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A TECHNIQUE FOR INSTANTANEOUSLY SELECTING EITHER "FULL ENGINE" OR "HALF ENGINE" PERFORMANCE

By

Mohammad Loghavi

AN AE 811 TECHNICAL PROBLEM REPORT

Submitted to

Michigan State University

in partial fulfillment of the requirements

for the degree of

MASTER OF SCIENCE

Department of Agricultural Engineering

1975

ABSTRACT

A TECHNIQUE FOR INSTANTANEOUSLY SELECTING
EITHER "FULL ENGINE" OR "HALF ENGINE" PERFORMANCE

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Deactivating half of the cylinders of an engine to require the remaining cylinders to work at a higher percentage of their capacity is an effective means to improve the fuel efficiency. A mechanism has been developed to deactivate and reactivate the cylinders by controlling the opening of the valves. The operator can instantly select the full engine for maximum power or the half engine for improved fuel economy.

Approved: ______________________
Major Professor

____
Department Chairman

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INTRODUCTION

The traditional and typical U.S. automobile is large by world standards and usually has a powerful engine that is not noted for fuel economy. Until the recent advent of shortages and higher fuel prices the need for increased efficiency was of little concern to the average U.S. driver.

Now, however, with the awareness and concern for energy conservation that has been occurring throughout the world during the last two years, many in the U.S. have been prompted to consider ways to improve the efficiency and hence the economy of operation of existing automobile engines.

Deactivating half of the cylinders of an engine has been shown to be an effective means to improve the fuel efficiency (Gerrish *et al.*, 1975).

When pulling a trailer or driving in the mountains, etc., it would be desirable to instantly reconvert to the larger "full" engine. This suggests that a dashboard controlled switch for quick conversion would be highly desirable, thus allowing the driver to quickly select the type of engine performance needed.

REVIEW OF LITERATURE

In 1917 the Enger Motor Car Company used the idea of changing an engine from a twelve to six cylinders by holding the exhaust valves on the left block of the V-12 in an open position, and by closing a butterfly valve in the intake manifold to the left block (1). This technique was abandoned later, probably because of the pumping losses through the exhaust ports.

A concept advanced by Gerrish, Wilkinson, Baker and Kampe of the Agricultural Engineering Department at Michigan State University was to reduce the horsepower output of the existing engine. These engineers argued that by deactivating half of the cylinders of an engine, the remaining ones would be forced to work at a higher output per cylinder to achieve the same horsepower output as the full engine. The "half engine" could easily deliver the needed power and the cylinders could be working at a higher volumetric efficiency, hence a fuel saving would result.

This theory was tested by Gerrish *et al.* using a 1968 Chevrolet 307 cubic inch V-8 engine (3). By closing the valves on four cylinders, the engine was made to run as a V-4. The fuel economy on road tests was measurably improved.

The E.P.A. Tests at Ann Arbor (2) confirmed that the car had a 19-percent improvement in fuel economy. Performance was sacrificed to get the higher fuel economy, but this was not considered a major disadvantage on most roads with a steady moderate speed. Gerrish *et al.* were impressed with the result of "big car comfort and safety and small car economy."

Primary disadvantages of the Gerrish engine are that: 1) Modification requires several hours to complete, and 2) Once converted a "half engine" is not readily changed back. The driver-owner is committed to a low performance engine.

PART I

DEVELOPING THE MECHANISM

The Problem and Approach

Designing, building and testing a mechanism to activate or deactivate some of the engine cylinders at the driver's discretion was the challenge of this technical problem.

Deactivation of the cylinders by closing both intake and exhaust valves was shown by Gerrish *et al.* to be the least detrimental to engine performance, as pumping losses were minimized. It was decided to use this method of cylinder deactivation.

Several approaches were considered. A promising idea was suggested by Dr. R. H. Wilkinson to interrupt the valve-opening mechanism by means of individual solenoids mounted on the rocker arms of the four deactivated cylinders. By energizing or deenergizing the solenoids, the engine could be operated on either eight cylinders or four cylinders as driving conditions required.

This approach was followed and required the development of a special mechanism to carry out the function of activating and deactivating the cylinders.

A 350 cubic inch V-8 Oldsmobile-Rocket engine was used for this experiment. This engine was run on an electric dynamometer to carry out performance versus fuel consumption tests. The original firing order was 1-8-4-3-6-5-7-2. Every other cylinders 8-3-5-2 were de-activated in the four-cylinders operation to give a new V-4 firing order of 1-4-6-7.

Four-cylinders operation was considered to be the best engine running mode to achieve maximum fuel economy, and eight-cylinders operation was to be the temporary running mode when there was a demand for high speed or high power output.

Parts Used in the Engine Conversion

1. Eight 12-volt D.C. continuous duty Guardian solenoids.
2. Eight new rocker arms.
3. Eight 5/16 x 1-1/4 stove flat head bolts with eight tightening nuts (used for clearance adjustment).
4. Eight spring holding collars (made in research lab) with eight tightening screws.
5. Eight compressive type spring (no. of active coils - 4, coil diameter - 7/16", wire diameter = 3/64").

6. Eight thin wire springs for spring loading the solenoid plungers.
7. Sixteen 6-32 steel bolts (used for solenoid installation).
8. Two spst toggle switches.
9. Two rectangular 22" x 5" sheet metal plates (used as temporary rocker arm cover).

Rocker Arm Deactivating Mechanism

To disengage the rocker arms on the deactivated cylinders the point of contact between each rocker arm and its push rod was drilled out to permit the push rods to move up and down through these holes without activating their respective rocker arms. The cylinders became inactive as their intake and exhaust valves remained closed regardless of the cam and push rod position. Figure 1 shows a rocker arm deactivated by this procedure.

To prevent the push rods from being "kicked out" by the cam action and to reduce noise by maintaining lifter and cam contact at engine running speeds, a push rod retainer spring was installed as shown in Figure 2.

Each push rod was fitted with a spring retaining collar and a set screw. A flat spot was made on each push rod to receive the set screw and secure the collar position. These springs kept the push rods and lifters in contact providing smooth operation, were also necessary

