A MULTIPLE RESTRIKE IGNITION SYSTEM AS A DEVICE TO REDUCE COLD START EMISSIONS

REPORT

BY

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Prepared for

State of Alaska
Department of Highways

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*Consisting of three volumes:
Vol. 1 "Cold Start Automotive Emission in Fairbanks, Alaska"
Vol. 2 "Multi Restrike Ignition System as a Device to Reduce Cold Start etc."
Vol. 3 "Carbon Monoxide Emission from Moving Vehicles in Fairbanks, Alaska"
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A Multiple Restrike Ignition System as a Device to Reduce Cold Start Emission - Vol. 2

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Excessive concentrations of carbon monoxide (CO) are found in the exhaust gases of motor vehicles during the cold start and warm-up phase of vehicle operation. In Fairbanks, Alaska, a large portion of ambient CO observed during the winter months is produced from these cold start emissions. A Multiple Restrike Ignition System (M-R), manufactured by Labtronics, Inc. was evaluated for its effectiveness in reducing cold start CO emissions. Testing was carried out under field conditions in the Fairbanks area during the winter of 1975-1976. The M-R system is designed to improve combustion efficiency, thus reducing CO emissions and improving fuel economy. The results of this evaluation remain inconclusive due to the failure of the M-R system to function properly when cranking of a cold engine reduces battery supply voltage to less than minimum levels. This prevented the engines of the test vehicles to start after several hours of cold soaking at sub-zero temperatures. Thus the emission response data from the M-R system connected tests were not obtained to the degree necessary for comparison to the standard ignition test. The failure of the M-R systems to function properly under the environmental conditions to which they were exposed does not suggest failure of the theory on which the design concept is based, but merely indicates a necessity for a modification to the existing circuitry to avoid the voltage drop problem. After this is done, further tests are recommended.
Abstract

Excessive concentrations of carbon monoxide (CO) are found in the exhaust gases of motor vehicles during the cold start and warm-up phase of vehicle operation. In Fairbanks, Alaska, a large portion of ambient CO observed during the winter months is produced from these cold start emissions. A Multiple Restrike Ignition System (M-R), manufactured by Labtronics, Inc. was evaluated for its effectiveness in reducing cold start CO emissions. Testing was carried out under field conditions in the Fairbanks area during the winter of 1975-1976. The M-R system is designed to improve combustion efficiency, thus reducing CO emissions and improving fuel economy. The results of this evaluation remain inconclusive due to the failure of the M-R system to function properly when cranking of a cold engine reduces battery supply voltage to less than minimum levels. This prevented the engines of the test vehicles to start after several hours of cold soaking at sub-zero temperatures. Thus the emission response data from the M-R system connected tests were not obtained to the degree necessary for comparison to the standard ignition test. The failure of the M-R units to function properly under the environmental conditions to which they were exposed does not suggest failure of the theory on which the design concept is based, but merely indicates a necessity for a modification to the existing circuitry to avoid the voltage drop problem. After this is done, further tests are recommended.
ACKNOWLEDGEMENTS

For their invaluable assistance to this project we wish to acknowledge the following individuals and express our sincere thanks: Dr. Charles Behlke, Mr. H. J. Coutts and Mr. Mike Mraz for volunteering their personal vehicles for testing of the M-R units; Mr. Mike Mraz and Mr. Horace Black for an outstanding job of field engineering; and a special thanks to Dr. William Sackinger of the Dept. of Electrical Engineering and Mr. Dave Stinchcomb, a student in the EE Dept. for performing circuit analysis critical to this report.
INTRODUCTION:

In volume I of this report (Cold Start Automotive Emissions in Fairbanks, Alaska) we have shown that carbon monoxide (CO) emissions produced during the cold-start and warm-up phase of vehicle operation are responsible for a significant portion of the ambient CO found in the downtown area of Fairbanks during the winter months. We have also shown that those pollution control devices which are now standard equipment on production automobiles are not effective in reducing cold-start CO emissions. This being the case the question arises: do any techniques exist which could help control cold-start CO emissions?

