# IMPROVEMENT ON DOUBLE-EAGLE MACHINE SYNCHRONIZATION IN BOTH NEGATIVE AND POSITIVE MODES OF OPERATION*

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*Abstract*

Double-EAGLE has been serving as a reliable user radiation facility for the past 15 years. It is primarily a 2-MV, 4-MA, 85-ns pulse generator driving PRS or diode loads. It can be operated in short- and long-pulse modes for both positive and negative polarities to meet the requirements of the radiation front-end load. In the negative, short pulse mode, the generator delivers more than 4 MA current to the PRS load with a pulsewidth of about 85 ns, and in the long pulse mode, the generator delivers the same amount of current with a pulsewidth of 180 ns. In the positive short pulse mode, Double-EAGLE delivers multi-MA currents and 2 MV voltage into reflex diodes for user radiation. We have made substantial improvements in the reliability of Double-EAGLE by improving the operation of the water switches and the triggered gas switches. The machine can now operate consistently with better than 10 ns synchronization between the two EAGLE modules. We will present the Double-EAGLE facility operation data and capability.

## I. INTRODUCTION

Double-EAGLE is a 7-TW pulsed power generator [Reference 1] and has been on-line since 1984. Double-EAGLE consists of two EAGLE modules [References 2 and 3] whose outputs are combined in a vacuum region to drive the x-ray production load (Figure 1). During the past two years, we have fielded two types of loads: imploding plasmas for soft x-ray loads (< 4 keV) and reflex triode for harder x-ray loads (up to 2 MeV). We operate Double-EAGLE in its regular mode (short pulse with 85 ns voltage pulsewidth) for PRS radiation effects testing. We also operate Double-EAGLE in its long pulse mode (with increased voltage pulsewidth 180 ns) in support of the long-pulse implosion PRS research for Decade Quad. For hard Bremstrahlung x-ray production, we reverse the polarity of the Double-EAGLE output pulse (negative normally) and drive the symmetric reflex triode with positive short pulse. Double-EAGLE is able to deliver 7-TW to the load in the positive polarity as well.

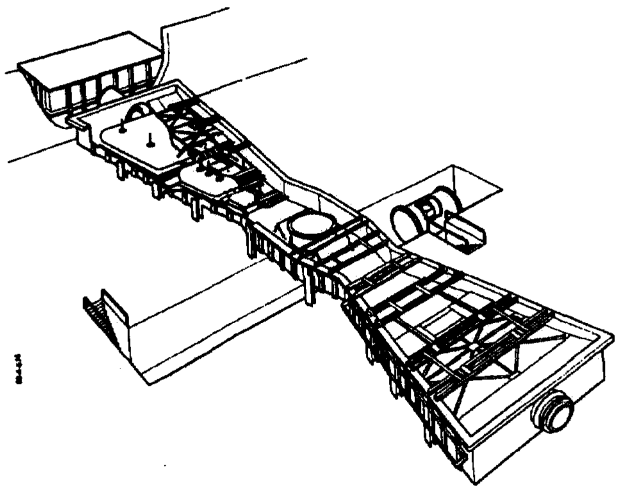

Figure 1. Sketch of the Double-EAGLE machine.

The machine power delivered to the load is optimized when the two EAGLE modules are perfectly synchronized. In practice, the loads on Double-EAGLE demand that the two module pulses arrive at the vacuum tube within a time window of 15 ns or less. Reliable operation of radiation sources strongly depends on the synchronization of the two EAGLE modules. We have made substantial improvements of the reliability of Double-EAGLE by improving the operation of the triggered gas switches and water switches. We can now operate Double-EAGLE consistently with the ideal timing of 10 ns synchronization or better between the EAGLE modules.

## II. APPROACH TO SYNCHRONIZING TWO EAGLE MODULES

The synchronization of Double-EAGLE is primarily determined by combination of the jitters of the EAGLE waterline switches (Figure 2), namely, the triggered gas switch (TGS), and two water switches downstream. The closure delays of the two water switches are self-compensating. An early closure of the first water switch (CPL) usually results in late closure of the water switch downstream (PFL). Conversely, a late CPL switch