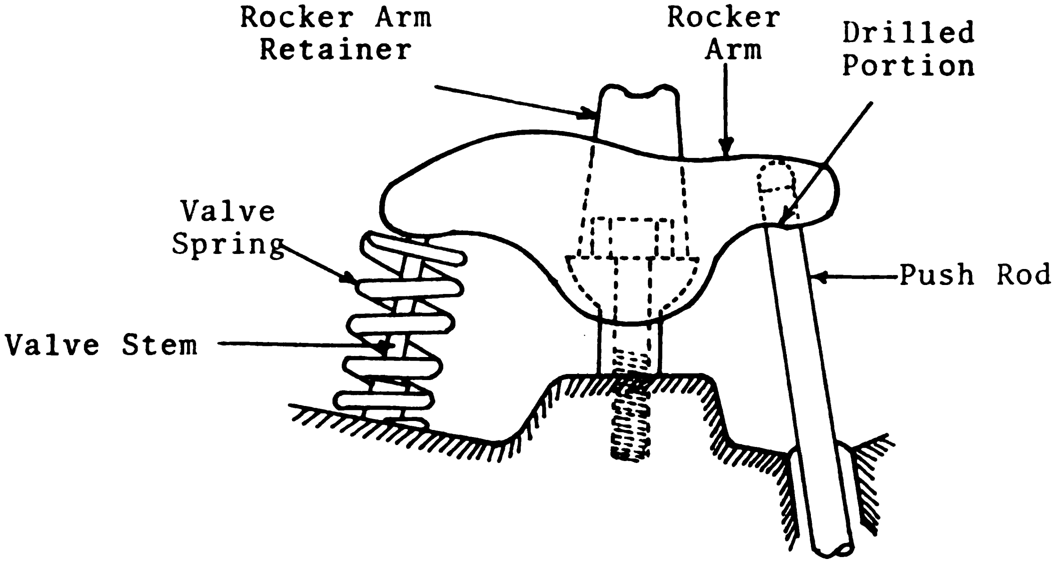


Figure 1 -- Deactivated Rocker Arm

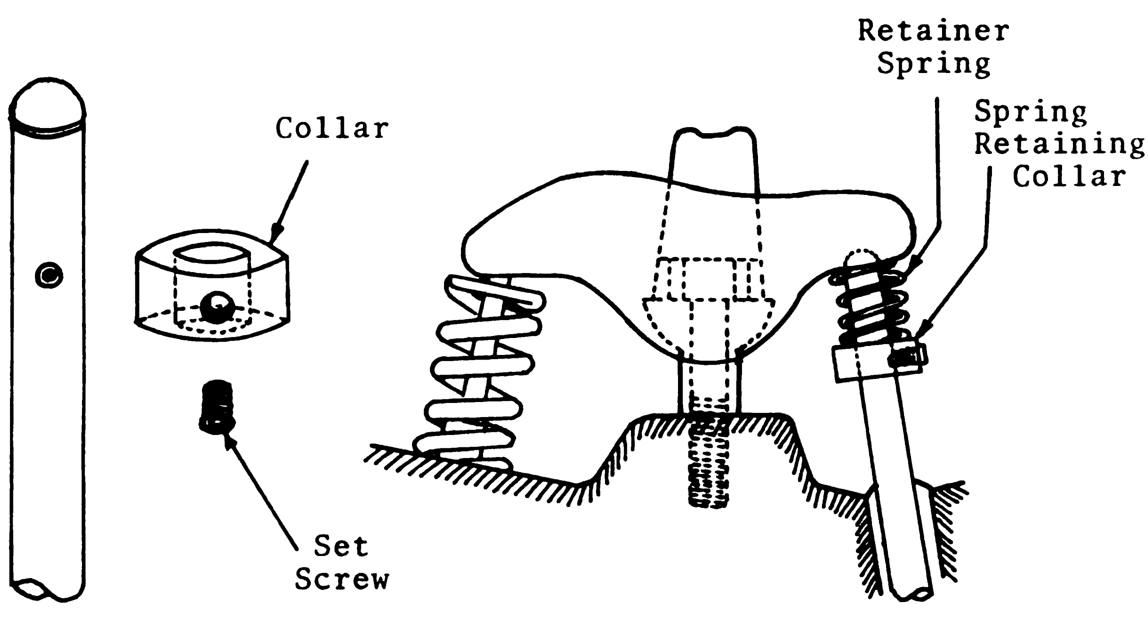


Figure 2 -- Deactivated Rocker Arm With Push Rod Retainer Spring

for proper functioning of the rocker arm reactivating mechanism as described next.

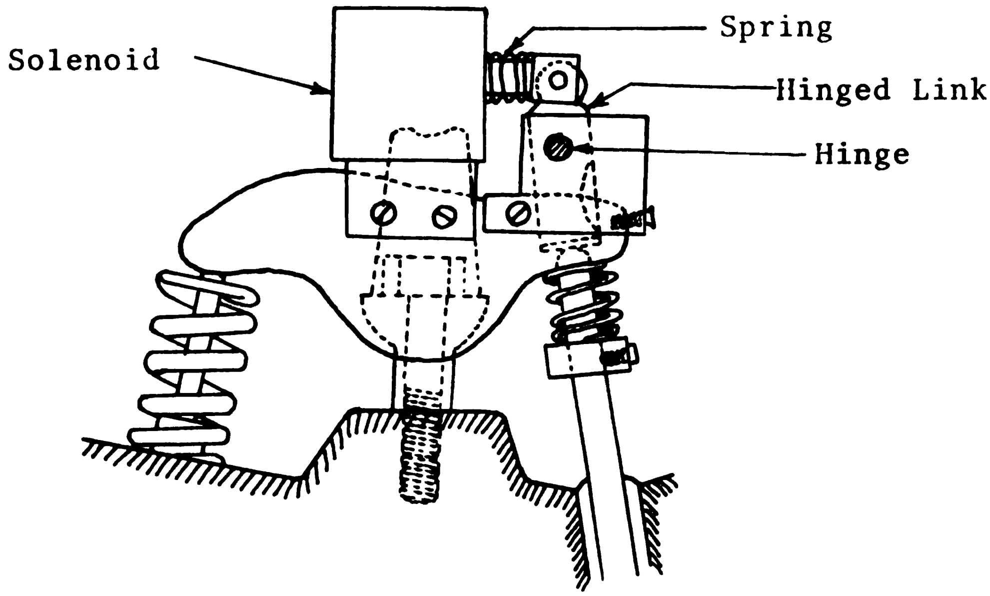
Rocker Arm Reactivating Mechanism

To reactivate the previously deactivated cylinders for eight-cylinders operation, a mechanism was needed to transmit push rod motion to the rocker arm to restore normal valve operation. A practical approach appeared to be a movable stop on a rocker arm to intercept the push rod motion and transmit it to the rocker arm and valve. This movable stop or hinged link is shown in Figure 3.

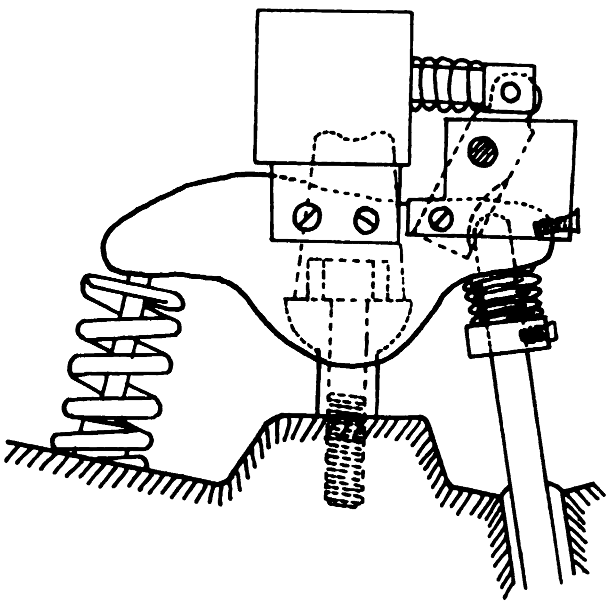
A prototype unit was made in order to test the feasibility and validity of the rocker arm reactivating mechanism. All parts were put together by screws, so the unit was not highly durable for extended use. A few minutes of operation proved that this mechanism was able to perform as intended. The results of the prototype test were encouraging.

A solenoid to swing the hinged link was mounted on each of the eight rocker arms to be deactivated. A rectangular bracket was welded on each rocker arm to provide a frame for installation of the solenoids. A U-shaped bracket was welded to each rocker arm as a base for installation of the hinged link (Figure 4).

The upper end of each hinged link was pinned to the solenoid plungers. Each plunger was spring loaded to keep the lower end of the hinged link clear of the push rod



(a) Rocker Arm Activated



(b) Rocker Arm Deactivated

Figure 3 -- Prototype Unit

strokes during the four-cylinders operation.

Energizing the solenoids causes the plungers to be pulled inside the solenoids and the hinged links are rotated to obstruct the drilled push rod holes. The solenoids cannot rotate the hinged links until the push rods are moved down to their lowest position by the retainer springs. At engine running speed this process takes place in a fraction of a second.

The initial tests showed that little or no clearance was desirable between each push rod and its corresponding hinged link bottom. Minimum clearance prevents alteration of valve opening and closing time, change in valve range and noisy operation of the valve system. An adjusting mechanism was added to each rocker arm to maintain a zero or minimum clearance. This consisted of an adjusting bolt with its tightening nut over each valve stem (Figure 4). Valve clearance was adjusted to just permit free swinging of the hinged link. No extra gap was necessary because hydraulic valve lifters were employed on the engine.

The valve system was lubricated by an oil duct through each push rod originating from the lifter and ending on the top of the push rod head. The hinged links were provided with an oil groove to permit lubrication of the valve train during the eight-cylinders operation (Figure 5). The hinged link bottoms were shaped in such a way to match the push rod head curvature in order to increase the contact area and reduce the contact stresses.

