DOE/ER/12115--2

DE93 003068

The Railplug: Development of a New Ignitor for Internal Combustion Engines

Annual Report

January 16, 1992 - January 15, 1993

R. D. Matthews, S. P. Nichols, and W. F. Weldon
Center for Energy Studies and Center for Electromechanics
The University of Texas at Austin
Austin, Texas 78712

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.

RECEIVED OSTI
NOV 18 1992

October 1992

PREPARED FOR THE U. S. DEPARTMENT OF ENERGY
UNDER GRANT NUMBER DE-FG05-91ER12115

MASTER
DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

Railplug Project

The goal of the railplug project is to commercialize a new type of ignitor, the miniaturized railgun or "railplug", as an engine technology as rapidly as possible. To improve the technology transfer process, a board of industrial advisors was established. A list of representatives is included at the end of this annual report. The third meeting of the Railplug External Advisory Board (REAB) during 1992 was held in Austin on April 3, 1992. The forth meeting of the REAB will be held in San Francisco, California on October 18, 1992. These meetings have proven to be most useful in assuring that this project is conducted as efficiently as possible.

The railplug project is essentially divided into three main tasks: I) Railplug System Development, II) Application of Railplugs to Engines, and III) Railplug Durability. The status of each of these tasks is described below.

I. Railplug System Development

Railplug system development is subdivided into two categories: power supply development and ignitor development. In addition to these two categories, there is also a significant amount of work in progress to standardize the evaluation techniques used to measure railplug system performance. These issues are described below.

I.a. Power Supply

The railplug requires a high voltage spike to breakdown the gap between the rails followed by some sustained voltage to drive the arc down the rails. The power supply chosen is a parallel circuit supply. The parallel circuit utilizes a high voltage (~20 kV) ignition coil in parallel with relatively low voltage (<600 V) capacitors to supply the breakdown and follow-on energies to the plug. The capacitors are charged off of line voltage while an automotive battery and opening switch provide the input to the ignition coil. The circuit is simple, inexpensive, and reliable, but has the drawback of requiring a high voltage diode to isolate the low voltage capacitors from the high voltage impulse. This is not really a single element, but rather consists of many diodes serially connected to achieve a high stand-off voltage. It has a limited average current rating, which means that high rep rates (>~30 Hz) are currently not attainable. The diode also consumes significant amounts of energy. This power supply has consistently discharged railplugs at pressures up to 500 psig.

I.b. Railplug Design

Two types of railplug geometries have been investigated over the course of the contract, coaxial railplugs and parallel railplugs. These designations refer to the geometry of the electrodes or rails.

Parallel railplugs, in which the arc moves out of the plug between two parallel rails, proved to be difficult to fabricate. There are several reasons for this. First, the ceramic insulator that encapsulates the rails and shields the back end of the plug from high combustion temperatures is difficult to make due to its brittle nature and non-axisymmetric geometry. Secondly, at elevated pressures it was very hard to prevent the plug from breaking down at the external connection rather than in the bore. Also, it was difficult to accurately drill the long, small hole through the breech plug insulator that captures the rails and maintains them in alignment. Finally, the welded initiation point that controls where the spark will break down could not be made consistently from one plug to the next.

For these reasons, it was decided to develop a coaxial geometry railplug, in spite of the fact that a coaxial railplug may suffer slightly in performance. This is because the inductance gradient (L') that is proportional to the driving force on the plasma is typically lower in a coaxial geometry than in a similarly sized parallel one (about 0.22 μH/m for the coax vs. 0.30 μH/m for the

