuated water flow switch which senses the loss of cooling water flow, and a thermostat which senses excessive temperature of the diffusion pump body were installed on the BG-2c station. Both of these devices turn off the diffusion pump heaters to prevent damage to the housing and the fluid in the case of a cooling water or a fore pump failure, respectively. Several setbacks in the realization of optimum vacuum system performance were encountered this quarter. Most of these problems, which are discussed in the following paragraphs, stemmed from the failure of the recently installed water cutoff sensor.

During an experimental run hiatus occurring at about the middle of the quarter, the supply of water which cools the diffusion pump on the BG-2c vacuum station was interrupted because of a building outage. When the water supply to the station was cut off for a period of about 2 hours, the water flow sensor which switches off the diffusion pump heaters failed, resulting in a severe overheating of the silicone diffusion pump fluid. The only indication of this failure came long after cooling water was resumed to the diffusion pump, when an unusual fluctuation in the pressure reading of the Penning Tube monitoring the accelerator cavity was noticed.

Later in the term, another water interruption occurred, except that this time the building water system was down much longer due to campus construction. Once again, the water flow sensor which had been replaced after the last cooling water outage failed to turn off the heating elements. As a result, the diffusion pump had been overheated to the point that the cooling water lines wrapped around the pump had become detached, the solder attaching the copper cooling coils to the pump body had melted in places, and the diffusion pump fluid, of which only about 50% was left, had been scorched.

In investigating possible causes of this near catastrophe, some loose plastic of unknown composition originally in the chilled water supply was found to be lodged in the water flow sensor, blocking the switch from closing. In responding to these major vacuum station problems, three remedies were proposed and initiated. First, the water flow sensor was repaired and reinstalled in a more reliable location. Second, the diffusion pump was removed, thoroughly cleaned, sandblasted, and re-wrapped with new copper tubing to try to upgrade the cooling coil arrangement. After reinstallation into the BG-2c support frame, new silicone diffusion pump fluid (Dow-Corning #704) was added. Third, a thermostat designed to shut off the diffusion pump cart heaters in the event of pump overheating was installed on the pump body as a backup to the water flow sensor.

The above listed repairs and improvements to the CVC diffusion pump are expected to prevent the loss of valuable accelerator run time. Currently, the BG-2c vacuum station has been fully resd and is operating continuously at an optimum level. The vacuum in the accelerator is now stable at about 4×10^{-6} Torr. Furthermore, the modifications made should preclude most other foreseeable major problems in the future.

2. Task B: Installation of Charge vs. Radius Apparatus

The particle charge vs. radius (Q/A) measurement apparatus developed at FSU (Figure 9) has been described in detail in Technical Progress Report No. 2. Based on the "Millikan Oil Drop" principle, the device uses a chamber bounded by 2 electrodes producing an oscillating electric field into which particles are introduced. The particles are illuminated by a laser beam, and a video recording system rapidly measures the charge and the mass of individual aerosol particles. The recorded data is then analyzed, giving a Q/A ratio.

Final preparations for the electron beam particle precharging experiments involved the relocation of the gas flow control system which samples and measures a test aerosol stream to allow easier operation by the Q/A technician. Previously, the position of the gas flow control switch required the assistance of another researcher to activate. Extending the control cable consisted of splicing in an additional 10 feet of cable and installing a second control switch. Another change which was needed was a new video signal cable. The previously used cable was required for another research project and had to be disconnected. Consequently, another cable was routed and assigned to the Q/A system, and then fitted with the appropriate connectors.

The first two preliminary Q/A measurement runs which were designed to test the equipment were completed during this contract period. As expected, the rapid build-up of Hydral particles on the observation window of the particle charge measurement cell was still found to be a problem. This coating significantly obscures the video viewing of the charged particles, drastically reducing the length of time in which data can be taken. An interim solution involved periodic interruptions in the experimental procedure to allow the operator to clean the observation window manually with a cotton swab. Obviously, halting the experiment to remove this particle film is not an entirely satisfactory solution, however, no feasible alternative is currently available. Other rapid cleaning methods will be actively pursued.

