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Z DRIVER POST-HOLE CONVOLUTE STUDIES UTILIZING MYKONOS-V VOLTAGE ADDER

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Abstract

The modern high current, high voltage pulsed accelerators utilize vacuum-post-hole convolutes to add the current of a number of parallel self Magnetic Insulated Transmission Lines (MITL) to a single one located very close to the centrally located load.

The reason of course of using several parallel MITL's to transfer the current pulse from large, ~1.5 m, radii to the 1-2 cm load is to reduce the transfer inductance. For example, the vacuum chamber of the 24-26-MA Z machine has a 1.45-m radius vacuum section containing four parallel conical MITLs merging into one 6cm radial disc MITL adjacent to the centrally located load via a double post-hole convolute array located at 7.62 cm from the axis.

Although special care has been taken to reduce the electrical stresses on the cathode hole surfaces in order to avoid electron emission, substantial current losses, 4-6 MA, are observed most probably due to plasma formation and the unavoidable magnetic nulls.

In the proposed experiments we will study the behavior of only one convolute using the MYKONOS-V driver. MYKONOS-V is a Linear Transformer Driver (LTD) voltage adder composed of 5 nominally 1-MA cavities connected in series. The voltage adder radial A-K cavity is deionized water insulated. The experimental set-up is designed in such a way to reach conditions on the convolute very similar to those existing on Z. Most importantly, in contrast to Z, it provides full view of the convolute for optical and spectroscopic imaging and gives the flexibility and freedom to study various options in an effort to reduce the convolute losses without affecting the day- to-day Z experiments. This is going to be a dedicated convolute study experiment. The hardware design, numerical simulations and proposed diagnostics will be presented and discussed.

I.INTRODUCTION

The Z accelerator is the most powerful pulse power driver in the world [1,2] (Fig.1). It utilizes conventional technology based on Marx generators, intermediate storage capacitors, laser triggered high voltage switches and water pulse forming and transmission lines. The Marxes, intermediate store capacitors and laser triggered 5-6 MV switches are located in a circular oil tank. The remaining pulse forming and transmission lines are inside a deionized water tank concentrically located and surrounded by the oil tank. The water tank encloses at its center the vacuum section. The walls of the vacuum chamber are composed of water–vacuum-insulating rings sandwiched between metal grading rings. The power pulse from the erected Marxes are compressed and transmitted into the center of the vacuum chamber by passing through two dielectric barriers: oil-water and water-vacuum. In order to generate the extremely high current, 23-25 MA, 36 independently triggered energy storage and pulse compression modules are necessary.

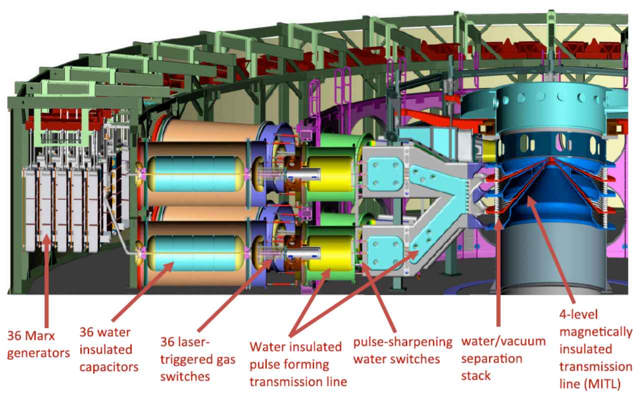

Figure 1. Side section of the Z machine identifying the various pulse-forming components.

The 36 pulses arrive in synchronism and add up in the water section just before entering into the vacuum section through 4 conical self magnetically insulate transmission lines. These transmission lines have a radius of approximately 1.5 meters. The four pulses of the four MITLS are again combined together with the aid of twelve double post-hole convolutes (Fig. 2). The post-hole convolutes, in order to reduce the inductance of the vacuum section, are located very close (7.8 cm radius) to the axis of the device where the load is placed.

