COORDINATED DIAGNOSTICS FOR A HYDRO EXPERIMENT DRIVER *

J. Williams[ξ], **C. Y. Tom, E. Peterson**
Bechtel Nevada, North Las Vegas Operations, Las Vegas, NV 89125

J. Stokes
Los Alamos National Laboratory, Los Alamos, NM 87545

W. Broste
Keystone International, Albuquerque, NM 87113

Abstract

Hydrodynamic testing constitutes a large part of the Stockpile Stewardship program. The increasingly complex modeling of hydro phenomena requires precise information on the pulsed-power mechanisms propelling the imploding driver shell. For Atlas, a large pulsed-power machine, this means accurately recording the current waveform delivered to the target. Bechtel Nevada and Los Alamos National Laboratory diagnostic personnel have continued to improve the diagnostic suite that provides this vital information for Atlas experiments. Recent efforts to refine the accuracy and expand the dynamic range of magnetic and electric field sensors used to monitor Atlas performance are described in this paper. An optical loop for a Faraday rotation diagnostic records the total current delivered to the load with greater accuracy and less sensitivity to electromagnetic interference than the B-dot sensors. Rogowski loops provide information on relative output from individual pulsed power units. Optical switch monitors provide high-resolution simultaneity measurements. A variety of inductive loop sensors (B-dots) are used to assess current symmetry and simultaneity at varying distances from and within the central load assembly. B-dots placed in the transmission lines reveal simultaneity problems by picking up current reversal down a late-firing line, and can be used to identify the physical location of breakdowns. Load B-dots are better able to record local current transients that are blurred by the spatially averaging Faraday sensor. Techniques used to reduce spurious signals in the typically hostile pulsed-power environment are discussed and examples of results presented.

I. INTRODUCTION

The planning and execution of quality hydrodynamic experiments at the Atlas facility [1] will depend on precise knowledge of the drive current profile. Further, before physics experiments can proceed, it will be necessary to demonstrate that all elements of the machine are performing to requirements. By acquiring and interpreting data from a wide variety of machine sensors, drive current profiles can be known and performance can be assured. [2] Because of the complex nature of a research-quality pulsed-power facility such as Atlas, no single diagnostic could provide all the information necessary to reliably monitor the behavior of the system. The need for a variety of diagnostics was most critical during the start-up phase of the new facility, when operating norms were being established and the inevitable malfunctions required identification and correction. This paper presents results from the early checks made of the Atlas machine's operation at the Nevada Test Site (NTS).

II. FARADAY ROTATION

The Faraday rotation diagnostic [3] is based on the principle that the magnetic field produced by current flowing in a conductor encircled by an optical fiber causes rotation of the polarization of light traveling around the

* DOE/NV/11718--1034. Work supported by the U.S. Department of Energy, National Nuclear Security Administration Nevada Site Office, under Contract No. DE-AC08-96NV11718.
Approved for public release; further dissemination unlimited.
ξ email: williajt@nv.doe.gov

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
JUN 2005	**N/A**	**-**

4. TITLE AND SUBTITLE	
Coordinated Diagnostics For A Hydro Experiment Driver	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Los Alamos National Laboratory, Los Alamos, NM 87545**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
See also ADM002371. 2013 IEEE Pulsed Power Conference, Digest of Technical Papers 1976-2013, and Abstracts of the 2013 IEEE International Conference on Plasma Science. IEEE International Pulsed Power Conference (19th). Held in San Francisco, CA on 16-21 June 2013.

14. ABSTRACT
Hydrodynamic testing constitutes a large part of the Stockpile Stewardship program. The increasingly complex modeling of hydro phenomena requires precise information on the pulsed-power mechanisms propelling the imploding driver shell. For Atlas, a large pulsedpower machine, this means accurately recording the current waveform delivered to the target. Bechtel Nevada and Los Alamos National Laboratory diagnostic personnel have continued to improve the diagnostic suite that provides this vital information for Atlas experiments. Recent efforts to refine the accuracy and expand the dynamic range of magnetic and electric field sensors used to monitor Atlas performance are described in this paper. An optical loop for a Faraday rotation diagnostic records the total current delivered to the load with greater accuracy and less sensitivity to electromagnetic interfereence than the B-dot sensors. Rogowski loops provide information on relative output from individual pulsed power units. Optical switch monitors provide highresolution simultaneity measurements. A variety of inductive loop sensors (B-dots) are used to assess current symmetry and simultaneity at varying distances from and within the central load assembly.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**SAR**	**4**	

