“CAMSHAFT” BUNCH KICKER DESIGN FOR THE ALS STORAGE RING*

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Abstract

ALS is a 1.9 GeV third generation synchrotron light source that has been operating since 1992 at Lawrence Berkeley National Laboratory. There are two typical modes of operation of the ALS storage ring. In multibunch mode, the ring is filled to a current of 400 mA in 276 consecutive bunches with a single "camshaft" bunch located in the middle of the 52 bucket gap (h=328). Twice each year, ALS operates in "two-bunch" mode for periods of two weeks delivering 20 mA of average beam current in two diametrically opposite bunches to a small group of users requiring light pulses at lower rates. We plan to build a fast kicker system that will supply single bunch light to users during multibunch operation by displacing the orbit of the camshaft bunch at a prescribed frequency (every N turns). Realization of this project will increase ALS beam availability to multibunch users by at least 10%. This paper will describe the hardware design (pulse generator and beam deflection device) and the test results of the prototype kicker unit.

INTRODUCTION

There are generally two different ways to modify the trajectory of the camshaft bunch in the ALS storage ring.

The first method uses a single kicker to put the camshaft bunch at a permanent closed orbit that is different from the rest of bunches in the ring. The main technical challenge of this method is the required 1.5MHz kicker repetition rate (ALS storage ring revolution frequency).

By adding more kickers along the ring, one could more precisely shape the global orbit of the camshaft bunch. This method has a few advantages such as a flexible kicker frequency and the fact that the camshaft bunch trajectory distortion could be localized for a specific group of users without disturbing the beam in other parts of the ring. Currently there is only one location in the ring where we can locate a kicker constraining us to the single kicker method.

Given our minimum transverse stay clear, pulse length and repetition rate, a simple analysis shows that a strip transmission line kicker is the most effective solution.

PULSE AMPLITUDE REQUIREMENTS

In the transmission line type kicker two pulse generators operating in push-pull mode generate the plane wave which propagates along the kicker lines.

The deflecting force experienced by the beam is the combined effect of the electric and magnetic forces generated by the propagating TEM mode.

For the beam traveling in the same direction as the pulse:

$$F_\perp = eE_\perp - ec\beta B_\perp \tag{1}$$

where: $F_\perp$ -transverse deflection force
$E_\perp$ -transverse E-field strength
c -speed of light
$B_\perp$ -induction of the transverse B-field
β -speed factor ($\beta = v/c$)

The relationship between E and H field for the TEM mode in vacuum is described by equation (2)

$$\frac{E_\perp}{H_\perp} = Z_0 = \sqrt{\frac{\mu_0}{\varepsilon_0}} \Rightarrow E_\perp = \frac{B_\perp}{\sqrt{\mu_0\varepsilon_0}} = B_\perp \cdot c \tag{2}$$

For highly relativistic ALS electron beam equation (1) shows zero deflection for beam and pulse moving in the same direction.

For the beam traveling in the opposite direction to the kicker pulse the deflecting forces due to the electric and magnetic fields are equal (for β=1) and they add up.

$$F_\perp = eE_\perp + ec\beta B_\perp = 2eE_\perp \tag{3}$$

During the passage along the kicker electrodes the beam gains transverse momentum:

$$\Delta p_\perp = 2F_\perp \cdot \Delta t = \frac{4eV_g}{d} \cdot \frac{l}{c} \tag{4}$$

Taking into consideration that:

$$\frac{\Delta p_\perp}{p} = \tan\Theta \cong \Theta \text{ and } E = p \cdot c$$

the required amplitude of the kicker pulse on each plate equals:

$$V_g = \frac{E \cdot d \cdot \Theta}{4 \cdot l \cdot g} \tag{5}$$

where: E -beam energy (in eV)
d -distance between kicker plates
Θ -deflecting angle
l -kicker length
g -geometry factor for long flat electrodes [2]
g=tanh(πw/2d)
w -stripline width

For the required beam deflection angle of 80mrad, beam energy 1.9GeV, effective kicker plates spacing 1.5cm and kicker length 0.6m, the required voltage applied to each electrode should be about 950 V.

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KICKER DESIGN PROCESS

The transverse dimensions of the ALS camshaft kicker were optimized using ANSOFT Designer SV 2-D, a finite element electrostatic code [1]. The resulting geometry is shown in Fig.1A. Figure 1B shows the E-field value along the horizontal median line for the 1kV kicker pulse. The characteristic impedance of the kicker for odd-mode excitation (kicker operation mode) is Z_{ood} =50Ω. For even mode excitation (beam excitation) Z_{oe} =75Ω. The total power dissipated in each electrode is the sum of the power dissipated due to the power flow from the pulse and the beam image current flowing along the electrode surfaces. The finite element code, HFSS 3-d [1], was used to calculate the power losses in the stripline due to the generator current. The power losses resulting from the image currents were calculated analytically. Total losses for the worse expected scenario (1kV kicker pulse with 66ns length and 10% duty factor plus 500mA beam current with 20ps RMS bunches) are expected to be less than 1.5 W per electrode.

