1

LA-UR-84-2346

CONF-840812--15

NOTICE

PORTIONS OF THIS REPORT ARE ILLEGIBLE. It has been reproduced from the best available copy to permit the broadest possible availability.

Los Alamos National Laboratory is operated by the University of California for the United States Department of Energy under contract W-7405-ENG-36

LA-UR--84-2346

DE84 015523

TITLE APPLICATION OF OPTICAL-FIBER PINS TO EXPLOSIVE, PULSE-POWER GENERATORS

AUTHOR(S) R. S. Caird, R. F. Benjamin, R. G. McQueen and D. J. Erickson

SUBMITTED TO Conference on Fiber Optics in Adverse Environments II SPIE'S 28th Annual International Technical Symposium and Instrument Exhibit, San Diego, CA, August 19-24, 1984.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

MASTER

By acceptance of this article, the publisher recognizes that the U.S. Government retains a nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or to allow others to do so, for U.S. Government purposes.

The Los Alamos National Laboratory requests that the publisher identify this article as work performed under the auspices of the U.S. Department of Energy.

Los Alamos

Los Alamos National Laboratory
Los Alamos, New Mexico 87545

FORM NO 836 R4
ST NO 2629 5/81

506-21

Application of optical-fiber pins to explosive, pulse-power generators

R. S. Caird, R. F. Benjamin, R. G. McQueen and D. J. Erickson

Los Alamos National Laboratory
Group M-6, MS J970, PO Box 1663, Los Alamos, New Mexico, 87545

Abstract

Arrays of optical-fiber pins, known as microballoon optical pins, have been used to diagnose the dynamic deformation of an explosive pulsed-power generator. The pin data determine the effects of multimegampere electrical current loading on generator performance. The pins are required to work in the adverse environment of the generator, consisting of explosives and explosive products and very large, rapidly-changing electrical currents that give rise to intense electromagnetic interference.

The optical pin is a shock arrival-time sensor consisting of an optical fiber tipped with a gas-filled microballoon about 200 microns in diameter. When a strong pressure pulse impinges on the microballoon, the shock-heated gas within the spherical shell emits a bright flash. The light is transmitted via the optical fiber to an electronic streak camera which simultaneously records signals from many pins. The signals from an array of these sensors measure the time profile of the impact of the explosive-driven armature with the stationary conical stator. Details of the microballoon pin are described at this meeting by Benjamin and Mayer.

The microballoon pin was compared with the conventional flash-gap technique in which air, confined in a much larger space, is shock-heated to produce a time-of-arrival flash. The two methods gave essentially identical results on the first shot. Since the microballoon was more convenient to use and indicated a greater range of usefulness in future applications, we used it exclusively on the subsequent shots. The microballoon optical-fiber pin gave us the data necessary for the next generator design iteration and will be used extensively in the future.

Introduction

Explosive-driven magnetic flux compression generators have been used for many years to produce megagauss magnetic fields and megajoule electrical pulses.[1,2] The chemical energy of the explosive is converted to electrical energy. We have tested a large coaxial generator[3] designed to produce 20 MJ of electrical energy in a 10 nH inductive load with a current-doubling time of 10 μs. Microballoon optical-fiber pins were used to obtain data needed for correcting future generator designs. The generator is shown schematically in Fig. 1.

An initial current, which provides the working magnetic flux, is established in the coaxial generator by the discharge of a capacitor bank and the subsequent action of a helical booster generator. The helical booster generator has a long rise-time and amplifies the initial current by a factor of 30. The coaxial generator supplies a further current amplification of 5-6 with a shorter rise-time. The explosive is detonated at the input end. As the detonation front moves toward the load end at a velocity of 8.8 km/s, the armature is driven radially outward at 3.3 km/s to form a conical shape. The magnetic flux is trapped between the moving armature and the stationary stator and is eventually swept into the coaxial load volume. The internal diameter of the stator is about 63 cm at the widest point. The high-performance explosive is in a cylinder 23 cm in diameter and 76.5 cm long. The total weight of explosive in the booster and coaxial generators combined is about 150 kg. The stator carries currents in excess of 50 MA, changing at rates of 5×10^{12} A/s. The physical and electromagnetic environments are therefore harsh in the extreme. We are replacing or complementing many of our electrical diagnostics by optical techniques.