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14. ABSTRACT
**Double-EAGLE has been serving as a reliable user radiation facility for the past 15 years. It is primarily a 2- MV, &MA, 85ns pulse generator driving PRS or diode loads. It can be operated in short- and long-pulse modes for both positive and negative polarities to meet the requirements of the radiation front-end load. In the negative, short pulse mode, the generator delivers more than 4 MA current to the PRS load with a pulsewidth of about 85 ns, and in the long pulse mode, the generator delivers the same amount of current with a pulsewidth of 180 ns. In the positive short pulse mode, Double-EAGLE delivers multi-MA currents and 2 MV voltage into reflex diodes for user radiation. We have made substantial improvements in the reliability of Double-EAGLE by improving the operation of the water switches and the triggered gas switches. The machine can now operate consistently with better than 10 ns synchronization between the two EAGLE modules. We will present the Double-EAGLE facility operation data and capability.**

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closure, in general causes an early PFL switch closure. The cumulative shot-to-shot wear on switch electrodes plays an important role in the switch performance in subsequent shots. The mega-ampere currents through the Double-EAGLE switches cause erosion and alteration in the shapes of the switch electrodes. In a normal shot, the current through the TGS amounts to 0.7 MA, while the water switches carry currents from 1 to 2 MA each. We have developed a procedure to use the running shot-to-shot machine behavior to guide the daily operation of the switches. We always start with the same mechanical conditions (as much as practicable) for the switches to be installed on both EAGLE modules. We periodically inspect and adjust the switch hardware to insure its mechanical consistency. In addition, we refine the switch geometry details to improve the switch jitter performance.

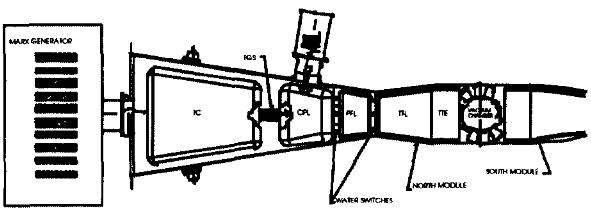


Figure 2. An EAGLE Module. There are three switches in the waterline. We short out the water switch between the PFL and TFL to produce long pulse (180 ns FWHM in voltage) to drive PRS loads in the vacuum chamber.

The two water switches in each EAGLE module have multiple-switch sites. We have increased the number of switch sites to share the current through the switch electrodes to reduce the shot-to-shot change in the switch geometry. We have also replaced the 304 stainless steel electrodes with electrodes made of harder material (17-4 PH stainless steel) to better maintain the switch geometry against the daily wear. To reduce switch jitter in positive polarity mode, we have redesigned the water switches to be negatively enhanced. The above modifications to the switch hardware have led to reproducible good jitter performance.

Low jitter operation of the externally triggered gas switch (TGS) in the water line is crucial to synchronizing the EAGLE modules. Each TGS in an EAGLE module gets a fast-rise 100 kV trigger pulse from the same trigger generator. We have rebuilt the trigger generator to make it capable of producing reproducible trigger pulses of good voltage and timing jitters. In the TGS itself, the jitter resides primarily in the triggered stage [Reference 4]. We have added a UV-illuminator to the trigger isolation gap of the TGS to ensure this gap's low jitter performance. We have also replaced all 304 stainless steel trigger electrodes with electrodes made of harder material (17-4 PH stainless steel) to better maintain the switch geometry against the shot-to-shot wear. We have also operated the TGS at the appropriate gas pressures (about 15 psi higher than the switch self-break pressure) to reduce timing jitter of the switch.

## III. PERFORMANCE DATA

Figure 3 illustrates the low jitter performance of the TGS trigger system. We overlay in this figure the trigger monitor waveforms from fourteen consecutive Double-EAGLE shots. The start time for the waveforms comes from the command trigger that fires Double-EAGLE. The trigger monitor on a TGS trigger cable is located at 320 ns away from the TGS. The consistent trigger arrival time for the 14 shots demonstrates the low jitter operation of the of the trigger generator. The closure of the trigger isolation gap is characterized by the first dip in the trigger waveform. The second dip in the waveform is due to the subsequent closure of the main trigger gap. The reproducible waveform from shot to shot clearly shows that we have achieved consistent low throughput jitter operation of the entire TGS trigger system.

