Status on the Sphinx Generator Based on 1 Microsecond Current Risetime LTD Stages[1]

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Abstract – Sphinx is the new name of the facility developed for soft X-ray production at Centre d'Etudes de Gramat (CEG), France. This facility is based on the ECF2 generator which was designed as a 1–3 MJ, 1 µs rise time, 5–10 MA current driver. In this paper, we present a detailed view of the technology used for the capacitor bank. Some details are also given for the central vacuum part and for the Z-pinch load. The capacitor bank is based on the 1 µs LTD technology; it now stores 1 MJ with 12 parallel branches and 8 LTD stages per branch (each stage charged under 50 kV). We plan to have within the next 2 years, 3 MJ stored energy with 16 branches, 10 LTD stages per branch (charged under 70 kV). Improvements made on the LTD stages and on the trigger system are presented. The modularity of this driver and the design of central vacuum part allow to test different schemes: flux compression up to 2003 [1] and direct drive Z-pinches now. We give details on the mechanical arrangements and some examples of experimental results.

1. Generator Overview

Sphinx is a 1 µs inductive storage generator used at Centre d'Etudes de Gramat, France, for K-shell radiation source studies (Fig. 1).

Fig. 1. Sphinx generator before May 2004 16 m diameter, 3 m height

Previously used to study the magnetic flux compression amplification scheme (Ref. [1]), this generator is now used in direct drive mode, with no amplification system, for driving *Z*-pinch loads. A simple electrical equivalent circuit is given in Fig. 2.

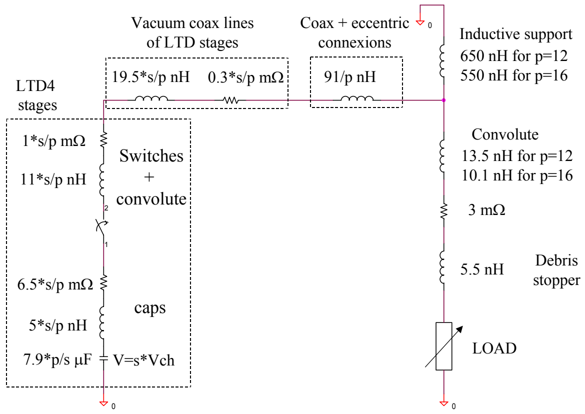

Fig. 2. Equivalent electrical circuit of the Sphinx generator where *p* is the number of branches in parallel, *s* is the number of LTD stages in series per branch and *V*ch is the charging voltage

Until May 2004 12 LTD branches ($p = 12$) of 8 LTD stages ($s = 8$) with charging voltage 50 kV were used, giving about 1 MJ stored energy (Tab. 1).

Table 1. Stored energy (in MJ) as a function of *V*ch and generator configuration

*V*ch (kV)	50	60	70
1 single stage	0.010	0.014	0.019
12 lines with 8 stages/line	0.95	1.37	1.86
16 lines with 8 stages/line	1.26	1.82	2.48
16 lines with 10 stages/line	1.58	2.28	3.10

From May 2004, 16 branches are connected to the central part. The charging voltage is planned to be increased up to 60 kV at the beginning of 2005 and 70 kV before summer 2005. The number of stages can also be increased up to 10 per branch. The currents profiles calculated for these post-May-2004 configurations are given in Fig. 3 and are to be compared with the experimental ones with 12 branches @ 8 stages/branch configuration.

LTD stages are connected in series to obtain a positive polarity output (inner conductor is anode). To change the polarity, each stage can be rotated around its vertical axis.

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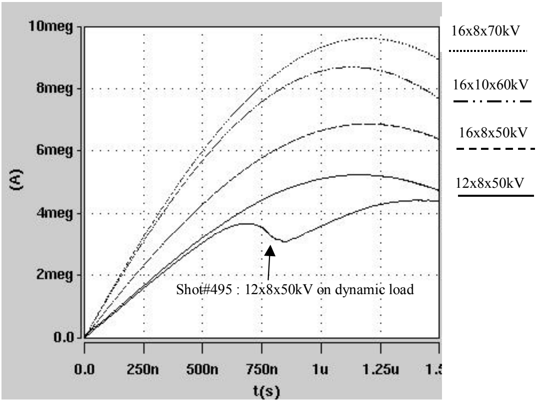

Fig. 3. Measured currents for 12x8 stages at 50 kV configuration and predicted currents for next generator configurations (with 5.5 nH dummy load, except for experimental curve of shot#495 with a dynamic wire-array load)

2. LTD Stage Overview and Improvements

Each LTD stage is composed of two Haefely-Trench capacitors (3.95 μF–10 nH–13 mΩ–90 kV maximum charging voltage), two Patented multigap multichannel switches [3], a central-stage-convolute, a steel magnetic core and a polyethylene vacuum interface (Fig. 4).