A crucial feature of the generator design requires matching the cone angle at the output end of the stator as closely as possible to the cone angle of the armature in order to minimize the current rise-time. This configuration maximizes the rate at which flux is pushed into the load. Under no-load (zero current) conditions, it is relatively easy to calculate and measure this angle. It is quite difficult, however, to calculate the armature motion in the presence of currents that produce magnetic forces in the gigapascal range. We proposed to estimate these effects by measuring the arrival time of the armature at the stator over the length of the output cone. The overwhelming electrical background militated against the use of electrical pins. We therefore chose to use an optical signal coupled by optical fibers as indicated in Fig. 1.

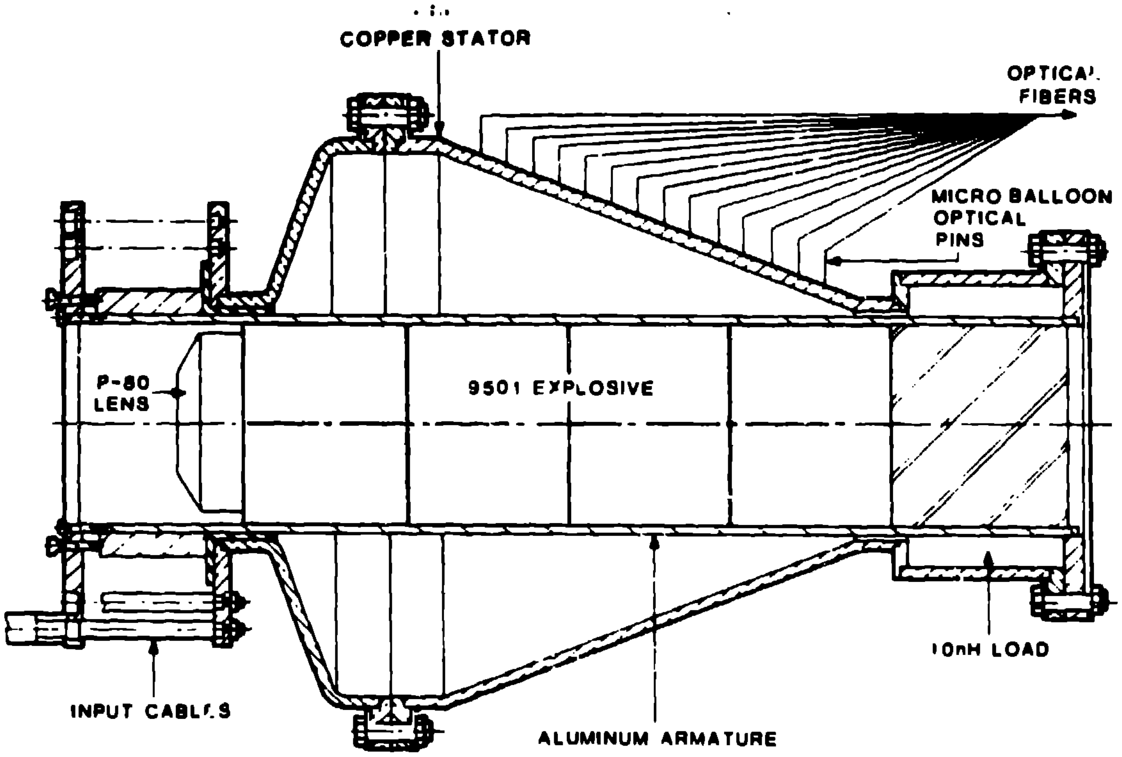

Figure 1. Coaxial generator with optical arrival-time pins imbedded in the stator.

