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Pulsed powered plasma blasting for lunar materials processing

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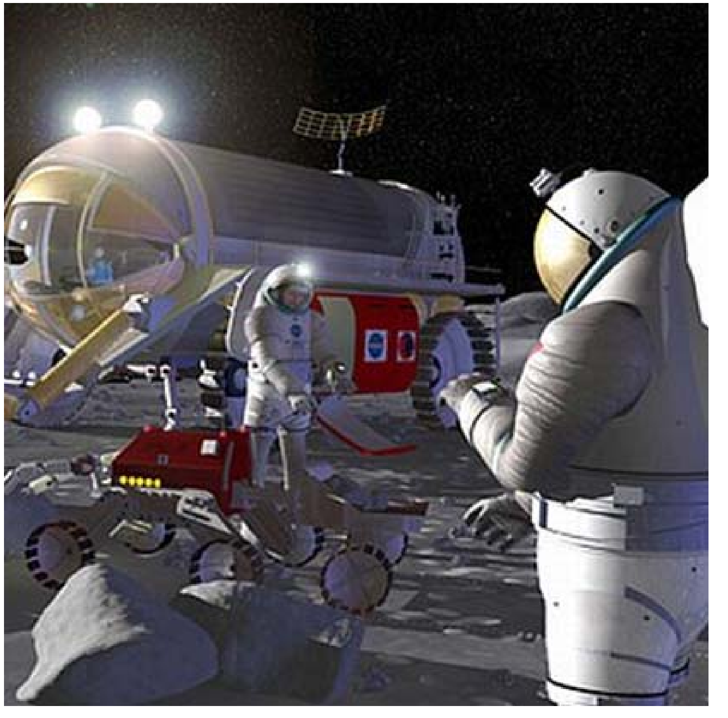
Overview

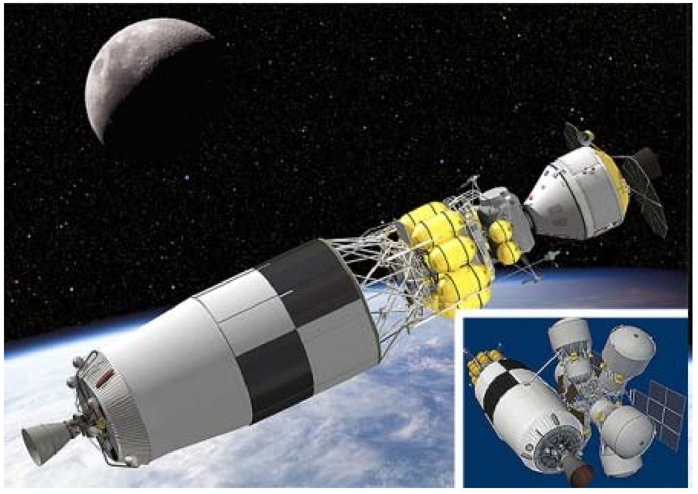
- Introduction
- Objectives
- Plasma Blasting Technology
- Bernardes-Merryman Topology
- Test Rig components
- Results
- Summary and Conclusions

Introduction

- Drilling and excavation on the moon's surface imply some complications:
  - Prohibitive to carry chemical explosives.
  - Significant transportation cost and safety concerns in using payload explosives are very detrimental program issues.



Introduction



- An alternative method of surface blasting
- Incorporates the use of electrically powered plasma blasting.
- Allows easily adjusted explosive yield control for additional safety.

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Objectives

- Design, construct, and test a prototype plasma blasting power system and blasting probes to be used in lunar excavation.

Plasma Blasting Technology

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- Plasma Blasting Technology involves the production of a high voltage pulsed discharge through a blasting probe inserted in a bore hole drilled into a rock.
- A medium of a small quantity of inert material fills the void around the blasting probe tip.
- A high voltage pulse produces shock / pressure waves in the medium, and then into the rock, leading to fracture.

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Plasma Blasting Technology

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- Potential advantages of plasma blasting system for space application

  - Minimal scattering of fly-rock.
  - No chemical reaction – inert, non-explosive.
  - Discharge portion is reusable.
  - Reduced machinery mass is required.