So far our research has found only one technique to be of much help, which has been the engine preheater as discussed in Vol. 1. The theory for controlling the CO produced during cold starts is quite elementary. CO emissions are caused by poor combustion efficiency, therefore any method of improving combustion efficiency during cold start should help. Preheating provides for higher cylinder head temperature before start-up than would exist under normal ambient conditions. A warmer environment allows for better vaporization of fuel in the combustion chamber. A properly vaporized mixture will ignite readily and burn more efficiently, thus resulting in an increase in combustion efficiency and a reduction in CO emissions.

But what methods other than preheat might be useful? Two techniques under investigation by the General Motors Corp. are the Quick-Release Choke and the Quick-Heat Intake Manifold. While these devices were mentioned in the literature as early as 1972 (Callahan, 1972, and Miles, et al., 1973) they have not found their way into production. They do however have a great potential in cold regions if their performance matches the claims made so far, but until evaluations can be made under
field conditions their possible benefit to the Fairbanks CO control problem remains unknown.

Another technique by which combustion efficiency might be improved would involve the refinement of the ignition system by producing a more powerful and sustained spark. In an effort to test this theory we purchased several Multiple Restrike Ignition Systems from Labtronics Inc. of Ypsilanti, Michigan. This solid state electronic device is sold nationally for less than $80 and designed to be compatible with the existing ignition systems of most automobiles.

In the advertising literature Labtronics claimed that the device would increase fuel economy and reduce CO emissions. It appeared that such a system might be very useful in reducing cold-start CO emissions if a significant increase in ignition performance could be obtained. This report is concerned with the testing of the Multiple Restrike Ignition System as a retrofit device for the control of CO emissions during the cold-start and warm-up phase of vehicle operation. Only gasoline-fueled spark-ignition engines are considered. The following pages contain the results of that testing effort.
THEORY:

For the typical spark ignition, gasoline fueled automobile engine, the period of least efficient combustion occurs during the cold start and warm-up phase of vehicle operation. Since incomplete combustion of the fuel results in CO formation it is also a period of vital concern when control of CO emissions is at issue. The cold-start and warm-up parameters which affect incomplete combustions and thus CO emissions are as follows:

1). **Overly Rich Mixtures** For proper ignition a charge of air and fuel enters the combustion chamber, with the fuel vaporized and/or atomized, creating a relatively homogeneous mixture which is within the limits of 6:1 to 20:1 (lb. air/lb. fuel). Between these extreme of Air Fuel Ratio (A/F) lies the normal range of inflammability for a typical engine, (Henein, et. al., 1972). However, when both fuel and ambient air are cold, as well as engine parts, evaporation of the fuel does not readily occur requiring closure of a choke valve to increase the richness of the mixture to as much as 1:1 A/F. Figure 1 is taken from (Moore, et. al., 1957) and shows the effects of fuel volatility on cold starting performance at various temperatures. As indicated by the figure, several seconds of cranking are required at -20°F for even the most volatile of fuels before the first successful ignition. Under these conditions when ignition does occur there is insufficient air in the combustion chamber for complete oxidation and a CO exhaust emission results.

2). **Dilution of A/F Mixture by Exhaust Gas** Just after a cold start has taken place and the engine is in the early stages of warm-up, the choke valve is normally closed to increase the richness of the mixture resulting in manifold pressures well below ambient. As the piston nears the end
EFFECT OF FUEL VOLATILITY ON COLD STARTING PERFORMANCE

PERCENT EVAPORATED AT 158°FAHRENHEIT

FIGURE 1
of the exhaust stroke (we consider here a typical automotive engine with a four stroke cycle) the intake valve opens. Since the pressure within the cylinder is slightly above ambient at this point in the cycle some of the exhaust gas remaining in the combustion chamber will enter the intake manifold as shown in Figure 2. **As the piston moves past TDC (Top Dead Center) and begins the intake stroke the exhaust valve closes while the intake valve remains open and a fresh charge of A/F mixture is drawn into the cylinder accompanied by the exhaust gas which previously entered the intake manifold. Since, during warm-up, the engine is running at idle with the throttle less than 20% open (the typical condition) it is likely that the residual exhaust gas will comprise something in excess of 20% by wt. of the total fuel-air charge entering the combustion chamber as shown in Figure 2.** 

For engines with greater than normal valve overlap the percentage of dilution would be greater. This dilution effect tends to impede combustion because exhaust gas is essentially inert and can not contribute to the combustion process. Misfires often occur because of the dilution effect causing increased hydrocarbon emissions while partial burning of the diluted mixture results in CO production.