Experimental arrangement

The optical pin stations were distributed in two straight lines on the surface of the stator cone with 16 stations per line. The lines were 90° apart to permit an estimate of the azimuthal symmetry of the armature motion. The stator was fabricated with a half-angle of 19°--- our computed estimate of the armature cone angle under full-current conditions. The first station was 2.5 cm below the top of the cone. The remaining stations were distributed at equal intervals along a slant distance of 49.5 cm to the output throat. A blind hole was drilled into the stator at each station to receive a microballoon or flash-gap at the bottom of the hole. When the armature struck the stator, a strong shock was sent through the stator wall and impinged on the optical pin. The distance from the bottom of the hole to the inner surface of the stator was held constant to equalize the transit times of the shocked material. The microballoons were gas-filled glass or plastic spheres about 200 microns in diameter glued to the ends of optical fibers with an index-matching resin. When a strong, fast pressure pulse traverses the sphere, the shock-heated gas emits a bright flash of light. This light is then transmitted by the optical fiber to an electronic streak camera in the firing bunker 25 m away. The run of the fibers was carefully positioned so that no shock waves from the explosive could damage the fibers before the impact measurement was completed. A more detailed description of the optical-fiber pin is given in an accompanying paper by Benjamin and Mayer.[4]

The first shot employed both flash-gaps and microballoons. The flash-gap technique is commonly used in explosive equation-of-state measurements. The arrangement consisted of a thin aluminum shim at the bottom of the hole, an air gap and a transparent plastic disc. The flash gap and the microballoon pin operate on the same basic principle. The air gap flashes when a shock wave runs through it, giving rise to the optical signal. The plastic acts to couple the light to an optical fiber and also to quench the signal after several shock traversals within the air gap.

The Imacon electronic sweep cameras were set to give a total sweep record covering 35 μs on the first shot and 15 μs on subsequent shots. The sequence of events from the discharge of the capacitor bank through the initiation and run-up of the helical and booster generators to final impact occupied 480 μs. A small percentage error could have caused the camera to trigger too early or too late to record the armature-primary collision. Therefore, we used such slow sweep speeds to provide a generous allowance for possible timing errors.

However, we found that our timing was accurate to a few microseconds and the signals fell in the central region of the sweep on all four shots. The camera resolution was only 100 ns for these shots owing to the slow sweep speeds. The turn-on time of the pins was probably less than 10 ns.[4]

The fiber-holder at the cameras had space for only 16 pins on these shots in order to simplify the early trials. Two cameras were available for the first shot to implement the comparison of the microballoons and the flash gaps. We had only one camera on the last three experiments; therefore, only half the stations were occupied. There is no reason the number of pins recorded could not be increased to 100 (set by the spatial resolution of the camera).

Experimental results

The first shot was fired with an initial current of 2 MA provided by the capacitor bank alone. No helical booster was used. The purpose was to check the no-load predictions and the diagnostic techniques. The data from the first shot are plotted in Fig. 2. Top and side refer to the two lines of stations 90° apart. The arrival time is plotted against the station number.