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Bernades-Merryman (BM) Topology

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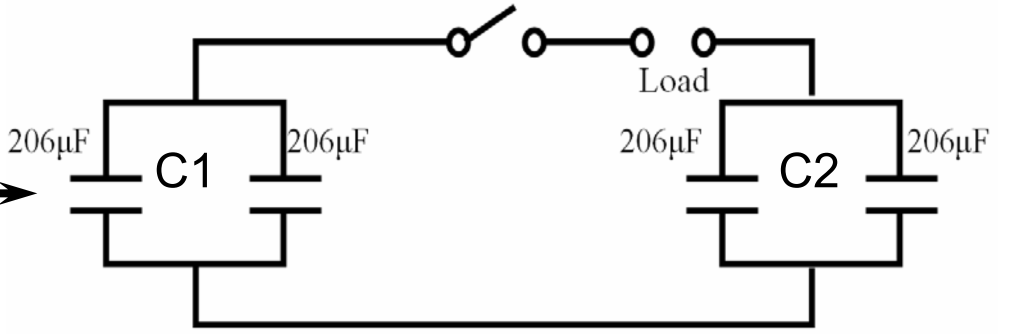
Initially Charged



•An alternative to a voltage reversal protection scheme using a crowbar circuit is the Bernardes-Merryman (BM) capacitor bank configuration.

•It is the nature of such a BM bank that if the system is electrically under-damped, the remaining energy will continue to move between the two capacitor banks of the BM system until equilibrium is achieved or circuit current thresholds have been reached.

•Neither capacitor bank is ever subjected to a negative polarity voltage swing extending capacitor lifetime. The BM design could also easily include recovery schemes to reclaim a portion of the unused electrical energy.

Plasma blasting test rig components

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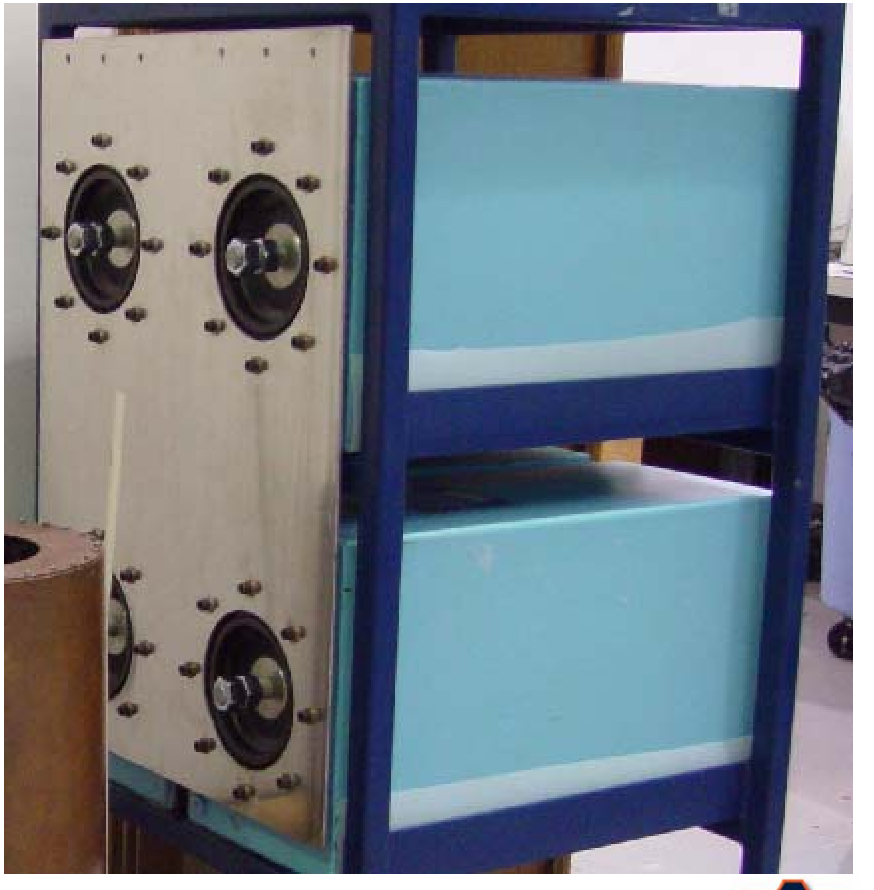
- Two banks of 2 capacitors-parallel
  - 206μF each, Maxwell (General Atomics) Mod. 32317
  - 22 kV rated voltage
  - 400 kA Max. peak current (parallel)

- Capacitors charged slowly, and then discharged rapidly through high current switch into the load.