parallel). However, the consistency with which the coaxial railplug can be fabricated outweighs this drawback and recommends it for evaluation. All of the problems cited above in the construction of parallel plugs are eliminated in the coaxial geometry. Plugs have been made at the University with both a low cost, low temperature plastic insulator for non-engine evaluation and a high temperature Torlon insulator for use in the engine. The design is disassemblable to allow for non-destructive inspection of the electrodes. There have been four different designs, the standard UT-D coaxial plug and three other plugs, each with the same L' (but different from UT-D) and different center electrode diameters. UT-S has a small center electrode, UT-M has the same size center electrode as UT-D, and UT-L has a large center electrode. Champion Spark Plug Company has also built coaxial geometry railplugs. Three designs of the Champion railplugs are being made in both a 12 mm design for use as a cold-start ignitor in the Volkswagen IDI diesel and a 14 mm design that may be used in the combustion bomb or a variety of spark ignition engines. The Champion 688 and Champion 689 are 12 mm and 14 mm railplugs respectively and similar to the UT-D. The Champion 705 is a 14 mm railplug with a larger center electrode.

Both the coaxial and parallel geometry railplugs have been successfully fired at elevated pressures (up to 500 psi), high rep rates (>20 Hz), and in an engine environment. The coaxial plugs will remain the primary choice for engine and combustion bomb studies, but parallel plugs will continue to be made on a selected basis for specific investigations.

I.c. Railplug System (Test and Evaluation)

We developed standardized tests to use in the evaluation of different railplug and power supply configurations. This sequence of tests is designed to evaluate railplug performance before the plug is tested in an engine, thereby reducing the amount of time spent performing the more complicated and costly engine tests. In these evaluation tests, we characterize plasma velocity, penetration, and impulse. The combustion bomb has been built and used extensively as an evaluation tool. Railplug testing has been performed resulting in a second technical paper (appended). The rate of pressure rise, approximated by the ratio of peak pressure (P_{max}) to the time to reach this peak (t_{peak}), shows the spark plug is about 1.8 psi/ms at an equivalence ratio of 0.75, while the best railplug with "matched" electronics is about 8.2 psi/ms. Tests so far have been conducted with 130 μF capacitance steps. We are now able to get 50 μF steps and more "matching" tests will be conducted

II. Application of Railplugs to an Engine Environment

There are several applications for which the railplug is currently being considered for use as an ignition source. The specific engine applications which will be evaluated at UT include 1) replacement of spark plugs in dilute homogeneous charge (DHC) 4-stroke spark ignition engines and 2) use as a cold starting device for indirect injection diesel engines. Several other applications have been identified and will be pursued as funding permits. UT researchers are currently working on cooperative efforts with industry to pursue these applications. These applications include methanol fueled engines (in cold weather conditions), direct injection 2-stroke engines, and gas turbine engines.

The status of the DHC SI and diesel cold start evaluation efforts is provided below.

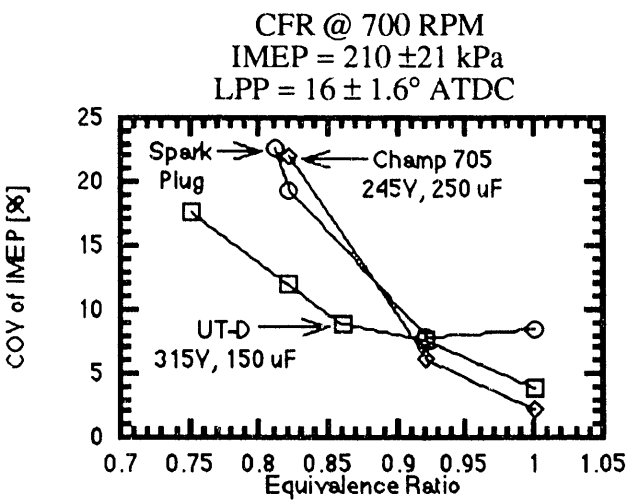
II.a. Dilute Homogeneous Charge SI Engine

