PULSED POWER SYSTEMS FOR ENVIRONMENTAL AND INDUSTRIAL APPLICATIONS

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ABSTRACT

The development of high peak power simulators, laser drivers, free electron lasers, and Inertial Confinement Fusion drivers is being extended to high average power short-pulse machines with the capabilities of performing new roles in environmental cleanup and industrial manufacturing processes. We discuss a new class of short-pulse, high average power accelerator that achieves megavolt electron and ion beams with 10's of kiloamperes of current and average power levels in excess of 100 kW. Large treatment areas are possible with these systems because kilojoules of energy are available in each output pulse. These systems can use large area x-ray converters for applications requiring greater depth of penetration such as food pasteurization and waste treatment. The combined development of this class of accelerators and applications, at Sandia National Laboratories, is called Quantum Manufacturing.

1. INTRODUCTION TO HIGH AVERAGE POWER ACCELERATOR TECHNOLOGY DEVELOPMENTS

Competition is creating a demand for more durable products and for more economical manufacturing methods while maintaining or improving the quality of the environment. These demands led to the emergence of a number of commercial applications that require continuous, high average power electron beams, ion beams, and x-ray sources. These applications benefit from non-thermal effects when energy is applied to a specific volume or to a specific product component. The efficiency comes from using short pulses, typically 50 ns to 500 ns FWHM, to create high specific energy states in the material before thermal diffusion effects transfer energy to the bulk of the material. Specific radiochemistry effects are used to destroy wastes such as pesticides or SO₂ and NO_x in flue gases. Applications are shown in Figure 1 that also indicates the power level available from present high voltage commercial technology.

High peak power accelerator developments, such as the use of large-scale saturable magnetic switches,^(1,2) linear induction voltage adders (LIVA's),⁽³⁾ and large-

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area electron and ion beam diodes,⁽⁴⁾ with the addition of thermal heat management techniques, make the short-pulse accelerator a candidate for high average power processing. The Repetitive High Energy Pulsed Power (RHEPP) accelerators typify this new generation of high average power devices.⁽⁵⁾

Figure 1. New applications require more than 200 kW of beam power.

Figure 2. The Physics International CLIA accelerator demonstrates short-pulse, high average power beam generation technology.

Short-pulse accelerators at Physics International Company, Science Research Laboratory, Inc. and Sandia National Laboratories are delivering beams with 10 - 100 kW average power, with 350 kW expected within the year. The PI Compact Linear Induction Accelerator (CLIA), shown in Figure 2, uses thyratrons in the primary stage and has ten cells of linear induction voltage addition to 750 kV. CLIA achieves a beam power level of 120 kW, with operating periods of about five seconds.⁽⁶⁾ The SRL SNOMAD IV accelerator, now operating at 38 kW for few minute runs, uses semiconductor switches for primary pulse compression. This module can

be configured as a beam injector, or as a series of linear induction adder (LIA) beam acceleration stages generating a 1 - 6 mm diameter electron beam.⁽⁷⁾ The SNL RHEPP-I accelerator⁽⁵⁾ uses magnetic switches to generate a 1 MeV beam and has been tested at 90-kW. All components came to thermal equilibrium at or below design limits in runs of about 20 minutes. A second accelerator will provide a 2.5 MeV, 350 kW. Both accelerators provide large area electron beams (1000 cm²) from field emission cathodes. System efficiencies, from wall plug to output, can be 50% or greater. Short-pulse accelerators will be important for future industrial applications because they can supply very high average power beams that are beyond the capabilities of present commercial accelerators.

2. HIGH AVERAGE POWER ACCELERATOR APPLICATIONS

2.1 Flue Gas Cleanup

Fossil fuels in power plants produce sulfur dioxide (SO₂) and nitrogen oxides (NO_x) emissions. U.S. utilities relying on high sulfur coal will be affected by regulations, such as the New Clean Air Act, that requires significant NO_x emissions reduction after 1995. Non-thermal plasma techniques offer an efficient approach to the destruction of both oxides. These plasma processes can be induced by electron beam irradiation or by flowing the gas through a high electric field corona cell. Both methods increase the electron temperature while leaving the gas at near ambient. The dissociation and ionization of the gas stream produces free radicals which subsequently cause the decomposition of the pollutants.