Switching device

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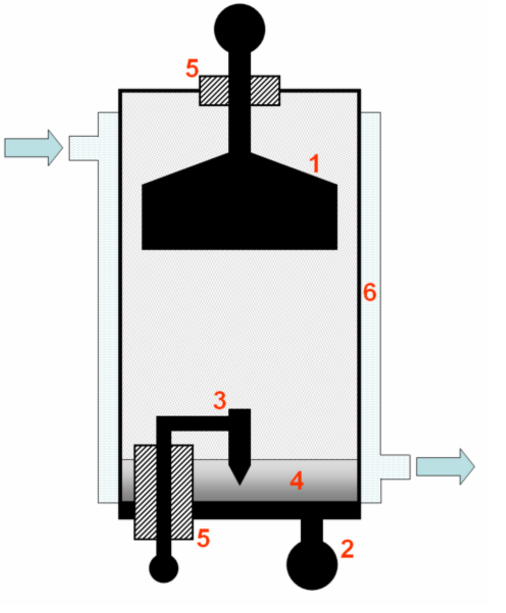
National Electronics Ignitron Mod. NL-1058

- Pulsed-Power Class Ignitron
- Reverse Current Design
- Max Voltage: 25 kV
- Peak Current: 600 kA



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Ignitron Trigger circuit

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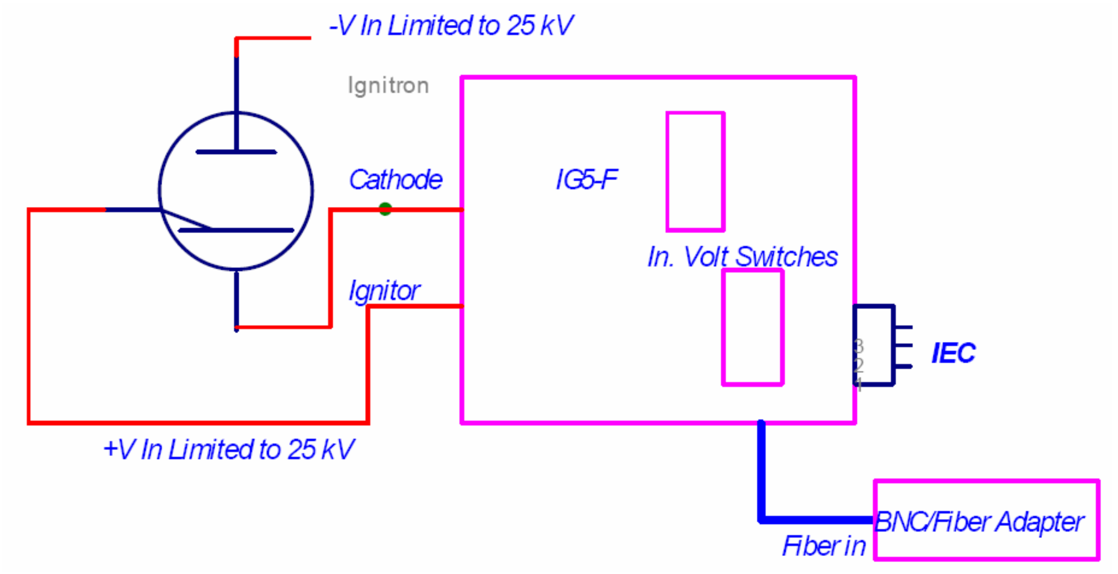