Another accomplished goal was the installation of a second remotely controlled closed circuit television camera and video monitor to allow a second observation perspective of the Electron Beam Precipitator wind tunnel located in the 3 MeV accelerator vault. This task consisted of mounting a Panasonic CCTV camera on top of a motorized panning head fastened to a tripod. A separate coaxial video cable had to be laid from the control console in an adjacent room out to the camera, along with a new six-wire control cable for the panning head. The new arrangement permitted the simultaneous viewing of the vacuum station controls and gauges on one video monitor, the precharger and collector analog current meters on a second monitor, and aerosol particles flowing through the Q/A charging cell on a third monitor.

F.S.U. Charge / Radius Measurement System

Figure 9 The FSU Particle Charge vs. Radius (Q/A) Monitoring Apparatus, showing the Laser Beam, the Video Viewing and Monitoring System, and the Particle Charge Measurement Cell.

Due to impending staff changes, a new chief operator for the charge vs. radius apparatus was needed for the remainder of the contract period. Therefore, the instruction of a new operator in the intricacies of the Q/A system became the paramount objective for the last month of the present term. The new operator was instructed in the theory of ionic and electronic particle charging, and the function of the charge vs. radius measurement apparatus and its component subsystems were recited in detail. Emphasis was placed on the importance of the care and maintenance of the system, especially in the process of dismantling and cleaning the Q/A measurement cell. The operation of the system in its current configuration was practiced, and procedures were formalized concerning the analysis of data collected by the system using a spreadsheet and several graphing packages with the Apple Macintosh and IBM PC microcomputers.

3. Task C: Modification and Installation of Pulsed Power Supply

Pulsed power to drive the electron beam precharger anode will be provided by a rotating spark gap power supply (Figure 10) which was transferred from an earlier project on the pulse energized electron reactor (PEER). This power supply was described in the first Technical Progress Report of this contract, and it has been installed adjacent to the precharger and modified as necessary.

At the beginning of this term, a test run of the electron beam precharger was attempted using the pulsed power supply instead of a DC power supply. The outcome of this initial dry run was that it exposed a potentially serious problem with the ability of the data collection systems to function properly when the rotating spark gap is operating. Systems affected by the rotating spark gap include, principally, the μ Mac analog-digital converter (Figure 11), the Climet CI-225 optical particle counter and CI-210 multichannel analyzer, and the microcomputer and peripherals.

The pulsed power supply produces pulses with a width of approximately 200 nsec, a rise-time of approximately 20 ns, and an amplitude of up to 80 kV. The fast rise-time of this pulse is achieved by using a motorized double pole mechanical spark gap (Figure 12), rotating at 60 Hz, which produces an inordinate amount of RFI. Initially, the operation of this power supply at a normal voltage level of 60 kV rms caused a temporary failure of the entire data acquisition system due to induced noise generated in the signal lines. As the magnitude of this electrical noise grossly exceeded the noise tolerance level of the computer, it began to behave in an unpredictable and random manner. This behavior rendered the possibility of acquiring any meaningful data from the particle size analyzer or the precipitator current meters useless.

After meticulously separating the grounding networks of the pulsed power supply from the data acquisition system and adding EMI/RFI filtering to all of the AC power inputs, normal continuous operation of the computer was resumed. However, a significant amount of ambient noise which was generated by the rotating spark gap was still causing erroneous readings from the Climet CI-225 optical particle counter to be sent to the CI-210 multichannel analyzer. The particle counter located in the accelerator vault is connected to the multichannel analyzer in the control room via a long run (60 ft.) of 50 ohm impedance transmission cable. It is this coaxial transmission line that remains the root of the problem since it acts as an antenna for the high frequency noise emanating from the pulsed power supply.

During the next term, plans are to attempt to electrically isolate the multichannel analyzer and the microcomputer from the particle counter with some sort of optical coupling system in the signal transmission line, perhaps employing fiber optic technology.

H.V. Pulse Generator Circuit

(a) H.V. AC supply (Modification of DC H.V. source)

(b) Pulse Forming Network

Figure 10 Schematic Diagram of the High Voltage Pulse Generating Circuit to be used for E-Beam Pulsed Particle Precharging.

Figure 11 Circuit Layout of the Micromac (μ Mac) Analog-to-Digital Converter showing the connections to the Precipitator Plate Electrodes and the Host Computer.