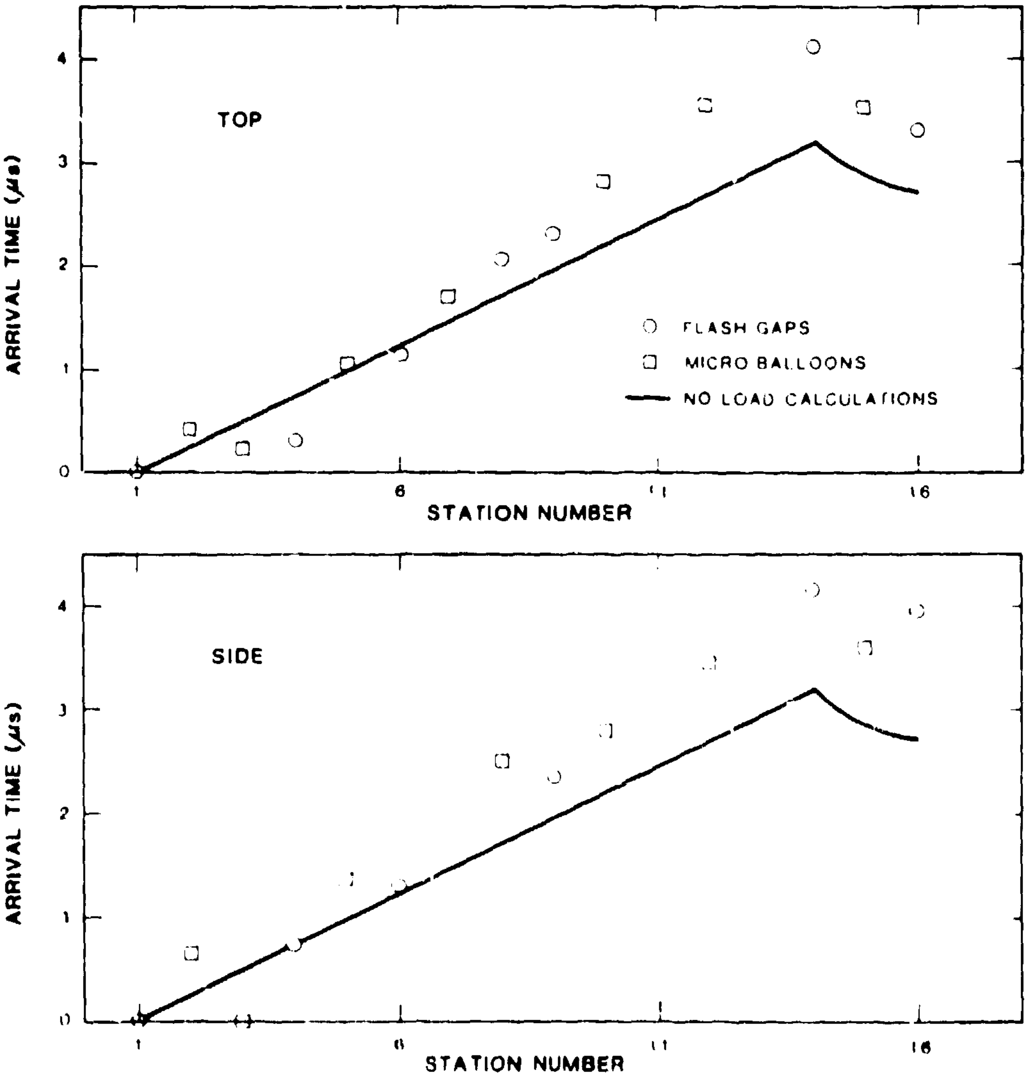

Figure 2. Flash-gap and microballoon data from the low-power generator test. Solid line is computed arrival-time curve.

The armature first hits the stator near the input end and sweeps rapidly toward the output end. For comparison, a predicted arrival curve is presented that was calculated from a two-dimensional hydrodynamics code. This predicted curve is very sensitive to the armature cone angle --- a change of 0.5% in the angle would entirely remove the one microsecond discrepancy near station 14. Such angular accuracy exceeds the accuracy of the code; consequently, we conclude that the agreement is excellent. The departure from linearity at station 14 reflects the fact that the armature shape departs from a cone at small expansions. It is also evident that the flash-gap data are indistinguishable from those of the microballoons.

The succeeding three shots were conducted at full current and employed microballoon pins entirely since they were more convenient to field and seemed applicable to a wider variety of situations. Good data were obtained on all three shots. The data from one of the tests are plotted in Fig. 3. The peak current was 50 MA. Again, the no-load curve is displayed for comparison purposes. On the basis of this data, we were able to conclude that the generator dynamics were unaffected by current loading at the 50 MA level.

An interesting effect was evident in the records of the three full-power shots. An early, low-intensity streak was observed in many cases prior to the bright flash that indicated the arrival of the main shock. We conjecture that the magnetic forces caused the stator to move a few tenths of a millimeter before the generator run was complete. The early light signal might be eliminated by leaving a small gap between the bottom of the hole and the pin.

