# SPHINX Machine Diagnostic Package for Characterization of 800ns Implosion Time Aluminum Nested Arrays [1]

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**Abstract – The SPHINX machine based on microsecond LTD technology is used in direct drive mode to implode nested aluminum wire arrays (see[1]). In order to study the source a panel of diagnostics has been installed. Load current characterization is given by upstream Rogowski coil and Bdots, downstream Bdots and Bdots inside arrays; load voltage is estimated via LdI/dt of the inductive load support. Return current can is apertured so that sixteen radial line of sight and an axial one can be used. Visible optical images of the source are obtained thanks to 1D optical streak cameras with radial resolution and 2D optical framing camera. X-ray images of the pinch are made with filtered time-integrated multi pin-holes camera and a time resolved x-ray camera ; 1D imaging is also given by an array of 16 time resolved Xray detectors. X-ray pulse is studied thanks to photoconducting diamonds detectors (PCDs), vitreous carbon cathode x-ray diodes (XRDs), filtered gold bolometer for x-rays above 1keV and bare Nickel bolometer for X-UV. Spectroscopy is done with time integrated crystal spectrometer (KAP) with axial resolution and a time resolved spectrometer. XRD are used for axial total power estimates. Piezoélectric quartz gauges and VISAR interferometer are used for radiation effects measurements**

## 1. Introduction

Sphinx facility (1µs rise time, 5 MA )[2][3] has been developed for soft X-ray production at Centre d'Etudes de Gramat (CEG), France; First experiments were performed with Aluminum nested wire arrays Z-pinches for k-shell production. K-shell yield up to 25 kJ and a FWHM of the x-ray pulse of about 50 ns was obtained with 800 ns implosion time and 4MA peak current[1]-[4]-[5]. The parameters are outer array radius of 7 cm, inner array radius 3.5 cm, height 5 cm, wire diameter 10.4 µm, number of outer array wires between 198 and 120, and number of inner array wires between 99 and 50. A schematic illustration of the load and the relative orientations of the diagnostics are given in figure 1.

In order to study and to improve load implosion and characteristics of the x-ray pulse, a panel of diagnostics had been fielded and constantly improved. This paper is a review of the diagnostic package available on Sphinx in September 2006.

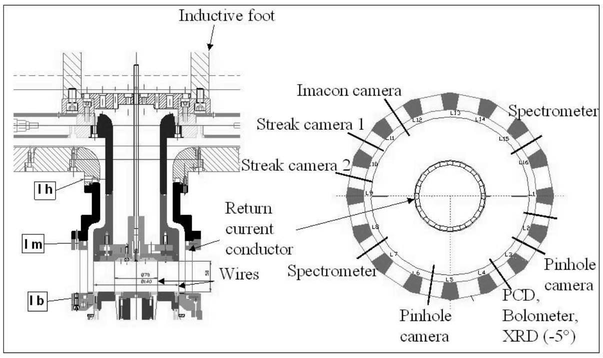


Fig.1 : Load configuration. The 16 lines are connected to the convolute, the inductive support (foot) is above it and the load below. Also shown are main diagnostic position; Ih, Im, and Ib are b-dot probes.

## 2. Load current and voltage characterization

The current flowing into the load is a critical parameter for studying the wire array implosion. We decided to put redundant measurements in order to improve reliability of the data obtained. First the current flowing in the sixteen lines of the generator is measured thanks to Rogowsky coils (one for each line) just upstream of the convolute. The support of the convolute creates an inductance of 525 nH parallel to the load. The current flowing in this inductive support (called inductive foot) is also obtained thanks to one Rogowsky coil and one b-dot probe. The sixteen signals of the lines are then added and the inductive foot current is substracted in order to unfold the load current. This way of doing makes the assumption that there is no power flow issue and therefore no losses between the convolute and the load. To confirm these point (Fig. 2), four b-dot probes are placed between the convolute and the load and two others are located downstream the load. These probes are calibrated individually before each shot; a Fourier analysis is then used to unfold the signal. The three different altitudes used are a way to confirm that there is no power flow issue between the convolute and the load.