The routinely utilized convolute assembly contains 12 double post-hole convolutes. Downstream of the convolutes is a circular bi-plate MITL transmission line which contains a coaxial cylindrical transmission line at its center. This final very short transmission line brings the power pulse into the load. For a more detailed description please see David Rose's and coworkers' paper on the Z machine [3]. Z has become a very versatile platform to study various aspects of high-density physics, including ICF, IFE, radiation effects, solar, planetary physics, astrophysics, and material behavior under extremely high pressures. It is impressive to note that despite the extremely large number of components and large likelihood of something to fail, the operation of the device is clock work reliable, firing one shot a day, every day. This is accomplished with the aid of a very skillful operational personnel and expert pulsed power and engineering support

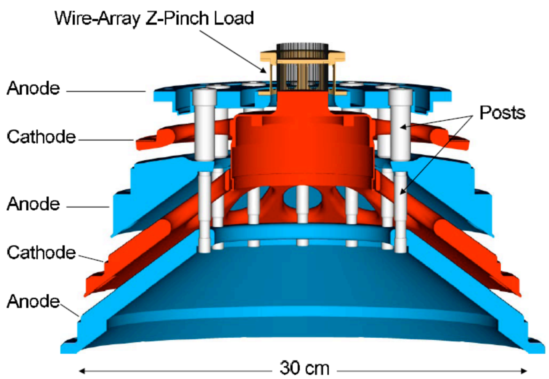

Figure 2. Side section of the Z 12 double post-hole convolutes symmetrically located around the axis of the central section.

Despite the fact that the behavior and performance of the various sections of the Z machine are well understood and the circuit and numerical simulations fairly accurately reproduce the experimental results, the observed convolute losses remain a mystery. LSP simulations have reproduced the losses by using the convolute gas desorption as a code tuning parameter [3]. M. Gomez [4] has done in situ a limited number of measurements. The accessibility of the convolutes to observation unfortunately is very poor because of their location at the center of the Z device. Hence the physics processes occurring in that region where extremely high fields are present is to a large extent unknown. This is why we were motivated to study the behavior of one of the post-hole convolutes in a surrogate and much smaller device, the MYKONS-V accelerator, which will provide practically unlimited observation capabilities. The experimental set-up is designed in such a way to reach conditions on the convolute very similar to those existing on Z. Most importantly, in contrast to Z, it provides full view of the convolute for optical and spectroscopic imaging and gives the flexibility and freedom to study various options in an effort to reduce the convolute losses without affecting the day- to-day Z experiments

In the next sections we describe the MYKONOS-V (section II) accelerator, the experimental setup to be attached at the front end of MYKONOS-V (section III) and finally the diagnostics to be utilized and proposed experimental measurements.

II.MYKONOS-V DRIVER

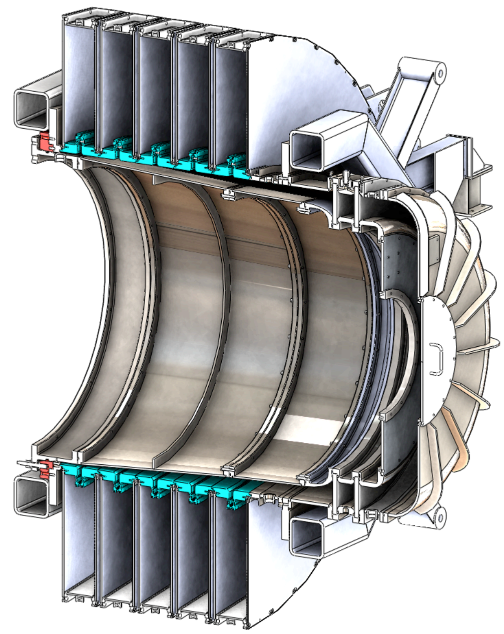

Figure 3. Side section of Mykonos-V driver.

Figure 3 shows a schematic side section of the device, while Figure 4 is a photograph of the device without the front end load.

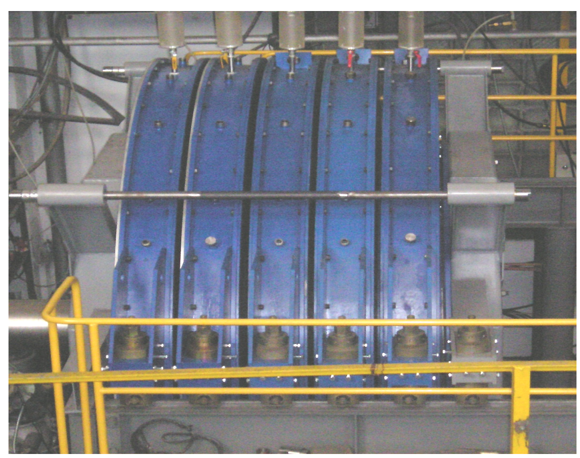

Figure 4. MYKONOS –V five stage assembly without the front load. Each stage is 20 cm long and 3 m in diameter.