Pulsed Power Supply

1 - High Voltage Rectifier	7 - D.C. Isolation Capacitor
2 - Faraday Cage	8 - Corona Ball
3 - Capacitor Bank	9 - Current Limiting Resistor
4 - Mechanical Spark Gap	10 - D.C. Ammeter
5 - Strobe Lamp	11 - Precharger Electrodes
6 - Tail Resistor	12 - Current Limiting Resistor

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Figure 12 Top View of High Voltage Pulsed Power Supply showing the Rectifier Network, the Capacitor Bank, the Rotating Spark Gap, and various other components.

In addition, construction of a Faraday cage is planned in order to completely enclose the rotating spark gap portion of the pulsed power supply. Emission of RF energy from the gap should be dramatically reduced by the grounded Faraday cage, thereby virtually eliminating the major source of interference. A second goal for the next term is to acquire a digital storage oscilloscope to monitor the output of the pulsed power supply in order to verify its proper operation. The laboratory currently lacks an oscilloscope capable of displaying the voltage and current waveforms that the power supply produces.

4. Task D-H - Preparations for Experiments

a. High Concentration Aerosol Generation

During the last term, the fluidized bed/screw feeder aerosol generation system (Figure 13) was extensively redesigned and was transformed into a workable, properly functioning device. A new PVC ring surrounding a semi-porous screen was fitted into a new plexiglass pipe having opening top and bottom ports. Covering the screen to a depth of 1 cm is a layer of glass beads forming the fluidized bed. Dust is fed into the side of the pipe just above the agitating glass bead bed via a PVC sleeve containing the rotating screw. A gas feedback loop equalizes the pressure in the dust hopper and the upper chamber of the fluidized bed.

This term, an air preheater was added to the compressed gas inlet line supplying the lower chamber of the fluidized bed. Consisting of a strip heater mounted within an insulated stainless steel cylinder, the air preheater delivered a warm (50°C), dehumidified, compressed gas which aided the fluidization and deagglomeration processes. The test dust, namely hydrated alumina or "Hydral", is a very hygroscopic material which tends to form into clumps in both the screw feeder and the fluidized bed. Even though the heated air coursing up through the porous screen, glass beads, and dust layer broke down many of the clumps, compaction of the bulk Hydral in the screw feeder still remained a problem. Plans call for the installation of a positive pressure flow pathway which will force warm, humid, dehumidified air through the dust hopper to alleviate this difficulty.

EBP Fluidized Bed Aerosol Generator

Florida State University

Figure 13 Schematic Diagram of the Fluidized Bed/Screw Feeder Aerosol Generator used for High Concentration Resuspension of Bulk Fly Ash and Hydrated Alumina.

b. Aerosol Dilution and Measurement System

In preparing various Electron Beam Precipitator (EBP) wind tunnel subsystems for the upcoming particle precharging experiments, one focus this quarter was directed toward the particle size and number measurement system. This entails having a reliable and accurate method of monitoring the output of the fluidized bed/screw feeder aerosol generation system in order to insure that an even and consistent supply of resuspended Hydral dust is delivered to the EBP wind tunnel. The system used to fulfill that requirement consisted of a Climet CI-225 optical particle counter in cascade with a Climet CI-294 dilution system having a 100:1 air-to-aerosol ratio (Figure 14). Since no device currently available will measure the extremely high particle concentrations produced at the outlet of the fluidized bed, the aerosol was instead sampled from the EBP wind tunnel at the normal location just downstream from the collector.

The CI-294 dilution system extends the operating range of the CI-225, permitting it to operate on aerosol streams which are normally far too concentrated for the light scattering apparatus to handle ($> 10^7$ particles/min). Information in the form of particle size and number data integrated over a period of one second is sent to a Climet CI-210 multichannel analyzer and then to a microcomputer for storage and analysis (Figure 15). One of the design advantages of the Climet system is that it produces a "real-time" indication of particle concentration in the wind tunnel. This allows rapid diagnosis of the effects of electron beam precharging or other precipitator perturbations.

In order to insure the accuracy of the Climet optical particle counting system, an aerosol of a known size at very low concentration was fed directly into the CI-225, and the data output from the CI-210 was then verified. This test was accomplished using polystyrene latex (PSL) spheres of 1.32 and 1.5 μm in diameter. The plan to proceed with a test of the Climet units using an aerosol suspended in the EBP wind tunnel was delayed, however, because both of the CI-225 Particle counters were found to be operating defectively. One of the units would not calibrate properly, and the second unit could not be pressure-balanced.