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Load voltage can therefore be inferred from measurement of current flowing through the load and through the inductive support :

$$L_{foot} \cdot \frac{dI_{foot}}{dt} - L_{convolutetopinch} \cdot \frac{dI_{pinch}}{dt} =$$

$$= \frac{dL_{pinch} \cdot I_{pinch}}{dt} = U_{pinch} \qquad (1)$$

On dedicated shots, small b-dot probes (called μbdots) are placed between the array and inside the inner array. These probes consist of a single loop of copper wire surrounded by a dielectric material. The height of probes was 2 out of the cathode surface. Results obtained are shown on Fig. 2.

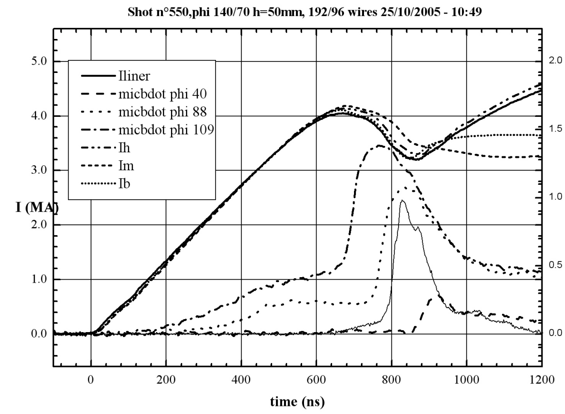


Fig.2 : Comparison of signals obtained from rogowsky coil and b-dots probe on shot 550. Signals obtained from μbdots probe.

## 3. Visible optical images

The implosion is diagnosed thanks to two 1D optical streak cameras. These two cameras are Thomson TSN 506N and are placed on LOS 9-10 and 10-11. The presence of the return current conductor does not allow to see the whole implosion as some part are masked due to the wall of the return current conductor (RCC). The goal of the second camera is to see the outer array start of the implosion. Therefore an optical system with mirror is used to increase the field of view of the camera. However the quality of the image is altered. In order to prevent the image to be perturbed by light reflection or light noise, bandpass filters have been tried. These filters were selected thanks to AASC to let only light resulting from aluminum emission to be selected. This way of doing was tried but not maintained as the light level became too small to obtain enough information of the load behaviour.

The implosion is also studied thanks to a 2D optical framing camera. This diagnostic (IMACON) gives eight frames (Fig. 3) of the implosion with a 10ns exposure time. The frame timing is selected before the shot thanks to 0D calculations of the implosion time. The load is viewed through a window placed on the vacuum chamber. PMMA and glass material had been tested for this window. PMMA gives better results as glass windows become opaque at pinch time.

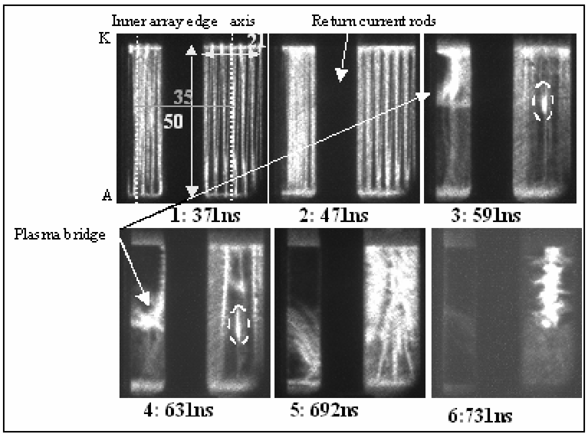


Fig.3 : Framing camera images showing wire initiation. This diagnostic allows to better understand the axial features of the implosion

## 4. X-ray images

The stagnated pinch is diagnosed thanks to time integrated pinholes images. The camera consists of five pinholes from 50 μm up to 200 μm in diameter and Kodak Tmax film. A different filter is put on each pinhole to select the spectral range of interest.

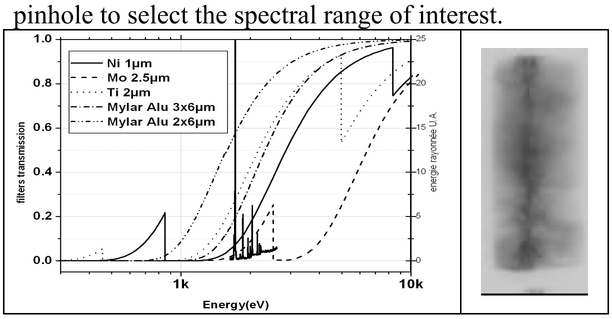


Fig. 4 : Filters used on pinholes camera and pinholes images of the pinch for shot 565 with 2 layers of 6 μm of aluminized mylar.