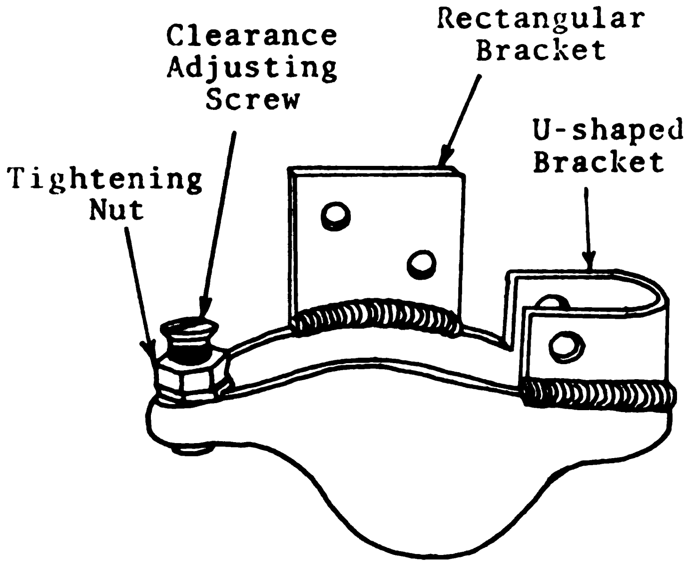


Figure 4 -- Modified Rocker Arm

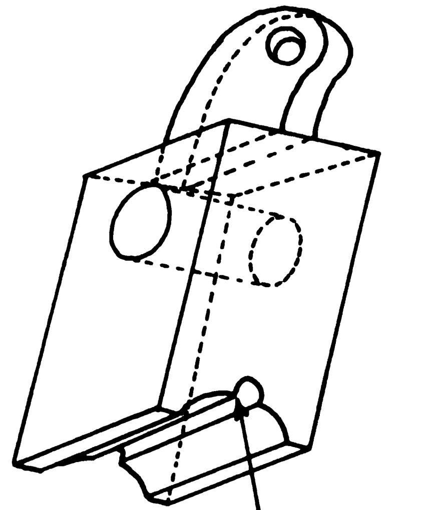


Figure 5 -- Hinged Link

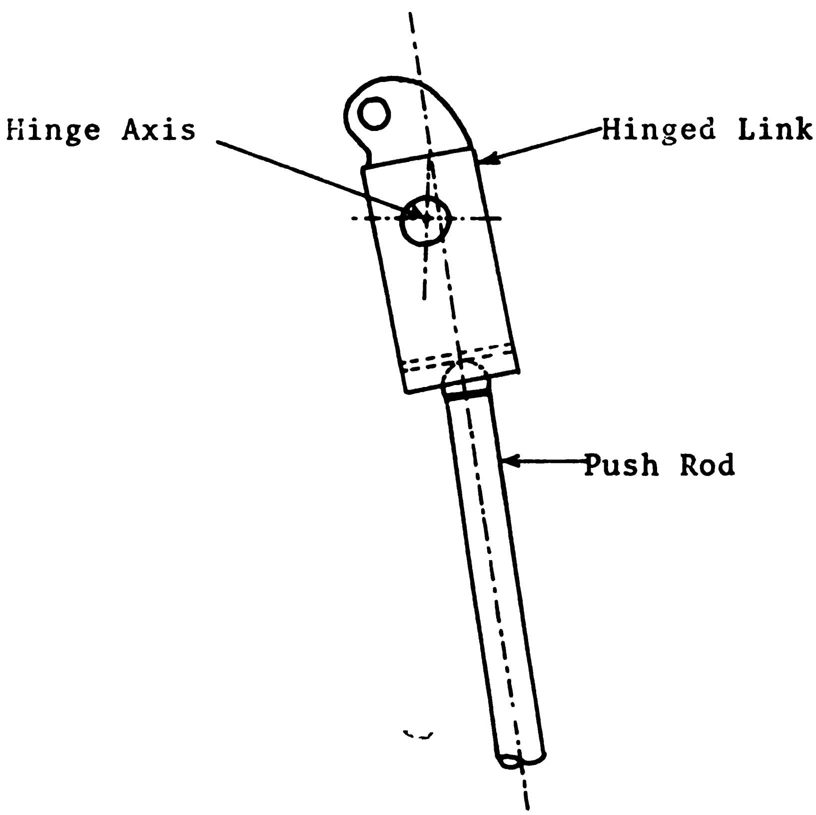


Figure 6 -- Push Rod--Hinged Link Configuration

Figure 6 shows that each hinged link must be installed in a position such that the line extending along the push rod passes just to the right of the hinged axis, otherwise the moment applied by the push rod about the hinge axis overcomes the solenoid pulling force and the hinged link will be forced back to its neutral position.

The violent oscillations of the rocker arms, especially at high engine rpm, was one of the critical factors in the design and installation of the parts and elements. The rapid oscillation of the rocker arms caused the solenoid mounting screws to work loose from the brackets during eight-cylinders operation. This problem was partially solved by safty wiring the two solenoid installation screws on each rocker arm. Steel wire and solder was used for this purpose. The rectangular and U-shaped brackets were arc welded to the rocker arms.

An important factor which made the problem of inertia force on solenoids more severe was the fact that the rocker arms were mounted in pairs, leaving only one side of each rocker arm free to mount the solenoid. Connecting the solenoids to their mounting frames by just one face causes the inertia force to produce a twisting moment in the solenoid frame. This particular method of rocker arm mounting also prevented a more compact installation, which would help to reduce inertial stresses.

Both rocker arm covers removed for installation of the modified rocker arms would not fit over the new components. To prevent oil spilling from the rocker arms, two rectangular 22" x 5" sheet metal partitions were installed in place of the rocker arm covers.

In order to energize the solenoids a simple circuit, using a spst toggle switch was made to connect all of the solenoids to a 12-volt battery. But disconnecting the whole circuit, which consequently deactivates all of the intake and exhaust valves at the same time, was expected to have the following hazard. If the valves were deactivated just after the intake and before the exhaust stroke in one of the four part-time working cylinders, the exhaust valve on that particular cylinder would remain closed at the end of the power stroke. The trapped high pressure combustion products in that cylinder could cause a violent shock and possibly damage the engine.

To eliminate this problem, two spst toggle switches were employed in such a way that the solenoids mounted on the exhaust rocker arms and those mounted on the intake rocker arms could be energized independently. The switches were labeled "intake" and "exhaust" switches (Figure 7).

With this arrangement, deactivating the intake valves prior to the exhaust valves even by a fraction of a second eliminates the possibility of trapping the burned gases. Turning both switches on at the same time reactivates the rocker arms without introducing any problem.

After completing the electrical circuit, the modified engine was ready for test. The engine was

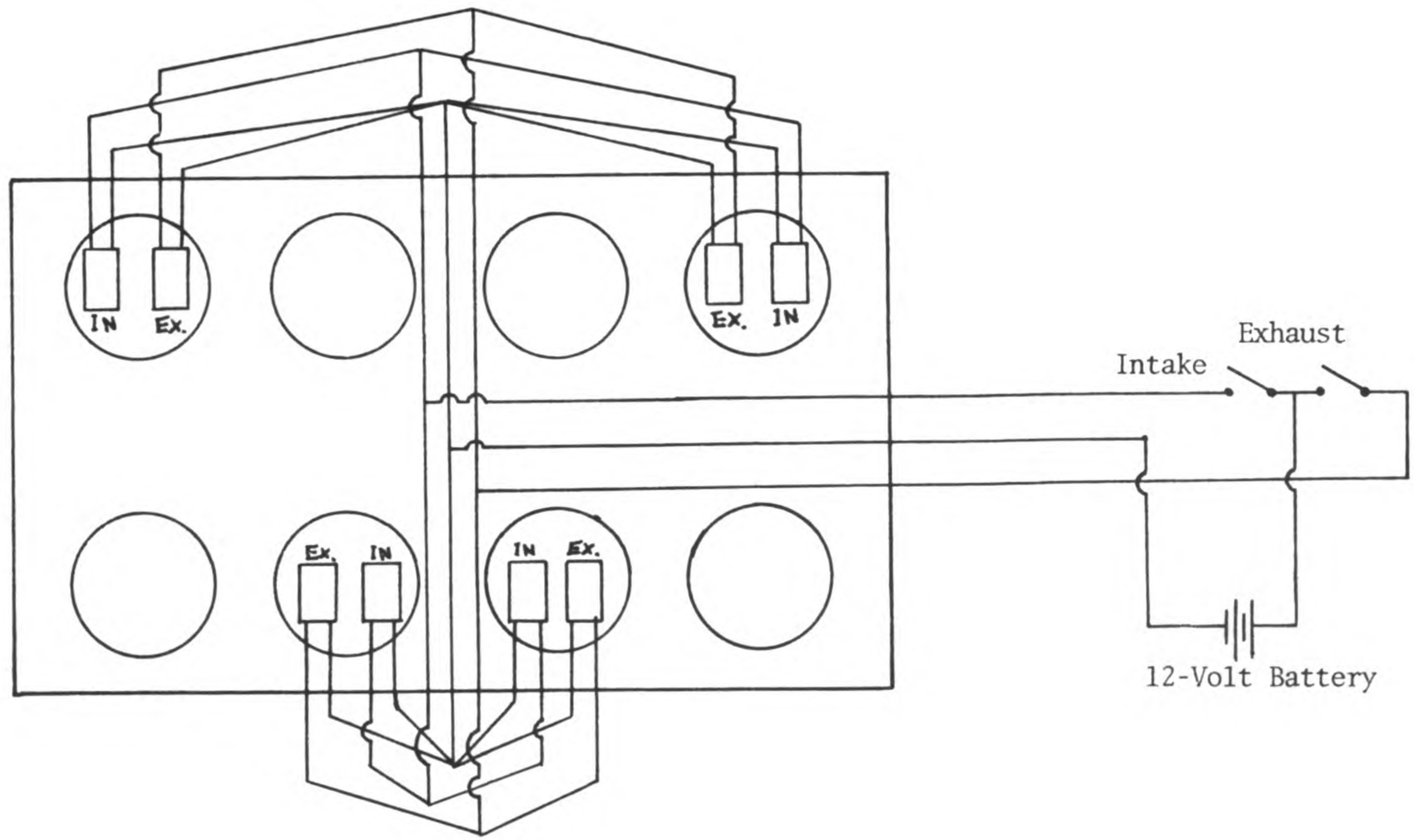


Figure 7 -- Electrical Circuit Diagram

started on eight active cylinders; i.e., all of the solenoids were energized. The engine started normally and the modified rocker arms functioned well.

Starting with only four active cylinders was expected to require a higher starting torque due to the compression in the first dead cylinder. However, when this piston gets through the top dead center, it recovers most of the energy of compression which assists in the remaining starting operation (Gerrish *et al.*, 1975). Later tests showed that the engine could be started with four active cylinders without any significant hesitation or delay.

After a few cycles of running the engine on four active cylinders the amount of air inside the dead cylinders reaches an equilibrium which is less than the amount of air at starting point. This stress relief probably leads to a smoother operation. When the engine is running with four active cylinders, the amount of work which is done to compress the air inside the dead cylinders in each upward stroke will be recovered by expansion on the next down stroke.