3). **Flame Quenching** During cold-start and warm-up operation the surfaces of the cylinder head and cylinder walls are, by definition, colder than normal operating temperature. Due to the thermal inertia of the materials from which these parts are made (cast steel in most cases), several minutes after start-up are required before the surfaces forming the combustion chamber reach normal operating temperature. Because of this condition the combustion efficiency is further inhibited by a process known as **Flame Quenching**. There are factors other than temperature at the walls which effect flame quenching and a more comprehensive treatment can be found in Henin et. al., 1972. We will, however, present an elementary description of the process.
FIGURE 2
SCHEMATIC OF MIXTURE DILUTION CAUSED BY VALVE TIMING OVERLAP AND GRAPH SHOWING %DILUTION AS A FUNCTION OF THROTTLE OPENING (TAKEN FROM, DANIEL, 1967-70)

EXHAUST GAS ENTERS BOTH EXHAUST AND INTAKE MANIFOLD

PISTON MOVING UP NEAR THE END OF EXHAUST STROKE

% FULL THROTTLE

RESIDUAL FRACTION IN \( \Delta V \)
As ignition of a new A/F charge begins in the combustion chamber, the flame propagates through the mixture at a rate dependent on the temperature, pressure and other parameters which need not be discussed here. Suffice it to say that, as the flame front moves toward the cold wall of the combustion chamber, it begins to encounter a mixture which has been affected by contact with the cold surface. In this region the mixture lacks homogeneity and will be much less likely to support combustion than that found in the more central portions of the combustion chamber. For this reason flame propagation ends some distance from the surface of the wall. The colder the wall, the greater the distance. The result of the terminated flame propagation is a residue layer of unburned or partially burned fuel adjacent to the cold wall which will be swept out of the cylinder with the exhaust stroke to appear as hydrocarbon and CO emissions.

While there is no single cure for the aforementioned ills of cold start combustion, there are techniques which could help. The one technique which will be considered here is the improvement of the ignition process or more specifically the improvement in the quality of spark produced at the spark plugs.

Multiple Restrike Ignition System The M-R system is manufactured by Labtronics, Inc. of Ypsilanti, Michigan. The device is composed of a solid state electronic circuit (see diagram Figure 3) enclosed in a metal box suitable for mounting within the engine compartment of the vehicle. A wiring harness is also provided which is adaptable to most motor vehicles and no additional materials are required for installation. The system is intended to be compatible with the standard coil and distributor, thus providing for a very simple retrofit installation. A six-pin connector is provided into which the wiring harness may then be plugged to restore the standard equipment ignition system. This quick-disconnect feature makes comparative testing (M-R system vs. Standard ignition) very convenient.
FIGURE 3.
The M-R system is designed to produce a rapidly repeating spark of power levels much higher than that produced by conventional inductive ignition systems. Figure 4 compares the voltage response of both the M-R and the conventional system, where \( V_b \) is the breakdown voltage required to initiate the arc at the plug, and \( V_i \) is the ionization voltage which appears across the gap once the arc is established and current has begun to flow.

Figure 5 has been redrawn from the M-R system literature and shows in schematic form the energy transmitted by the arc for the various types of ignition systems. For this report it should not be necessary to delve into the circuit theory of the M-R system to explain how this repetitive spark is produced. From an emissions control standpoint we need only know that a spark is produced with higher energy and sustained over a longer period of time than the conventional system.