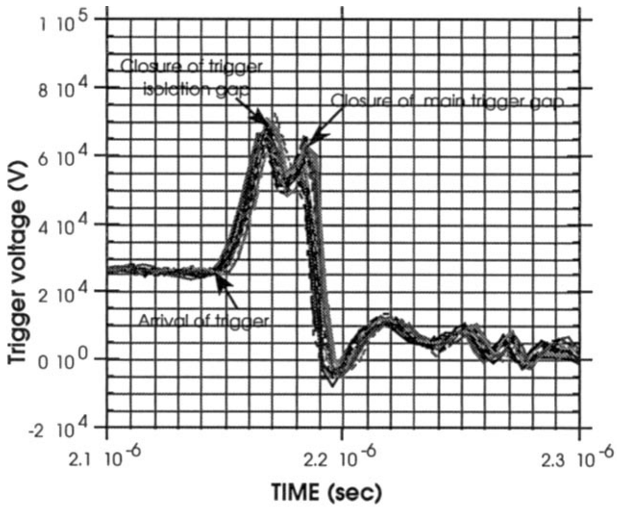


Figure 3. Overlay of trigger monitor waveforms from 14 consecutive shots illustrates the low jitter performance of the TGS trigger system.

Excellent TGS jitter leads to good module synchronization. Figure 4 is a plot of the module timing spread in nanoseconds as a function of the shot number with Double-EAGLE operated in its negative polarity mode. The module timing spread is the difference in pulse arrival times at the tube voltage monitors of two modules. The data in Figure 4 includes shots from recent short and long pulse PRS experiments at 60 and 65kV Marx charge voltages. In the short pulse mode, Double-EAGLE delivers about 7 TW power to the load at 60 kV Marx charge. About 80% of the shots in Figure 4 have ideal timing (10 ns spread or better) while more than 90% of the shots have timing at or better than 15 ns spread. This represents significant improvements in the machine synchronization over the historical standard that only 80% of Double-EAGLE shots could synchronize within 15 ns.

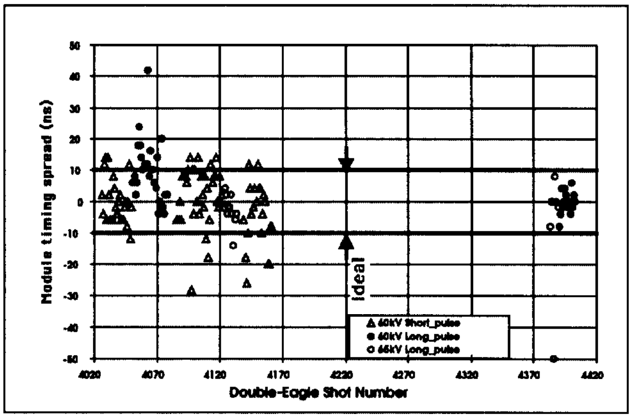


Figure 4. Shot record of the timing spread between two EAGLE modules for negative polarity operation at 60 and 65 kV Marx charge voltages. About 80% of the shots have ideal timing (†10 ns).

We started pulsing Double-EAGLE in the positive polarity mode for the symmetric reflex triode about a year ago. We have successfully operated the machine in positive polarity with good synchronization up to 7 TW level. Figure 5 illustrates the substantial improvements on the machine synchronization. In this figure, the module timing spread is plotted as a function of the shot number for positive polarity operation in two pulsing sessions. Ideal timing shots increase from 34% in August 1998 to 68% in March 1999.

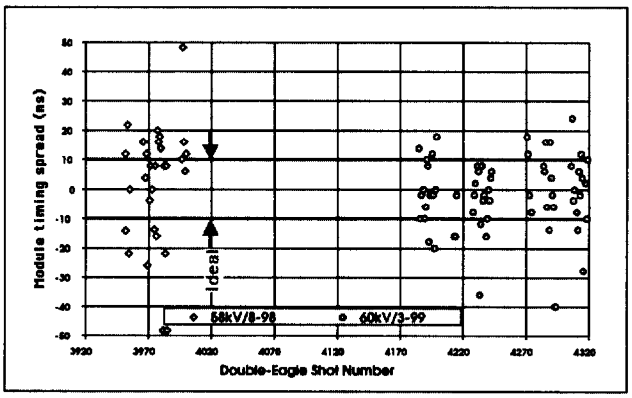


Figure 5. Shot record of the timing spread between two EAGLE modules for positive polarity operation at 58 and 60 kV Marx charge voltages. The percentage of shots with ideal timing doubled as we went from the pulsing session in August of 1998 to the pulsing session in March of 1999.

## IV. CONCLUSIONS

We have made substantial improvements of the reliability of Double-EAGLE by improving the operation of the water switches and the triggered gas switches. The machine can now operate consistently with better than 10 ns synchronization between the two EAGLE modules.

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