fiber through an angle proportional to the magnitude of the current (Fig. 1). The constant of proportionality is dependent on the Verdet constant of the fiber, the wavelength of the light, and the number of loops the light travels around the current [2], shown as

$$I = \frac{(\lambda real / \lambda Verdet)^2 \times \alpha}{Nloops \times \upsilon}, \quad (1)$$

where υ is the Verdet constant measured at wavelength λVerdet, α is the rotation angle, λreal is the operating wavelength of the system, and Nloops is the number of total and partial loops the light makes around the current. For a typical system at Atlas, the constant is 2.4 MA for a full polarity revolution, or 6.67 kA per degree.

The light is injected by a constant-current laser diode and travels through a fiber looped around the center conductor. After exiting the field, the light is split and sent through two polarized lenses, set roughly 45 degrees apart. The intensity of the light passing through the two lenses is recorded on a pair of optical receivers.

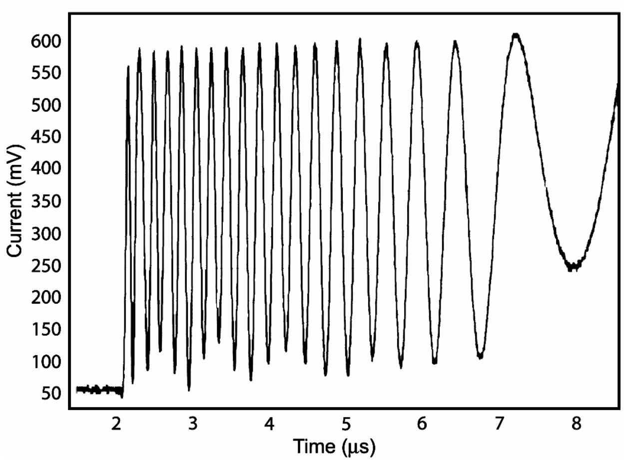

Figure 1. Faraday data from current start to maximum.

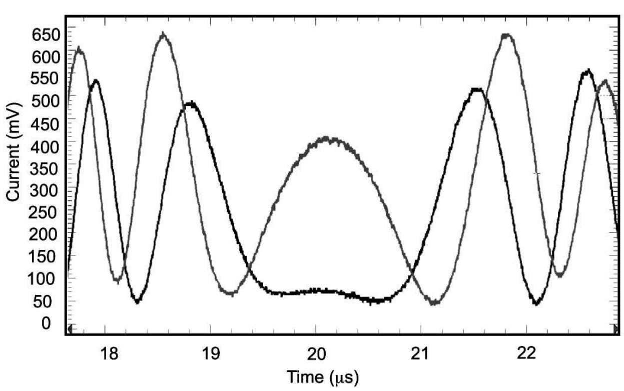

Figure 2. Two signals showing the local maximum.

Analyzing the data consists of normalizing the data and summing the change in angle between points. Analysis of the two signals recorded from the same system can be used to identify the local maximums and minimums. As one signal is leading the other approaching the maximum, it will lag on the falling side (Fig. 2).

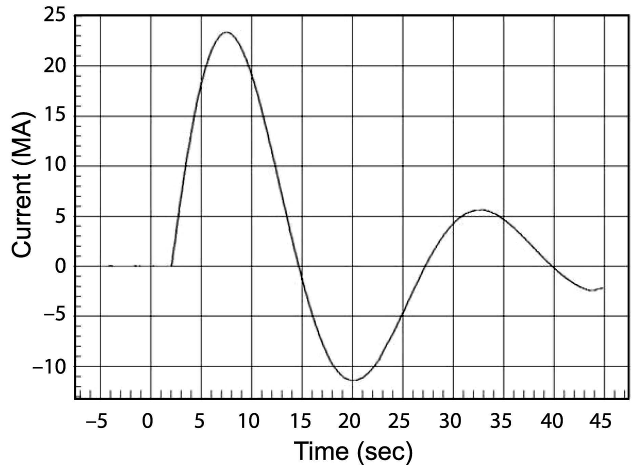

Figure 3. Analyzed signal.

The analysis of a Faraday rotation signal is not explicitly dependent on amplitude, and can give an accurate measurement without knowledge of signal attenuations or calibration factors. However, signals with more vertical resolution will yield more accurate data in the intervals between maximums and minimums (Fig. 3).