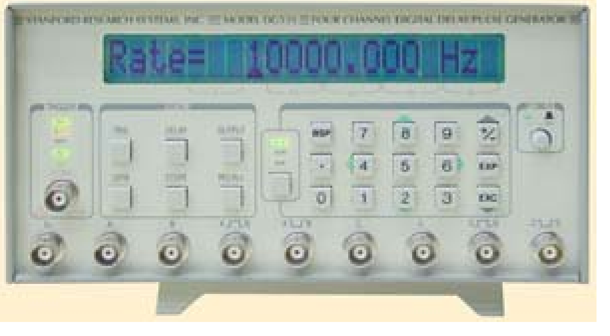

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Pulsed Power Transmission Cable

Power Loss and fusing current as a function of cable length for welding cables

WELDING CABLE SIZE	Resistance Ohm	Power Loss kW	Resistance for Melting Ohm	Fusing Current kA	Fusing Joule Integral A^2s	Temperature Rise/pulse °C
6	0.007857	3142.603224	0.040677778	99.16339501	1.967E+06	146.627
4	0.005441	2176.294746	0.028169905	119.161869	2.840E+06	101.541
2	0.003256	1302.294776	0.016856871	154.0428389	4.746E+06	60.762
1	0.002615	1046.187963	0.013541831	171.866528	5.908E+06	48.813
1/0	0.002055	822.1557928	0.010641964	193.8737909	7.517E+06	38.360
2/0	**0.00163**	**652.1908934**	**0.008441943**	**217.6751226**	**9.476E+06**	**30.430**
3/0	0.001283	513.1993915	0.00664284	245.3878732	1.204E+07	23.945
4/0	0.000991	396.2678846	0.005129282	279.2554931	1.560E+07	18.489
250 MCM	0.000815	326.0954467	0.004220971	307.8391106	1.895E+07	15.215
350 MCM	0.000593	237.1603249	0.003069797	360.9733539	2.606E+07	11.065
500 MCM	0.000403	161.0475336	0.002084595	438.0453998	3.838E+07	7.514

Assuming: Pulse Voltage (kV) = 10, Pulse Current (kA) = 20, Discharge time (μs)=200 and temperature raise per pulse given by $\Delta T = \frac{\varepsilon}{mCp}$

Pulsed Power Transmission Cable

- Based on resistive losses and temperature increase calculations we selected an AWG 2/0 cable, with an increase of only 15ºC per pulse for each 3m.
- Carried out electric breakdown test on three different insulations : Super vu-tron, Flex-A-Prene EPDM, Carolprene Premium EPDM.
- Constructed a Coaxial cable based on this AWG 2/0.

Plasma Blasting Probe

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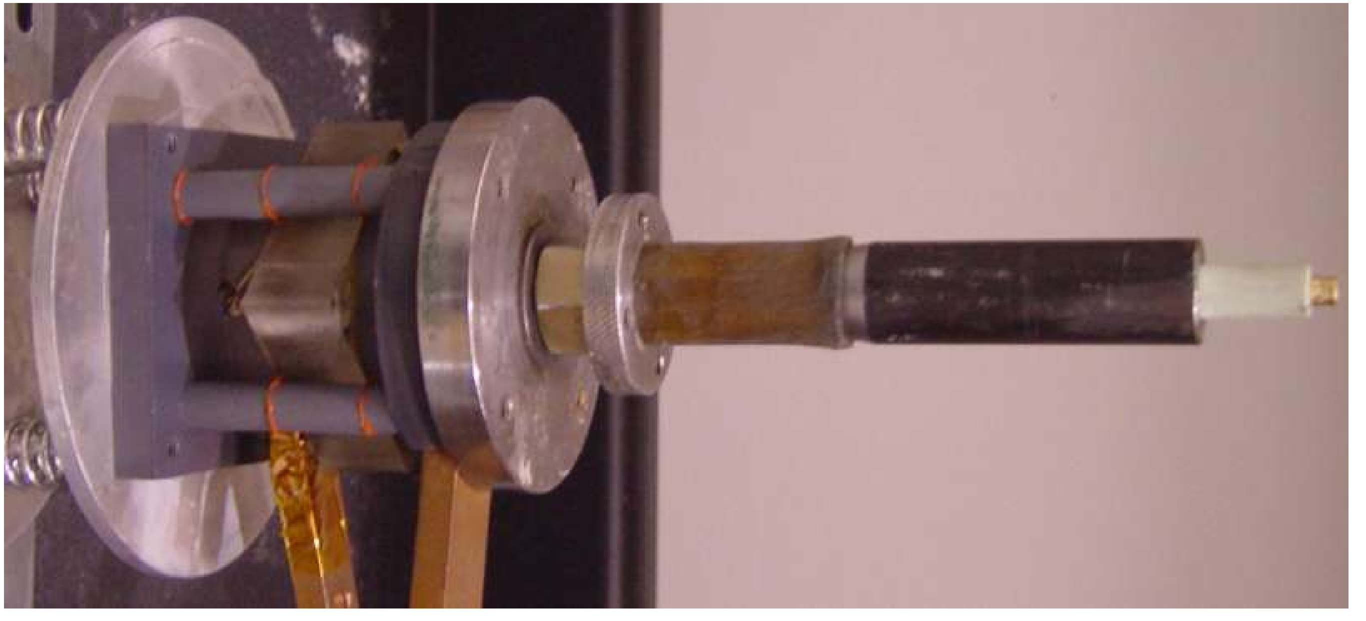
- Two concentric electrodes separated by a dielectric material
- Probe diameter: 25.4mm
- Lengths: 152mm and 305mm
- Probe inserted into a 26mm borehole filled with medium.