**Emission Reduction**

It was the hypothesis of this experiment that a reduction in the cold start CO emissions from gasoline engines can be realized by using the M-R system because of the effect a better quality spark would have on the parameters effecting combustion efficiency. The following is the theory behind this hypothesis:

1). **Overly Rich Mixture**

Since during cold start the A/F ratio within the combustion chamber is well below the stoichiometric ideal, complete combustion can not occur regardless of the type of ignition. However, many of the misfires and flame-outs caused by the overly rich mixture should be eliminated if a "hotter", to use the common expression, spark could be produced. With a conventional ignition the spark is often its weakest under these circumstances because raw fuel has wet the electrode, thus impeding the establishment of a strong arc. If the M-R system could maintain the integrity of the spark at this critical period of operation, some reduction in CO emissions might be visible in exhaust analysis.
Comparison of Voltage Waveform

**Figure 4**

Arc Energy Comparison Schematic

- **Multiple-Restrike System**
- **Inductive Discharge System**
- **Capacitor Discharge System**

**Figure 5**
2). **Dilution of A/F Mixture by Exhaust Gas**  Here again the failure of the flame to propagate effectively through the mixture is the cause of the CO emission. With the conventional system the strongest spark appears across the gap at the beginning of the arc and then decays with time (reference Figure 4). If the mixture does not ignite during the first part of the arc or if ignition begins and then fails, it is not likely that reignition would occur until the next cycle. But, due to the sustained quality of the restruck arc of the M-R system, it is reasonable to expect that sustained propagation in a flame which might have otherwise failed and/or reignite a flame which has failed to propagate is possible. Just how effectively the M-R system would be at accomplishing these tasks should be indicated by lower CO levels in the exhaust gas.

3). **Flame Quenching**  The M-R system could not, of course, eliminate the cold wall temperature which are the cause of flame quenching. However, if we assume that the flame front will be driven by a more powerful spark of longer duration, it is reasonable to hypothesize that the M-R system might narrow the layer of unburned and partially burned fuel between the terminated flame front and the combustion chamber wall. This would effectively improve combustion and reduce CO emissions.

This theory is extremely qualitative and only of academic interest should it prove correct, but we find the improvement in reduced CO emissions is less than significant. The practical test for effectiveness then would be the analysis of the exhaust gas with and without the M-R system connected. **Procedure**  A procedure for testing several M-R units was developed in an effort to determine whether or not the system would substantiate the theory and prove effective as a device to control cold-start CO emissions. Five model VI M-R units with adjustable spark duration were ordered from
Labtronics, Inc. One unit, which had previously been purchased by the Electrical Engineering Department, was also placed at our disposal. We decided to use five different vehicles in the study. This would leave one M-R unit in reserve should a malfunction occur during the testing. The vehicles used were:

A. 1975 model 3/4 ton Chevrolet Pickup truck w/ 350 CID (5735 cc.) V8 engine.
B. 1971 model GMC "Jimmy" Four-wheel-drive w/250 CID (4096 cc) 6 cylinder engine.
C. 1971 W Square Back with 1600 CID (97.6 in$^3$) 4 cylinder engine
E. 1968 model Chevrolet 1/2 ton pickup Truck w/250 CID (4096 cc) 6 cylinder engine.

Each of the vehicles tested was In-Use and privately owned. No special tune-ups or maintenance was performed on any vehicle; however, each was generally in good operating condition and no specific problems were observed to indicate any vehicle was not a typical example of its type and age group. The object here was to select vehicles which would be typical of those found in-use in the Fairbanks area. The M-R units were installed on the test vehicles. The connecting jack, (discussed in the previous section) made it a simple matter to perform a series of tests with the M-R system activated and then switch to the conventional system for a comparative test. The tests were to be carried out as follows:

**Emissions Test** Following the procedure outlined in volume 1 of this report, the cold-start emissions of each vehicle would be sampled for CO content using the Olsen-Horiba CO/HC Analyzer, first with the conventional ignition system and then with the M-R system. The results should indicate if CO emissions were significantly reduced. These comparative tests were to be matched as closely as possible in cold soak time and temperature.
They would be repeated in sets, with and without the M-R system, at various temperatures and cold soak times. After each cold-start test the warm idle CO emissions of the vehicle would be recorded.

Drivability Test Regardless of how effectively the M-R system controlled cold-start CO emissions, it would be of little use to drivers in Fairbanks if, for some reason, the device reduced drivability under the extreme conditions experienced during the winter months. For this reason an important part of the test procedure was to be the drivability test. It was comprised simply of a record to be kept by the owner and driver of the vehicle. They were asked to report any unusual performance characteristics, changes in fuel economy, ease of starting, etc. In short, they were asked to evaluate the unit as would a potential consumer and to tell us how they liked it.