When the engine was switched to the four-cylinders running mode by turning off the intake and exhaust switches, and with the throttle set at a fixed position, the engine rpm increased. Conversely, switching from four- to eight-cylinders operation decreased the rpm. The reason for this is suspected to be due to the change in air capacity or volumetric efficiency. Variation of volumetric efficiency is in turn due to sudden change in suction rate of the four- and eight-cylinders running conditions.

The initial tests of the valve deactivation technique were impressive and encouraging. The concept of the rocker arm deactivating mechanism was shown to be possible and practical, needing only more work to improve reliability.

PART II

ENGINE PERFORMANCE TESTS

Objective

To determine performance characteristics of the modified engine under both eight and four cylinders running conditions. Fuel economy was the main consideration and thus the principal basis of comparison between the two running modes.

Test Procedure

Preliminary tests showed that comparing the performance data while keeping the throttle plate at the same position both under four and eight cylinders operation was not a reliable approach. The main reason was the significant loss of volumetric efficiency in the eight-cylinders running mode, especially at low throttle sets.

Then an attempt was made to maintain the same manifold pressure at similar rpms of eight- and four-cylinders operation. This method also failed to give relevant data for a conclusive comparison because at any specific manifold pressure, eight-cylinders running always gives higher power output.

A test procedure was arranged to maintain a similar power output range while running on both eight and four cylinders.

An electric dynamometer was used to load the engine for different running conditions. A vacuum gage was installed to indicate the value of manifold vacuum pressure at each reading point. The fuel consumption rate was measured by a Rotameter. The engine temperature was kept constant by connecting the radiator to an external continuous water flow.

No attempt was made to reduce engine performance to standard atmospheric temperature and pressure. A simple comparison between the four- and eight-cylinders engine performance was desired and tests were run one after the other under the same conditions, so comparison was on the same basis.

In each test the speed was varied from 1000 to 2000 rpm by 200-rpm increments. Four ranges of Brake Horsepower were to be obtained in four pairs of tests for eight- and four-cylinders running conditions. Each pair of tests was started with case of four active cylinders at 2000 rpm with an arbitrary low or medium applied load. With the fixed throttle set the applied load was increased gradually and the values of applied load, fuel flow and manifold vacuum were taken at each 200-rpm increment.

Then the engine was switched to the eight-cylinders running mode and the same test procedure was repeated.

But in this case at each 200-rpm increment the horsepower output was maintained equal to its respective point during the four-cylinders running test by varying the throttle and load. A single curve representing the variations of B.H.P. versus rpm for both running modes was obtained. Three additional pairs of tests were carried out at different ranges of power output to provide data over a relatively wide range.

Analysis of Test Results

Fuel economy was the primary concern in these comparative tests and is given in the form of Brake Specific Fuel Consumption (B.S.F.C.).

Brake Specific Fuel Consumption is defined as the pounds of fuel used per hour for each horsepower developed (5). It is a comparative parameter that shows how efficiently an engine is converting fuel into work (4). Its value can be evaluated by knowing the Brake Horsepower developed and the rate of fuel consumption. Gallon per hour is used to designate rate of fuel consumption and the parameter B.S.F.C. has been presented here in terms of gallon/BHP-Hr.

The Brake Horsepower developed, B.H.P., can be computed as follows (4).

$$\text{B.H.P.} = \frac{2\pi PLN}{33000} = \frac{PLN}{5252}$$

where P is the applied load in pounds, L is the dynamometer arm length in feet and N is engine rpm. The values of applied torque PL, often abbreviated T, are tabulated in Tables 1 through 8. In this case the arm length L was 1.5 ft.

Results and Discussion

Tables 1 through 8 contain some measured and calculated parameters required for studying the performance characteristics of the modified engine. Fuel economy was the main objective in these tests, thus fuel consumption data as a function of engine speed and horsepower developed was taken. Curves of Brake Specific Fuel Consumption (B.S.F.C.) and Brake Horsepower (B.H.P.) versus engine rpm and Brake Specific Fuel Consumption (B.S.F.C.) versus Brake Horsepower at specified speeds have been plotted in Figures 8 through 16.

Figures 8 through 11 each consist of two Brake Specific Fuel Consumption Curves representing the engine performance at eight- and four-cylinders running conditions, and one Brake Horsepower Curve representing engine power output which is the same for both running modes.

Figures 8 through 11 show that in the range of 5 to 23 B.H.P., eight-cylinders operation has always higher values of Brake Specific Fuel Consumption than four-cylinders operation. Figure 11 indicates that running the engine in the range of 23 to 28 B.H.P., either with four or eight active cylinders gives almost the same values of B.S.F.C. The same figure shows that four-cylinders operation at more than 28 horsepower output gives higher values of B.S.F.C. than running with eight cylinders. Figures 12 through 16 confirm these results. Figure 16 shows that by keeping the engine speed at 2000 rpm, we could get better fuel economy with four active cylinders than eight active cylinders as long as the Brake Horsepower output did not exceed 32 B.H.P.

There were several factors which contributed to the improved fuel economy with four active cylinders at low and moderate power outputs. Higher volumetric efficiency and reduced burning time losses are thought to be of primary importance.

Tables 1 through 8 show higher values of manifold pressure at four-cylinders operation which in turn leads to more efficient and complete combustion. The following relation shows how indicated mean effective pressure, imep, is improved by increasing the volumetric efficiency, η_v (5).

$$\text{imep} = (\gamma_i \, F \, e_c \, \eta_i \, J/144)\eta_v$$

where:

γ_i = Inlet air density, lb/ft^3

F = Fuel-air ratio

e_c = chemical energy per pound of fuel

η_i = Indicated thermal efficiency

J = 778 ft-lb/Btu

In this relation, F can be assumed constant at moderate manifold pressures.

Burning time losses are those losses due to the motion of the piston during conbustion process. High intake pressure which is a characteristic of the four-cylinders operation increases the density of the cylinder gases. Higher gas density leads to higher velocity of the flame front which in turn reduces the burning time losses and improved efficiency is achieved (4).

Loss of fuel economy at power outputs greater than 28 BHP (variable speed) and 32 BHP (at 2000 rpm) was thought to be due to the excessive enrichment by the carburetor economizer system at very high manifold pressure. The economizer is actuated by manifold pressure to ensure maximum-power mixture and also to give additional enrichment for detonation control at high outputs (5). Although Table 7 shows that power output was not very high, the vacuum level in manifold was low enough due to the four-cylinders operation to actuate the economizer system for excessive enrichment.

Very high inlet pressure also increases the tendency to detonate because of its effect on the shortening of delay period (5). This may be a factor which contributes to the reduction of the four-cylinder running efficiency at high power outputs, but detonating was not observed.

Table 1. Four-cylinders operation performance data -- Test No. 1(a)

RPM	LOAD lb.	VACUUM In.-Hg	FLOW	GAL/ HR	TORQUE ft-lb	BHP	B.S.F.C. Gal/BHP-hr
2000	8.0	15.0	67	1.13	12.0	4.57	0.247
1800	11.8	14.0	67	1.13	17.7	6.06	0.186
1600	17.0	13.0	64	1.08	25.5	7.76	0.139
1400	22.0	11.2	58	0.98	33.0	8.79	0.111
1200	25.5	9.6	57	0.97	38.2	8.74	0.110
1000	29.0	7.8	53	0.90	43.5	8.28	0.108

Table 2. Eight-cylinders operation performance data. Test No. 1(b)

RPM	LOAD lb.	VACUUM In.-Hg	FLOW	GAL/ HR	TORQUE ft-lb	BHP	B.S.F.C. Gal/BHP-hr
2000	8.5	19.0	100	1.68	12.75	4.85	0.346
1800	---	---	---	---	---	---	---
1600	17.0	18.0	82	1.37	25.50	7.76	0.176
1400	21.5	17.5	78	1.32	32.25	8.59	0.153
1200	25.5	17.0	70	1.18	38.25	8.74	0.135
1000	29.0	16.0	64	1.08	43.50	8.28	0.130

Table 3. Four-cylinders operation performance data. Test No. 2(a)

RPM	LOAD lb.	VACUUM In.-Hg	FLOW	GAL/ HR	TORQUE ft-lb	BHP	B.S.F.C. Gal/BHP-hr
2000	24.0	11.7	84	1.41	36.00	13.70	0.103
1800	29.0	10.6	82	1.38	43.50	14.90	0.092
1600	32.0	9.2	80	1.34	48.00	14.62	0.091
1400	37.5	8.0	80	1.34	56.25	15.00	0.089
1200	51.5	6.6	85	1.43	77.25	17.65	0.081
1000	56.0	5.0	75	1.26	84.00	16.00	0.078

Table 4. Eight-cylinders operation performance data. Test No. 2(b)

RPM	LOAD lb.	VACUUM In.-Hg	FLOW	GAL/ HR	TORQUE ft-lb	BHP	B.S.F.C. Gal/BHP-hr
2000	24.0	18.0	120	2.05	36.00	13.71	0.149
1800	29.0	17.6	112	1.90	43.50	14.90	0.127
1600	32.0	17.2	100	1.68	48.00	14.62	0.115
1400	37.5	16.8	95	1.62	56.25	15.00	0.108
1200	51.5	15.0	100	1.68	77.25	17.65	0.095
1000	56.0	13.4	87	1.46	84.00	16.00	0.091