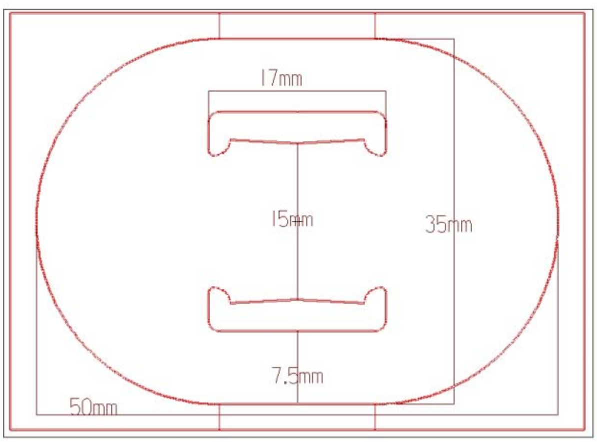

Fig.1A

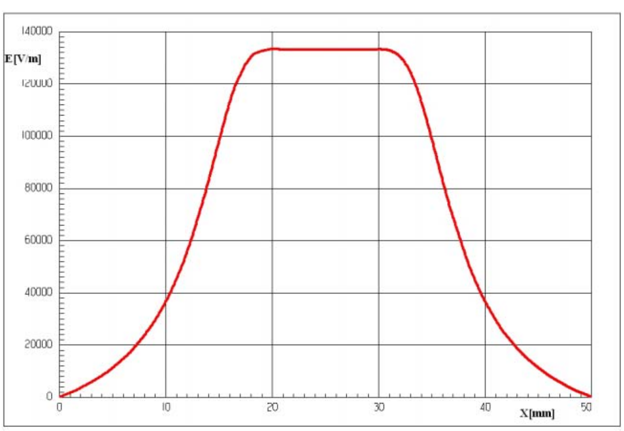

Fig.1B

Each electrode will be made of copper plated molybdenum and will be attached by two ceramic studs to the kicker cover plates (see Fig.2). The kicker will use HN type CERAMSEAL vacuum feedthroughs welded to the kicker cover plates. To insure low electrical resistance the inner conductor of each feedthrough will be brazed to the striplines.

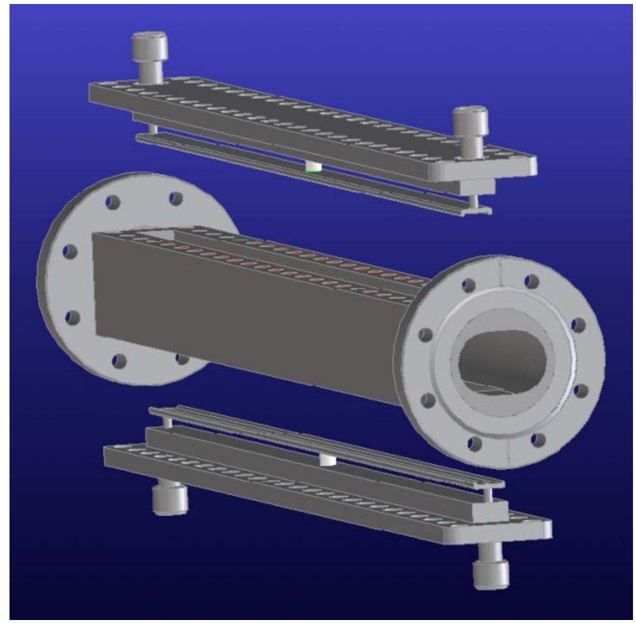

Fig.2

KICKER PULSE AMPLIFIER

DEI's (Directed Energy, Inc.) recently developed DE-series high power high voltage MOSFETs opened up the possibility of building a very simple pulse amplifier powerful enough to fulfill the camshaft bunch kicker requirements. The device of choice was the DE275X2 102N06A push-pull RF power MOSFET. We took advantage of the high substrate isolation voltage of this device (>2500V) and connected two transistors in series to obtain a 2kV pulse amplifier unit. The final stage is driven by a single DEI DEIC420 CMOS high speed current gate driver. The DEIC420 can source and sink 20A of peak current while producing voltage rises and falls of less than 4ns with minimum pulse widths of 8ns. The DEIC420 driver input is TTL and CMOS compatible. The simplified schematic diagram of the unit is shown in Fig.3.