Charging Circuit Protection Box

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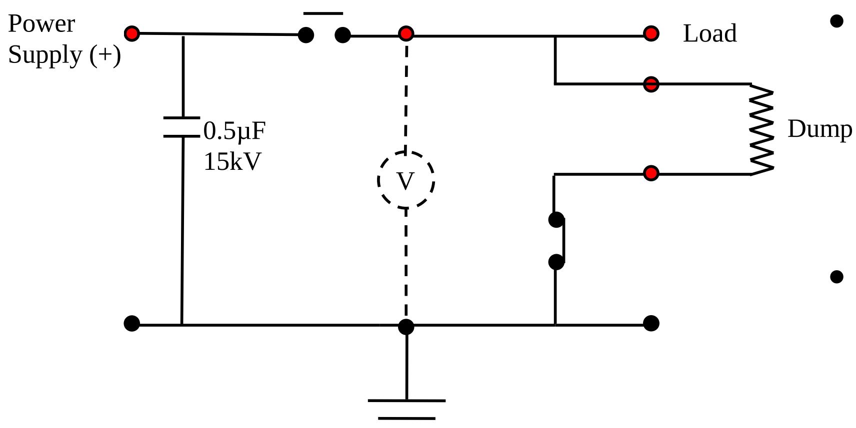
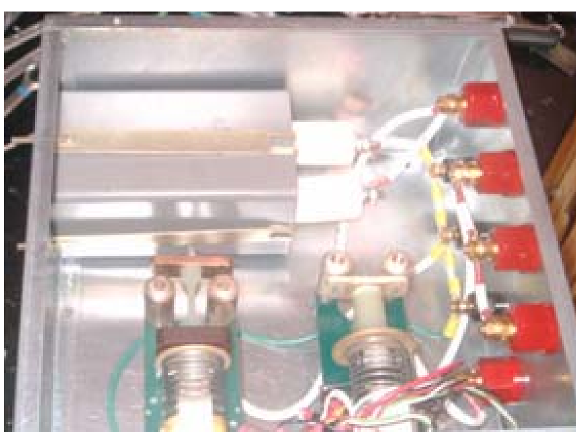


- Isolate and protect power supply from the high voltage and current capacitors pulse.

- Discharge the capacitor bank through the dump resistor in a controlled way.