Table 5. Four-cylinders operation performance data. Test No. 3(a)

RPM	LOAD lb.	VACUUM In.-Hg	FLOW	GAL/ HR	TORQUE ft-lb	BHP	B.S.F.C. Gal/BHP-hr
2000	38.0	8.0	120	2.05	57.0	21.70	0.094
1800	43.0	7.2	116	1.98	64.5	22.10	0.089
1600	48.0	6.8	105	1.78	72.0	21.93	0.081
1400	54.5	5.4	112	1.90	81.7	21.79	0.087
1200	58.5	4.5	100	1.68	87.7	20.05	0.084
1000	62.0	3.2	80	1.34	93.0	17.70	0.076

Table 6. Eight-cylinders operation performance data. Test No. 3(b)

RPM	LOAD lb.	VACUUM In.-Hg	FLOW	GAL/ HR	TORQUE ft-lb	BHP	B.S.F.C. Gal/BHP-hr
2000	37.5	14.0	146	2.55	56.25	21.42	0.119
1800	43.0	15.5	140	2.43	64.50	22.10	0.110
1600	48.0	15.0	130	2.23	72.00	21.93	0.101
1400	56.0	14.2	121	2.07	84.00	22.39	0.092
1200	59.0	14.0	106	1.80	88.50	20.22	0.089
1000	63.0	9.0	103	1.74	94.50	17.99	0.096

Table 7. Four-cylinders operation performance data. Test No. 4(a)

RPM	LOAD lb.	VACUUM In.-Hg	FLOW	GAL/ HR	TORQUE ft-lb	BHP	B.S.F.C. Gal/BHP-hr
2000	61.0	3.2	200	3.64	91.50	34.84	0.104
1800	65.0	2.5	185	3.32	97.50	33.41	0.099
1600	65.5	2.2	168	2.98	98.25	29.93	0.099
1400	69.5	2.0	145	2.53	104.25	27.79	0.091
1200	70.5	1.8	124	2.13	105.75	24.16	0.088
1000	71.0	1.2	94	1.6	106.50	20.27	0.079

Table 8. Eight-cylinders operation performance data. Test No. 4(b)

RPM	LOAD lb	VACUUM In.-Hg	FLOW	GAL/ HR	TORQUE ft-lb	BHP	B.S.F.C. Gal/BHP-hr
2000	62	13.2	184	3.30	93.0	35.41	0.093
1800	65	13.0	172	3.05	97.5	33.41	0.091
1600	65	12.8	152	2.65	97.5	29.70	0.089
1400	69	12.3	146	2.54	103.5	27.59	0.092
1200	71	12.0	120	2.05	106.5	24.33	0.084
1000	71	12.0	103	1.74	106.5	20.27	0.085

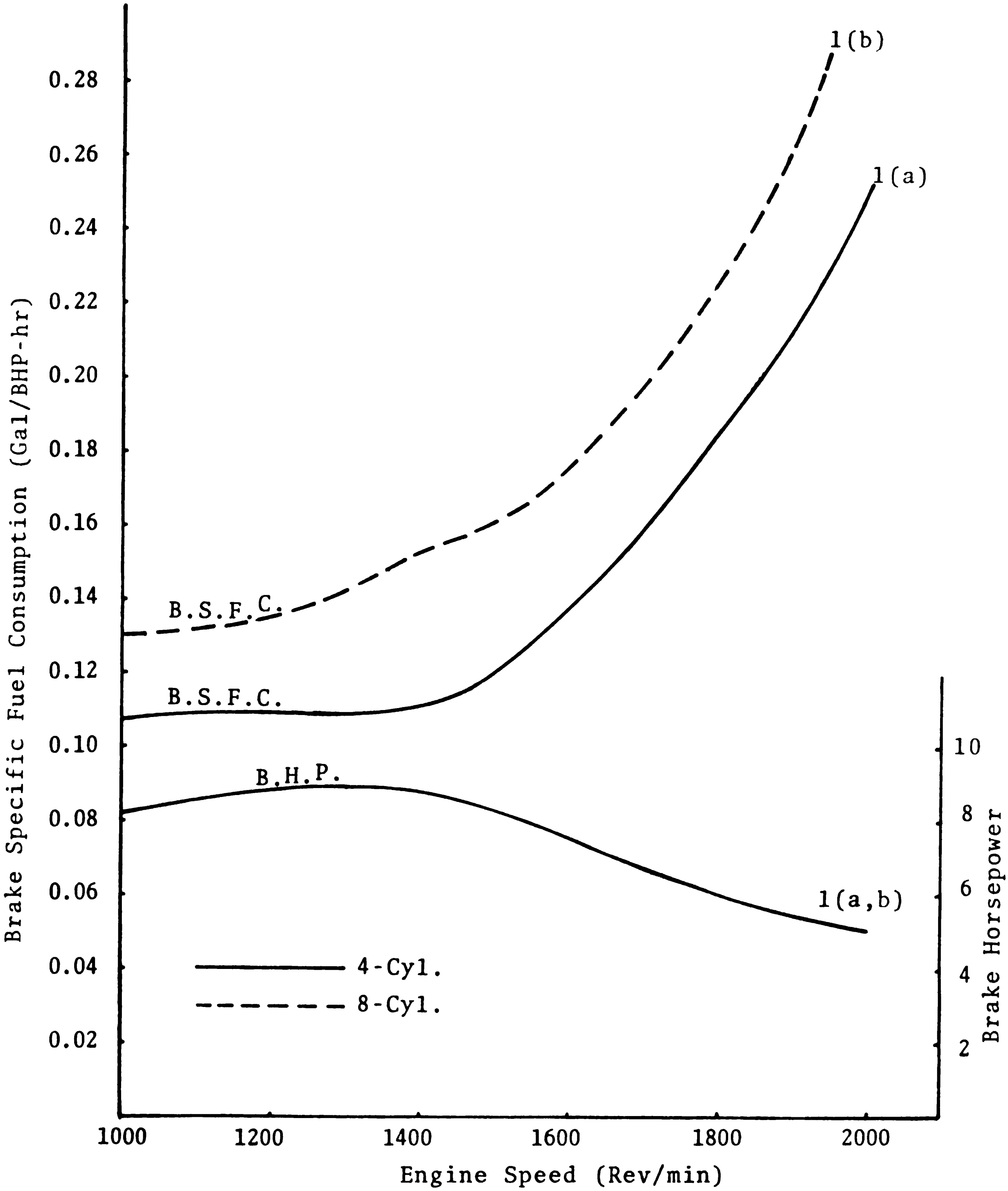


Figure 8 -- Fuel Consumption Comparison Test No. 1(a,b).

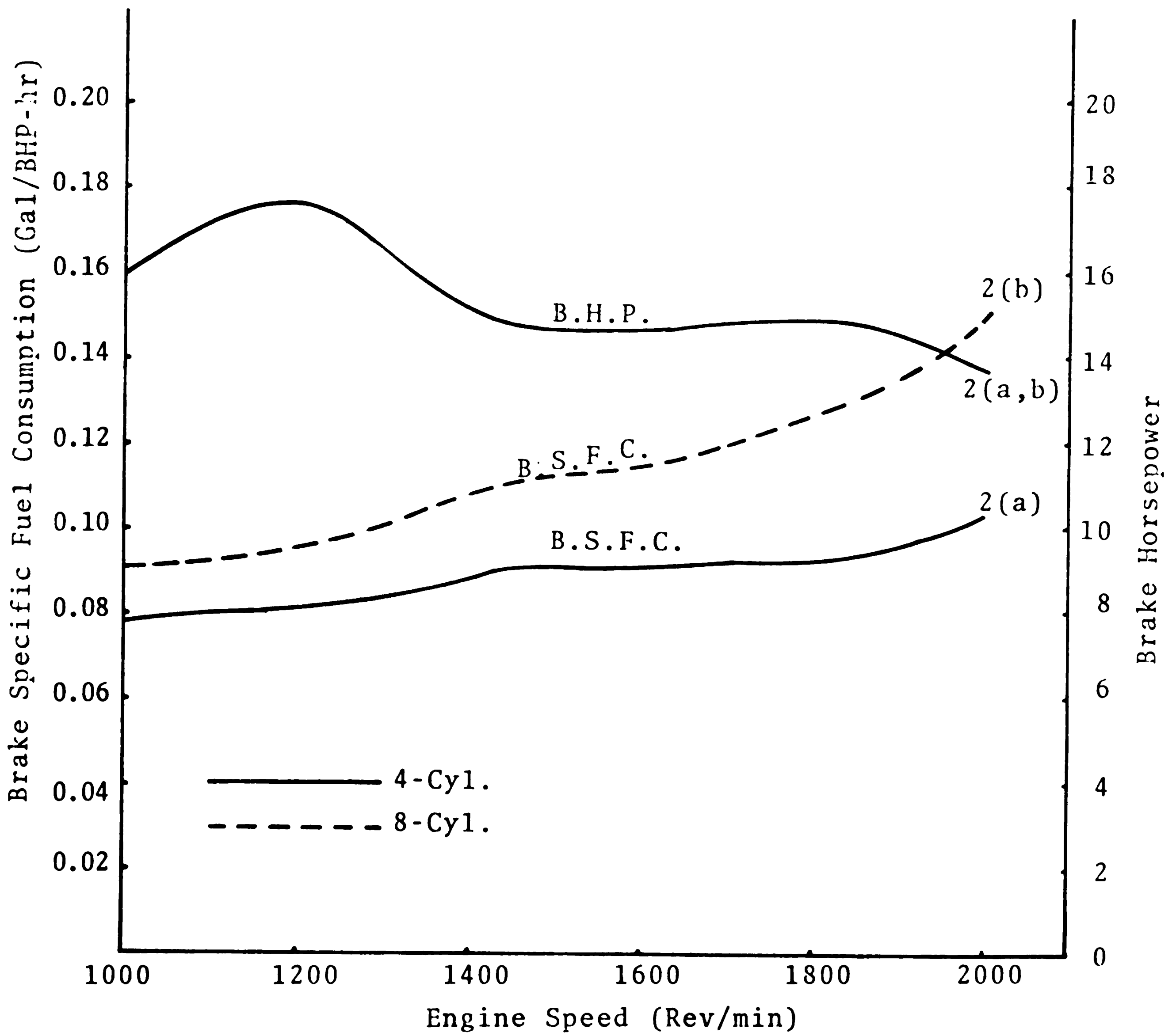


Figure 9 -- Fuel Consumption Test No. 2(a,b).