The process of electronic calibration involves adjusting a front panel potentiometer while in the "calibrate" mode which causes the various particle size ranges and count totals to coincide. Pressure-balancing of the apparatus is needed in order to insure that the CI-294 dilution system dilutes the sample aerosol by a ratio of 100:1. Since the second machine could not be successfully pressure-balanced with the dilution system, the first machine, as advised by the manufacturer, was manually calibrated with 1.5 μm PSL, and then mated to one of the dilution systems. Effective sample dilution of a high concentration Hydral aerosol circulating in the wind tunnel could then be attempted. Tests subsequently conducted with the Climet optical counting system verified the functionality of this arrangement.

MICROCOMPUTER DATA ACQUISITION SYSTEM

Figure 14 The Climet Optical Particle Size Distribution Measurement System featuring the CI-225 Counting Unit and the CI-210 Multichannel Analyzer.

CI-225

FEATURES:

- ☐ 0.3 MICRON SENSITIVITY
- ☐ LONG DISTANCE DATA TRANSMISSION
- ☐ COMPACT DESIGN WITHOUT SACRIFICING VERSATILITY OR PERFORMANCE
- ☐ ELLIPTICAL MIRROR OPTICS

MODEL CI-225 OPTICAL SYSTEM:

The patented elliptical mirror light collection system is recognized as the finest in the world, gathering the greatest amount of scattered light for any given particle.

SPECIFICATIONS:

Power: 115/230 volt, 60/50 Hz.

Signals: (1) Digital Output, BNC Connector (J3)
(2) Analog Output for Particle Size Analysis, BNC Connector (J4)

Standard Particle Size Range: .3 to 10 microns and above

Flow Rate: .25 cubic feet per minute

Weight: 40 lbs.

Size: 9½" H, 11½" W, 19¾" L

CI-210 MULTI-CHANNEL ANALYZER

The Climet CI-210 Multi-Channel Analyzer is a microprocessor-controlled multiple pulse discriminator which receives pulses representing particle sizes from one to forty Climet Particle Sensors simultaneously. Pulses are continuously discriminated, accumulated, displayed, and recorded in the CI-210 according to the unit's ten internally stored programs. Most any number of sensors x size ranges per sensor combination ≤ forty can be specified. Alarms, data summaries, and computer interfaces are optional and available upon request.

Figure 15 The Microprocessor-based Data Acquisition and Analysis System serving the Electron Beam Precipitator.

C. PUBLICATIONS, PRESENTATIONS, AND PARTICIPATIONS

1. "Use of an Electron Beam for Particle Charging".

A paper entitled "Use of an Electron Beam for Particle Charging", authored by Akira Q. Mizuno, J. Sidney Clements, and Robert H. Davis, was published during this quarter in the IEEE Transactions on Industry Applications, Volume IA - 26, No. 1, pp. 29 - 35, January/February, 1990. This paper was originally presented at the IEEE - Industry Applications Society Annual Meeting held in Chicago, Illinois, in October of 1984. It was also published in preliminary reviewed form in the Conference Record of the Annual Meeting, pp. 1215-1219.

Electron beam precharging was investigated in this study using 1.1 and 3.0 μm particles in a bi-electrode electron beam precharger geometry. Particle charge levels higher than that expected by ionic field charging theory were found; free electron charging is thought to be responsible for the difference. This paper is reprinted on the following pages.

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2. "Flue Gas Cleanup Technology Utilizing Energetic Electrons"

The Final Contract Report entitled "Flue Gas Cleanup Technology Utilizing Energetic Electrons", by R. H. Davis and W. C. Finney (396 pp.), covers the work performed under the U.S. Department of Energy Contract Number DE-AC22-86PC91021, for the period May 6, 1986 - March 5, 1989. Two major Tasks incorporating more than twenty sub-Tasks were specified in the original two-year contract plus a four month no-cost extension, while six additional tasks were completed in a six-month funded contract extension period.

This report was submitted to the Pittsburgh Energy Technology Center, U.S. DOE, on February 23, 1990 and was accepted by PETC on March 12, 1990. The title page and a short summary of the work performed are reproduced here.