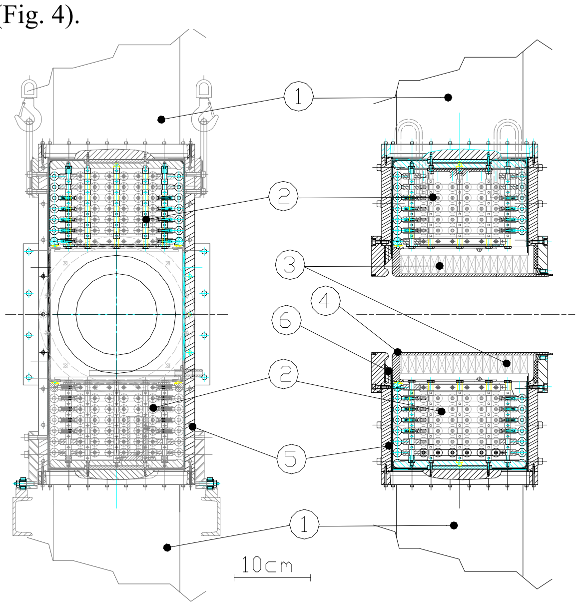

Fig. 4. LTD stage design: 1 – capacitor; 2 – stage-switch; 3 – magnetic core; 4 – convolute; 5 – Aluminum body; 6 – vacuum interface

The capacitors were specifically designed for life time more than 2000 shots at 600 kA maximum output current and 50% voltage reversal at 90 kV charging voltage.

The 1 μs LTD stages used for Sphinx have been improved from the original LTD03 version detailed in Ref. [4] from several points of view.

The new multigap multichannel switches (see patent Ref. [3]) operate with dry air at atmospheric pressure and without oil. The number of gaps has been increased to 7 (Fig. 5) but the polyethylene insulation between the spherical electrodes and the return current electrode (aluminum body of the stage) has been reduced to 3 mm, thus reducing the total inductance of the stage from 22 nH (Ref. [4]) to 16 nH. Other major improvements from the LTD03 version is the dielectric insulation of the HV cables connections into the switch, the insulation of the HV cables through the stage body (see patent Ref. [5]) and the design of trigger electrode which is made of a bared HV cable going through the spherical electrodes of the switch.

Today Sphinx generator routinely operates at 50 kV to conduct direct drive Z-pinch studies with no risk of prefires or stages damage. Nevertheless some tests with stages charged at 60 kV show prefires; so improvements must still be done for reliable operation up to nominal 75 kV charging voltage. Possible axes of reliability improvements concern the trigger (1 single row of balls should be triggered instead of the 6), reduction of electrostatic discharges during HV charging and optimization of the gap between balls. The improved version of the stage should be validated end of 2004.

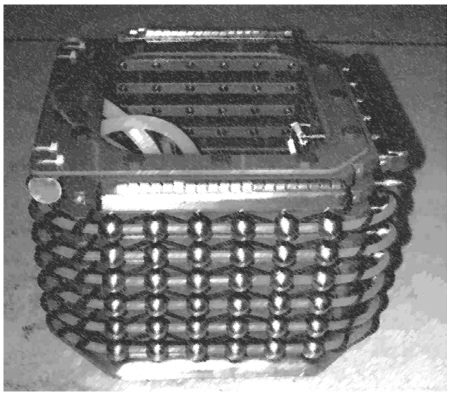

Fig. 5. Patented LTD04 switch of Sphinx generator. 18 channels; 7 gaps

3. Premagnetizing and Trigger Systems

The magnetic core of each LTD stage is made of 17 rings of steel tape. They are premagnetized via 8 (1 for 2 branches) independent pulsed generators which inject about 1.5 kA with a 60 μs rise time before the shot; this allows to withstand a volt·second integral of 47 kV·μs for each core during the main pulse before core saturation.

To avoid any significant current into the load before the main pulse, a surface closing switch is used, located on the ground side of each coaxial LTD branch (Fig. 6). It is designed to withstand the ~ 12 kV of the premagnetizing sequence and then flashover when the main pulse appears.