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Power Supply

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Capacitor Charging Power Supply

- General Atomics CCS series
- 20 kV Maximum
- 12 kJ/sec avg. charge rate

Diagnostics

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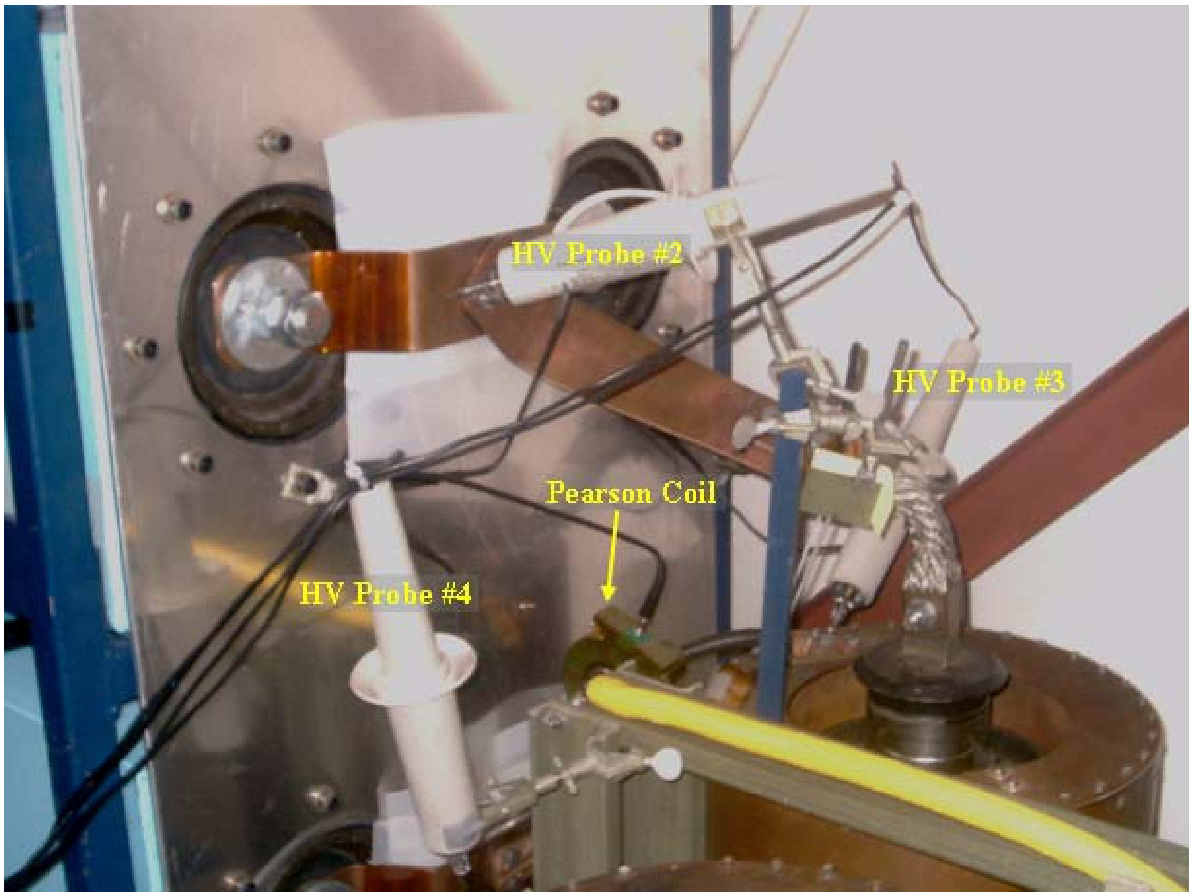