Because the analysis is dependent on a summation, the loss of data, or obscuring of data by noise could lead to the inability to analyze the data from that point forward. If it can be shown that the data lost occurs only between a local maximum and minimum pair, the signal will only be lost for that interval. If, however, the loss of one or more local maximums or minimums occurs, the remainder of the signal cannot be recovered.

A traceability study performed at the National Institute of Standards and Technology determined that the Verdet constant, at 1.2 percent, in the Atlas installation is the main source of error. The uncertainty of the angle at maximum current varies due to the possible error in counting the partial revolutions at the beginning and end of the rising current portion of the waveform. For the data presented, the uncertainty of the angle is 0.35 percent; the full accuracy is ±1.3 percent.

III. TRANSMISSION LINE DIAGNOSTICS

Each of the twenty-four parallel plate transmission lines that carry current from the left and right halves of the twelve pulsed-power maintenance units (MU) was instrumented with a set of capacitive electric (V-dot) and inductive loop (I-dot) probes. The probes provide information on the voltage and current waveforms passing through the transmission line when the machine is triggered. Following reassembly of the machine at NTS, the inductive probes showed that several of the MUs were firing as much as 250 ns later than the bulk of the system. As part of recording system improvements recently made, 1-gigasample-per-second recording capability was added to the I-dot signal originally recorded at 40 megasamples per second. With this higher resolution information available, careful inspection and maintenance of the triggering system reduced the unit-to-unit variation to within 30 ns, as shown in Figure 4. This level of simultaneous pulse firing is needed to ensure symmetric drive of hydrodynamic loads.

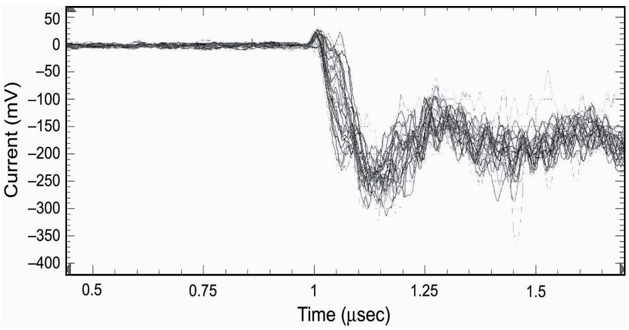

Figure 4. Current start detected by B-dots.

IV. LOAD B-DOTS

While the transmission line magnetic and electric field sensors discussed previously were able to assist in achieving temporal uniformity in the drives from each MU, the probes are mounted in a complex geometry that does not allow quantitative calibration of the probes. Even if relative calibration of the detectors were possible, irregularities in impedance in the central regions could disturb current flow symmetry, and neither the transmission line sensors nor the Rogowski coils on the individual headers could provide confirmation of drive field symmetry in the central load region. For that purpose, a set of inductive loop sensors (B-dots) are used to sense the magnetic field produced by the current in the load region at appropriately spaced positions around the load. For prehydro experiment machine testing, four detectors of three types were installed in the test load, spaced azimuthally at 90-degree intervals. While the sensors did not provide the absolute current measuring accuracy of the Faraday rotation diagnostic, they functioned as backups to the more complex Faradays. Carefully installed, the probes yielded relative field measurements to ±5 percent, with absolute scale uncertainties of twice that. During machine tests with one third of the MUs firing, the load B-dot nearest an MU where one half of the unit was not functioning, showed a 30 percent reduction in field, confirming the sensor's ability to locate irregularities in machine function.

Using the information from the three four-sensor sets, each of which was rotated roughly ten degrees apart in azimuth, an azimuthal profile of the field internal to the test load was obtained when only one of the MUs was fired. Figure 5 is a plot of the relative field strength as a function of angle from the nominal position of the pulsed-power unit.

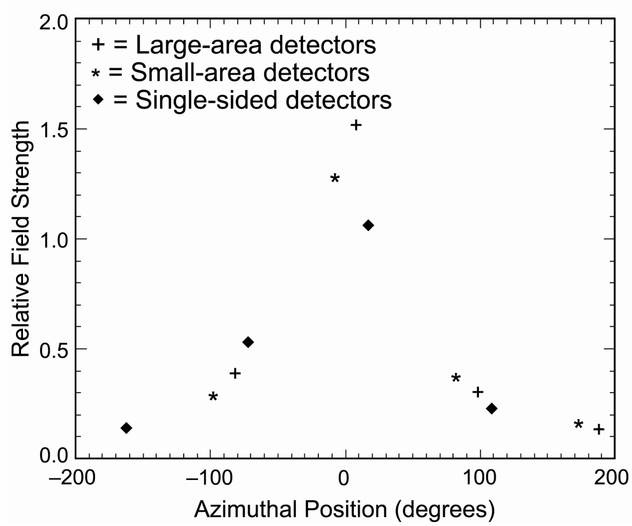

Figure 5. Magnetic field strength vs. position.