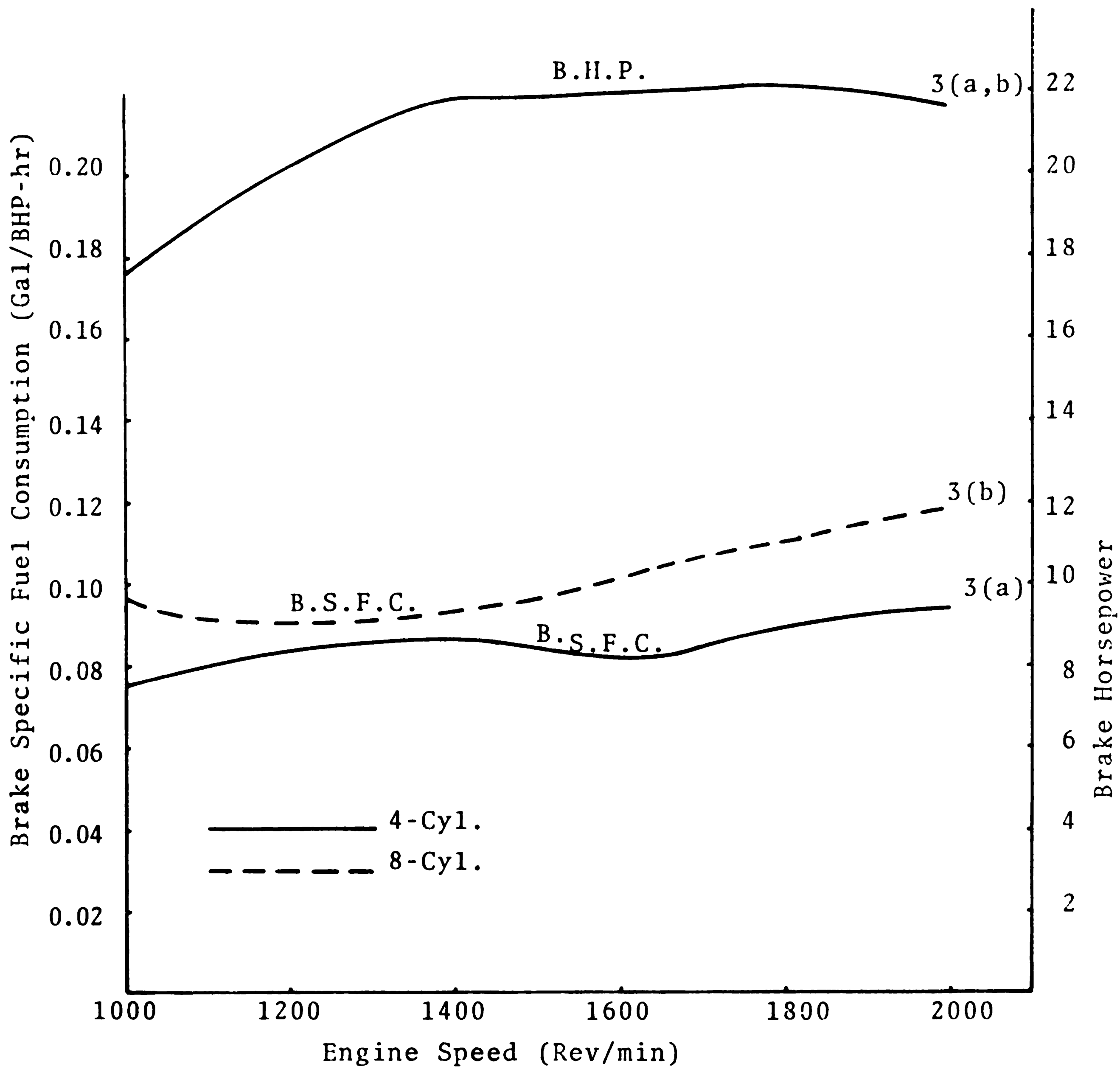


Figure 10 -- Fuel Consumption Comparison Test No. 3(a,b).

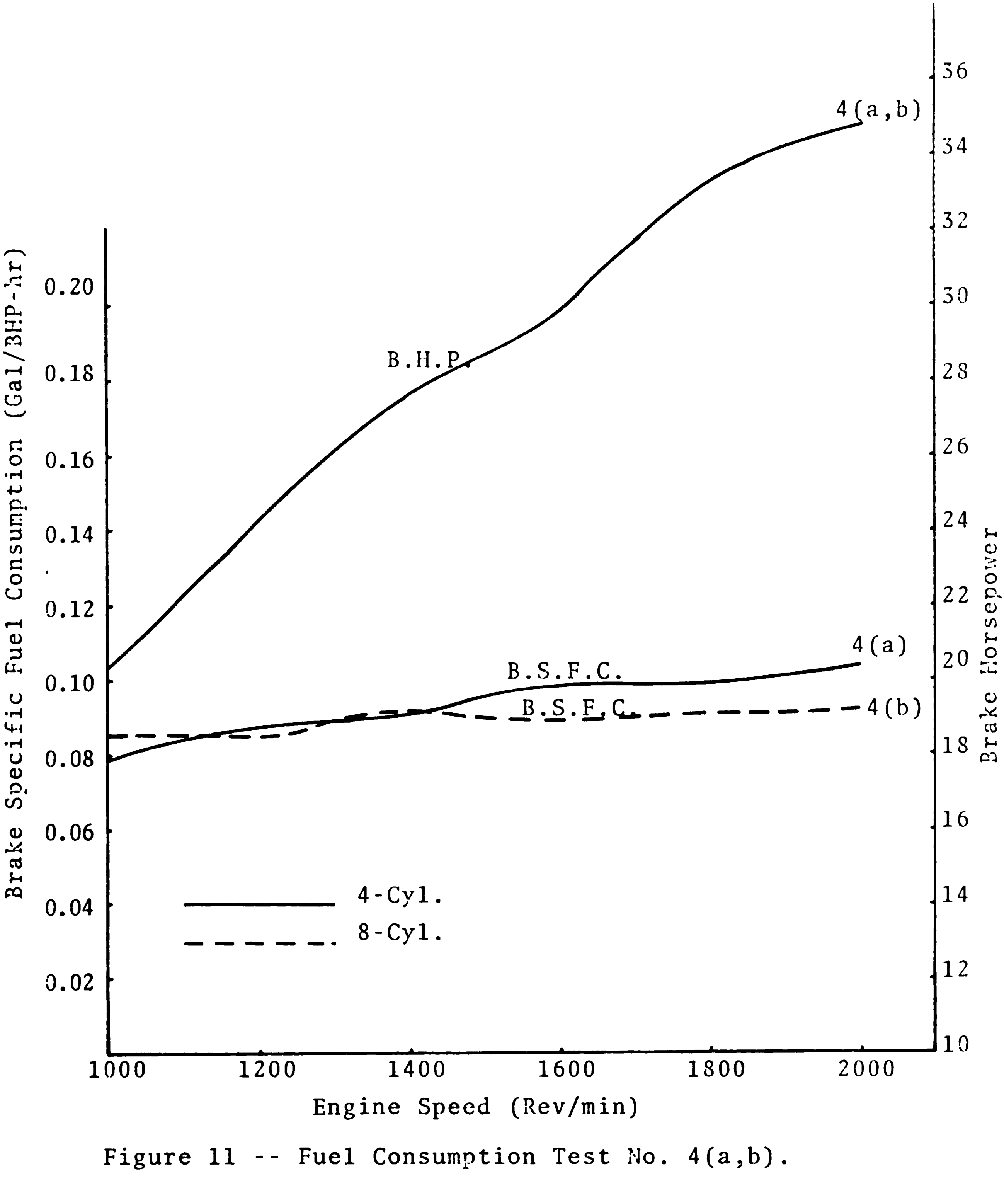


Figure 11 -- Fuel Consumption Test No. 4(a,b).