RESULTS:

After having outlined a rather simple testing procedure it would be gratifying to report in straight-forward fashion the results, listing tables and diagrams where by the M-R system could be readily evaluated. Unfortunately all did not go as planned as the following narrative will reveal.

Emissions Testing The tests began with the installation of the first M-R system on the 1975 Chevrolet pickup. The warm idle emissions were then sampled, comparing the CO content of the exhaust for the conventional and the M-R systems, and producing the following results:

<table>
<thead>
<tr>
<th>1975 Chevy Pickup</th>
<th>CO Exhaust Emission</th>
<th>CO Exhaust Emission</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>% by volume at idle</td>
<td>% by vol. at 2500 Rpm</td>
</tr>
<tr>
<td>Conventional System</td>
<td>1.1</td>
<td>0.13</td>
</tr>
<tr>
<td>M-R System</td>
<td>0.15</td>
<td>0.15</td>
</tr>
</tbody>
</table>
From this preliminary measurement there was an indication that for the idle condition an improvement resulted when the M-R system was used, but when the other test vehicles had been fitted with M-R system and the same comparative tests performed there was little cause for optimism as indicated by the following table.

**TABLE I**

<table>
<thead>
<tr>
<th>VEHICLE DESCRIPTION</th>
<th>TEST #</th>
<th>CO w/Conv. IDLE</th>
<th>CO w/M-R IDLE</th>
<th>2500RPM</th>
<th>2500RPM</th>
</tr>
</thead>
<tbody>
<tr>
<td>A 1975 Chevy PU</td>
<td>1</td>
<td>1.1%</td>
<td>0.13%</td>
<td>0.15%</td>
<td>0.15%</td>
</tr>
<tr>
<td>B GMC &quot;Jimmy&quot;</td>
<td>1</td>
<td>0.5%</td>
<td>0.13%</td>
<td>0.5%</td>
<td>0.15%</td>
</tr>
<tr>
<td>C VW Squareback</td>
<td>1</td>
<td>7.2%</td>
<td>10.00%</td>
<td>7.5%</td>
<td>9.7%</td>
</tr>
<tr>
<td>D Ford Capri</td>
<td>1</td>
<td>0.75%</td>
<td>0.75%</td>
<td>1.3%</td>
<td>0.8%</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>1.3%</td>
<td>0.8%</td>
<td>0.6%</td>
<td>0.45%</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>1.3%</td>
<td>0.8%</td>
<td>1.25%</td>
<td>0.65%</td>
</tr>
<tr>
<td>E 1968 Chevy PU</td>
<td>1</td>
<td>No data, Never started</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

With the exception of test #2 performed on the Ford Capri and the test performed on the 1975 Chevy PU, there is no significant difference between the CO emissions produced by either the M-R or conventional systems. As for the variation observed in test #2, it was noticed that there was a drop of about 100 RPM between the M-R and conventional test. We are not sure why a slight drop in engine speed could affect the CO emissions unless the choke was partially closed during the conventional test and then opened completely by the time the M-R system was connected. Whether or not the drop in CO was due to choke action or not would be only speculation; what is clear, however, is that tests 1 and 3 performed on the same vehicle did not produce the results of test #2 nor did any of the other tests listed in Table 1.
In order to determine if the CO reduction at idle observed in tests on the 1975 Chevy Pickup would apply to the cold-start case, a schedule of cold-start tests was arranged. We intended to concentrate on the 1975 Chevy Pickup for cold-start emissions testing while the other test vehicles were observed for drivability by their owners. The idea was that since the 1975 Chevy had shown a comparative difference during idle testing it might be more likely to show measurable results for the cold start, and since we had a limited amount of time available for testing the M-R systems we followed up on this assumption.