Electron beam treatment of flue gases has been the subject of research in Japan, the USA, Germany, and Russia since 1970.^(8,9,10,11) Electron beams removed more than 94% of SO₂ and 80% of the NO_x in tests in Japan.⁽¹²⁾ Studies by Kuznetsov showed an order of magnitude increase in the efficiency of breaking down SO₂ molecules by using a specific electron beam current density.⁽¹³⁾ Even with this increase in efficiency, the power conditioning system will be required to supply an electron beam with approximately 1% of the power plant output.

2.2 Destruction of Hazardous Chemicals and Wastes

Electron beams have been shown to be very effective (>99%) in destroying organic compounds such as trichloroethylene, propanes, benzenes, phenols, and halogenated hydrocarbons found in low concentration levels in contaminated water.^(14,15) Others have shown effective destruction of pesticides and solvents such as Malathion[®], Lindane[®], carbon disulfide and carbon tetrachloride by electron beam irradiation.⁽¹⁶⁾ The low levels of organics are removed when the irradiation of aqueous solutions creates the free radicals, e⁻_{aq}, H^{*}, and OH^{*}.

Electron beam irradiation has also been shown to be capable of destroying ferrocyanides in solution.⁽¹⁷⁾

Various hazardous chemicals such as PCB's, high explosives residue, trichloroethylene, and others can be found as soil contaminants at a number of sites. Electron beams, operating at 9 to 10 MeV have been shown to be effective in destroying the organics in a vapor extraction process using wells driven into sub-surface sources of contamination. It is estimated that a 10 MeV, 350 kW, electron beam accelerator will be needed for this cleanup application.⁽¹⁵⁾

2.3 Materials Processing

Researchers demonstrated improvement in material surface properties by bombardment with pulsed ion beams.^(18,19) This technology improves hardness, corrosion resistance, and the tribological properties of materials. Intense, pulsed, high energy Ion Beam Surface Treatment (IBEST) produces surface conditions ranging from localized high temperature annealing to surface melting, followed by rapid thermal quenching to ambient temperatures.⁽²⁰⁾ This produces surface alloys by liquid phase mixing and/or by forming non-equilibrium microstructures including amorphous, disordered crystalline, and nanocrystalline phases. Applications include etching of polymer films, surface glazing and sealing of ceramic surfaces, and dry processing for surface deburring, polishing, and cleaning without the use of solvents. Ion beams offer the advantage of treating large (200-1000 cm²) surface areas for reduction of edge effects in lower cost, high throughput, materials processing applications.

2.4 Food Pasteurization

Consideration of food pasteurization is driven by a concern for the safety of the food supply. As many as 10,000 deaths per year, in the U.S., are attributed to food poisoning, and use of electronic food pasteurization (EFP) could drastically reduce this rate.⁽²¹⁾ Reduction of food spoilage and extension of shelf-life is a second reason for using EFP. As much as 40% of produce harvested is lost due to spoilage before it reaches the consumer. Up to 90% of the fish harvest is lost due to spoilage. This loss amounts to several billion dollars annually and will be reduced by the use of EFP. Third-world countries have food contamination and spoilage problems due to less advanced transportation and refrigeration systems,⁽²¹⁾ so the use of EFP could significantly increase the available food supply. A large database shows that no radiolytic byproducts are introduced into the food as a result of the treatment process at FDA approved treatment levels.⁽²²⁾

Some food pasteurization is underway using Cobalt-60 sources. Analysis of the throughput requirements of a typical U.S. meat packing plant shows that approximately 40 kW of x-ray power, produced by a 960 kW of electron beam, will be re-

quired for EFP to the FDA recommended treatment level of 3 kGy (300 krad). Plant payback is estimated at 3 years with treatment costs of a few cents per pound.

3. CONCLUSION

Over 20 years of research have been conducted on the beneficial applications of electron and ion beams. Defense applications concentrated on single pulse accelerator operation. University experiments demonstrated the usefulness of beams in mitigating hazardous organics and other industrial pollution. Irradiation of food with Cobalt-60 sources is now seeing acceptance in the U.S.. Scientists and engineers who fought the cold war now find themselves in a position to convert defense oriented devices, such as short-pulse simulators, to tools for dealing with environmental and industrial problems. Availability of long-life, short-pulse, high average power accelerators is occurring on a parallel path with the development of an awareness of society's need to deal with problems such as waste pollution, bacteriological outbreaks, and a desire for new and less polluting manufacturing methods. Creative and economical solutions can be expected from the scientific establishment, with the assistance of short-pulse, high average power accelerators. The applications described in this review are intended to indicate some of the possibilities for pulsed beams and coronas that are awaiting sufficient economic and political emphasis to be commercialized.

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