The trigger system fires each LTD switch at the time the premagnetizing current peaks. Triggering operation of the switch is based on a pulsed distortion of gaps electrical fields created by a controlled discharge of the HV trigger cable going through the balls. The complete system is based on a 2 steps switches cascade shown on Fig. 7. The “trig-trig” switch and the 16 “trigger” ones are identical and are based on the same technology as LTD switches. Trigger cables are charged in about 30 s with an independent high voltage power supply. This trigger system – when charged under 55 kV – allows to fire each LTD stage of each branch simultaneously with a global spread of about 50 ns (Fig. 8).

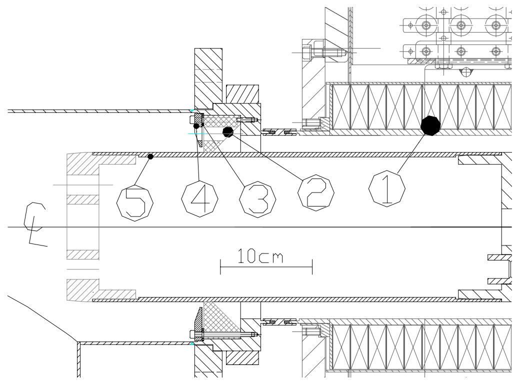

Fig. 6. Closing switch located on ground side of each LTD vacuum coaxial line: 1 – LTD stage and external (cathode) conductor; 2 – Rexolite ring; 3 – Plastic ring; 4 – Copper ring; 5 – internal (anode) conductor

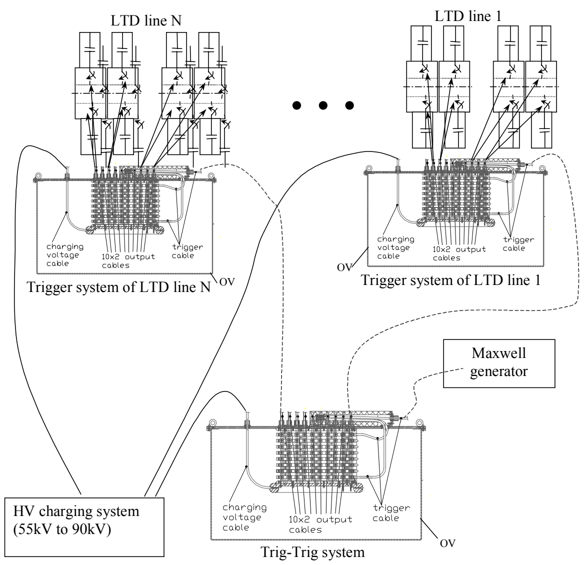

Fig. 7. Trigger system from the Maxwell pulse generator (model 40168, 50 kV) to each switch of the LTD stages

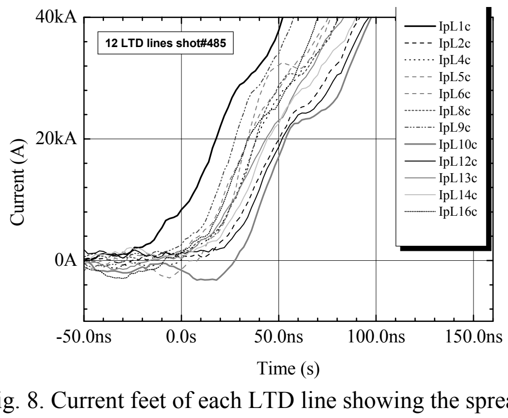

Fig. 8. Current feet of each LTD line showing the spread

The overall jitter will be reduced when charging voltage of LTD stages will increase; it can also be reduced by increasing the charging voltage of the trigger system itself: tests shows that 65 kV leads to about 35 ns spread.

4. Vacuum Power Flow

Analysis of losses within the vacuum parts of the generator presented here is based on current profiles measurements for shots with a wire-array load and a 12 branches of 8 stages charged at 50 kV generator configuration. The major conclusion of the shots made during the past 12 months is that about 11% of total current delivered by the generator is lost between the LTD stages and the load (Fig. 9). Among these 11%, about 4% are lost in the inductive rod support of the convolute (about 150 kA/3.6 MA at compression time). A Rogowsky loop placed at the output of a LTD branch compared to another Rogowsky loop placed at the ground side of the same branch show a 6% loss within this zone including the LTD stages coax and its 120 cm long extension, the eccentric connection and the 30 cm small coax connected to convolute (see Figs. 6 and 10). Losses on the 12-branches-convolute itself seem to be quite negligible (difference between $I_{convolute}$ and $I_{up} \sim 0$ on Fig. 9).