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Results

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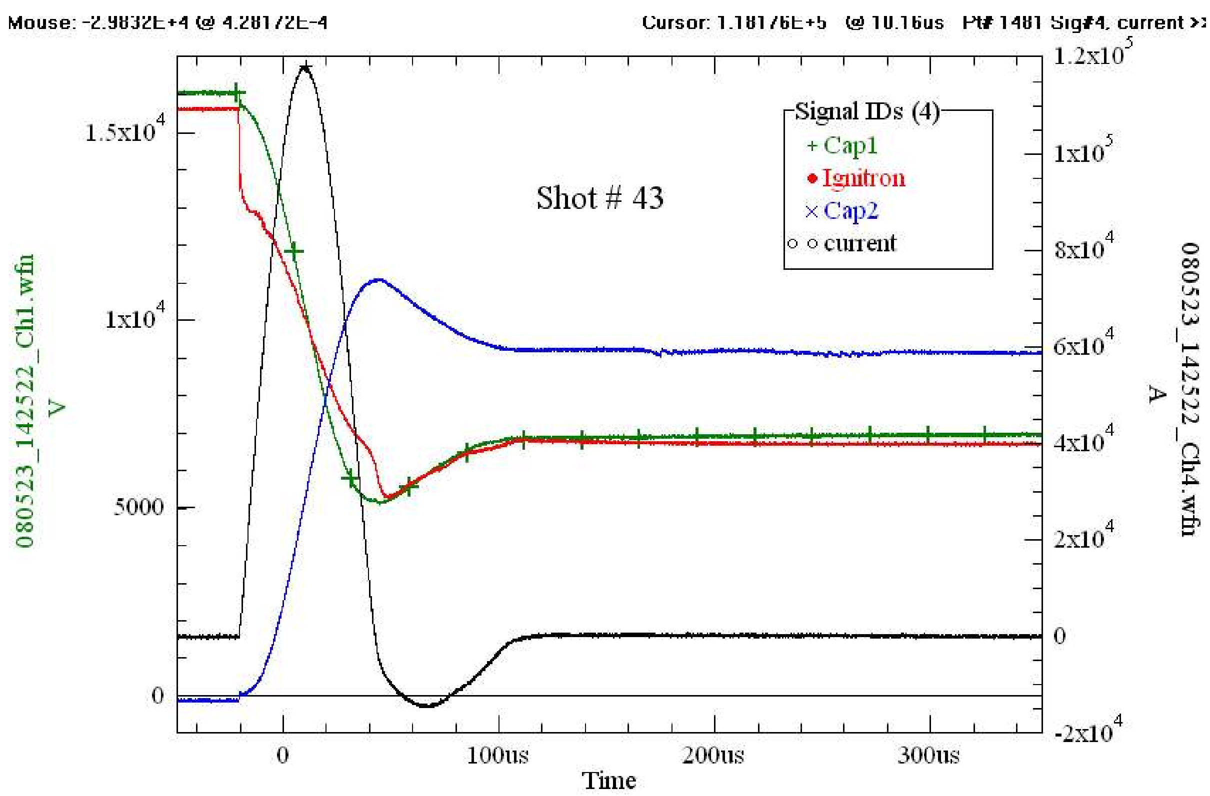
- Pulse rise times were around 15 μsec and pulse lengths on the order of 100 μsec were achieved