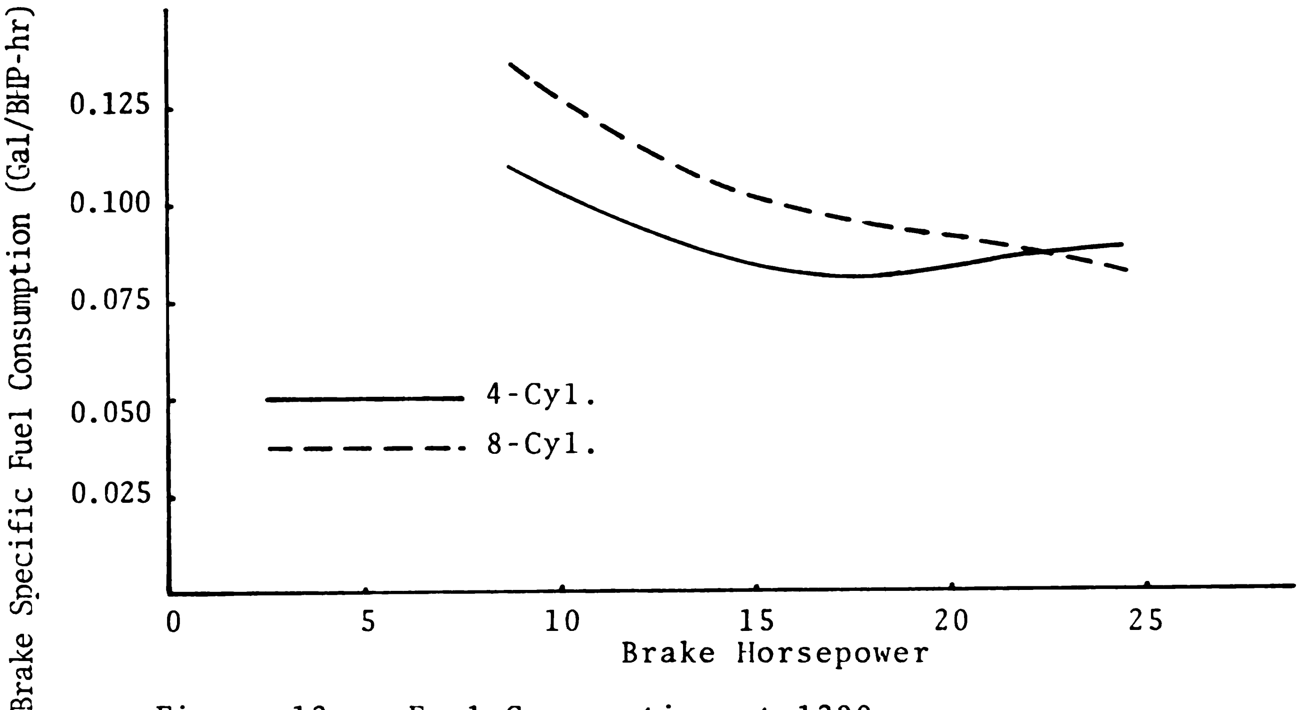


Figure 12 -- Fuel Consumption at 1200 rpm.

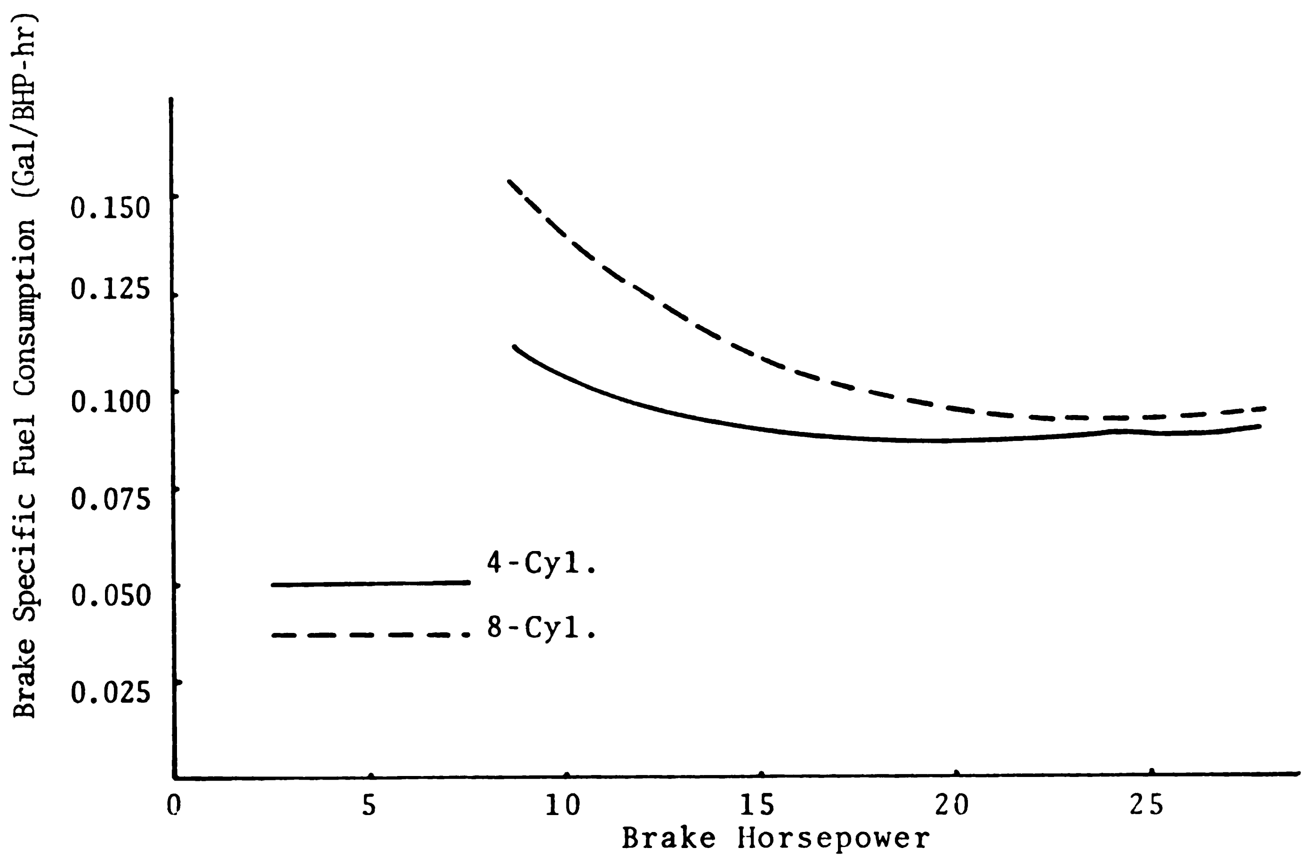


Figure 13 -- Fuel Consumption at 1400 rpm.

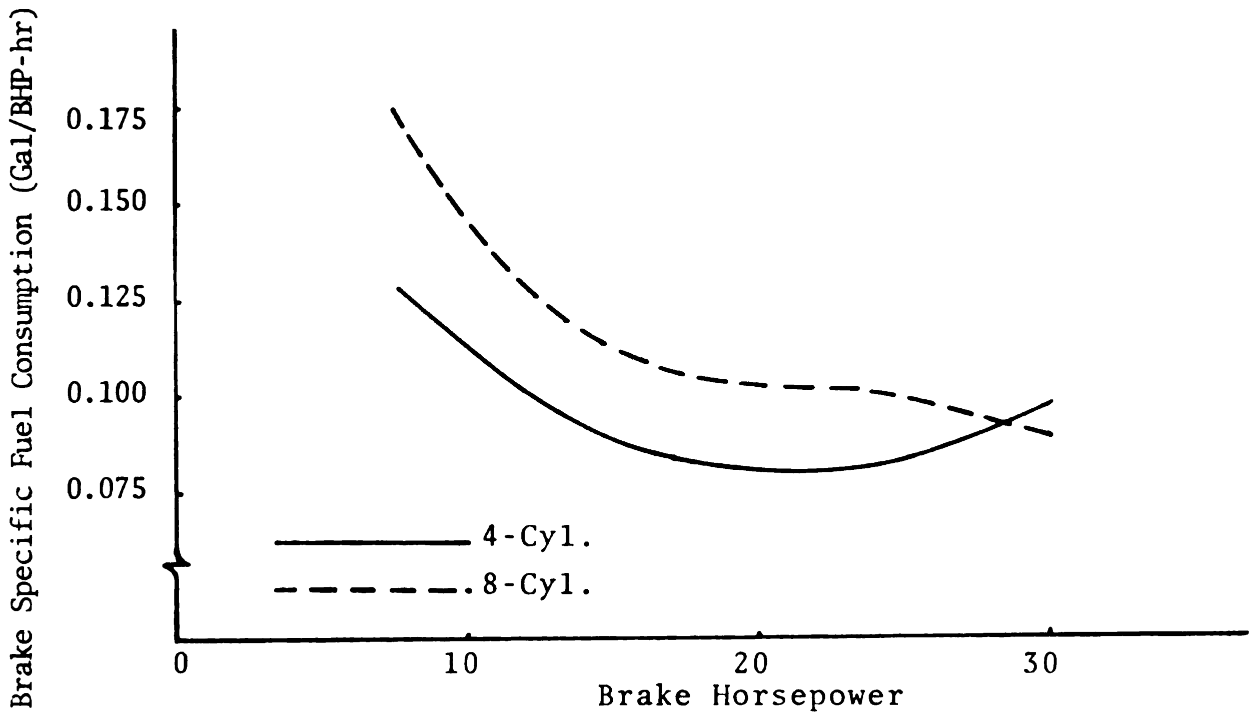


Figure 14 -- Fuel Consumption at 1600 rpm.