The Florida State University
Tallahassee, Florida 32306-3016

Department of Physics

Final Report to the
U.S. Department of Energy
Pittsburgh Energy Technology Center

DOE Contract Number DE-AC22-86PC91021

FLUE GAS CLEANUP TECHNOLOGY UTILIZING ENERGETIC ELECTRONS

For the Period
May 6, 1986 - March 5, 1989

Submitted by

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IMPORTANCE OF THE AEROSOL PHYSICS PROJECT AT FSU

The primary motivation for the development of electron beam precharger technology continues to be the problem of efficiently collecting high resistivity fly ash in electrostatic precipitators. High resistivity fly ash, produced by burning low sulfur coal in power plant boilers, limits the operation of conventional electrostatic precipitators by initiating debilitating "back corona". If the charging and collecting functions are separated into a two-stage system comprising an upstream precharger and a downstream electrostatic precipitator operated at high electric field but low current (Figure I-1), the back corona problem can be avoided. Back corona does not exist in fabric filters which, in part, accounts for the popularity of that technology in recent years. However, filtration in baghouses can be made more efficient by first charging the particles; this has stimulated interest in two-stage systems involving prechargers and fabric filters.

Both electrostatic precipitators and baghouses are expensive to purchase and maintain, and the possibility of reducing these costs has led to the investigation of a number of new technologies for the removal of particulate matter. A moderate increase in fly ash collection efficiency can mean a substantial reduction in the capital cost of the physical plant as well as reduced operating expenses. The prospect of more stringent emissions standards for respirable particulate matter adds further impetus to the development of new technologies for the removal of fly ash.

The physical reason for the use of an electron beam in a precharger is that copious ionization is produced by energetic electrons in a gas. In an electron beam precharger, the ionization flux created by the primary beam is separated into two monopolar components, one of which is used to charge the particles in a charging zone energized by an applied electric field. Because of the copious ion currents, space charge enhancement of the charging electric field is an advantageous possibility because of the dependence of particle charge on the electric field.

The earliest experiments at FSU demonstrated the copious ionization of electron beams in

TWO STAGE SYSTEMS FOR RESPIRABLE PARTICLE REMOVAL

Two Stage Particle Removal Systems using an Electron Beam Precharger
as the First Stage.

electrode geometries adaptable to electron beam prechargers. Based on these results, a laboratory-scale closed circuit wind tunnel was constructed for the test of various experimental electron beam prechargers in two-stage operation with an electrostatic precipitator (Figure I-2). Promising results as indicated by high particle charging and collection efficiencies were obtained using model aerosol particles under controlled conditions. Later tests proved that E-beam precharger technology can operate using more realistic concentrations of fine, high resistivity dust. The results obtained with the most recent precharger design (the Mk. III) confirm the impressive effectiveness of electron beam precharging and have pointed out the need for further design modifications to achieve optimum performance.

In conventional electrostatic precipitators, fly ash particles are predominantly charged by negative ions, and the population of free electrons is small. In contrast, the population of free electrons in electron beam prechargers is markedly increased. The early reports by other workers of superior particle charging by free electrons as compared to particle charging by negative ions motivated a separate investigation of free electron charging. The superior charging of aerosol particles by free electrons has been confirmed at FSU, and an original theory has been developed to explain the experimental results.

A spinoff of the Aerosol Physics Project is the invention of a new technology for the removal of the gaseous species SO_2 and NO_x from flue gas. This discovery was the result of an effort to reduce the electron beam source capital cost in electron beam prechargers by increasing the radiation dose with large electric fields. The new process utilizes positive pulsed streamer corona for the production of oxidant radicals from the flue gas which, in turn, convert SO_2 and NO_x to easily collectable particulate matter. The university has obtained a patent on the "PEER" technology and Combustion Engineering, Inc. is the licensee. During the last several years, this new technology has been actively pursued in Japan, Italy and West Germany. The F.L. Smidth Company of Copenhagen, Denmark has initiated an R & D program and has sent their Project Engineer to work on the new technology in the Aerosol Physics laboratory at Florida State University.

D. PERSONNEL

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2. Mr. Wright C. Finney	Associate in Research

Graduate Student Assistants

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END

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