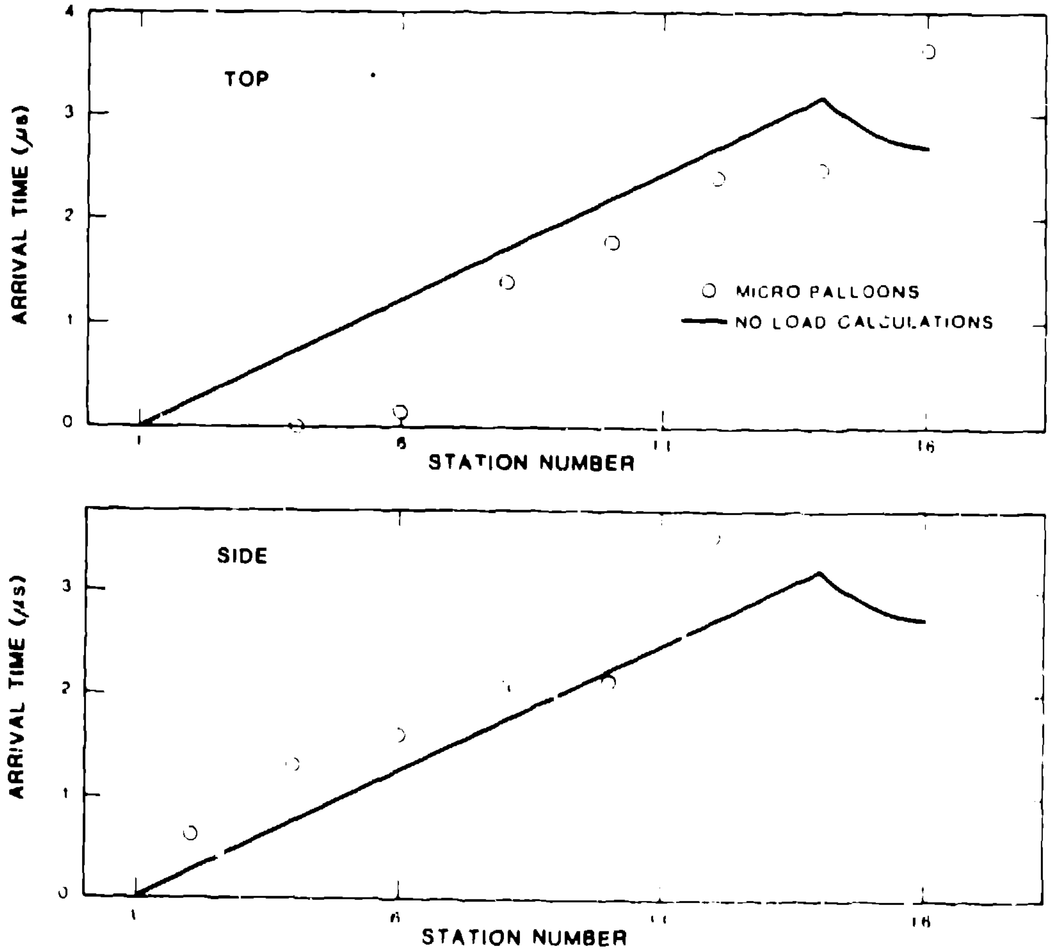

Figure 3. Microballoon data from the second full-power generator test. Solid line is computed low-power curve.

Conclusions

The microballoon fiber-optic pin has proved its reliability and usefulness as a shock-arrival sensor in the very hostile environment of explosive-driven generator experiments. We plan to employ its capabilities extensively in future generator development.

Acknowledgements

The work described in this paper was supported by the United States Department of Energy. We also should like to acknowledge the help of the following people and organizations: Vivian Gurule and Connie Gomez for fabrication of the pins; Peter Kruse for supplying the optical fibers; EG&G for suggestions about fiber handling; and KMS Fusion for supplying most of the microballoons.

References

1. H. Knoepfel. Pulsed High Magnetic Fields. North-Holland Publishing. 1970.

2. R. S. Caird. C. M. Fowler, D. J. Erickson. B. L. Freeman. and W. B. Garn. "A Survey of Recent Work on Explosive-Driven Magnetic Flux Compression Generators," in Energy Storage. Compression and Switching, Vol. 2. pp. 1-18. Plenum Publishing. 1983.

3. F. S. Felber. R. S. Caird. C. M. Fowler. D. J. Erickson. B. L. Freeman and J. H. Goforth. "Design of a 20 MJ Coaxial Generator." Third International Conference on Megagauss Magnetic Field Generation and Related Topics. Novosibirsk. USSR. June 13-17. 1983.

4. R. F. Benjamin and F. J. Mayer. "Microballoon-tipped optical fibers as sensors of pressure pulses in adverse environments." Paper 506-20. SPIE Conference on Fiber Optics in Adverse Environments II. San Diego. California. August 22-24. 1984.