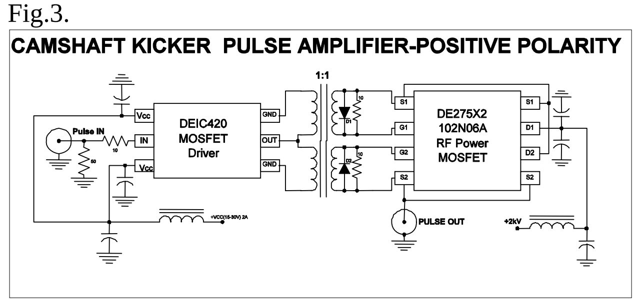

Fig.3

Because of the high power gain the final stage exhibited a tendency to oscillate. The circuit was stabilized with 10Ω resistors across each gate-source joint. The 1kV kicker pulse shape is shown in Fig.4.

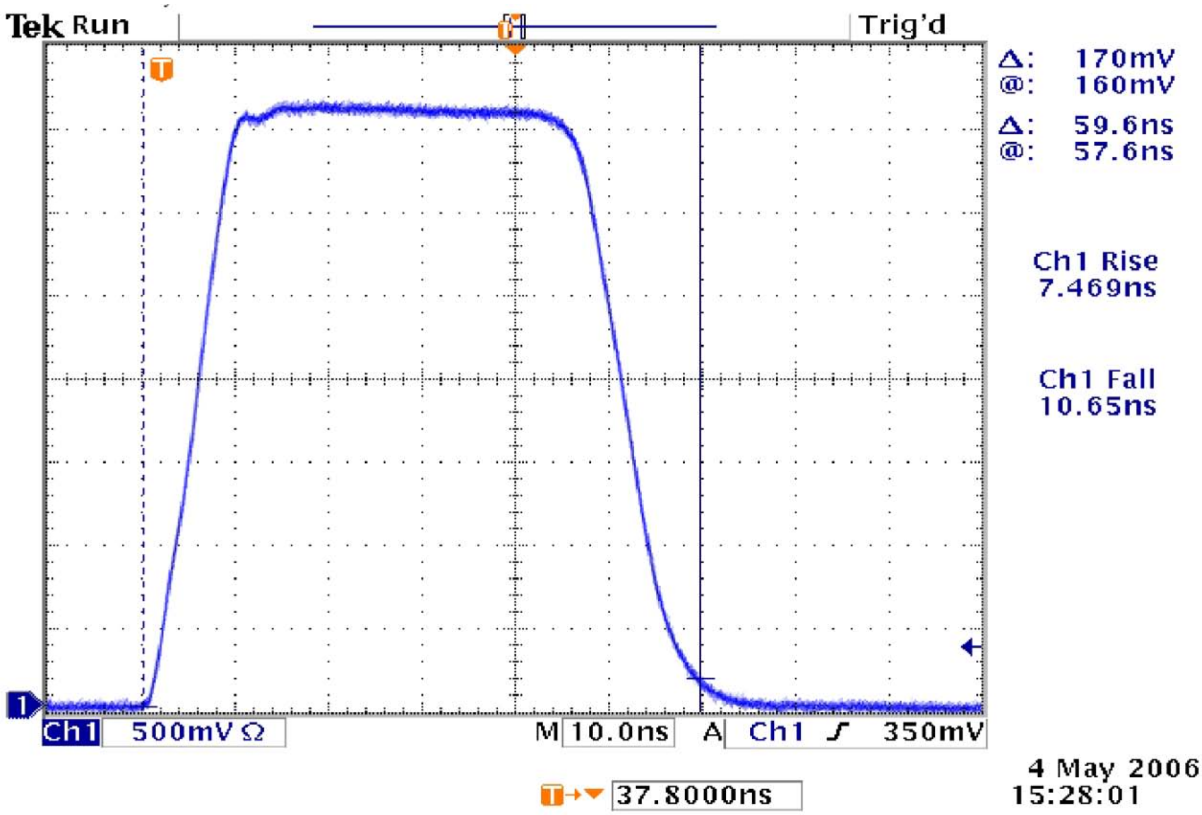

Fig. 4

We have successfully tested the prototype unit up to the 1.5 MHz repetition rate for 1kV output pulses. For higher pulse amplitude values, the repetition rate has to be lowered so as not to exceed the MOSFET and/or vacuum feedthroughs power handling capabilities. In the production unit we will solder the MOSFET case to the water cooled heat sink pushing its power handling capabilities up to the 1kW level.

CONCLUSION

The pulser part of the "camshaft" bunch kicker has been finished and the test results are presented in this paper. The project has been fully funded and the mechanical design of the stripline kicker is under way. We plan to build and install the new kicker in the ALS storage ring during next shutdown period (October 2006).

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