MYKONOS –V is a voltage adder composed of five Linear Transformer Driver (LTD) stages. Each of these stages can in principle drive into a 0.1 Ω matched load a sinusoidal 100 ns, 100 kV, 1 MA pulse.

The LTD stages, in contrast with the conventional voltage adder stages where the pulse arrives from an outside pulse-forming network, enclose the entire pulse-forming network that generates the output pulse [5]. This pulse is applied across the insulator that separates the anode and cathode output electrodes (A-K gap) of the cavity.

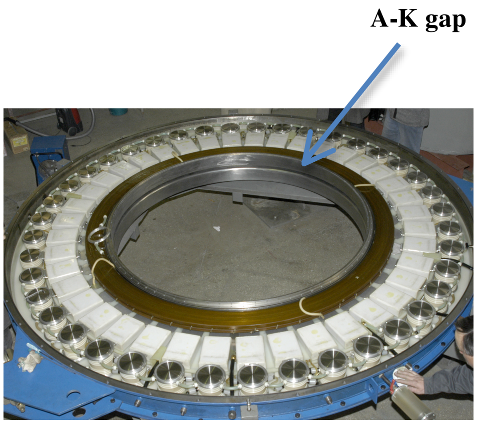

Figure 5. The 1-MA LTD cavity top lid and plastic insulator removed.

The cavity shape is similar to a flattened doughnut with the axial A-K gap at the center of the inside cylindrical surface [5]. In Fig. (5) we present the 1-MA LTD cavity. The top metal cover and the plastic insulator that insulates the charged parts from the cavity top wall are removed.
The cavity contains two circular arrays of 40 double-ended capacitors, 40-nF, 15-nH each especially developed for our LTD program. The bottom array is separated from the top by a ~1 cm plastic insulator plate. The top capacitors can be charged up to + 100-kV maximum charge and the bottom ones up to -100kV. Each pair of positively and negatively charged capacitors is connected in series through an individual gas switch. We call this subsection a brick. Therefore each cavity encloses 40 bricks. Presently, in order to eliminate air–bubble problems trapped at the top of the cavity, four bricks were eliminated at that location and the charging voltage is conservatively limited to +/- 90 kV to avoid arcing inside the oil. Now the matched load for each cavity is 0.13 Ω, and the current and voltage are 900 kA and 90 kV respectively.
Mykonos-V contains five 1-MA LTD stages connected in series. The cathode stalk diameter decreases from the first to the fifth stage in order to increase the impedance of the transmission line and keep the current constant through the entire device. The anode cylinder is formed by the central bore of the cavities and is insulated from the cathode stalk with deionized water. This makes the diameter of the cathode stalk matched to stage impedance 10% smaller and the transit time from stage to stage 9% longer than it would have been if we had vacuum insulation. These futures are very useful since they make the radial A-K gap at the beginning of the voltage adder more reasonable, and also the increase of the transit time is quite useful for pulse shaping.
The load is a liquid resistor of adjustable resistivity contained between two concentric polycarbonate cylinders [6]. Its length is 3cm and the average diameter is 1.7m. A recirculating system keeps the water solution at constant temperature during multi-pulsing. MYKONOS-V can be multi-pulsed up to 5 pulses per minute.

III.POST_HOLE CONVOLUTE EXPERIMENTAL SET_UP

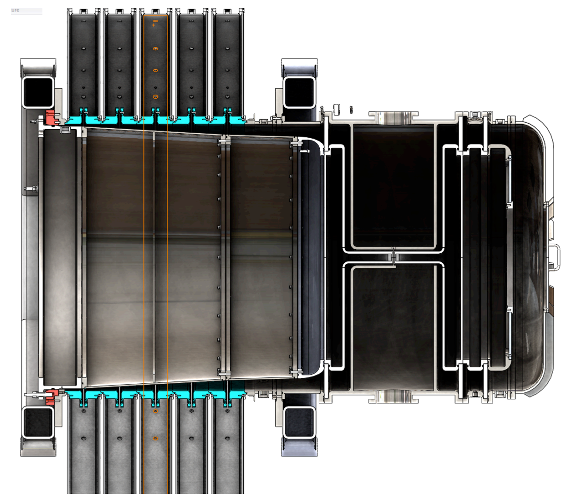

Figure 6. Side section of MYKONOS-V with post-hole convolute chamber attached on the front.