A time-resolved x-ray camera is now under installation on Sphinx. It consists of an MCP camera with four gold strip lines. The strip lines can be gated at four different times giving the timing resolution. The minimum width of the gate is 2 ns. Pinhole array with selected filters will allow to make up to four images of the source on each strip line that is to say at each selected time.

Two zipper array provided by AASC are now installed on Sphinx. They consist of an array of 16 IRD Silicon pin diodes. The vertical gap between each diode is 5 mm. A nine meter line of sight and a slit placed at about 3 meters from the pinch gives the magnification needed for having only two to three mm of the pinch seen per diode. Therefore the delays between signals given by these 16 diodes are representative of the zippering of the pinch. This diagnostic will allow to study and to control axial homogeneity of the pinch implosion.

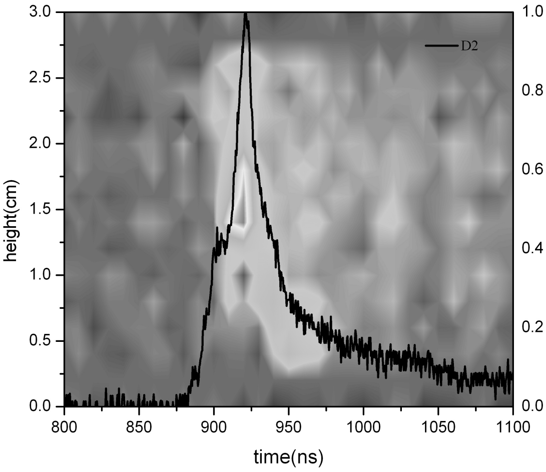


Fig.5 : Result from zipper array compared with PCD signal for shot 572. A zippering of the pinch is observed with a start of the pulse near the cathode (top) and a more emissive region at the center of the pinch

## 5. X-ray pulse characterization

Two bare Nickel bolometers are used to infer the total yield. Three gold bolometers filtered with 8 μm of Kapton give the k-shell yield. These detectors are located at a range of about 5 meters in order to reduce the fluence on the element. One line of sight (2 gold bolometer, 1 Nickel ) has a –5° angle from the horizontal, the other one (1 gold, 1 Nickel ) a +5° angle. The detector heads are protected with 1ms-fast valves. Angle, range and fast valves allow to protect detector from debris. The bolometer elements are manufactured and characterized at Sandia Labs. The level of noise generated by Sphinx generator is low enough to make it easy to obtain quite noise free data. Therefore this diagnostic is considered on Sphinx as the first reference to infer yields.

Five PCDs are fielded one a five channel head protected by a fast valve. These detectors have been cross-calibrated on Sphinx i.e. results of PCDs filtered by 8μm of Kapton have been compared to the bolometer results. The normalized responses of gold bolometer filtered by 8 μm of Kapton and PCDs with the same filter are actually quite identical. After this calibration phase, filters have been selected. This filter set consists of 4μm Kimfoil, 8μm Kapton, 24 μm Kapton, 87.5 μm Kapton, and 250 μm Kapton. It allows to use these PCDs to do wide band spectrometry by subtracting detector response, to infer pinch temperature thanks to the most filtered three detectors located on the aluminum continuum, and to obtain accurate measurement of the k-shell power.

Fig.6: PCDs, bolometer and XRDs used on Sphinx

## 6. Spectroscopy

Two time-integrated crystal spectrometer is used on each shot. Signal from the source is reduced thanks to two layer of 6 microns of aluminized mylar. A slit is placed between the source and the crystal to allow spatial resolution of the spectra ( an horizontal slit is used for axial resolution ). The slit is replaced by a 9% transmission mesh when no spatial resolution is needed. The crystal used are convex KAP (100) with radius of curvature of 200 mm. The spectra is obtained on a Kodak Tmax film. Unfold of the spectra consists of film scanning on a calibrated scanner, calculation of lines position thanks to ray-tracing software, correction of filter transmission, crystal reflectivity and film response. For these two last point a constant reflectivity is taken as the crystal has not been calibrated yet and a bibliographic data are used for the film response. A time resolved spectrometer provided by AASC has just been fielded on Sphinx. It will use TlAP crystal at first order for aluminum shots and second order for Argon shots. Ten Si pin diode will be put at the line position to give temporal resolution.