We soon found, however, that obtaining the cold start comparative data was no easy matter. After 10 attempts to produce meaningful cold-start data at various temperatures and cold-soak times, only the four-hour soak test resulted in a comparison worth presenting in this report. Figure 6 illustrates that comparison but unfortunately it is of little help in determining whether or not the M-R system is useful as a cold start CO emissions control device. Actually the comparison shown in Figure 6 is what we had originally expected to be typical of the worst case we might observe. Here we find the response of the test with the M-R system to be what is normally expected during a cold start, but when the conventional ignition test was performed the choke stuck closed and the CO emission level did not decrease as the engine warmed up. You will note that during the first two and a half minutes of the test both ignition systems performed about the same. There is some divergence of the two curves prior to the 2 1/2 minute mark, but its significance could only be quantified with repeated testing, and this we were unable to do. After 2 1/2 minutes the two curves diverge as the CO from the M-R system curve decreases and the
COMPARATIVE COLD START TEST

VEHICLE: 1975 3/4-TON CHEVROLET PICK-UP
ENGINE: 350 CID (5735 cc) V-8

- M-R IGNITION, 4 HOUR COLD SOAK, TEMP. -16°F
- STD IGNITION, 4 HOUR COLD SOAK, TEMP. -14°F

ACCELERATOR PEDAL PUMPED TO FREE CHOKE

EXHAUST GAS CO CONCENTRATION
% by VOL.

TIME IN MINUTES

FIGURE 6
engine begins to warm up. The choke then begins to open causing an increase in combustion efficiency. The conventional ignition system curve, however, does not fall off; in fact it increases slightly and then levels off. At about 5 minutes and 50 seconds into the test the accelerator pedal is pumped in an effort to free the choke but after a short spike the CO climbs back to 2.8% and the test is terminated.

The point of presenting this particular test, even though it has resulted in nothing conclusive, is to illustrate the type of data we expected at the outset, but did not successfully obtain. Only this one test produced two comparable, continuous curves. In all other cases the tests were interrupted by failure of the engines to start at cold temperatures, engines stalling after they had been started, causing an interruption in the data and transients to be produced in the CO response.

These aborted tests soon became chronic for all vehicles tested, when a cold start was attempted with the M-R system connected. As our data base began to build, it immediately became evident that, while we were getting successful tests with the conventional ignition systems, we were not getting the necessary comparative data for the M-R system. Vehicles being tested with the M-R system were continually failing to start after cold soak. Even those vehicles undergoing the drivability tests by their owners experienced this response. Table II shows the results of the drivability tests.

It was clear that cold soaking was somehow affecting the starting performance of the vehicles when the M-R systems were connected, since the vehicles would readily start when the conventional ignition system was switched on. It was also possible to start the engine with the conventional ignition system and then, when the engine had warmed up switch to the M-R system. But cold starting with the M-R systems was not possible.
<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Operator</th>
<th>Date</th>
<th>Time</th>
<th>Ambient Temp</th>
<th>Cold Soak Time</th>
<th>Ease of Starting</th>
<th>Type of IGN.</th>
<th>Engine or Battery Heater</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>E</td>
<td>Coutts</td>
<td>1-20-76</td>
<td>08:30</td>
<td>0</td>
<td>18</td>
<td>Wouldn't</td>
<td>M-R</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>Z-4-76</td>
<td>08:30</td>
<td>0</td>
<td>18</td>
<td>OK</td>
<td></td>
<td>M-R</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>Z-5-76</td>
<td>08:30</td>
<td>10</td>
<td>18</td>
<td>OK</td>
<td></td>
<td>M-D</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>Z-9-76</td>
<td>08:30</td>
<td>-25</td>
<td>30</td>
<td>Wouldn't</td>
<td></td>
<td>M-D</td>
<td>Yes</td>
<td>Switch to Std Ign</td>
</tr>
<tr>
<td>E</td>
<td>2-9-76</td>
<td>08:30</td>
<td>-25</td>
<td>30</td>
<td>OK</td>
<td></td>
<td>Std</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>Coutts</td>
<td>Z-2-76</td>
<td>08:20</td>
<td>+5</td>
<td>30</td>
<td>Wouldn't</td>
<td>M-0</td>
<td>No</td>
<td>Switched to Std. after 10 attempts</td>
</tr>
<tr>
<td>E</td>
<td>Z-2-76</td>
<td>08:22</td>
<td>+5</td>
<td>30</td>
<td>OK</td>
<td></td>
<td>Std</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>Mraz</td>
<td>Z-7-76</td>
<td>14:00</td>
<td>-20</td>
<td>3</td>
<td>Wouldn't</td>
<td>M-R</td>
<td>No</td>
<td>Engine would not fire switched to std. ign.</td>
</tr>
<tr>
<td>D</td>
<td>Z-10-76</td>
<td>14:00</td>
<td>-20</td>
<td>3</td>
<td>OK</td>
<td></td>
<td>Std</td>
<td>No</td>
<td>Engine turned over slowly, plugged-in heater, try later</td>
</tr>
<tr>
<td>D</td>
<td>Z-10-76</td>
<td>16:00</td>
<td>-25</td>
<td>7</td>
<td>Wouldn't</td>
<td></td>
<td>M-R</td>
<td>No</td>
<td>Engine turned over easily but no start switch to Std. Ign. 2 hr</td>
</tr>
<tr>
<td>D</td>
<td>Z-10-76</td>
<td>14:00</td>
<td>-25</td>
<td>9</td>
<td>OK</td>
<td></td>
<td>Std</td>
<td>Yes</td>
<td></td>
</tr>
</tbody>
</table>
In an effort to identify the reason for this behavior by the M-R ignition system, an experiment was performed to investigate the system's response to varying supply voltage. **Response Test**