Figure 6 shows side section of MYKONOS-V with the post –hole convolute experimental hardware attached at the frond end of the device. A polycarbonate water vacuum interface takes the place of the annular resistor that now is relocated at the end of 60 cm long cylindrical vacuum chamber. Also a stainless steel plate is located just before the water vacuum interface to separate the inside of the cathode stalk that is open in the air from the vacuum chamber. In contrast with MYKONOS II [7,8] the interior of the cathode stalk is open to the air to reduce the total wait of the assembly. At the front, downstream from the water vacuum interface, a circular bi-plate transmission line connects to the coaxial transmission output line of the voltage adder. At about the middle horizontal diameter of the bi-plates the geometry converts into a strip line configuration. Namely, at the innermost circular cathode plate a triangular horizontal plate is attached which passes through a similar width slot through the anode plate. Two identical triangular plates are attached on the circular anode electrode above and below that slot. This way the pulse is transmitted from a bi-plate circular transmission line to a tri-plate strip line. The cathode electrode of the tri-plate has double walls to accommodate heating elements if necessary. Figure 7 shows a three-dimentional cut away of the assembly, and Fig. 8 shows a top view of the convolute region.

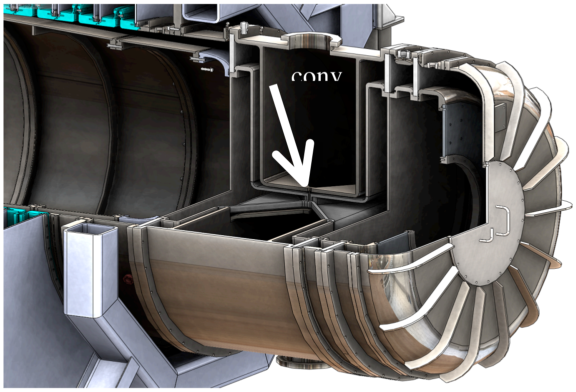

Figure 7. A three- dimentional cut-away of the assembly.

The post-hole convolute is located close to the downstream narrow edge of the tri-plate (Fig.). The middle electrode of the tri-plate has a tubular hole through which passes the post connecting the two anodes. The power flow transmission is converted again from tri-plate to bi-plate. The bi-plate transmission line downstream of the convolute has the same dimensions and shape as upstream and connects to the load with a coaxial transmission line identical to that located at the entrance of the vacuum chamber.

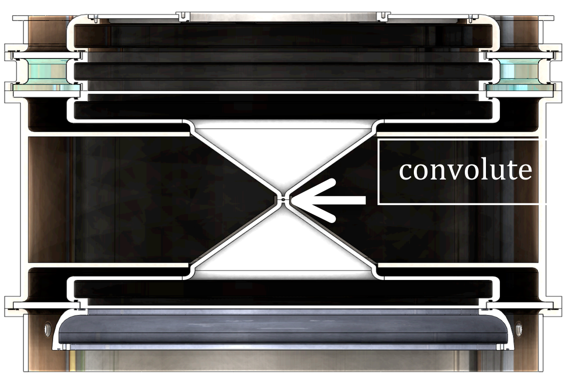

Figure 8. Top view of the triangular convolute plates.

Except for the triangular bi-plate, the transmission line downstream from the convolute is a mirror image of the one upstream. The gaps of the circular bi-plate are of the order of 4 cm to avoid electron emission, while the gap of the strip lines are one cm in order to induce electron emission and operate as self-magnetic insulated transmission lines (MITL) close to the convolute. The vacuum chamber has large horizontal and vertical windows to facilitate assembly and easy optical observation of the convolute region

The cathode of the tri-plate line near the convolute has a replaceable rectangular section to facilitate changing the hole diameter as necessary.

Current measuring monitors (B dots) are located on the circular bi-plate anodes and cathodes and on the strip lines before and after the convolute. A number of optical fibers are inserted in the vacuum chamber to collect light emission at different angles relative to the convolute plane. The fibers are connected to a spectrograph located at an adjacent to the Z facility. The Mykonos laboratory is located at an adjacent to the Z accelerator building.

Detailed analytical calculations of the inductance resistance and transition times for every component of the experimental assembly were done. Those values were utilized as input into the set-up circuit model. With the aid of SCREAMER circuit code the current and voltage at the convolute and load were estimated. Figure 9 and 10 present the voltage and current on the 3 nH liquid resistor load.