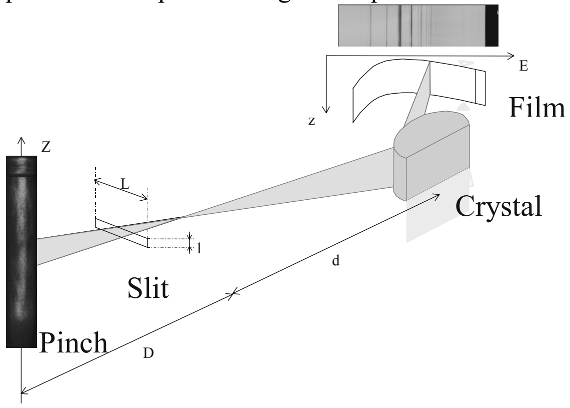


Fig.7 : Schematic illustration of time integrated crystal spectrometer system used on Sphinx

## 7. Axial total power

In order to obtain information about the axial power radiated by the source, a dedicated line of sight has been installed. A diagnostic hole of 5 mm in diameter is made through the bottom electrode (anode). A five channel head protected by a fast valve is then placed at a range of 3 meter . No angle was needed for the line of sight as tests had proved that detectors were protected enough from hot gases and debris thanks to the fast valve. Two carbon XRD, filtered with 0.5 µm of Mylar and a bare Nickel bolometer are put on this head. The bolometer gives a reliable measurement of the total axial yield emitted through the hole. Integral of XRD signal is then fitted to the bolometer result. XRD signal is then multiplied by this factor to deduce the axial power.

## 8. Radiation effects measurements

The x-ray source optimized for Al k-shell is used to do radiation effects studies on relevant materials. Rear face response of irradiated samples is diagnosed thanks to piezoelectric quartz gauge developed at CEG. A filter of 50 µm of Lithium prevents the sample to be irradiated by UV emission. Lithium is selected because its transmission does not vary during the whole x-ray pulse even if it is heated by the absorbed energy. As Lithium is a very reactive material (metal quickly oxides in air ), the stack Lithium filter/sample/quartz gauge has to be prepared and conserved in a neutral gas atmosphere ( Argon ). Therefore a specific assembly has been developed (Fig. 8); it allows to prepare the stack separately and to keep it in an hermetic box under Argon gas. This box and its support are installed in the vacuum chamber in front of the pinch. When the level of vacuum is correct, a shutter opens the box in order to allow irradiation of the sample. This last operation is done at least two hours before the shot to avoid any problem with the Argon gas relieved near the load.

Visar interferometer is also used for radiation effects studies. The interferometer used on Sphinx is a two channel one from VALYN ( VMBV-04 ). The laser is a Verdi 5W with a wavelength of 532 nm. The velocity per frange (VPF) is set to 100 m/s which is the lowest one available with this model. New interferometer with lower available VPF will be soon fielded to obtain better resolution on the range of interest.

## 9. Conclusion

Sphinx machine diagnostic package has been constantly improved since the start of Z-pinch experiments at CEG. This effort of better characterization and understanding of the source will be pursued in the future with integration of an XUV spectrometer, a framing XUV camera, and X-pinch radiography.

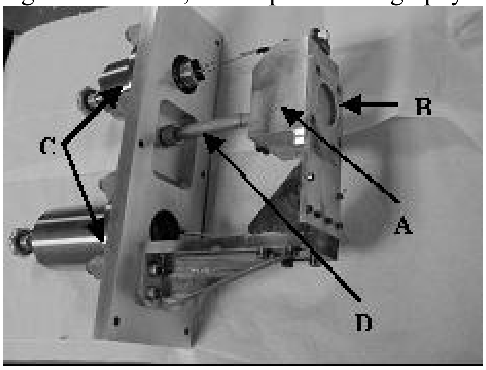


Fig.8: Radiation effects assembly ready to be installed on the vacuum chamber of the machine. The stack Lithium filter/sample/quartz gauge is located on the hermetic box (A), the shutter piece (B) is removed to allow irradiation, this operation is made in vacuum thanks to (C), data goes to the digitizers through cable (D)

**Acknowledgment**

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## References

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[5] H.Calamy et al, "Wire Array Z-pinches on Sphinx Machine: Experimental Results and Relevant Points of Microsecond Implosion Physics," in *AIP Conf. Proc.*, vol. 808, pp. 15-20, 2006.