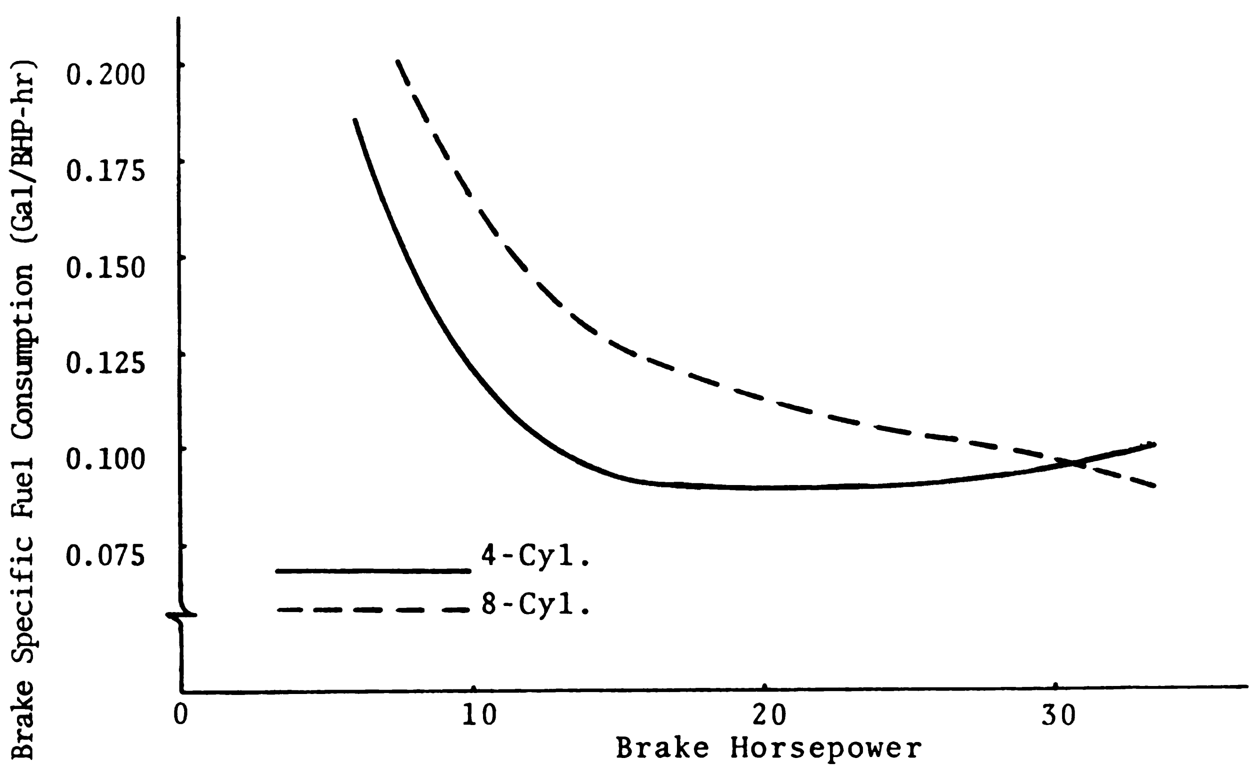


Figure 15 -- Fuel Consumption at 1800 rpm.

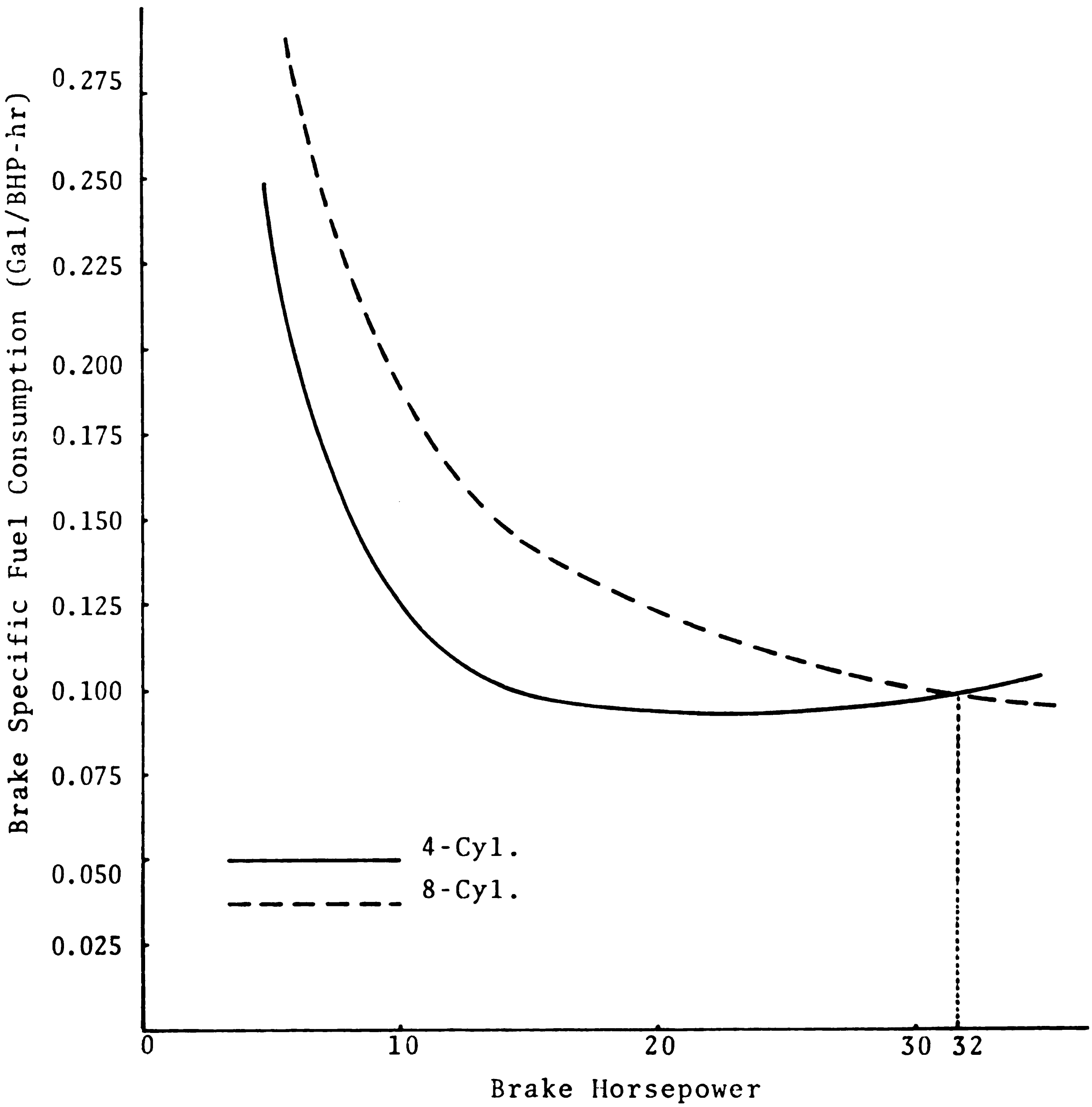


Figure 16 -- Fuel Consumption at 2000 rpm.

CONCLUSIONS

1. The rocker arm deactivating and reactivating mechanism was shown to be a practical approach for switching the engine running mode from eight- to four-cylinders operation and vise versa.

2. Violent oscillation of the rocker arms, especially at high speeds, was the most critical consideration in the design and installation of the rocker arm reactivating units.

3. Improved fuel economy was achieved by running the engine with only four active cylinders at low and moderate power outputs.

4. The most efficient (economically) range of power output with four active cylinders was 15 to 25 BHP.

5. The four-cylinders operation in the range of 1800-2000 rpm had better fuel efficiency than eight-cylinders operation up to about 30 to 32 BHP.

6. The manifold vacuum level was a good indicator of the four-cylinders running efficiency.

RECOMMENDATIONS

1. Special oil-proof solenoids which can also withstand violent mechanical vibrations must be designed and constructed for this purpose.

2. A compact design must be provided to minimize the magnitude of inertia forces on the solenoids.

3. Engines which do not employ the U-shaped paired rocker arm retainers should be more adaptable to a compact, less troublesome rocker arm modification. Unmodified rocker arm covers may also fit the modified system.

4. Carburetor modifications, like plugging the main jet, enrichment jet and accelerator pump nozzle in the unused side of the carburetor at four-cylinders operation is expected to provide further fuel saving. These modifications must be synchronized with the rocker arm switching function to restore the normal carburetor conditions at eight-cylinders operation.

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