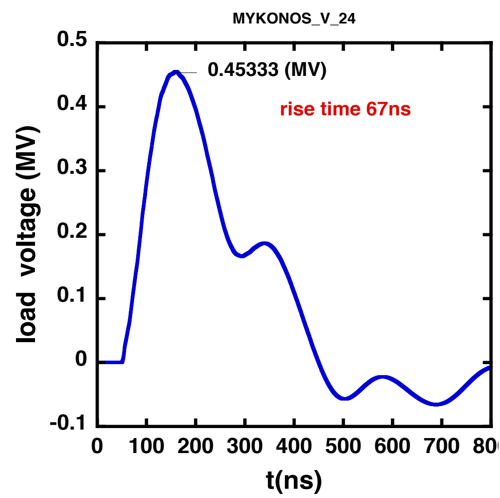

Figure 9. Load voltage.

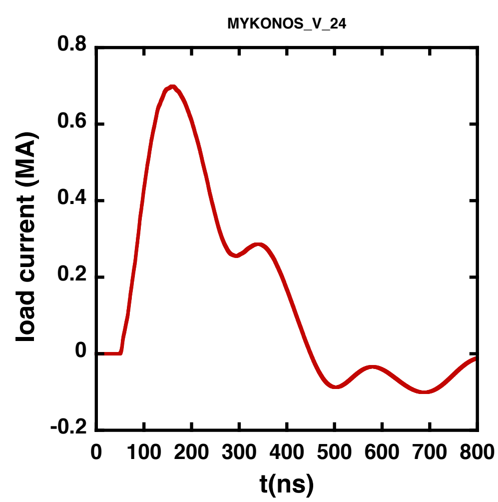

Figure 10. Load current

Table 1. Comparison of Z with MYKONOS-V convolute parameters.

	MYKONOS -V	**Z**
Magnetic field on post surface	55 T	38 T
Magnetic field on the hole surface	28 T	15.6
Electric field on the post surface	2.6 MV/cm	2.8 MV/cm
Electric field on the hole surface	1,3 MV/cm	1.17 MV/cm
Current density around the hole	0.35 MA/cm	0.54 MA/cm
Voltage	0.45 MV	2 MV
Current per convolute	0.7 MA	1.5 MA

At the first stage of experimentation a convolute with a sufficient large hole will be selected to measure the current transmission without convolute losses, a kind of null experiment. In parallel a digital camera will observe the convolute for possible light emission. Similar monitoring will be done with the spectrometer.

Gradually we will decrease the hole diameter until we observe substantial convolute losses as well as light emission. The final measurements will be done with the post-hole convolute parameters approaching the linear current density and electric field condition existing at the actual Z convolutes (see Table I). To achieve those conditions, a very precise centering of the post inside the hole will be necessary since the radial gap should be of the order of 3 mm.

Following the loss measurements, we are going to apply a number of techniques to possibly reduce or eliminate losses. First we will heat the electrodes above 100^0 C to clear out adsorbed water on the electrode surfaces. This can be accomplished in two ways. The simplest one is heating the electrodes by multi-pulsing MYKONOS-V. Another way is attaching heating tapes on the electrodes. If the losses disappear with heating this will be a proof that the losses are due to the water vapor being ionized and partially shorting the convolutes. If the losses decrease but not completely eliminated this will suggest that other additional contaminants are adsorbed on the electrode surfaces. The spectroscopic analysis of the plasma emitted light hopefully will give us information about the composition of the desorb materials. Then we will utilize RF discharge cleaning for further more thorough surface cleaning. To pinpoint the source of electron emission and plasma formation we could coat selected areas with tracer elements for spectroscopic analysis.

The feasibility of utilizing on Z the most successful current loss elimination technique will be analyzed and eventually implemented on the actual Z convolutes.

IV. SUMMARY AND FUTURE PLANS

Following a number of modifications of the 1 MA cavities [7,8], it is projected that MYKONOS-V will be assembled and operational by the time of the present conference. A number of commissioning shots of the device will be necessary before it will be available for experimentation. One of the experiments to be installed on the front end of the voltage adder will be the presently described convolute study work.

V. ACNOWLEDGEMENT

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VI. REFERENCES

[1] L. Liljeby, C. Petit-Jean-Genaz, and J. Poole, "Preparation of Papers for EPAC'98," Stockholm, (1998)

[1] D. H. McDaniel, M. G. Mazarakis, D. E. Bliss, J. M. Elizondo, H. C. Harjes, H. C. Ives III, D. L. Kitterman, J. E. Maenchen, T. D. Pointon, S. E. Rosenthal, D. L. Smith, K. W. Struve, W. A. Stygar, E. A. Weinbrecht, D. L. Johnson, and J. P. Corley, "The ZR Refurbishment Project," in Proceedings of the 5th International Conference on Dense Z-Pinches, Vol. 651 (2002), pp. 23-28.