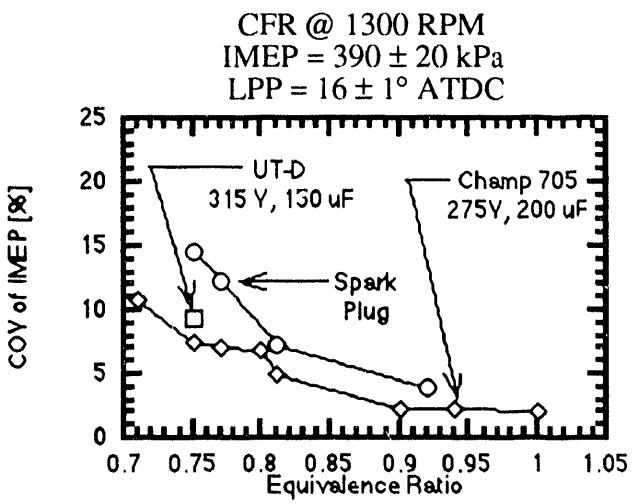
Initial testing of the railplug system was performed in a single cylinder research engine. Based upon input from the external advisory board, subsequent testing is scheduled to be performed in a production-type automotive engine. Results from the preliminary testing in the research engine and the status of the production engine set-up are discussed below.

A single cylinder Cooperative Fuel Research (CFR) engine was used to compare the performance of railplugs to a spark plug. The coefficient of variation of the indicated mean effective pressure (COV of imep) was used as an indicator of performance. The COV of imep was

calculated from 500 engine cycles, which gives a more statistically correct result than the 40 cycle analysis that was used last year. There are test points that GM, Ford, and Chrysler use for evaluation of engines. Operating the engine at these points give a good indication of the overall engine performance without running a complete engine map. GM has three test points (at 700, 1300, and 2200 rpm), and the Ford and Chrysler test points are very similar to the GM 1300 rpm test point. For all conditions, the peak cylinder pressures were aligned at approximately 16 degrees ATDC (which roughly corresponds to MBT timing). Thus far, the CFR has been run at 700 and 1300 rpm.

The graphs presented below show the trend of COV of imep vs. equivalence ratio using the spark plug and railplug as an ignition source. The UT-D railplug was "matched" to optimal electronic settings. The first graph indicates that at 700 RPM, the UT-D railplug reduces COV in half and was successful in extending the lean operating limit in the CFR engine. The Champion 705 railplug does not show a decrease in COV as compared to the spark plug, but this railplug was not properly "matched". Ignition timing at an equivalence ratio of 0.82 changed from 36° BTDC with a spark plug to 20° BTDC for the UT-D railplug. This indicates faster combustion and thus improved cycle efficieny. In the next graph, at 1300 RPM, both railplugs show a decrease in COV as compared to a spark plug. Also, the lean limit was extended for the Champion 705 plug. Ignition timing at an equivalence ratio of 0.75 changed from 35 BTDC with a spark plug to 26° BTDC with the Champion 705 railplug.

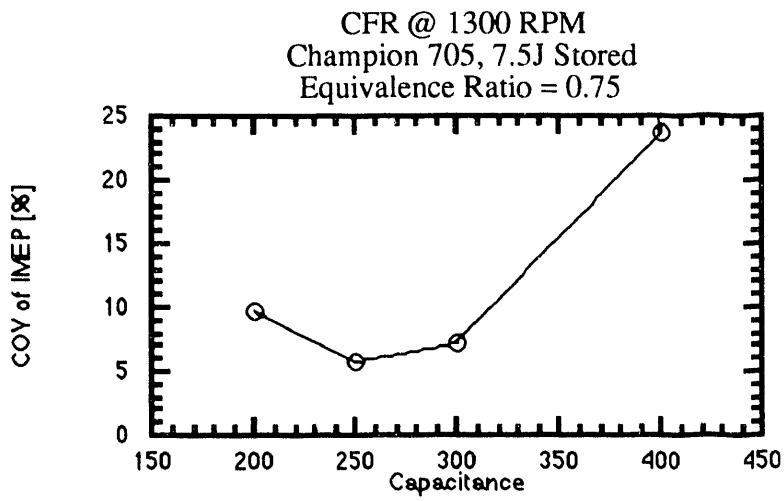




The Champion 689 railplug was not tested in the CFR due to the resistive design of the plug, which produces heat within the plug. In place of the Champion 689 railplug, the UT-D railplug was used, which is similar to the Champion 689.