One of the test vehicles was selected. The entire ignition power for this test was supplied by a regulated D.C. power supply separate from the vehicle's normal battery-alternator system. The output of this voltage supply was monitored by a digital voltmeter and the voltage at the primary of the ignition coil was observed on an oscilloscope.

Figure 7 shows in schematic form the wave displayed on the scope with the M-R system operating normally. Beginning at ten volts on the regulated power supply, the voltage was decreased and the voltage at the coil was observed. Table III indicates the response of the M-R system to this reduced voltage. It is clear that at 8 volts or less of applied supply voltage the M-R system would not function acceptably. Therefore, if there was some reason that the voltage of a vehicle's ignition system were to drop to 9 volts or less during start-up with an M-R system connected, it would not be surprising if the vehicle failed to start.

There is, of course, a condition which does exist during cold starting that might have caused low terminal voltage to appear at the input of the M-R system: reduced battery voltage due to excessive current drain, with a very cold battery. Figure 8 gives the performance of a typical lead acid storage battery with respect to ambient temperature. At 0°F, according to this graph, battery efficiency is reduced to about 40% and, as temperature continues to drop, efficiency decreases rapidly.

The next step in our testing was to determine the effect of this loss in efficiency on battery terminal voltage during cranking.
M-R SYSTEM WAVEFORM

![M-R System Waveform Diagram]

FIGURE 7

**TABLE III**

<table>
<thead>
<tr>
<th>SUPPLY VOLTAGE</th>
<th>PEAK VOLTAGE</th>
<th>STEP VOLTAGE</th>
<th>OBSERVED BEHAVIOR</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.0</td>
<td></td>
<td></td>
<td>Steady</td>
</tr>
<tr>
<td>9.0</td>
<td>240</td>
<td>99</td>
<td>Steady</td>
</tr>
<tr>
<td>8.0</td>
<td>219</td>
<td>90/0.0</td>
<td>Step erratic</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>inoperative</td>
</tr>
</tbody>
</table>
Performance of Typical Lead-Acid Storage Battery

Figure 8

Temperature in Degrees F

Efficiency

Electrolyte Freezing

Specific Gravity
Battery Test  A 1971 Ford Pinto owned by our field engineer Mr. Black was selected for use during the battery test. The battery with which this vehicle was equipped was fairly new (less than six months old) and was a heavy duty model recommended for cold weather use. On several occasions, and at various temperatures the engine was cranked while the battery terminal voltage was monitored. Table IV shows the results of this testing. From the voltage drops indicated we concluded that weak batteries due to cold ambient operation resulted in aborted start attempts when the M-R systems were connected.

In an attempt to confirm our theory, a call was made to Labtronics, Inc. When asked about the observations which we had made, Mr. Melvin Gable agreed with our conclusion; however, he was surprised to learn that the minimum voltage acceptable to the M-R system proved to be 8 volts as indicated by our testing. Mr. Gable was under the opinion that the cut-out voltage should have been closer to 6 volts. He did indicate that a different circuit arrangement could eliminate this problem, but it was not discussed in detail.