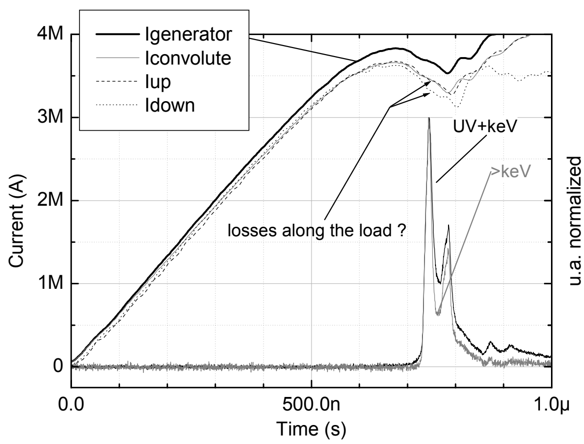

Fig. 9. Currents of the Sphinx generator for shot #502: delivered by the LTD lines ($I_{generator}$), just after the central convolute ($I_{convolute}$), before and after the load (I_{up} & I_{down})

The last 1% current loss giving the 11% total may be lost due to the impedance of the premagnetizing cables (60 Ω charged under about 40 kV/stage).

Figure 9 also shows that about 3% of current shall be lost along the length of the dynamic Z-pinch load at the compression time (see Ref. [6]).

These estimations show – up to now – no major problem of losses in vacuum during the complete implosion phase of the load; this analysis will continue and be improved shots after shots, especially after the generator will fire with 16 branches.

We also work on the analysis of vacuum flashovers occurring after the pinch time to see how these phenomena can affect the maintenance cycle of the generator, and possibly how they can be controlled to protect LTD stages from ringing.

5. Central Vacuum Chamber and Load Region

The new design of the central part is shown in Fig. 10. The inductive rods support the 16 branches and the central convolute. The debris stopper (angled coaxial line) and wire-array load are connected to the output of this convolute. In this configuration wire-array is at positive polarity (positive for wire array, ground for return current electrode)

Until May 2004, wire-array was at negative polarity (ground for wire array, positive for return current electrode). This is the main difference between the two configurations (except the fact that 16 branches are connected to the convolute instead of 12 before May 2004).

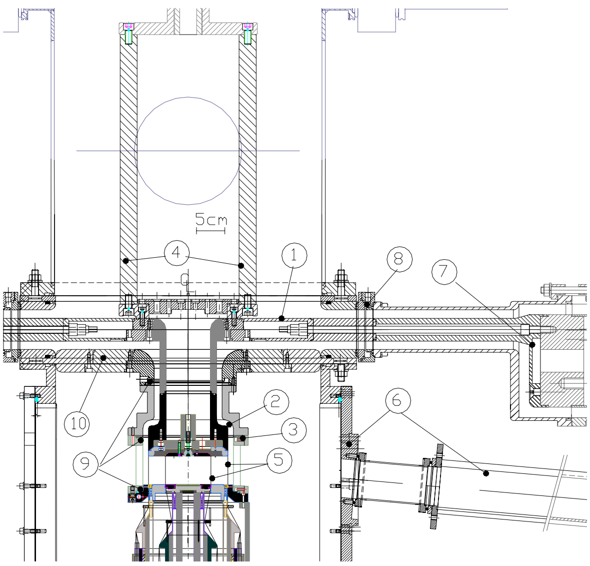

Fig. 10. New central vacuum part connected with the 16-branches generator (post-may 2004): 1 – 16 branches convolute; 2 – debris stopper; 3 – return current; 4 – inductive rods; 5 – nested wire arrays; 6 – diagnostic port and vacuum line; 7 – eccentric connexion of LTD line output; 8 – Rogowsky coil; 9 – Bdot probes locations; 10 – Disc at ground voltage

Sixteen ports are available for diagnostics in between 2 LTD branches. Inside the 40 cm diameter vacuum chamber, some of these ports will be used for higher fluence irradiation of samples. The new design shown on Fig. 10 needs no more inductive support in this zone and gives ground voltage on the return can and surrounding, which make more easy the integration and shielding of cassettes for the radiation effects experiments.

First experimental results obtained with simple wire-arrays and nested wire-arrays direct-drive aluminum loads during mid-2003 to mid-2004 period are presented within this conference (Ref. [6]). Those results show more than 10 kJ of energy radiated above 1 keV, with pulse widths of 30–50 ns for a total radiation yield around 100 kJ.

References

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