In the next graph, the effect of capacitance at constant energy is shown. A change in capacitance of 50 μF (resulting in a change in current pulse shape) can almost halve the COV (studies on the combustion bomb were performed in 130 μF steps). Thus, "matching" the electronics is an even more critical issue in the engine than in the bomb and studies using more refined steps in capacitance are planned for the near future..

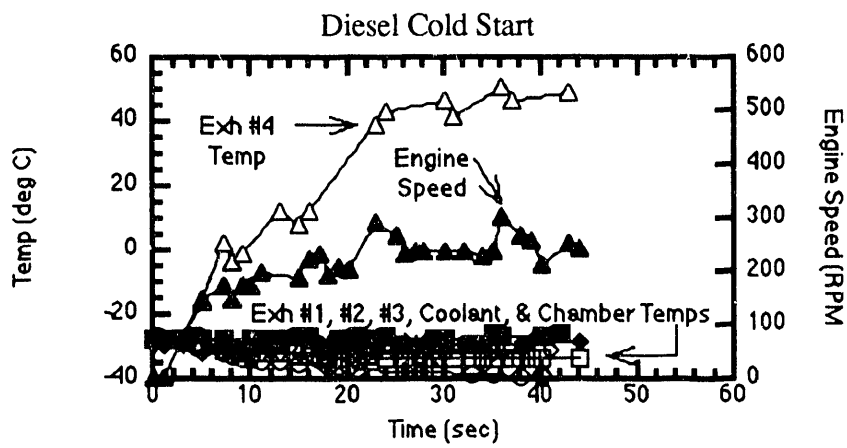
We are currently working to set-up our production engine test facility for railplug evaluation. A General Motors 2.2 liter 4 cylinder engine has been chosen for testing purposes and we have been working closely with GM powertrain engineers on our test plan. The engine is mounted on the dyno stand. Instrumentation still needs to be completed.



II.b. IDI Diesel (Cold Start)

For this application, Volkswagen of America has donated a 1992 production model 1.6 liter IDI diesel engine. Champion Spark Plugs has built coaxial railplugs for this engine. A railplug was installed in the threaded glow plug hole of one cylinder of this engine. All four exhaust ports are instrumented with thermocouples to monitor the exhaust gas temperatures during the starting transient. Exhaust gas temperature histories from the three non-railplug cylinders will be compared with that of the railplug cylinder. This test plan represents a simple and cost-effective means for demonstrating superior cold start capabilities when using railplugs.

The next graph shows that the railplug is successful at firing the #4 cylinder at -30° C. This temperature is slightly below that for which glow plugs will consistently start the engine with 2 minutes of preheating.



III. Durability

Durability testing has been conducted using a railplug in a 200 psig pressurized vessel with an inert atmosphere. Results show a life of 200,000 cycles at repetition rate of 18.33 Hz on the Champion 705 railplug with 1 J delivered. This corresponds to 3 hours. The repetition rate corresponds to 2200 RPM, which is the high speed General Motors test point.

A Briggs and Stratton lawn mower engine is being set up for testing in an engine environment. This engine should be in operation and results obtained before the end of the year.

RAILPLUG EXTERNAL ADVISORY BOARD

Larry Amstutz
Chief, Electrical Machinery Team
Belvoir RD&E Center, Bldg. 326
Fort Belvoir, VA 22060
(703) 664-5081 or 5587

Dr. Richard W. Anderson
Principle Staff Engineer, Engine Research Dept.
Ford Motor Company
Suite 800, VP
23400 Michigan Avenue
Dearborn, MI 48124
(313) 322-4657; FAX 313-323-1875

Dr. Thomas W. Asmus
Powertrain Research Specialist
Chrysler Motors Corporation
Detroit, MI 48288-1118
(313) 252-8568; FAX 313-252-7152

Norris J. Bassett
Manager of Advanced Ignition Development
Mail Station 18-211
Delco-Remy Divisoin
General Motors Corp.
P.O. Box 2439
Anderson, IN 46018
(317) 646-2144; FAX 317-646-7470

Dr. Sam W. Coates
Manager, Computational Engineering
Mercury Marine
P.O. Box 1939
Fond du Lac, WI 54936-1939
(414) 929-5035; FAX 414-929-5060

Dr. Thomas M. Kiehne
Assoc. Director, Institute of Advanced Technologies
The University of Texas
Austin, TX 78712
(512) 471-9060; FAX512-471-9096

Walter M. Kreucher
Manager, Advanced Environmental Engineering
Ford Motor Company
World Headquarters
The American Road, Room 259
Dearborn, MI 48121-8247
(313) 845-8247

Dr. Scott W. Jorgensen
Sr. Research Engineer, Fuels and Lubricants Dept.
General Motors Research Labs
30500 Mound Road
Warren, MI 48090-9055
(313) 986-1915; FAX 313-986-2094

Don McCaw
Alternative Fuels, 81U
Engine Engineering
John Deere Product Engineering Center
P.O. Box 8000
Waterloo, Iowa 50701
(319) 292-8233

Ron Nitschke
Powertrain Division, General Motors Corporation
895 Joslyn Avenue
Pontiac, MI 48058-1493
(313) 857-2282; FAX 313-857-1251

Dr. Peter J. O'Rourke
Group T-3, MS B216, Los Alamos Natl. Laboratory
Los Alamos, NM 87545
(505) 667-9091; FAX 505-665-4055

James E. Sibley
Sr. Staff Engineer, System Technology Division
Caterpillar, Inc.
Engine Division
P.O. Box 610
Mossville, IL 61552-0610
(309) 578-8329; FAX 309-578-8433

Daniel L. Tribble
Vice President, Product Engineering
Champion Spark Plug Company
P.O. Box 910
Toledo, OH 43661-0001
(419) 535-2190; FAX 419-535-2147

Randy Williams
Supervisor - Combustion Group
Garrett Auxilliary Power Division
Dept. 93-732/1302-2R
2739 E. Washington St., PO Box 5227
Phoenix, AZ 85010
(602) 220-3547; FAX 602-220-3292

Charles D. Wood
Vice President
Engine and Vehicle Research Division
Southwest Research Institute
P.O. Drawer 28510
San Antonio, TX 78284
(512) 522-2618; FAX 512-522-2019

Listing of Publications

1. Matthews, R.D., M.J. Hall, R.W. Faidley, J.P. Chiu, X.W. Zhao, I. Annezer, M.H. Koenig, J.F. Harbor, M.H. Darden, W.F. Weldon, and S.P. Nichols (1992), "Further Analysis of a Railplug as a New Type of Ignitor", SAE Technical Paper 922167.

2. Faidley, R.W., M.H. Darden, and W.F. Weldon (1992), "The Railplug: A New Ignitor for Internal Combustion Engines", 6th Symposium on Electromagnetic Launch Technology

3. Ellzey, J.L., M.J. Hall, and X. Zhao (1992), "Computational and Experimental Study of a Railplug Ignitor",Western States Meeting of the Combustion Institute, Corvallis, Oregon, March 23-24, 1992.

4. Ellzey, J.L., M.J. Hall, and X. Zhao (1992), "Computational and Experimental Study of a Railplug Ignitor", accepted for publication by Experiments in Fluids.

reprint + preprints removed; conf paper cycled separately.
ds

END

DATE FILMED

12/4/92