Early hydro-dynamic experiments will be monitored by two sets of six B-dot sensors at varying radii from the load to confirm drive symmetry and assist in diagnosis in case of performance irregularities.

V. ROGOWSKI COILS

Rogowski coils are set in the 24 cable headers that transfer current from the capacitor banks to the transmission lines. The acquired data is most useful for comparing a capacitor bank's output performance over several shots. The fast rise time of the signal, similar to the B-dot, can be used for timing as well (Fig. 6).

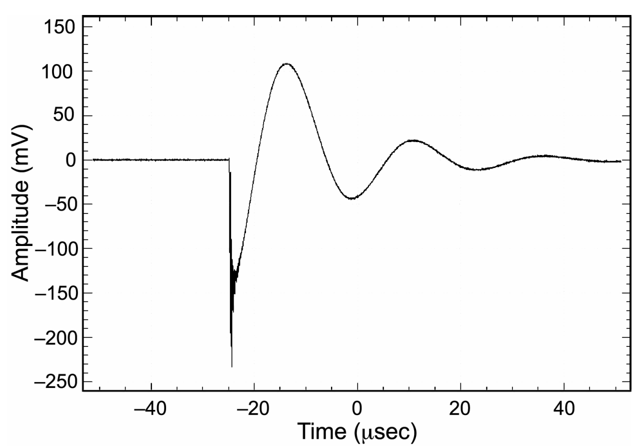

Figure 6. Typical Rogowski signal.

VI. OPTICAL SWITCH MONITORS

The switch monitors detect the breakdown in each rail gap switch and convert the electric field into light. The signals self-trigger the recording system; therefore, they are used primarily as a failure diagnostic. No correlation between amplitude and current delivery has yet been demonstrated (Fig. 7).

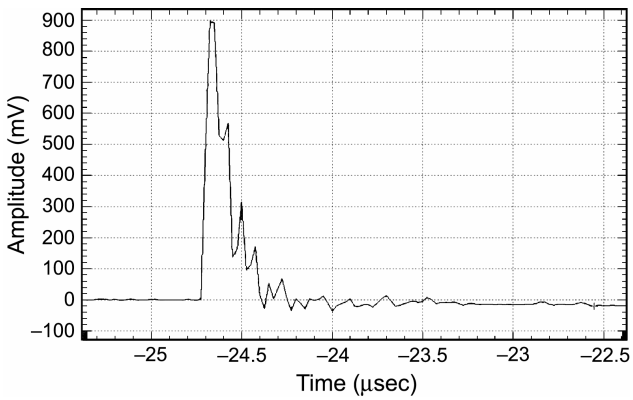

Figure 7. Typical switch monitor signal.

VII. CONCLUSION

A variety of electric, magnetic, and optical machine diagnostics have been used to diagnose and optimize the performance of the Atlas Hydrodynamic Experiment Driver. The body of information obtained from pulsed-power unit, transmission line, and load regions diagnostics has been used to diagnose both successful current delivery profiles and developmental machine tests.

VIII. REFERENCES

[1] "Atlas," DOE/NNSA, http://www.nv.doe.gov/news&pubs/dirpdfs/ATLAS.pdf, cited May 17, 2005.

[2] R. E. Reinovsky and W. L. Atchicson, "Pulsed Power Performance of the Atlas System at the NOE Nevada Test Site," presented at 5th IEEE International Pulsed Power Conference, 2005.

[3] G. I. Chandler and Franz C. Jahoda, "Current measurements by Faraday rotation in single-mode optical fibers," Review of Scientific Instruments, vol. 56, (5), p. 852.

This manuscript has been authored by Bechtel Nevada under Contract No.DE-AC08-96NV11718 with the U.S. Department of Energy. The United States Government retains and the publisher, by accepting the article for publication, acknowledges that the United States Government retains a non-exclusive, paid-up, irrevocable, world-wide license to publish or reproduce the published form of this manuscript, or allow others to do so, for United States Government purposes.