[2] M. E. Savage, L. F. Bennett, D. E. Bliss, W. T. Clark, R. S. Coats, J. M. Elizondo, K. R. LeChien, C. Harjes, J. M. Lehr, J. E. Maenchen, D. H. McDaniel, M. F. Pasik, T. D. Pointon, A. C. Owen, D. B. Seidel, D. L. Smith, B. S. Stoltzfus, K. W. Struve, L. K. Warne, J. R. Woodworth, C. W. Mendel, K. R. Prestwich, B. Shoup, D. L. Johnson, J. P. Corley, K. C. Hodge, T. C. Wagoner, P. E. Wakeland, W. A. Stygar, " An Overview of Pulse Compression and Power Flow in the Upgraded Z Pulsed Power Driver." in Proceedings of the 16th IEEE Pulsed Power Conference (2007) p. 979-984.

[3] D. V. Rose, D. R. Welch, E. A. Madrid, C. L. Miller, R. E. Clark, W. A. Stygar, M. E. Savage, G. A. Rochau, J. E. Bailey, T. J. Nash, M. E. Sceiford, K. W. Struve, P. A. Corcoran, B. A. Whitney, "Three- Dimensional Electromagnetic Model of the Pulsed- Power Z-Pinch Accelerator," Physical Review Special Topics – Accelerators and Beams, vol. 13, (no. 010402), pp. 1-12, (2010).

[4] M. R. Gomez, M. E. Cuneo, R. D. McBride, G. A. Rochau, D. J. Ampleford, J. E. Bailey, A. D. Edens, B. Jones, M. Jones, M. R. Lopez, M. E. Savage, D. B. Sinars, W. A. Stygar, " Spectroscopic Measurements in the Post-Hole Convolute on Sandia's Z-Machine ." in Proceedings of of the 18th IEEE Pulsed Power Conference (2011) p. 688- 695.

[5] A. A. Kim, M.G. Mazarakis, V.A. Sinebryukhov, B.M. Kovalchuk, V.A. Visir, S.N. Volkov, F. Bayol, A.N. Bastrikov, V.G. Durakov, S.V. Frolov, V.M. Alexeenko, D. H. McDaniel, W. E. Fowler, K. LeChien, C. Olson, W.A. Stygar, K. W. Struve, J. Porter, and R.M.

Gilgenbach, Phys. Rev. ST Accel. Beams **12,** 050402 (2009).
[6] Michael G. Mazarakis, Steve Cordova, Ron Gilgenbach Gilgenbach, David L. Johnson, Alexander A. Kim, Keith J. LeChien, Joshua J. Leckbee, Finis W. Long, M. K. Matzen, Randall G. McKee, John L. McKenney, Bryan V. Oliver, John L. Porter, Vadim A. Sinebryukhov, William A. Stygar, David M. VanDevalde, Kevin Ward, John W, Weed, Joseph R. Woodworth, Dillon H. McDaniel, Kenneth W. Struve, " Linear Transformer Driver (LTD) Development at Sandia National Laboratory", in Proceedings of the 17th IEEE Pulsed Power Conference (2009) p. 138- 145
[7] M.G. Mazarakis, M.E. Savage, W.E. Fowler, L.F. Bennett, M. Jones, F.W. Long, M.K. Matzen, D.H. McDaniel, R.G. McKee, J.L. McKenney, J.L. Porter, B.S. Stoltzfus, K.W. Struve, W.A. Stygar, J.R. Woodworth, A.A. Kim, V.A. Sinebryukhov, K.L. LeChien, P. Wakeland, K. Ward, J.G. Puissant, T.F. Chavez, P.A. Jones, D.J. Lucero, G. Natoni and S.A. Lewis, " Experimental Validation of the First 1-MA water-Insulated MYKONOS LTD Voltage Adder", in Proceedings of 18th IEEE Pulsed Power Conference (2011) p. 625- 628
[8] M. G. Mazarakis, A. A. Kim, M. E. Savage, W. E. Fowler, K. R. LeChien, V. A. Sinebryukhov, F. W. Long, D. J. Lucero, M. K. Matzen, D. H. McDaniel, R. McKee, G. Natoni, J. L. Porter, S. A. Roznowski, K. W. Struve, W. A. Stygar, P. E. Wakeland, "Operating the First Water-Insulated Mykonos II LTD Voltage Adder" (Plenary talk) in Proceedings of the 17th International Symposium on High Current Electronics (2012) Tomsk, Russia to be published.