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Results

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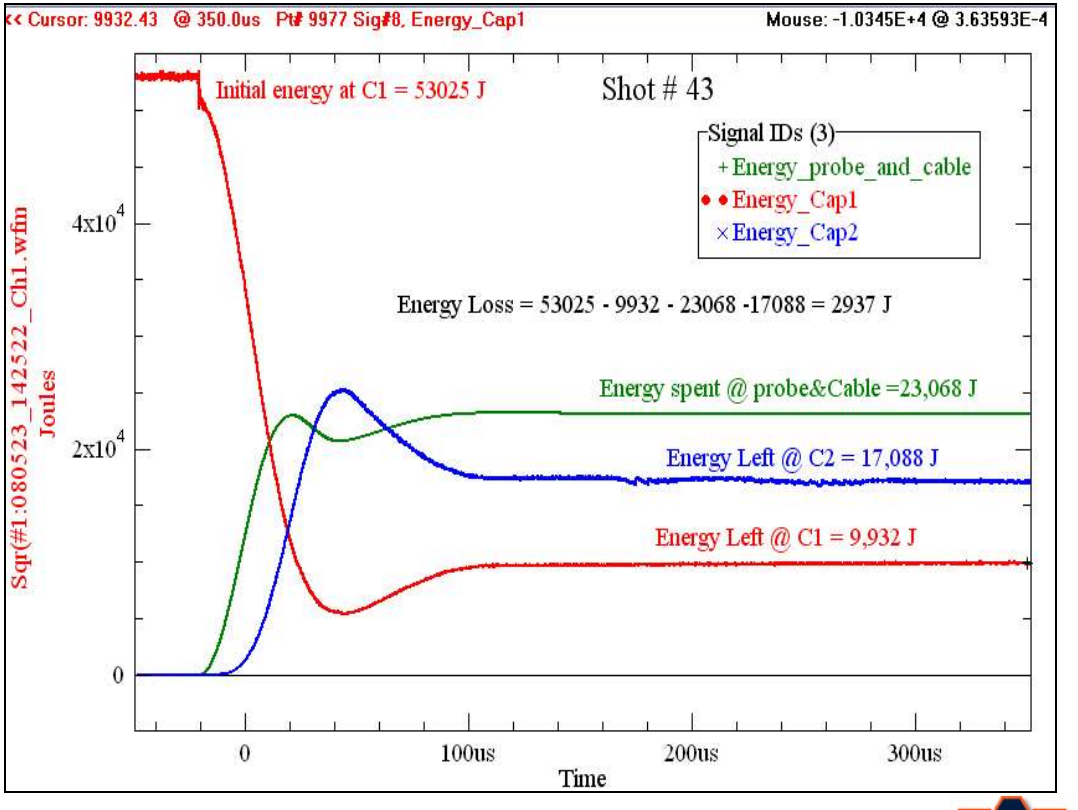
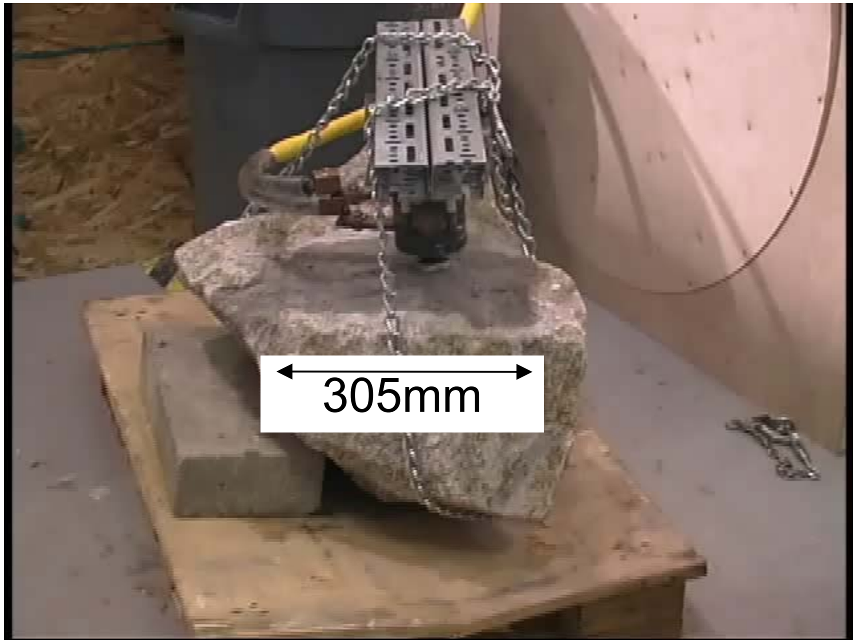
Example Test Result Summary

- 43% of initial energy was used to break the specimens.
- 32% of initial energy can be recuperated from Cap 2.
- 19% remained in Cap 1.
- 5% losses in cable, ignitron, etc.



Results

- Granite sample, 25 kJ pulse, 152mm probe



Results

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- Concrete Sample, 53 kJ pulse, 305mm probe.

Summary and Conclusions

- A prototype of plasma blasting system was constructed.
- Uses a capacitor bank in BM topology configuration charged slowly at low current (power), discharged rapidly at very high current breaking concrete and rocks.
- Scalable prototypes of the plasma blasting probes for electrically powered pulsed plasma rock blasting were designed and constructed.
- The blasting system is able to provide pressures well above the tensile strengths comparable to those of common rocks, i.e. granite (10-20 MPa), tuff (1-4 MPa) and concrete (7 MPa).

Summary and Conclusions

- The system was successfully tested by reducing concrete specimens into numerous fragments.
- Blasting probe net energy levels from 9 kJ to 23 kJ have been demonstrated and higher levels planned.
- Tests on concrete and granite rock test samples were presented.
- Various probe designs were tested and evaluated for effectiveness.
- Pulse rise times: ~ 10-15 μsec.
- Pulse lengths: ~ 100-200 μsec.

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Acknowledgements

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- Any opinions expressed are those of the authors and do not necessarily reflect the views of NASA.

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