At this point further testing of the M-R system was terminated and our attention was shifted back to the continuing study of moving vehicle emissions.

SUMMARY:

Because the testing of the M-R system, as a control device for cold start CO emissions, was only a small part of the overall study of cold start, and moving vehicle CO emissions in Fairbanks, we were unable to spend the time and effort on the subject that we would have liked. For this reason it would be inappropriate to make any more than general statements about the effectiveness of the system. The theory of reducing CO emissions
## TABLE IV

COLD BATTERY VOLTAGE TEST

Test Vehicle: 1971 Ford Pinto w/Heavy Duty 12 v. Battery

<table>
<thead>
<tr>
<th>Test #</th>
<th>Date</th>
<th>Length of Cold Soak</th>
<th>Ambient Temp. °F</th>
<th>Initial Battery Voltage (Before Cranking)</th>
<th>Battery Voltage During Cranking</th>
<th>Charging Voltage After Start</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3-10-76</td>
<td>10 hrs.</td>
<td>-31</td>
<td>14.0</td>
<td>9.0</td>
<td>16.0</td>
</tr>
<tr>
<td>2</td>
<td>3-16-76</td>
<td>14 hrs.</td>
<td>-4</td>
<td>13.5</td>
<td>9.5</td>
<td>15.5</td>
</tr>
<tr>
<td>3</td>
<td>3-30-76</td>
<td>10 hrs.</td>
<td>-31</td>
<td>11.0</td>
<td>8.0</td>
<td>14.0</td>
</tr>
</tbody>
</table>

Note: Several random tests made on other vehicles after cold soaks at -20 °F showed that 8-9 volts battery voltage was found to be common during cranking. (This random data was not recorded.)
during cold-start and warm-up by improving ignition efficiency is sound. The theory of developing a high energy repeating spark, as a technique to improve ignition efficiency, also appears to be well founded. During this investigation problems with the M-R system’s adaptability to extremely cold climates resulted in our failure to confirm or deny the validity of the afore-mentioned theory.

A testing procedure was developed to test the cold-start effectiveness of the M-R system. The procedure failed to yield useful results because during cold starts the M-R systems would not function properly and the engines could not be started. An investigation into the reason for the malfunction indicated that severe voltage drop at the battery terminals during cranking at very low temperatures will not permit the M-R system to receive the minimum input voltage necessary to produce a useful spark at the plugs. The plausibility of this explanation was confirmed by the manufacturer.

Changes in M-R system circuit design may overcome the problems we experienced during this investigation. If these design changes could, at some time in the future, be worked out it would be useful to reinvestigate the effectiveness of the M-R system as a control device to reduce cold start CO emissions.

CONCLUSIONS:

'The Model VI Multiple Restrike Ignition System in its present form appears to have design features which do not allow it to function properly, during routine use, in a climate as cold as that of Fairbanks. For this reason the original objective of this investigation, to determine its effectiveness for reducing cold start CO emissions, has not been accomplished. We still do not know whether or not the M-R system is
effective. During the investigation, however, we were able to isolate the problem affecting cold weather performance of the device and we have been advised by the factory that circuit modifications could be made to the existing system which would make the system adaptable to Fairbanks winter conditions. We must therefore conclude that the M-R system may yet prove to be potentially helpful as a device for reducing cold start CO emissions and at some future date another investigation should be undertaken.

**RECOMMENDATIONS:**

This investigation has proved to be a disappointing attempt at fully evaluating the M-R system, but we should not abandon the idea based on this one failure. There are very few techniques which have any potential as cold-start CO emission controls, and therefore no single technique should be discarded before its full potential has been evaluated. We may eventually find that no technique, by itself, is effective enough and that only by a combination of various techniques can cold start CO emissions be significantly reduced.

We have learned from the experience of this investigation, if only how best to proceed with future evaluations so that they might go more smoothly. However, we would strongly recommend that in the future this device be tested in conjunction with other control techniques so that a more careful and detailed evaluation be made than we were able to carry out this time because of more pressing problems associated with the rest of the cold start and moving vehicle emissions study.
REFERENCES:


