AN INVESTIGATION OF FARM TRACTOR PERFORMANCE

by

FLOYD NORMAN REECE

B. S., Kansas State College
of Agriculture and Applied Science, 1952

A THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Agricultural Engineering

KANSAS STATE COLLEGE
OF AGRICULTURE AND APPLIED SCIENCE

1959

TABLE OF CONTENTS

INTRODUCTION 1
    The Farm Tractor in Agriculture 1
    The Nebraska Tractor Law 3
    Review of Literature 4
PURPOSE OF INVESTIGATION 6
    Standard for Comparison to Nebraska Tractor Tests 6
    Determination of The Effect of Neglect of Maintenance on Tractor Performance 6
METHOD OF PROCEDURE 7
    Method of Selecting Tractors 7
    Test Equipment 8
    Procedure for Testing 24
AGE AND MAKES OF TRACTORS TESTED 27
COMPARISON OF TEST RESULTS TO NEBRASKA TRACTOR TESTS 28
    Horsepower 28
    Fuel Consumption 31
TEST RESULTS 33
    Engine Governor Condition and Adjustment 33
    Air Cleaner Condition 42
    Service to Spark Plugs 45
    Adjustment of Carburetor 53
    Ignition Timing 55
    Part-Load Fuel Consumption 57
STATISTICAL ANALYSIS OF TEST RESULTS 57
    Nebraska Test Comparisons 57
    Changes in Power and Fuel Consumption Due to Adjustments 59

CONCLUSIONS 60

RECOMMENDATIONS FOR FURTHER STUDY 62

ACKNOWLEDGMENTS 65

REFERENCES 66

APPENDIX 68

INTRODUCTION

The Farm Tractor in Agriculture

The farm tractor is the prime mover for agriculture. Since the tractor is used for nearly every farming operation, it is the most important and most used single item of mechanized equipment on the farm.

According to the 1954 Census of Agriculture (15), there are 165,401 wheel tractors on 120,291 Kansas farms, or an average of 1.38 tractors per farm. The almost complete change from animal power to mechanical power as a source of power for Kansas agriculture has taken place since 1920. In 1920 there were 1,326,129 horses and mules on Kansas farms, and only 17,177 tractors. In 1954 there were only 91,360 horses and mules on Kansas farms. The number of farms reporting horses and mules but no tractors decreased from 25,215 in 1945 to 4,643 in 1954. These changes are shown graphically in Figs. 1 and 2.

With the almost complete mechanization of agriculture and the resultant increase in number of tractors and other machines on the farm, it is logical to assume that there has been a corresponding increase in machinery costs in agriculture. According to the 1956 Farm Management Summary and Analysis Report (4) where records were kept on 1,007 Kansas farms, the cost of depreciation, repairs, fuel, and lubricants for the farm tractor and other machinery was the largest single item of farm expense, accounting for about one-third of the total farm operating costs.

Fuel cost is one of the largest items in total machinery cost. This is especially true with respect to the farm tractor. Kansas farmers spent $58,286,189 for gasoline and other fuels and oils in 1954 (15). On the 1,007 farms included in the 1956 Farm Management Report, the average cost for

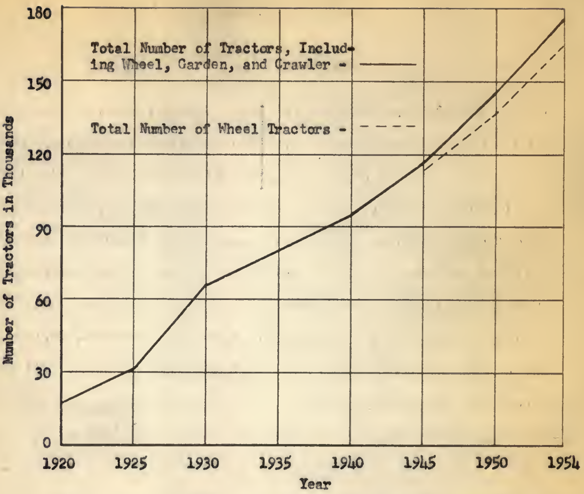


Fig. 1. Graph showing the increase in number of tractors on Kansas farms since 1920 according to the Agricultural Census.

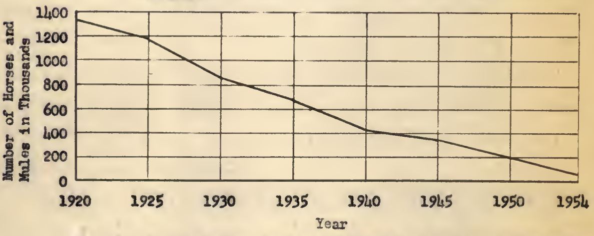


Fig. 2. Graph showing decrease in number of horses and mules on Kansas farms since 1920 as reported by the Agricultural Census.

fuel and oil was $1,018 per farm (4). Further examination of the 1956 Farm Management Report showed that the cost for fuel and oil was approximately equal to the cost for machinery repairs. Machinery depreciation cost was almost double the cost for fuel and oil. The analysis included all the machinery on these farms. When the farm tractor is considered as an individual unit, the cost of fuel assumes a more important role. Fairbanks and Fenton (5) found, in analyzing a typical farming operation involving a tractor and plow, that fuel cost was 40 per cent of the total cost for fuel, depreciation, and repairs.

The operating efficiency of the farm tractor is one of the important factors determining the relative amount of fuel consumed by the tractor. Since fuel cost is one of the major costs of operating the farm tractor, it follows that an increase in operating efficiency of the tractor should result in a significant decrease in total cost of operating the tractor.

The Nebraska Tractor Law

The Nebraska Tractor Law was enacted in 1919. The purpose of this law was to encourage the manufacture and sale of improved tractors and to contribute to a more successful use of the tractor for farming (13).

The Nebraska Tractor Law provided that a stock tractor of each model sold in the state should be tested and passed upon by a board of three engineers under State University management, and that each company, dealer, or individual offering a tractor for sale in Nebraska should have a permit issued by the State Railway Commission. The permit for any model of tractor was issued after a stock tractor of that model was tested at the University and the performance of the tractor compared with the claims made for it by the manufacturer.

Testing of models of tractors offered for sale in Nebraska was started in 1920 and has been continued through the years (13). This unique law has resulted in a situation where it is possible to have an accurate, unbiased evaluation of practically all models of new tractors offered for sale in the United States. The American farmer has come to accept the Nebraska Tractor Tests as an accurate method of determining such characteristics as horsepower and fuel efficiency of new tractors which are offered to him for sale.

The Nebraska Tractor Tests are performed on new tractors which are operated in the best possible condition and adjustment. It is logical to assume, after a new tractor is put in service on a farm, that the operating characteristics will change from those determined by the Nebraska Tests. The amount of change should depend upon many factors, including original design, wear, operating conditions, and maintenance procedures. It appears that if the farmer is to use the Nebraska Tractor Tests for evaluating a new tractor, then he should also have some method of knowing how much the operating characteristics might change with time and use.

Review of Literature

Very little work has been done in determining the operating characteristics and efficiency of tractors operating on farms. Most of the work dealing with changes in operating efficiency caused by improper maintenance is out of date. It was not possible to find published comparisons of tractors operating under actual farm conditions made to their capabilities as determined from the Nebraska Tractor Tests.

Smith and Larsen, at the University of Nebraska, studied factors affecting efficiency on 25 farm tractors. Their work was referred briefly by Weber (16), who reported that "Smith and Larsen showed an average gain of eight per cent in power and 10 per cent in efficiency". Attempts to obtain details on the work done by Smith and Larsen has led to the conclusion that complete results of this work were not published, and are not available for reference.

Bateman and Weber (2) tested 18 tractors under the condition in which they were being operated on Illinois farms, and again after simple repair and adjustment. They reported an average increase of 16 per cent in maximum horsepower, and an average decrease of 16 per cent in fuel consumption as a result of correcting improper maintenance procedure and simple repair. These tests were conducted during the period 1938-1947 when conversion from distillate fuel to gasoline was an important factor in tractor efficiency. Therefore, most of this work was concerned with changing the intake manifold, compression ratio, ignition timing, and carburetor setting on tractors burning gasoline which were originally designed for distillate. They found that 80 per cent of the decrease in fuel consumption was obtained by adjustment of the carburetor. Since conversion from distillate fuel to gasoline is no longer a major factor in tractor operation, some doubt may be expressed about the continued validity of these tests.

In 1955, Weber (16) examined 60 farm tractors in Champaign County, Illinois for indications of improper maintenance procedures. No attempt was made to evaluate the effect on the operating efficiency of the items examined.

It was established that several maintenance deficiencies which could result in a decrease in maximum horsepower and fuel efficiency were prevalent among the 60 tractors examined. Those listed as occurring most frequently were dirty air cleaners, improper valve adjustment, pitted ignition points, and excessive engine speeds (16).

PURPOSE OF INVESTIGATION

Standard for Comparison to Nebraska Tractor Tests

One of the objectives of this investigation was to determine a method of evaluating tractor performance as a function of Nebraska Tractor Test results. It is logical to assume that a tractor will not maintain the optimum operating characteristics as determined by the Nebraska Tests after it is put into service on the farm. It appears that a determination of the magnitude of the change as exhibited by the average farm tractor should be of value.

This standard of comparison could be used in at least two ways. First, if it is known how much the average tractor changes in service from the results obtained in the Nebraska Tests, then an evaluation would exist for estimating the actual performance to be expected of any given tractor in service. Second, with the increasing availability to the farmer of a commercial means for determining horsepower and fuel efficiency of the farm tractor, a standard for comparing a tractor to the Nebraska Tests would provide a means of evaluating the performance of a given tractor with respect to the mean. This would provide an indicator for determining the possible need for major repairs and adjustments.

Determination of the Effect of Neglect of Maintenance on Tractor Performance

Since the farm tractor is the major source of power on the farm, and the cost of fuel for the tractor is one of the major farm expenses, any factors which might change the operating characteristics of the tractor should have a direct effect upon the economic status of the farm family.

It is known that certain maintenace practices have a direct effect upon overall tractor life and efficiency. Some maintenance practices are directly associated with tractor life and repair costs, and are indirectly associated with power output and fuel efficiency. These include such items as lubrication practices, housing, and adjustment of brakes and clutch. Other maintenance practices are directly associated with power output and fuel efficiency, and indirectly associated with tractor life and repair costs. These include such items as air cleaner service, engine governor adjustment, spark plugs, carburetor adjustment, ignition timing, and valve adjustment.

This investigation was primarily concerned with determining the extent to which maintenance practices having a direct effect on power and fuel efficiency were being neglected on a representative group of Kansas farm tractors, and the magnitude of the total and individual effect of the neglect of these maintenance practices on power and fuel efficiency. Maintenance practices which were examined in detail were (a) air cleaner service, (b) engine governor adjustment and condition, (c) spark plug condition, (d) carburetor adjustment, and (e) ignition timing.

METHOD OF PROCEDURE

Method of Selecting Tractors

A total of 50 farm tractors were tested in this investigation. Thirty-nine of the tractors were located in Riley County (Northeast) Kansas, and 11 in Wilson County (Southeast) Kansas.

Selecting the tractors to test presented considerable difficulty. It seemed desirable to approach the farmers individually for permission to test their tractors. It was felt that if the farmers were approached on a group basis that a disproportionately large number of tractors with some specific malfunction would be selected. It was feared that the farmer who knew that something was wrong with his tractor would request that it be tested with the hope that the malfunction would be corrected.

One plan that was considered was to obtain the names of tractor owners from implement dealers. This plan was abandoned when it was discovered that the implement dealers might have the tendency to select tractor owners with specific problems with their tractors.

The plan finally used to select the tractors was to obtain the name of one farmer in each of several communities from the County Agricultural Extension Agent. The farmer was then contacted for permission to test his tractor. This provided an opportunity to become acquainted with other tractor owners in a community and approach them for permission to test their tractors. This plan worked very well and it was possible to schedule tests with a minimum of delay and inconvenience to the tractor owners.

It is felt that the sample of tractors selected is representative of the tractor population in the eastern one-third to one-half of Kansas.

Test Equipment

<u>Measurement</u> <u>of</u> <u>Power</u>. All horsepower measurements were made with a M-W Hydra-gauge power take-off dynamometer. The dynamometer is a commercially built machine which is available for sale to implement dealers for use in tractor tune-up and repair. It connects to the standard tractor power take-off shaft. Power is transmitted through universal joints and a gear transmission to a gear-type hydraulic pump. The pump recirculates oil from a reservoir containing copper cooling coils through which tap water is circulated to cool the oil. Load is applied by throttling the discharge from the hydraulic pump.

Torque is measured indirectly by a pressure gauge which indicates the oil pressure generated by throttling the pump discharge. The speed of the power take-off shaft is indicated by a magnetic-type tachometer. Horsepower is determined by reference to a standard calibration chart for the dynamometer. Power absorbed is dissipated in the form of heat which is carried off by the tap water circulated through the copper cooling coils. A schematic diagram of this machine is shown in Fig. 3.

It was determined that the standard calibration furnished with the dynamometer was in error by about 10 per cent of the indicated horsepower. A maximum allowable error of plus or minus five per cent of indicated horsepower was established for this investigation. Therefore, it was necessary to recalibrate the dynamometer to obtain the desired accuracy.

The magnetic tachometer on the dynamometer was checked for accuracy, and since a considerable error was found to exist, the tachometer was calibrated by means of a Hasler Speed Indicator. The tachometer correction curve shown in Fig. 4 was obtained, and from this curve it was observed that the tachometer was in error by a constant 20 RPM in the desired operating range. Throughout the tests, a correction of plus 20 RPM was applied to the indicated tachometer reading to obtain the corrected power take-off speed.

To complete the calibration of the dynamometer, it was necessary to measure the torque input to the machine corresponding to various oil pressure readings obtained on the dynamometer pressure indicator gauge. This was accomplished by means of the SR-4 strain gauge torquemeter designed by Reece (10). The torquemeter and the Baldwin-Lima-Hamilton strain indicator which was used with the torquemeter are shown in Fig. 5. The torquemeter was installed in the power shaft between the tractor and the dynamometer. This made it possible to measure the total torque input to the dynamometer.

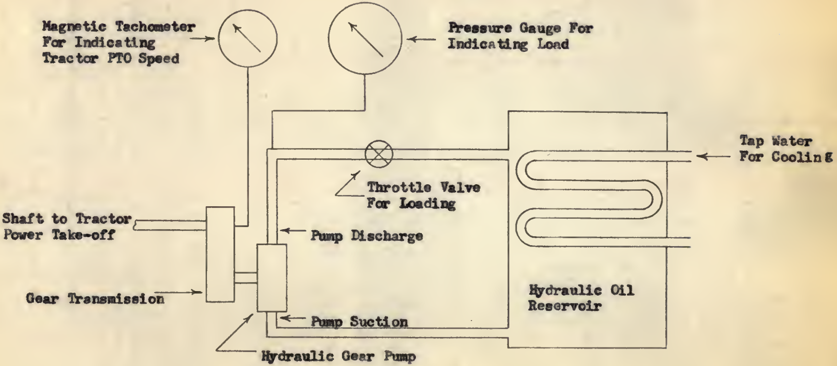


Fig. 3. Schematic diagram showing the principle of the M-W Hydra-gauge Dynamometer.

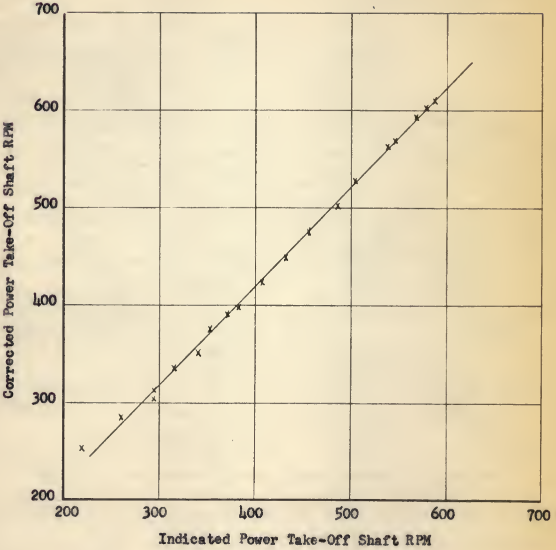


Fig. 4. The speed correction curve for the magnetic tachometer on the M-W Hydra-gauge dynamometer. A standard correction factor of plus 20 RPM to the indicated RPM was obtained from this curve.

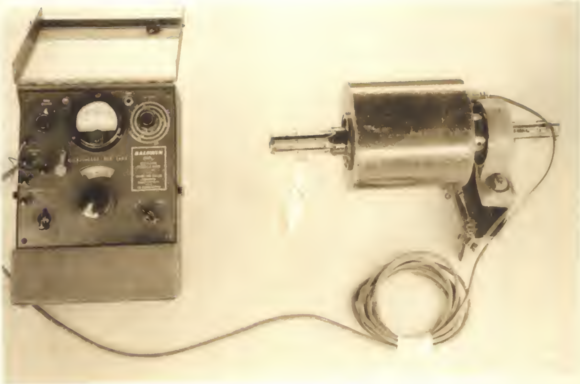


Fig. 5. The SR-4 Strain gauge torquemeter which was used for calibration of the M-W Hydra-gauge dynamometer is shown on the right. On the left is the Baldwin-Lima-Hamilton SR-4 strain indicator which was used to indicate the strains measured by the torquemeter.

The dynamometer was operated at speeds ranging from 400 RPM to 600 RPM, in increments of 25 RPM. At each speed, load was varied to obtain oil pressure readings from 200 lbs./sq. in. to 900 lbs./sq. in. in increments of 50 lbs./sq. in. At each speed and pressure the torque input to the machine was observed, and the resulting horsepower computed. From these data, the calibration curve shown in Plate I was constructed.

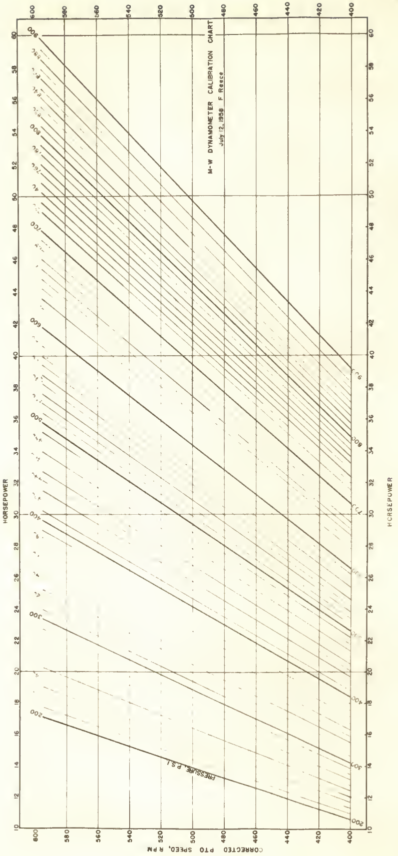
Recommendations furnished with the dynamometer indicated that the hydraulic oil temperature should be maintained at 160° F. The hydraulic oil temperature was regulated by varying the flow of tap water through the cooling coils by a hand valve. It was found that a steady oil temperature was almost impossible to maintain due to the rapid and large scale fluctuations in the oil temperature. Therefore, it was thought to be desirable to determine the effect of hydraulic oil temperature change upon the calibration of the dynamometer. This was done by determining the input horsepower by means of the SR-4 torquemeter corresponding to various oil pressure readings for two oil temperatures, 160° F. and 180° F., and a constant power take-off speed of 500 RPM. These data were used to obtain the curves shown in Fig. 6. From these curves, it was possible to determine that the error due to a change in oil temperature of 20° F. was 2.5 per cent of indicated horsepower at 20 horsepower, and 0.5 per cent of indicated horsepower at 50 horsepower. Since this error was well within the limits for this investigation, no subsequent corrections were made for variations in oil temperature. All tests were made however, with the oil temperature at 160° F. plus or minus 20° F. The calibration chart, Plate I, is for an oil temperature of 160° F.

The torquemeter used in the calibration is accurate to within plus or minus two per cent of indicated torque for the range used in the calibration.

EXPLANATION OF PLATE I

The calibration chart which was developed for the M-W Hydra-gauge dynamometer. The chart is entered with observed hydraulic oil gauge pressure and corrected power take-off speed. Horsepower is read from the abscissa.

PLATE I



M-W DYNAMOMETER CALIBRATION CHART

July 12, 1958 F Reece

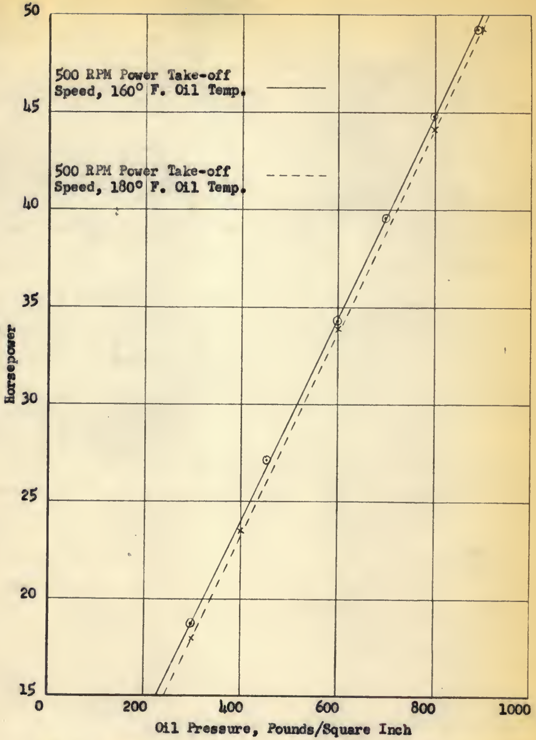


Fig. 6. Curves showing the effect of hydraulic oil temperature on the calibration of the M-W Hydra-gauge dynamometer. Curves were obtained by using the SR-4 strain gauge torquemeter to measure torque input to the dynamometer.

With the maximum error in power measurement due to variation in hydraulic oil temperature fixed at plus or minus 2.5 per cent, the root mean square accuracy of the power measurement in this investigation was approximately plus or minus 3.2 per cent.

The M-W dynamometer was factory equipped with wheels for portability in a shop, but the wheels were not designed for use on the road. Since it was necessary to transport the equipment over the roads, a trailer was designed and built which would accomodate the dynamometer, fuel measuring equipment, and an engine-powered centrifugal pump used to circulate dynamometer cooling water on farms without running water.

The dynamometer was made an integral part of the trailer, and mounted in such a way that the tractor could be connected to the power input shaft without disconnecting the trailer from the towing vehicle. The test equipment is shown attached to a tractor for testing in Fig. 1, Plate II, and in travel position in Fig. 2, Plate II.

Measurement of Fuel Consumption. Fuel consumption in all tests was determined by measuring the time required for the tractor to burn one pound of fuel. A 10-gallon fuel supply tank was mounted on Howe counter-balance beam scales. Immediately prior to the beginning of a test, the scales were balanced with the beam slightly light. As the beam swung down indicating the scales were balanced, a stop watch was started. Weight equivalent to one pound of fuel was removed from the scale beam. When the beam swung down the second time, the watch was stopped, indicating the time required to burn one pound of fuel. Turner (14) found that this method of measuring fuel consumption was superior to the method where an auxiliary tank is used to supply fuel while the main tank is weighed.

EXPLANATION OF PLATE II

Fig. 1. The portable test equipment is shown in position for testing a tractor.

Fig. 2. The test equipment in position for transportation.

PLATE II

Fig. 1

Fig. 2

Due to the sensitivity of the scales to vibration, it was necessary to isolate the scales from the trailer when the scales were in use. This was accomplished by the swinging table arrangement shown in Figs. 1 and 2, Plate II.

Fuel was delivered from the fuel supply tank to the tractor carburetor by means of rubber tubing and an electric diaphram-type fuel pump. The fuel pump maintained a discharge pressure of six to seven lbs./sq. in. Since fuel is normally delivered to the tractor carburetor under only a few inches of pressure head from the tractor fuel tank, it was necessary to reduce the pump pressure to the equivalent pressure as determined by the fuel tank location on any particular tractor. The fuel tank height and location varies considerably for different makes and models of tractors. This made it necessary that some means be provided to regulate the fuel pressure delivered by the electric fuel pump from about three feet to six feet of head.

A small standpipe with provision made to vary the fuel level in the pipe was designed and built to regulate the pressure of fuel delivered to the tractor. A schematic diagram of this system is shown in Fig. 7.

<u>Indicators for Engine Condition</u>. The carburetor air inlet pressure, which was used to determine the resistance to air flow of the air cleaner, was measured with a water-filled manometer with a range of 21 inches of water column. The manometer was connected to the carburetor inlet by means of rubber tubing and a hypodermic needle inserted in the rubber hose connecting the carburetor and air cleaner.

No-load engine speeds were determined by use of a Hasler speed indicator.

Engine intake manifold pressure was determined with a standard manifold vacuum gage calibrated in inches of mercury column.

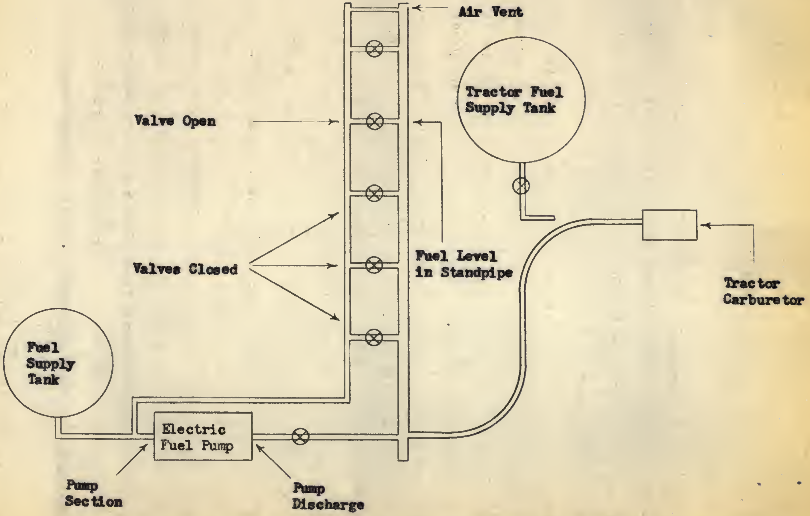


Fig. 7. Schematic diagram of system which was developed to obtain the correct pressure head on the fuel supplied to the tractor from the fuel weighing system.

An indication of the air-fuel ratio was obtained by an Electro Products exhaust gas analyzer. Turner (14) found that this instrument was not a reliable means of determining the absolute value of air-fuel ratio. It was not used in this investigation to determine absolute air-fuel ratio, but only as an indicator. The electric resistivity cell used in this instrument is subject to errors caused by variations in exhaust gas pressure on the cell, and accumulation of water which condenses from the exhaust gas. Consistent readings were obtained with this instrument by using a water trap to prevent entry of liquid water into the cell, and by keeping the gas pressure on the cell less than 0.5 inches of water column.

Ignition timing was determined by use of a Sun Electronic Distributor Timer. This instrument is a power timing light with a built-in electronic device for delaying each flash of the light for a precise, short period of time. The amount of delay is varied by changing a control on the instrument. The time of delay is calibrated in degrees of crank angle before top dead center. This makes it possible to use the top dead center timing mark to determine the running ignition timing of an engine. In use, the control knob on the instrument is rotated until the top dead center mark on the flywheel is illuminated by the timing light in the top dead center position. The spark advance in degrees of crank angle before top dead center is then read from the instrument.

The indicators used for determining engine condition are shown in Fig. 8.

The Implement and Tractor Shop Service Manual (8) was used as the reference for all manufacturer's specifications.

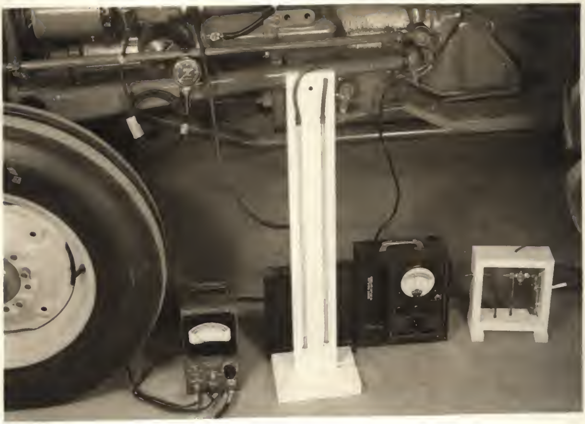


Fig. 9. The instruments which were used to determine the engine conditions are shown attached to a tractor. They are, left to right, manifold vacuum gauge (upper left), Sun Electronic Distributor Timer (lower left), the water manometer for indicating carburetor air inlet pressure, the Limited Products exhaust gas analyzer, and the device used to control the pressure and keep water out of the analyzer.

Procedure for Testing

The portable test equipment previously described was used to measure horsepower output, the resulting specific fuel consumption, and the condition of the various engine components and adjustments which have a direct effect on horsepower and fuel efficiency.

All testing was conducted on the farm operated by the tractor owner. This made it possible to test a relatively large number of tractors in a short time, and increased the number of tractors available for test since the owner was not inconvenienced by removal of the tractor from service for a period longer than that actually required to test the tractor. This also made it possible to test the tractors during the heavy summer work season. It was felt that, in the summer, the tractors would be in a condition more truly representative of that in which they operated most of the time.

The following tests, measurements, and corrections to the engine were made in the indicated order. All tests were conducted with the engine speed control lever set at maximum engine speed position.

Test 1. With the engine running free of load, the maximum no-load engine speed was obtained by observing the belt pulley or power take-off shaft speed and calculating the engine speed from the known speed ratio between engine and belt pulley or power take-off shaft. Carburetor air inlet pressure, intake manifold pressure, air-fuel ratio indication, and ignition timing were measured. The dynamometer was not connected during this test because it was found that the free-running load of the dynamometer was enough to affect the maximum no-load engine speed.

Test 2. The tractor was loaded until the engine governor had completely opened the carburetor throttle valve. This point was taken as the maximum observed horsepower. Power take-off shaft speed, horsepower, fuel consumption, carburetor air inlet pressure, intake manifold pressure, spark advance, air-fuel ratio indication, and engine cooling medium temperature were measured.

Test 3. The load on the tractor was decreased until the intake manifold pressure reached a point approximately half way between the no-load and the maximum load value. All measurements indicated in Test 2 were taken. This test was to determine the part load characteristics of the tractor.

Tests 2 and 3 were used to determine the operating characteristics of the tractor in the condition in which it was being operated by the owner.

Test 4. The no-load and full load engine speeds obtained in Tests 1 and 2 were compared to the manufacturer's specifications for the tractor. If the observed engine speeds were not within plus or minus 20 RPM of the specifications for the tractor, the engine governor was examined, and adjusted to specifications if possible. If the governor was changed or adjusted, the effects on maximum horsepower, fuel consumption, intake manifold pressure, air-fuel ratio indicator, and carburetor air inlet pressure were measured.

Test 5. The air cleaner was examined for possible excessive restriction to air flow. If the carburetor air inlet pressure indication in the preceding tests appeared normal for the model of tractor, the air cleaner was examined only for correct amount of oil in the cup, and amount of dirt accumulation in the cup. If the air cleaner was in satisfactory condition, this test was concluded at this point. However, if the air inlet pressure was abnormal, or if some deficiency was noted in examining the air cleaner, the cleaner was serviced to correct the abnormality. The effects on maximum power, fuel consumption, intake manifold pressure, air-fuel ratio indication, and carburetor air inlet pressure were measured.

Test 6. Unless new spark plugs had been installed in the tractor within the preceding two weeks, new spark plugs of the model recommended for the tractor were installed, and the effects on maximum power, fuel consumption, and air-fuel ratio indication were measured.

Test 7. The carburetor adjustment affecting the air-fuel ratio was adjusted for optimum results. The method of adjusting the carburetor was to lean the mixture until a slight loss of power was observed. The mixture was then enrichened slightly to regain the slight power loss. The effects on maximum horsepower, fuel consumption, and air-fuel ratio indication were measured.

Test 8. The ignition timing as observed in Tests 1 and 2 was compared to the manufacturer's specifications for the tractor. If the observed timing was not within plus or minus two degrees of the specifications, the ignition breaker points were examined and adjusted if the setting was not according to specifications. The effect of this setting on the timing was noted, and if the timing still was not within plus or minus two degrees of specifications, the distributor or magneto timing adjustment was changed to obtain the specified timing. With the engine developing maximum power the timing was retarded slightly and the effect on horsepower noted. If an increase was obtained by retarding the timing, the final setting was made at the point of maximum power. Otherwise, the final setting was made according to specifications. The effects of changes in ignition timing on maximum power and fuel consumption were measured. Intake manifold pressure, carburetor air inlet pressure, air-fuel ratio indication, and cooling medium temperature were measured. Test 8 was taken as the final condition of the tractor.

Test 9. A part-load test similar to Test 3 was conducted as the concluding test. The purpose of this test was to determine the cumulative effect on part load fuel consumption of various changes and adjustments which were made.

AGE AND MAKES OF TRACTORS TESTED

The average age of the 50 tractors tested in this investigation was 7.04 years. The oldest tractor tested was a 20-year-old IHC Model F-30, and the newest tractor was a Ford Model 861 which had been operated about 60 hours.

The age of each tractor tested is shown according to make in Table 1. The total number and average age of each make tested is also shown.

Table 1. Array of age of tractors tested by make, with number and average age of each make tested.

Ford Age (yrs)	International (IHC) Age (yrs)	John Deere (JD) Age (yrs)	Allis Chalmers (AC) Age (yrs)	Oliver Age (yrs)	Case Age (yrs)	Minneapolis Moline (MM) Age (yrs)
15	20	14	9	6	13	7
10	17	12	6	2	6	6
9	16	11	6		4	4
6	14	11	6			
5	8	9	4			
5	8	7				
3	8	6				
3	8	5				
0	7	3				
	6	3				
	6	1				
	5					
	5					
	3					
	2					
	2					
	1					
Total No. 9	17	11	5	2	3	3
Av. Age 6.22	8.00	7.45	6.20	4.0	7.67	5.67

COMPARISON OF TEST RESULTS TO
NEBRASKA TRACTOR TESTS

Horsepower

When comparing internal combustion engines tested under different atmospheric conditions, it is desirable to eliminate the effect of variations in barometric pressure and air temperature on maximum horsepower.

Test B, 100 per cent maximum belt horsepower test, in the Nebraska Tractor Test, is corrected to standard conditions of 60° F. air temperature and barometric pressure of 29.92 inches of mercury column. The corrected value is reported in the "Horsepower Summary" of the Nebraska Tests as "sea level (calculated) maximum (belt) horsepower based on 60° F. and 29.92" Hg".

Since it was desired to compare the maximum observed power take-off horsepower results obtained in this investigation to the Nebraska Test Results, all maximum horsepower readings which were compared to Nebraska Tests were corrected to standard conditions by the formula:

$$HP_c = HP_o \quad \frac{P_s}{P_o} \quad x \quad \left(\frac{T_o}{T_s}\right)^{\frac{1}{2}}$$

where HP_c = corrected horsepower

HP_o = observed horsepower

P_o = observed barometric pressure in inches of mercury.

P_s = standard barometric pressure of 29.92 inches of mercury.

T_o = observed absolute temperature in degrees F.

T_s = standard absolute temperature of 520° F.

The maximum observed power take-off horsepower of each tractor before any adjustment (initial condition) was corrected according to this formula and comparison made to the Nebraska Test Results for that tractor. Individual test results for horsepower are shown in Table 17 (Appendix).

The average results for each make of tractor are shown in Table 2.

Table 2. Average sea level maximum horsepower before adjustment (HP_i) and after all adjustments (HP_f) compared to Nebraska maximum sea level horsepower (HP_n) for each make of tractor tested.

Make	Ratio of HP_i to HP_n	Ratio of HP_f to HP_n	Avg. HP_n	Avg. HP_i	Avg. HP_f	HP - HP (Avg.)	% Increase in HP, Initial to final
Ford	0.697	0.740	34.58	24.10	25.60	1.50	6.22
IHC	0.788	0.888	37.92	29.87	33.66	3.79	12.69
JD	0.696	0.781	37.11	25.83	28.98	3.15	12.20
AC	0.747	0.852	37.69	28.14	32.12	3.98	14.14
Oliver	0.765	0.844	42.07	32.20	35.50	3.30	10.25
Case	0.904	0.917	28.21	25.50	25.87	0.37	1.45
M-M	0.745	0.860	40.08	29.87	34.47	4.60	15.40
AVERAGE	0.749	0.833	36.83	27.60	30.67	3.07	11.10

It was found that the average maximum corrected horsepower of all tractors tested before adjustment was 74.9 per cent of the Nebraska Test maximum corrected horsepower for the corresponding models of tractors (Column 2, Table 2). After all adjustments, this ratio increased to 0.833 (Column 3, Table 2), or an increase in maximum corrected horsepower of 11.1 per cent due to the various adjustments and corrections. These values are shown graphically in Fig. 9.

The Nebraska Test results are determined from the tractor belt pulley (13). The results in this investigation were obtained from the tractor power take-off shaft. Since there are differences in transmission power loss between the engine and belt pulley and the engine and power take-off shaft on many tractors, belt horsepower readings and power take-off readings may not be comparable. On one make of tractor where the belt pulley is mounted on the end of the crankshaft, but the power take-off shaft is driven through four gear sets, the maximum horsepower obtained at the belt pulley should be appreciably different from that obtained at the power take-off shaft.

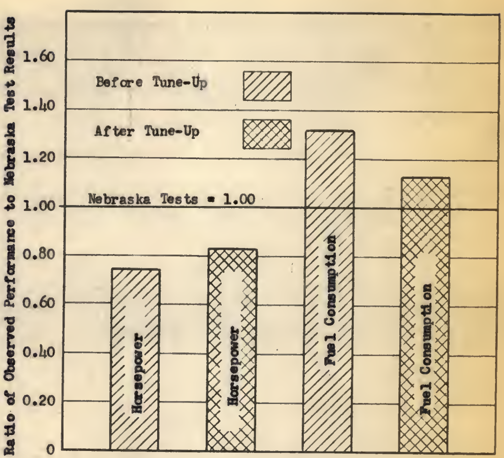


Fig. 9. Performance of tractors tested as compared to the standard determined from Nebraska Tractor Tests, before and after engine tune-up.

It seemed desirable to correct the values in Table 2 involving the Nebraska Tests to compensate for the difference in method of measuring horsepower in the Nebraska Tests and in this investigation.

This was done by multiplying the average Nebraska Test maximum corrected horsepower (HP_n) in column 4, Table 2 by the factor

$$(1.00 - L)$$

where L is the algebraic difference in transmission power loss from engine to belt pulley and engine to power take-off shaft as computed from the formula

$$L = \frac{(100 - E_g)}{100} \quad (G\ S_{pto} - G\ S_{bp})$$

where E_g is the assumed efficiency in per cent of one gear set, $G\ S_{pto}$ is the number of gear sets between engine and power take-off shaft, and $G\ S_{bp}$ is the number of gear sets between engine and belt pulley.

This method was used to correct the values in Table 2, and the results are shown in Table 3. A gear efficiency of 98 per cent was assumed.

Fuel Consumption

The specific fuel consumption in pounds per horsepower-hour was determined before any adjustment was made and again after all adjustments were made. These values were then compared to the Nebraska Test results for each tractor tested and are shown for each test in Table 18 (Appendix).

The average ratio of observed fuel consumption to Nebraska Test fuel consumption for each make of tractor tested is shown in Table 4.

It was found that the average specific fuel consumption of the tractors tested before adjustment was 132 per cent (Column 2, Table 4) of the average Nebraska Test specific fuel consumption. After all adjustments were made this ratio decreased to 1.13, or an average decrease in fuel consumption of 14.4 per cent due to the various adjustments and corrections.

Table 3. Ratios of initial (HP_i) and final (HP_f) maximum corrected horsepower to Nebraska Test Results (HP_{nc}) with correction made to eliminate difference in measuring horsepower at belt pulley and power take-off shaft.

Make	Ratio of HP_i to HP_{nc}	Ratio of HP_f to HP_{nc}
Ford	0.683	0.725
IHC	0.772	0.871
JD	0.741	0.831
AC	0.762	0.869
Oliver	0.750	0.827
Case	0.904	0.917
M-M	0.745	0.860
AVERAGE	0.754	0.836

Table 4. Average specific fuel consumption in Lbs./H.P. - Hr. before adjustment (FC_i) and after all adjustments (FC_f) compared to Nebraska specific fuel consumption (FC_n) for each make of tractor tested.

Make	Ratio of FC_i to FC_n	Ratio of FC_f to FC_n	Avg. FC_n (Lb/HP-Hr)	Avg. FC_i (Lb/HP-Hr)	Avg. FC_f (Lb/Hp-Hr)	FC_i-FC_f	% decrease in FC, initial to final
Ford	1.42	1.17	0.558	0.793	0.654	0.139	17.5
IHC	1.30	1.14	0.529	0.688	0.590	0.098	14.2
JD	1.30	1.14	0.576	0.748	0.656	0.092	12.3
AC	1.29	1.09	0.559	0.720	0.611	0.109	15.1
Oliver	1.42	1.20	0.508	0.723	0.609	0.114	15.8
Case	1.14	1.21	0.592	0.676	0.714	-0.038	-5.6
M-M	1.33	1.10	0.591	0.783	0.649	1.34	17.1
AVERAGE	1.32	1.13	0.551	0.730	0.625	0.105	14.4

A different value for specific fuel consumption will be obtained if the power take-off horsepower is used for computation than if the belt pulley horsepower is used. The difference in the two values will depend upon the difference in transmission losses between the engine and power take-off shaft and the engine and belt pulley.

To compensate for differences in method of taking horsepower in this investigation and in the Nebraska Tests, the values in Table 4 have been adjusted by using the same correction factor used to correct horsepower in the preceding section. The corrected values are shown in Table 5.

Table 5. Ratios of initial (FC_i) and final (FC_f) specific fuel consumption to Nebraska Test fuel consumption (FC_{nc}) with correction made to eliminate difference in measuring horsepower at belt pulley and power take-off shaft.

Make	Ratio of FC_i to FC_{nc}	Ratio of FC_f to FC_{nc}
Ford	1.45	1.19
IHC	1.34	1.16
JD	1.22	1.07
AC	1.26	1.07
Oliver	1.45	1.22
Case	1.14	1.21
M-M	1.33	1.10
AVERAGE	1.32	1.14

It will be noted that the values in Table 5 are not appreciably different from those in Table 4, except for those for the John Deere tractor. The reason for this is that there is no appreciable transmission power loss between the engine and belt pulley on this make of tractor, but the power take-off shaft is driven through three or four gear sets, depending upon the model of John Deere.

TEST RESULTS

Engine Governor Condition and Adjustment

All of the tractors tested had, as standard equipment, variable speed, centrifugal-type engine speed governors.

The purpose of the centrifugal governor is to maintain the operating speed of the engine at a predetermined, optimum value. Because of the operating principle of the centrifugal governor, the operating speed of the engine must be specified as a range of speeds. The range is usually indicated as "maximum no-load speed", which is the speed which the governor is to maintain when the engine is free of all load, and the "full load speed", which is the speed the governor is to maintain when the engine is developing maximum power. The difference between the no-load and full load speeds may be expressed as a percentage of their mean by use of the formula

$$R = \frac{2\ (N_h - N_L)}{N_h + N_L} \quad x\ 100$$

where R is the speed range in per cent, N_h is the maximum no-load engine speed in RPM, and the N_L is the full load speed in RPM. Most tractor engine governors are designed to obtain a value of approximately 10 per cent for R, although one manufacturer uses the value of 20.5 per cent for R in governor design. The no-load and full load speeds may also be expressed as a direct ratio r where $r = N_h / N_L$. Most tractor engine governors are designed to obtain $r \approx 1.10$.

The maximum no-load speed, and the full load operating speed were measured on each tractor tested, and a comparison made to the manufacturer's specifications for the tractor. If the governor was not maintaining the specified engine speeds, it was examined to see whether or not it was possible to obtain both of the specified engine speeds by normal adjustment of the governor. If this was not possible, no adjustment of the governor was made. The complete results of governor performance and comparison to specifications for each tractor tested is shown in Table 19 (Appendix).

The average results of the tests are shown for each make of tractor in Table 6.

The data were analyzed to determine the number of tractors with the observed load and no-load speeds falling within plus or minus 20 RPM of the specified no-load and full load speeds for the tractor. The results of this analysis are shown in Table 7. It was observed that only 20 per cent of the tractors tested were being operated with the governor in proper condition to maintain both the specified no-load speed and the specified full load speed plus or minus 20 RPM (Column 8, Table 7).

It is generally recognized that excessive engine speed and failure of the the governor to maintain full load speed are the two factors which have the greatest adverse effect on tractor engine life and operating efficiency. It was observed from Table 7 that 32 per cent of the tractors tested were being operated with engine speeds greater than 20 RPM above the manufacturers' recommendations. On 44 per cent of the tractors tested, the engine governor failed to maintain a full load speed of at least 20 RPM below the manufacturers' recommendations.

Of the 40 tractors tested where the no-load and full load speeds were not according to specifications, it was possible to perform simple adjustment and repair on the governor to correct the engine speeds on 10 tractors. Simple adjustment and repair included replacement of governor spring if needed, setting of the speed control adjustment, and adjustment of the linkages connecting speed control hand lever and governor, and the governor and carburetor. The results of adjusting the governors on the 10 tractors are shown in Table 8. An average increase in maximum horsepower of 9.1 per cent and a decrease in fuel consumption of 4.8 per cent were obtained by governor adjustment on these 10 tractors.

Table 6. Average observed no-load (n_h) and full-load (n_L) engine speeds in RPM compared to specified no-load (N_h) and full load (N_L) engine speeds for each make of tractor tested.

Make	Engine Speed (Specifications)		Engine Speed (Observed)		r (Spec.)	r (Observ.)	Dev. from Specs.		R (%)	
	N_h	N_L	n_h	n_L	N_h/N_L	n_h / n_L	N_h-n_h	N_L-n_L	Spec.	Obsv.
Ford	2267	2067	2134	1731	1.10	1.23	-132	-336	9.23	20.9
IHC	1710	1550	1692	1447	1.10	1.17	- 18	-103	9.82	15.6
JD	1198	1075	1197	1057	1.11	1.13	- 1	- 18	10.8	12.4
AC	1720	1400	1737	1400	1.23	1.24	+ 17	0	20.5	21.5
Oliver	1750	1600	1693	1483	1.09	1.14	- 57	-117	8.96	13.2
Case	1565	1392	1623	1292	1.12	1.26	+ 58	-100	11.7	22.7
M-M	1567	1425	1585	1348	1.10	1.18	+ 18	-115	9.49	16.2
AVERAGE	1683	1509	1657	1394	1.12	1.19	- 26	-115	10.9	17.2

Table 7. Number of tractors of each make tested with observed engine speeds (n_h and n_L) within and departing from specified engine speeds (N_h and N_L) ± 20 RPM.

Make	n_h within $N_h \pm 20$ RPM	n_h over $N_h + 20$ RPM	n_h under $N_h - 20$ RPM	n_L within $N_L \pm 20$ RPM	n_L over $N_L + 20$ RPM	n_L under $N_L - 20$ RPM	n_h and n_L within N_h and $N_L \pm 20$ RPM
Ford	1	1	7	0	0	9	0
IHC	5	7	5	6	0	11	4
JD	4	3	4	7	1	3	4
AC	2	1	2	2	1	2	2
Oliver	0	0	2	0	0	2	0
Case	0	2	1	2	0	1	0
M-M	0	2	1	0	0	3	0
TOTAL	12	16	22	17	2	31	10
% of total	24%	32%	44%	34%	4%	62%	20%

Table 8. Results of adjustment and simple repair to engine governor on tractors where correction to specified no-load and full load speeds was possible.

				Observed Horsepower			Observed Fuel Consumption (Lb/HP - Hr)				
Make	Model	Year	Test No.	HP before gov. adj.	HP after gov. adj.	% increase	Before gov. adj.	After gov. adj.	% decrease	Type of adjustment	Direction of adjustment
*IHC	H	1951	40	22.6	21.8	- 3.5				Speed	-
IHC	H	1950	48	16.3	19.5	+19.6	0.877	0.818	6.7	Spring	+
IHC	MTA	1953	39	34.7	41.1	+18.4	0.686	0.589	14.1	Speed, linkage	+
JD	B	1946	32	17.3	18.0	+ 4.0	0.694	0.629	9.4	Speed	+
JD	B	1947	2	16.3	18.1	+11.0	0.818	0.808	1.2	Speed	+
JD	B	1952	26	14.8	14.8	+ 0.0	0.670	0.665	0.7	Speed	+
JD	60	1955	27	27.2	28.6	+ 5.1	0.735	0.723	1.6	Speed	+
AC	WD	1952	52	25.5	26.9	+ 5.5	0.713	0.697	2.2	Speed	-
AC	WD45	1954	37	34.8	36.5	+ 4.9	0.663	0.652	1.7	Speed, linkage	+
Oliver	66	1952	49	18.5	20.1	+ 8.6	0.811	0.765	5.7	Speed	+
Oliver	Sup 88	1956	45	42.0	46.3	+10.2	.635	.603	5.0	Speed, linkage	+
**AVERAGE				24.7	27.0	+ 9.1	.730	.695	4.8		

* Test 40 is included to show the result of attempting to adjust a worn governor for speed. The no-load high idle speed was too high on this tractor. An attempt was made to correct the high idle speed to specifications, but the governor would not maintain the full load speed after this adjustment, resulting in power loss shown. Governor was returned to original setting.

** Test 40 is not included in averages.

Since it was not possible to correct existing governor malfunction on 30, or 60 per cent of the tractors tested, an investigation was made to determine the reasons for the prevalence of engine governor malfunction.

It was possible to obtain the governor flyball assembly from one of the tractors tested which exhibited the characteristic malfunction of low full-load speed (Test Number 50, 1941 IHC Model M). A new governor assembly for this tractor was obtained from the manufacturer, and its operating characteristics studied in the laboratory. This was done by simulating the operation of the governor assembly by operating it at various speeds and noting the response of the governor. Response was measured by observing the movement of the control rod which connects the governor to the carburetor throttle control valve. The flyball assembly from the test tractor was substituted for the new flyball assembly, and its characteristics studied in the same manner. The flyball assembly is shown in Fig. 1, Plate III. The results of these tests are shown in Fig. 10. It was noted with the new flyball assembly in the governor that a small variation in speed caused a rapid and large response in throttle opening. With the old flyball assembly installed, it was observed that it took a much larger variation in speed for the governor to respond by opening the throttle valve. Also, it was noted that a higher speed of the governor was necessary before the throttle valve would close. The old flyball assembly was examined for wear. Considerable wear was found in the pins carrying the weights, and in the linkage connecting the weights to the control levers. This resulted in a repositioning of the weights, which changed the characteristics of the assembly. It was concluded that as the engine governor wears, there is a tendency for the maximum no-load speed to gradually increase, and the full load speed to gradually decrease, resulting in an increase in the values of R and r. Wear of the parts shown in Fig. 2, Plate III is responsible

EXPLANATION OF PLATE III

Fig. 1. The flyball assembly from the governor which was used to obtain the curves shown in Fig. 10.

Fig. 2. The wear of these parts is responsible for the change in governor operating characteristics which was observed in 60 per cent of the tractor tests. Points of wear are indicated by arrows. The parts shown here were removed from Test Tractor Number 42. The cost of replacing the parts in this case was approximately $15.00.

PLATE III

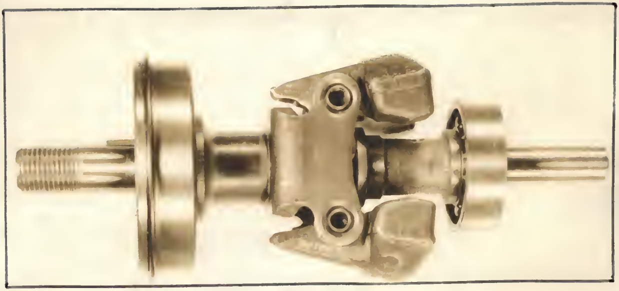


Fig. 1

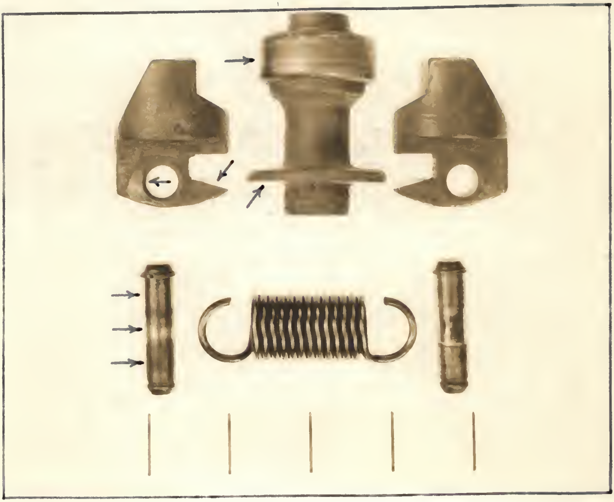


Fig. 2

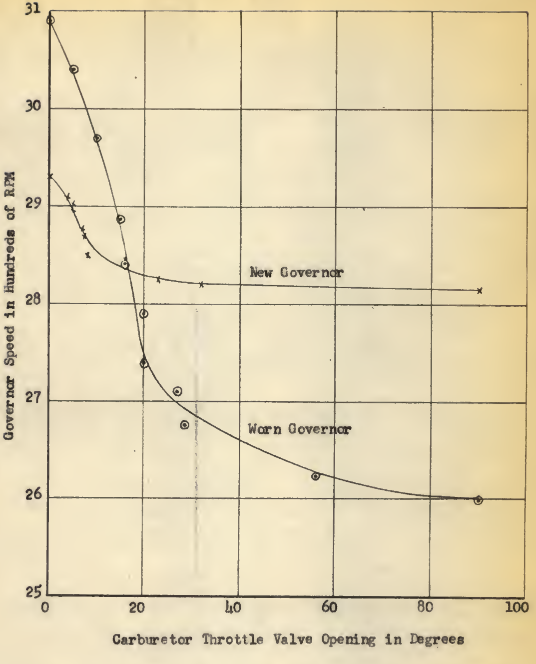


Fig. 10. Curves showing the effect of engine governor wear on sensitivity of the governor to speed change. The curves were derived experimentally by comparing a worn governor with a new governor of the same make and model.

for these changes. It was observed that both of the average values of R and r were appreciably greater for the tractors tested than the original values used in the tractor design (Table 6, Columns 6, 7, 10 and 11). The observed speed range for each make of tractor along with the specified range is shown graphically in Fig. 11. The foregoing assumes that the tension of the spring which balances the centrifugal force of the flyballs does not decrease with age. It is known that this spring may deteriorate with age. One case of extreme deterioration was found in this investigation (Test Number 48, 1950 IHC Model H). The decrease of the spring tension with age will tend to cancel the gradual increase in no-load speed caused by wear of the flyball assembly, but will add to the decrease in full load speed. This conclusion is supported by the fact that only 32 per cent of the tractors tested were operating with the no-load speed too high while 62 per cent were operating with the full load speed too low (Table 7).

Air Cleaner Condition

The condition of the engine air cleaner was measured by visual inspection and by measuring the resistance to air flow of the cleaner as indicated by the air pressure drop through the cleaner when the tractor was using the maximum amount of air. The pressure drop was determined by means of a water manometer connected to the carburetor air inlet.

A total of five tractors of the 50 tested exhibited some form of air cleaner malfunction. The results of correcting existing deficiencies are shown in Table 9. By servicing the air cleaner on these five tractors, the average horsepower was increased 7.6 per cent and fuel consumption decreased 11.4 per cent.

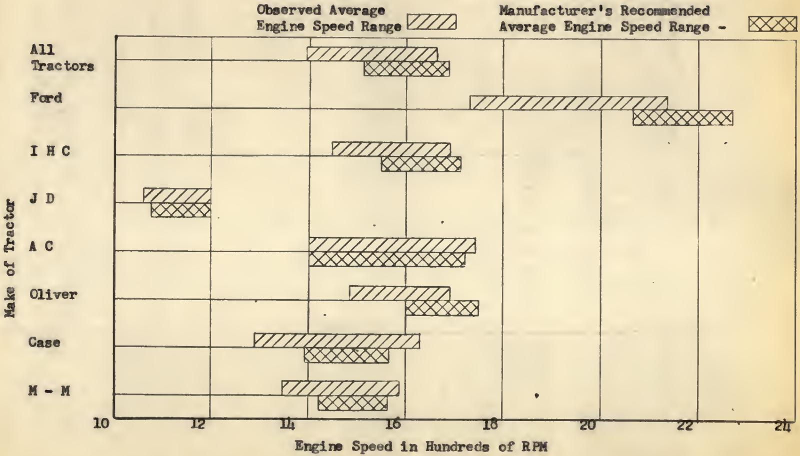


Fig. 11. Graph showing the effect of engine governor wear and maladjustment on engine speed range between maximum no-load speed and full load speed for makes of tractors tested.

Table 9. Results of service to air cleaner on the five tractors where air cleaner malfunction existed.

					*Air Horn Pressure (in. H_2O)			Observed Horsepower			Observed Fuel Consumption (Lb/H.P. - Hr.)			Type of Service Deficiency
					No load	Load								
Make	Model	Year	Test No.	Fuel	Before Service	Before Service	After Service	Before Service	After Service	% Increase	Before Service	After Service	% Decrease	
Ford	NAA	1953	5	G	- 1.5	-6.0	- 4.0	21.5	22.3	3.7	0.673	0.618	8.2	.37 lb. dirt in oil cup.
Ford	960	1956	4	G	- 2.0	- 9.0	- 7.5	29.5	29.8	1.0	0.740	0.706	4.6	.55 lb. dirt in oil cup.
IHC	400	1955	10	LPG	- 2.5	- 9.5	- 7.0	38.2	39.8	4.2	0.604	0.558	7.6	Chaff on under side of filter element.
AC	WD	1952	15	G	-10.0	Approx. -65.0	-10.0	22.6	28.7	27.0	0.817	0.633	22.5	1.75 lb. dirt in cleaner entrance passage.
AC	WD	1952	52	G	- 4.5	-16.5	- 8.5	26.9	28.7	6.7	0.697	0.615	11.8	Oil low in cup, element choked with chaff.
AVERAGE					- 4.1	Approx. -21.2	- 7.4	27.7	29.86	7.6	0.7062	0.6260	11.4	

* Air Horn Pressure is the pressure at the carburetor air inlet. It is less than atmospheric pressure by the amount of the pressure drop through the air cleaner caused by the resistance to air flow of the air cleaner. Negative sign indicates <u>less</u> than atmospheric pressure, and is measured in inches of water column.

It was observed that there is considerable variation in design pressure drop through the air cleaner being used by different tractor manufacturers. The pressure drop for each make of tractor tested in inches of water column at full load and no-load as determined from the tractors tested on which the air cleaner was in satisfactory condition is shown in Table 10.

Service to Spark Plugs

New spark plugs of the type recommended for each tractor were installed in every tractor which had not had new spark plugs installed within the two weeks preceding the time of test. New spark plugs were installed in 45, or 90 per cent, of the 50 tractors. The effects on horsepower and fuel consumption from changing the spark plugs on each tractor is shown in Table 20 (Appendix).

The average results of new spark plugs for each make of tractor tested are shown in Table 11. An average increase in horsepower of 5.6 per cent and decrease in fuel consumption of 6.1 per cent was obtained by installing new spark plugs in the 45 tractors.

It was observed that 14 per cent, or seven, of the tractors tested misfired under load. In all seven cases, the misfiring was eliminated by installing new spark plugs. The changes in horsepower and fuel consumption for for the seven tractors have been shown separately in Table 12. On the seven tractors, power was increased an average of 21.5 per cent and fuel consumption decreased 14.2 per cent by eliminating the cause of misfiring.

It was observed that, in several cases, there were excessive deposits on the plugs, even though the plugs were not worn excessively. The largest increases in horsepower due to new plugs occurred in these cases.

Fortunately, two tractors of the same make and model, each of which had been used about 1500 hours, appeared in the tests. One of these tractors

Table 10. Average carburetor air inlet pressures for makes of tractors tested as determined from tractors tested on which air cleaner was in satisfactory condition.

Make	No Load (in. H_2O)	Full Load (in. H_2O)
Ford	2.9	10.1
IHC	0.8	2.7
JD	1.0	2.6
AC	1.3	7.2
Oliver	1.0	3.9
Case	1.5	2.8
M-M	0.6	2.0

Table 11. Average change in horsepower and fuel consumption for each make of tractor tested due to installation of new spark plugs.

	Observed Horsepower			Observed Fuel Consumption (Lb/HP-Hr)					
Make	Before New Plugs	After New Plugs	% change	Before New Plugs	After New Plugs	% change	Total No. of Tractors	No. in which plugs changed	Total No. misfiring under load
Ford	22.69	23.70	+ 4.5	0.784	0.733	- 6.4	9	9	1
IHC	28.90	31.38	+ 8.6	0.682	0.610	-10.5	17	12	4
JD	24.56	26.25	+ 6.8	0.732	0.704	- 3.8	11	11	2
AC	28.83	29.20	+ 1.3	0.661	0.620	- 6.2	5	5	0
Oliver	33.20	33.20	0.0	0.684	0.677	-10.2	2	2	0
Case	23.83	23.70	- 0.6	0.610	0.621	+ 1.8	3	3	0
M-M	28.03	29.33	+ 4.6	0.719	0.666	- 7.4	3	3	0
AVERAGE	26.38	27.78	+ 5.6	0.710	0.666	- 6.1			

Table 12. Change in horsepower and fuel consumption due to installation of new spark plugs in tractors which misfired under load.

Make	Observed Horsepower			Observed Fuel Consumption (Lb/HP-Hr)		
	Before New Plugs	After New Plugs	% change	Before New Plugs	After New Plugs	% change
Ford 2N	14.2	15.4	+ 8.5	0.854	0.787	- 7.8
IHC F-30	15.8	31.8	+101.3	1.133	0.674	-40.5
IHC C	13.9	15.1	+ 8.6	0.791	0.685	-13.4
IHC H	21.8	23.7	+ 8.7	0.689	0.666	- 3.3
IHC 300	31.7	33.1	+ 4.4	0.642	0.604	- 5.9
JD B	18.1	20.2	+ 11.6	0.808	0.782	- 3.2
JD A	24.2	30.4	+ 25.6	0.698	0.617	-11.6
AVERAGE	19.96	24.24	+ 21.5	0.802	0.688	-14.2

(Test Number 53, 1956 IHC Model 300) exhibited excessive spark plug deposits. The spark plug shown in Fig. 3, Plate IV was removed from this tractor. All four plugs from this tractor were identical in appearance. The other tractor, (Test Number 55, 1956 IHC Model 300) exhibited exceptionally clean spark plugs as shown in Figs. 1 and 2, Plate IV. Both sets of plugs had been in service about the same length of time (one season). They were of the same make and were of the recommended type for the engine. It was observed that the increase in horsepower in Test Number 53 (plugs with deposits) due to new plugs was 8.7 per cent. The increase in horsepower in Test Number 55 (plugs without deposits) was only 4.4 per cent. The contrast is accentuated by the fact that one plug in Test Tractor Number 55 misfired under load due to excessive spark gap. The one plug with excessive gap shown in Fig. 2, Plate IV was the one which the owner frequently removed for installation of an air pump fitting. This plug was removed without the aid of a wrench. The resulting inability of this plug to dissipate heat through its base apparently resulted in burning of the electrode tip, thus increasing the gap.

Further examination of the test results for the two tractors indicated that the tractor with deposits, even after installation of new plugs, developed only 27.5 horsepower, although the tractor without deposits developed 33.1 horsepower. It was assumed that deposits similar to those on the plugs existed throughout the combustion chambers in the engine of the tractor Number 53, thus lowering its overall efficiency.

Raviolo (9) and Carpentier and Drinkard (3) found that approximately two-thirds of the power loss due to engine deposits was the result of decreased air consumption, and one-third was the result of decreased thermal efficiency.

Gibson, et al. (6) found that tetraethyl lead content of the fuel, engine design, and type of load were the most important factors affecting magnitude

EXPLANATION OF PLATE IV

Fig. 1. A spark plug removed from an engine which was exceptionally free of deposits. This plug was from Test Tractor Number 55, an IHC Model 300. Fuel used was regular gasoline containing 2.24 ml. tetraethyl lead per gallon.

Fig. 2. A spark plug removed from same engine as the plug in Fig. 1. Excessive burning of the center electrode was caused by the fact that this plug was loose in the cylinder head, resulting in poor heat dissipation.

Fig. 3. A spark plug from an engine exhibiting excessive engine deposits. This plug was from Test Tractor Number 53, an IHC Model 300. Fuel used was regular gasoline containing 2.32 ml. of tetraethyl lead per gallon from a company advertising the use of a phosphorus-base fuel additive.

PLATE IV

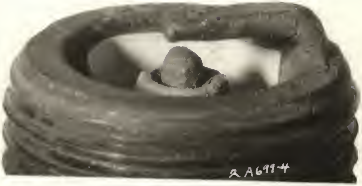


Fig. 1

Fig. 2

Fig. 3

of power loss due to engine deposits. They found that engine deposits were directly proportional to fuel tetraethyl lead content, and that an engine operated under constant speed and load lost up to five times as much power from engine deposits as a similar engine operated under variable load and speed. Base fuel type, fuel sulphur content, and engine oil were found to affect engine deposits, but to a lesser extent.

It appeared that the two tractors might provide some information about the cause of engine deposits which were observed in a number of the tractors tested. Comparison of the two tractors made it possible to eliminate two of the important factors cited by Gibson as affecting engine deposits--that of engine design and type of load--as both tractors were of the same design, and the loads were very similar. Difference in lubricating oil was eliminated as a contributing factor since the same brand and type of oil was used in both tractors. Neither tractor was consuming an excessive amount of lubricating oil.

Analysis of the spark plug deposit from Test Tractor Number 53 revealed that the deposit was 90.68 per cent lead compounds. The deposit was also found to contain approximately 2.1 per cent silica, and 1.54 per cent phosphorus.

Because the deposit was found to consist mainly of end products of tetraethyl lead, and since Gibson, et al. (6) found that engine deposits were proportional to the tetraethyl lead content of the fuel, the fuels used in the two tractors were examined.

Both tractors were using a regular grade of gasoline, but the fuel used in Test Tractor Number 53 came from a company advertising one of the phosphorus-base fuel additives. Presence of phosphorus in the deposit appeared to confirm that the gasoline used in Number 53 contained a phosphorus compound. The fuel used in Number 55 came from a company not claiming the use of additives in their fuel.

Difference in lead content of the fuels was ruled out as the factor causing the difference in the deposits in the two engines since there was no appreciable difference in lead content of the two fuels. The fuel used in Number 53 contained 2.32 ml. of tetraethyl lead per gallon and that used in Number 55 contained 2.24 ml. per gallon. Gibson, et al. (6) found that increasing the tetraethyl lead content from 1 ml. to 3 ml. per gallon increased the power loss due to engine deposits, on the average, from 4 per cent to 7 per cent.

In analyzing the available information, it appears that the phosphorus base additives used in some fuels might, under certain conditions, cause rapid and severe formation of lead compound deposits in tractor engines, resulting in appreciable loss of horsepower and efficiency of the tractor engine. Street (12) showed that the use of phosphorus base compounds such as tricresyl phosphate in fuels containing tetraethyl lead do have significant effects on the type of lead compounds formed in the engine. According to Street, the use of tricresyl phosphate reduces or eliminates the formation of lead oxybromides, lead bromide, and metallic lead in combustion. The elimination of these products is cited as desirable from the standpoint of eliminating spark plug fouling since these products have high electrical conductivities and low melting points. Street did not investigate the possible effect of tricresyl phosphate on engine deposits as related to power loss and engine efficiency, or the effect of tricresyl phosphate upon rate of deposit formation in the engine.

Adjustment of Carburetor

The air-fuel ratio was adjusted on each tractor by setting the carburetor air-fuel mixture control for optimum performance while the engine was developing maximum power. This was done by increasing the air-fuel ratio until a slight loss of power was observed. The ratio was then decreased until the slight loss in horsepower had been regained. A combustion meter was used to indicate the approximate air-fuel ratio.

The results of carburetor adjustment for each tractor tested are shown in Table 21 (Appendix).

Fourteen of the 50 tractors tested did not require a change in the carburetor adjustment from the original setting.

It was found that 23, or 46 per cent, of the tractors tested were being operated with the air-fuel mixture too rich. The average changes in horsepower and fuel consumption due to setting the carburetors on these tractors are shown in Table 13. The average specific fuel consumption was decreased 9.5 per cent on these 23 tractors by adjusting the carburetors.

Table 13. Average change in maximum horsepower and specific fuel consumption for each make of tractor due to adjusting carburetor on tractors on which original air-fuel mixture was too rich.

Make	Number of tractors	Observed Maximum Horsepower			Observed Fuel Consumption (Lb./H.P. - Hr.)		
		Before Adjust	After Adjust	% Change	Before Adjust	After Adjust	% Change
Ford	7	24.7	24.4	- 1.1	0.769	0.660	- 14.2
IHC	5	35.4	35.5	+ 0.5	0.604	0.571	- 5.3
JD	6	27.5	27.7	+ 0.7	0.767	0.707	- 7.7
AC	2	32.7	32.3	- 1.2	0.608	0.586	- 3.6
Oliver	1	20.1	20.4	+ 1.5	0.765	0.602	- 21.3
M-M	2	29.8	30.0	+ 1.0	0.736	0.694	- 5.7
AVERAGE		28.7	28.7	0	0.715	0.647	- 9.5

It was found that 13, or 26 per cent, of the tractors tested were being operated with the air-fuel mixture excessively lean, which is generally recognized as a factor contributing to premature valve failure. The results of adjusting the carburetors on these tractors are shown in Table 14.

Table 14. Average change in maximum horsepower and specific fuel consumption for each make of tractor tested due to adjusting carburetor on tractors on which original air-fuel mixture was too lean.

Make	Number of Tractors	Observed Maximum Horsepower			Observed Fuel Consumption (Lb./H.P.-Hr.)		
		Before Adjust	After Adjust	% Change	Before Adjust	After Adjust	% Change
Ford	2	20.3	20.9	+ 3.2	0.608	0.663	+ 9.1
IHC	2	34.3	35.8	+ 4.4	0.574	0.589	+ 2.7
JD	5	24.8	25.6	+ 3.6	0.630	0.596	- 5.3
AC	1	24.1	24.9	+ 3.3	0.641	0.709	+10.6
Oliver	1	46.3	46.3	0	0.589	0.606	+ 2.9
Case	2	16.2	16.4	+ 0.9	0.691	0.714	+ 3.8
AVERAGE		25.8	26.6	+ 2.9	0.623	0.631	+ 1.4

On one make of tractor (John Deere), it was found that five out of 11, or 45 per cent, were being operated with the air-fuel mixture too lean. It was also observed that the average specific fuel consumption on these five John Deere tractors was actually decreased an average of 5.3 per cent by decreasing the air-fuel ratio. This is opposite to the results expected and observed on the other makes of tractors. It was observed during the tests that the John Deere tractors were extremely sensitive to excessively lean carburetor settings. Rapid loss of power and erratic performance resulted as the mixture was leaned beyond the point of optimum performance. It is believed that this is caused by the unique two cylinder design of the John Deere tractor which results in uneven flow of air and fuel through the air-fuel induction system.

Ignition Timing

The ignition timing was observed on each tractor tested, and the spark advance in degrees before top dead center under full load was compared to the manufacturer's recommendation for the tractor.

If the timing was not within plus or minus two degrees of the manufacturer's recommendation, an attempt was first made to correct the timing by adjustment of the ignition breaker points. This was done in order to determine what percentage of the tractors which were out of time could be corrected by the extremely simple adjustment of the breaker points. If the timing could not be corrected by adjustment of the breaker points, the timing was corrected by adjustment of the magneto or distributor timing adjustment. Finally, with the engine developing maximum power, the timing was retarded slightly, and the effect on horsepower observed. If an increase in power was obtained by retarding the timing slightly, the final timing was left at the point of maximum horsepower. The complete results of engine timing are shown for each test in Table 22 (Appendix).

The average change in horsepower and fuel consumption due to ignition timing for each make of tractor tested is shown in Table 15.

An increase in horsepower or a decrease in fuel consumption was obtained by changing the timing on 26, or 52 per cent, of the tractors tested. On one tractor (Test Number 55) maximum power and best fuel economy was obtained from an ignition timing six degrees ahead of that recommended by the manufacturer. However, the timing was not set ahead of the manufacturer's recommendation as the final adjustment on any tractor because of the practice by some manufacturers of using late timing as a method for preventing excessive strain and breakage of engine parts.

Table 15. Average change in horsepower and specific fuel consumption obtained by timing adjustment for each make of tractor tested.

	Average Observed Horsepower			Average Observed Fuel Consumption (Lb/HP-Hr)			Number on which timing changed by		
Make	Before Timing	After Timing	% Change	Before Timing	After Timing	% Change	Pts. set	Dist. set	Pts. & Dist. set
Ford	30.4	31.4	+ 3.3	0.600	0.581	- 3.2	2	0	1
IHC	29.6	31.1	+ 5.1	0.624	0.584	- 6.4	4	5	3
JD	26.3	27.4	+ 4.2	0.666	0.645	- 3.2	1	2	1
AC	29.5	31.3	+ 6.1	0.634	0.609	- 3.9	0	2	1
Oliver	20.4	20.4	0	0.602	0.612	+ 1.7	0	1	0
Case	17.7	18.8	+ 6.2	0.692	0.591	-14.6	1	0	0
M-M	29.5	32.3	+ 9.5	0.638	0.594	- 6.9	2	0	1
AVERAGE	28.4	29.9	+ 5.3	0.632	0.598	- 5.3			

Initially, it was found that 15, or 30 per cent, of the tractors had the timing set ahead of specifications by an average of 7.1 degrees.

Twelve, or 24 per cent, were being operated with the timing set an average of 8.3 degrees later than specifications.

Twenty-three, or 46 per cent, were found to be timed according to specifications.

It was found that maximum power and best fuel consumption on 12, or 24 per cent of the tractors tested, were obtained by setting the timing an average of 4.3 degrees later than specifications.

An average increase in horsepower of 5.3 per cent and a decrease of 5.3 per cent in specific fuel consumption was obtained by setting the timing on the 27 tractors.

The timing was corrected by adjusting the breaker points on 10, or 37 per cent, of those changed. Setting of the magneto or distributor timing adjustment was required on an additional 10 tractors. On seven tractors it was necessary to change both the breaker points and timing adjustment.

Part Load Fuel Consumption

Thirty-eight of the tractors were tested for part load specific fuel consumption before any adjustment and again after all adjustments were made.

The method of determining the load to be applied in the part load tests was to set the speed control lever in the maximum speed position, and apply load until the manifold vacuum decreased to a value which was approximately equal to the arithmetic mean of the no-load manifold vacuum and the full load vacuum. On tractors not equipped with a manifold tap for attaching the manifold gauge, the mean engine speed between the no-load speed and full load speed was used to determine the amount of load to apply. The average part load horsepower obtained by these methods on the 38 tractors was 74.1 per cent of maximum horsepower.

It was found that all of the adjustments performed on the 38 tractors resulted in a decrease in specific fuel consumption of 8.2 per cent. The average specific fuel consumption before adjustments was 0.795 lbs./h.p.-hr., and 0.730 lbs./h.p.-hr. after all adjustments.

STATISTICAL ANALYSIS OF TEST RESULTS

The horsepower, fuel consumption, and Nebraska Test comparison data obtained from this investigation were treated statistically to determine the significance of the results obtained, and to obtain interval estimates on some of the means represented by the sample means obtained from the tests.

Nebraska Test Comparisons

One of the objectives of the investigation was to determine the maximum power output and fuel consumption of the average farm tractor in comparison to its capabilities as determined by the Nebraska Tractor Tests. This was done by expressing the performance of the tractors tested as a ratio of their capabilities as determined by the Nebraska Tests (Tables 2 and 4). The sampling ratios obtained and the t-distribution were used to obtain a confidence interval on the true mean ratio in the population of ratios represented by the sample tested. The following interval estimates were obtained at the 90 per cent confidence level.

Horsepower Ratio. The interval estimate of the mean ratio of the maximum horsepower to Nebraska Test maximum horsepower before adjustment (HP_i/HP_n) was found to be 0.723 to 0.775. The point estimate of this ratio was 0.749. The interval on the ratio after all adjustments (HP_f/HP_n) was found to be 0.807 to 0.859. The point estimate of this ratio was 0.833. The sample variance before adjustments was 0.01181 and the standard deviation was plus or minus 0.1086. After adjustments, the variance was 0.01184 and the standard deviation was plus or minus 0.1089. These values indicate that there was not much variation in the ratio among the tractors tested, and the variability was not changed appreciably by the adjustments.

Fuel Consumption Ratio. The interval estimate of the mean ratio of the specific fuel consumption at maximum power to the Nebraska Test fuel consumption before adjustment (FC_i/FC_n) was found to be 1.27 to 1.37. The point estimate of this ratio was 1.32. The interval on this ratio after all adjustments (FC_f/FC_n) was found to be 1.10 to 1.16. The point estimate of this ratio was 1.13. The sample variance before adjustment was 0.04141 and the standard deviation was plus or minus 0.2035. After adjustments, the variance was 0.01479 and the standard deviation was plus or minus 0.1216. These values indicate that the fuel consumption ratios were more variable before adjustments than the horsepower ratios, but that the adjustments decreased the variability of the fuel consumption ratios. The standard "F" test was used to show that the decrease in variability of the fuel consumption ratios due to the adjustments was significant at the 90 per cent confidence level. The fuel consumption ratios were only slightly more variable after adjustments than the horsepower ratios.

Changes in Power and Fuel Consumption Due to Adjustments

The changes in maximum power output and fuel consumption which were obtained by adjustment of the various engine components were treated statistically to determine the significance of the values obtained. The results of the analysis are shown in Table 16.

Table 16. Tabulation of the values of "t" from which the significance of the horsepower increases and fuel consumption decreases were determined.

	Horsepower Increase			Fuel Consumption Decrease		
Service to	Calculated "t"	"t" (.10)	Significant at 10% Level	Calculated "t"	"t" (.10)	Significant at 10% Level
Governor	3.242	1.812	Yes	3.645	1.812	Yes
Air Cleaner	2.058	1.533*	Yes	2.960	1.533*	Yes
Spark Plugs	3.840	1.301*	Yes	3.660	1.301*	Yes
Carburetor (Rich)	0.004	1.717	No	4.730	1.717	Yes
Carburetor (Lean)	3.080	1.782	Yes	0.610	1.782	No
Timing	6.450	1.703	Yes	4.110	1.703	Yes

* "t" (.10) for a "one tailed" test, which assumes that proper service on these two items (air cleaner and spark plugs) can logically be expected to never impair the performance of the tractor, except by chance.

It was found that the changes in horsepower and fuel consumption attributed to the various adjustments were all significant at the 10 per cent level except for the horsepower change due to leaning the mixture on the tractors with the initial air-fuel ratio too rich, and the change in fuel consumption due to decreasing the air-fuel ratio on tractors with the initial mixture too lean.

These results are logical, because it is reasonable not to expect to obtain a significant increase in horsepower by increasing the air-fuel ratio. The fact that there was not a significant increase in fuel consumption when the air-fuel ratio was decreased on the tractors which were operating with the mixture too lean tends to confirm the earlier observation that operating a tractor with excessively lean air-fuel mixture may not result in a real saving of fuel.

CONCLUSIONS

Several important conclusions may be reached as a result of this investigation.

For the sample of 50 farm tractors which were tested for horsepower output and specific fuel consumption under the condition in which they were being operated and again after a selected number of adjustments to correct deficiencies resulting from improper maintenance, it was found that:

The tractors, under the condition in which they were being operated, were capable of developing 74.9 per cent of maximum power as determined by the Nebraska Tractor Tests, and were using 1.32 times as much fuel as determined from the Nebraska Tests (Fig. 9).

After simple adjustment and maintenance to engine governor, air cleaner, spark plugs, carburetor, and timing, the tractors were capable of developing 83.3 per cent of maximum power as determined by the Nebraska Tests, and used 1.13 times as much fuel as determined by the Nebraska Tests (Fig. 9).

Simple adjustment and maintenance of the indicated items increased the maximum power by an average of 3.07 horsepower per tractor, or 11.1 per cent, and decreased the specific fuel consumption by 0.105 lb./h.p.-hr. per tractor, or 14.4 per cent (Fig. 9).

It was possible to adjust, to manufacturer's specifications, the engine governor on 10 of the tractors, resulting in an increase in horsepower of 9.1 per cent and a decrease in fuel consumption of 4.8 per cent. An additional 10 tractors did not require adjustment or repair of the engine governor. The governors on the remaining 30 tractors were worn so that new parts were needed to operate satisfactorily.

The air cleaners on five, or 10 per cent, of the tractors were found to be choked in varying degrees with dirt and chaff. Service of the air cleaner in these cases resulted in an average increase of 7.6 per cent in power, and a decrease of 11.4 per cent in fuel consumption.

Spark plugs were changed on 45, or 90 per cent, of the tractors, which gave an average increase of 5.3 per cent in power and a decrease of 6.1 per cent in fuel consumption. In seven cases, or 14 per cent of the tractors tested, the spark plugs were in such bad condition that they caused misfiring under full load. On these seven tractors, power was increased 21.5 per cent and fuel consumption decreased 14.2 per cent by installing new spark plugs. Several instances of excessive engine deposits were observed, the cause of which may be connected in some way with phosphorus-base additives used in some fuels.

Adjustment of the carburetor was needed on 36, or 72 per cent of the tractors. Thirteen of them were found to be set too lean, and 23 were found to be set too rich. On the 23 which were set too rich, the fuel consumption was decreased an average of 9.5 per cent. On one make of tractor, the John Deere, an attempt to save fuel by excessively "leaning" the carburetor may actually result in increasing fuel consumption, especially at full load.

Ignition timing was changed on 27, or 54 per cent, of the tractors. This resulted in an average increase of 5.3 per cent in maximum power and a decrease of 5.3 per cent in fuel consumption. On 10, or 37 per cent, of the 27 tractors, it was possible to obtain correct timing by merely adjusting the breaker points.

The average changes in horsepower and fuel consumption which were obtained by adjustment and service of the various engine components are shown in Fig. 12.

It was stated in the introduction that Kansas farmers spent $58,286,189 for petroleum products in 1954 (15) and that fuel costs averaged $1018 per farm on 1007 Farm Management farms in 1956 (4). By applying the results obtained in this investigation, it is possible to estimate that improper maintenance and adjustment of the farm tractor and other engines may be costing the Kansas farmer, collectively, up to $8,390,000 annually in wasted fuel. The average farmer in the Farm Management Association may be wasting up to $146 per year because of excessive fuel consumption caused by neglect of the farm tractor.

RECOMMENDATIONS FOR FURTHER STUDY

This investigation indicated several areas where further study is needed.

The problem of engine deposits as affected by engine design, fuel additives, and possible unknown factors, and the effect of engine deposits on engine efficiency should be explored further.

The investigation was concerned only with spark ignition engines. Although it is true that spark ignition engines are used in the overwhelming majority of farm tractors, the use of the diesel engine is increasing rapidly, and within a few years, may be a major factor in farm power. The operating efficiency of the diesel engine as affected by farm conditions and maintenance practices should be explored.

The prevalence of the malfunction of the tractor engine governor indicates the need for work leading to an improved governor which would not be as susceptible to wear as those now in use.

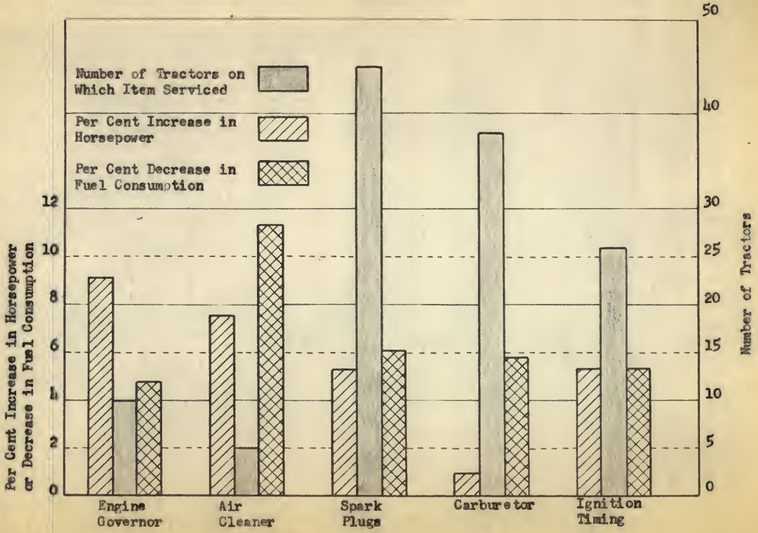


Fig. 12. Changes in horsepower and fuel consumption due to adjustments and service of engine components on fifty farm tractors.

This investigation demonstrated the value of the simple, portable dynamometer in evaluating the condition of farm tractors. The economic value of this type of equipment to the implement dealer should be explored to determine the feasibility of ownership of the portable dynamometer by the implement dealer and repairman.

ACKNOWLEDGMENTS

Appreciation is extended to Dr. G. H. Larson, Head, Department of Agricultural Engineering, for his cooperation, guidance, and assistance in this investigation. Acknowledgment is also made to Dr. H. C. Fryer, Director, Statistical Laboratory, for his assistance with the statistical analysis, and to Mrs. C. O. Jacobs for her assistance in preparing the manuscript.

Appreciation is also extended to the farmers and County Agricultural Extension Agents who cooperated in providing the tractors which were tested in this investigation.

Acknowledgment is made to the Champion Spark Plug Company, and to the International Harvester Company, for furnishing material used in the investigation.

REFERENCES

(1) Bainer, Roy, and others.
Tractors and their power units. New York: John Wiley and Sons, 1952.

(2) Bateman, H. P. and J. A. Weber.
Progress in solving farm problems in Illinois. Ill. Agr. Expt. Sta. Nine-year Rpt. (1938-1947). 1948.

(3) Carpentier, M. L. and W. E. Drinkard.
Development highlights and unique features of the new Chrysler V-8 engine. Soc. of Automotive Engg. Quart. Trans. 5:346-358. 1951.

(4) Coolidge, J. H. and others.
Farm management summary and analysis report. Kansas State College Extension Service. 1956.

(5) Fairbanks, G. E. and F. C. Fenton.
The cost of using farm machinery. Kans. Engg. Expt. Sta. Bul. 75, 1954.

(6) Gibson, H. J., C. A. Hall, and A. E. Huffman.
Combustion chamber deposition and power loss. Soc. of Automotive Engg. Quart. Trans. 6:594-605. 1952.

(7) Hanford, William D., editor.
Tractor field book. Chicago: Farm Implement News, 1958.

(8) Implement and tractor shop service.
Kansas City: Implement and Tractor Publications, 1955.

(9) Raviolo, V. G.
Some aspects of the engine fuel problem today. Soc. of Automotive Engg. Jour. 59 (1): 27-31. Feb., 1951.

(10) Reece, C. K.
Investigation and design of a torquemeter using SR-4 strain gages. Unpublished Master's thesis, Kansas State College, 1957.

(11) Snedecor, George W.
Statistical methods. Ames: Iowa State College Press, 1956.

(12) Street, J. C.
Mode of formulation of lead deposits in gasoline engines. Soc. of Automotive Engg. Trans. 61:442-450. 1953.

(13) The Nebraska Tractor Tests--1920-1949. Nebraska Expt. Sta. Bul. 397. 1950.

(14) Turner, G. M.
The performance of liquefied petroleum gas carburetors. Unpublished Master's thesis, Kansas State College, 1951.

(15) U. S. Dept of Commerce, 1954 census of agriculture. Washington: Government printing office. 1 (3). 1956.

(16) Weber, J. A.
Maintenance inspections of sixty farm tractors. Ill. Agr. Expt. Sta. Bul. 624. 1958.

APPENDIX

Table 17. Individual test results (horsepower).

								Maximum Observed Horsepower					
								-- After --					
Make	Model	Year	Test No.	Fuel	Neb. Max. H.P. (Corr.)	Initial H.P. (Corr.)	Initial H.P.	Gov. Adj.	Air Cleaner	New Plugs	Carb. Adj.	Timed	Final H.P. (Corr.)
Ford	2N	1943	6	Gas	23.87	15.2	14.2	*N.C.	OK	15.4	15.7	N.C.	16.8
Ford	8N	1948	22	Gas	27.32	17.8	16.7	N.C.	OK	18.0	19.3	N.C.	20.6
Ford	8N	1949	18	Gas	27.32	16.2	15.1	N.C.	OK	16.2	15.6	N.C.	16.8
Ford	8N	1950	38	Gas	27.32	18.5	17.2	N.C.	OK	18.6	17.7	N.C.	19.1
Ford	NAA	1953	7	Gas	32.41	20.5	19.1	N.C.	OK	19.1	18.6	N.C.	20.0
Ford	NAA	1953	5	Gas	32.41	23.0	21.5	N.C.	22.3	22.5	22.5	23.6	25.2
Ford	850	1955	8	Gas	46.89	33.6	31.9	N.C.	OK	34.3	34.6	N.C.	36.4
Ford	960	1956	4	Gas	46.76	30.7	29.5	N.C.	29.8	30.7	30.7	31.8	33.0
Ford	861	1958	20	Gas	46.89	41.2	37.9	N.C.	OK	38.5	37.9	38.8	42.1
AVERAGE					34.58	24.1							25.6
IHC	F-30	1938	28	Gas	33.30	16.9	15.8	N.C.	OK	31.8	32.0	N.C.	34.1
IHC	M	1941	50	Gas	39.23	35.8	33.5	N.C.	OK	N.C.	35.8	39.6	42.4
IHC	H	1942	51	Gas	27.90	20.4	19.1	N.C.	OK	19.1	N.C.	N.C.	20.4
IHC	H	1944	1	Gas	27.90	23.5	21.9	N.C.	OK	N.C.	N.C.	21.9	23.5
IHC	H	1950	48	Gas	27.90	17.4	16.3	19.5	OK	N.C.	N.C.	21.5	22.9
IHC	C	1950	30	Gas	22.18	14.9	13.9	N.C.	OK	15.1	N.C.	15.3	16.4
IHC	M	1950	34	Gas	39.23	35.6	33.3	N.C.	OK	35.1	35.7	36.7	39.3
IHC	H	1951	40	Gas	27.90	24.3	22.6	21.8	OK	23.7	N.C.	27.2	29.3
IHC	H	1952	24	Gas	27.90	21.2	19.9	N.C.	OK	N.C.	N.C.	23.1	24.6
IHC	Sup M	1952	41	Gas	48.56	39.5	36.5	N.C.	OK	37.4	N.C.	38.5	41.6
IHC	Sup M	1953	33	Gas	48.56	45.6	42.7	N.C.	OK	44.6	N.C.	44.6	47.6
IHC	MTA	1953	39	Gas	48.56	37.2	34.7	41.1	OK	41.1	N.C.	N.C.	44.0
IHC	Sup H	1953	47	Gas	34.61	27.5	25.8	N.C.	OK	25.8	25.8	27.8	29.7
IHC	400	1955	10	LPG	54.11	40.5	38.2	N.C.	39.8	42.3	42.8	42.8	45.4
IHC	300	1956	53	Gas	39.84	26.7	25.3	N.C.	OK	27.5	N.C.	N.C.	29.0
IHC	300	1956	55	Gas	39.84	33.3	31.7	N.C.	OK	33.1	33.4	33.1	34.8
IHC	450	1957	3	Gas	57.05	47.5	43.8	N.C.	OK	N.C.	43.6	N.C.	47.3
AVERAGE					37.92	29.87							33.66

* N.C. - No Change Made

Table 17. (cont.)

								Maximum Observed Horsepower -- After --					
Make	Model	Year	Test No.	Fuel	Neb. Max. H.P. (Corr.)	Initial H.P. (Corr.)	Initial H.P.	Gov. Adj.	Air Cleaner	New Plugs	Carb. Adj.	Timed	Final H.P. (Corr.)
JD	B	1946	32	Gas	28.69	18.5	17.3	18.0	OK	18.3	19.0	N.C.	20.3
JD	B	1947	2	Gas	28.69	17.5	16.3	19.1	OK	20.2	19.9	20.8	22.4
JD	B	1947	44	Gas	28.69	17.2	16.1	N.C.	OK	16.9	16.9	N.C.	18.1
JD	A	1947	16	Gas	39.45	25.7	24.2	N.C.	OK	30.4	30.7	N.C.	32.6
JD	A	1949	21	Gas	39.45	26.5	25.1	N.C.	OK	28.2	29.5	N.C.	31.2
JD	A	1951	17	Gas	39.45	30.4	28.5	N.C.	OK	30.7	30.7	N.C.	32.7
JD	B	1952	26	LPG	28.69	15.9	14.8	14.8	OK	14.8	16.4	18.2	19.6
JD	60	1953	25	Gas	41.57	29.1	27.3	N.C.	OK	29.1	29.7	N.C.	31.7
JD	60	1955	27	Gas	41.57	29.2	27.2	28.6	OK	28.9	29.7	30.3	32.6
JD	70	1955	31	Gas	50.35	40.4	38.0	N.C.	OK	39.1	39.1	40.2	42.7
JD	60	1957	43	Gas	41.57	33.7	31.5	N.C.	OK	32.1	32.6	N.C.	34.9
AVERAGE					37.11	25.83							28.98
AC	WD	1949	54	Gas	35.80	24.8	23.7	N.C.	OK	24.0	24.9	26.7	28.0
AC	WD	1952	15	Gas	35.80	24.0	22.6	N.C.	28.7	29.2	28.9	N.C.	30.7
AC	WD	1952	52	Gas	35.80	26.7	25.5	26.9	28.7	28.7	N.C.	N.C.	30.1
AC	WD	1952	36	Gas	35.80	28.3	26.5	N.C.	OK	27.9	N.C.	28.2	30.1
AC	WD45	1954	37	Gas	45.27	36.9	34.8	36.5	OK	36.2	35.7	39.0	41.7
AVERAGE					37.69	28.14							32.12
Oliv.	66	1952	49	Gas	26.05	19.7	18.5	20.1	OK	20.1	20.4	20.4	21.7
Oliv.	Sup 88	56	45	Gas	58.08	44.7	42.0	46.3	OK	46.3	46.3	N.C.	49.3
AVERAGE					42.07	32.2							35.5
Case	SC	1944	42	Gas	23.72	18.7	17.5	N.C.	OK	17.7	17.7	18.8	20.1
Case	D	1952	12	LPG	38.62	41.4	38.7	N.C.	OK	38.7	N.C.	N.C.	41.4
Case	VAC	1954	13	Gas	22.30	16.4	15.3	N.C.	OK	14.7	15.0	N.C.	16.1
AVERAGE					28.21	25.5							25.87

Table 17 (concl.).

Make	Model	Year	Test No.	Fuel	Neb. Max. H.P. (Corr.)	Initial H.P. (Corr.)	Initial H.P.	Maximum Observed Horsepower --After-- Gov. Adj.	Air Cleaner	New Plugs	Carb. Adj.	Timed	Final H.P. (Corr.)
M-M	UTA	1951	23	Gas	45.27	38.2	36.2	N.C.	OK	36.8	36.8	38.5	40.7
M-M	ZA	1952	19	Gas	37.48	22.4	20.9	N.C.	OK	22.7	23.3	26.7	28.7
M-M	ZA	1952	29	LPG	37.48	29.0	27.0	N.C.	OK	28.5	N.C.	31.7	34.0
AVERAGE					40.08	29.87							34.47

Table 18. Individual test results (fuel consumption).

						Observed Fuel Consumption, Max. Power (lb./H.P.-Hr.)						
							-- After --					
Make	Model	Year	Test No.	Fuel	Neb. Fuel Cons. Test R	Initial	Gov. Adj.	Air Cleaner	New Plugs	Carb. Adj.	Timed	Final
Ford	2N	1943	6	Gas	0.623	0.854	N.C.	OK	0.767	0.689	N.C.	0.689
Ford	8N	1948	22	Gas	0.546	0.684	N.C.	OK	0.629	0.691	N.C.	0.691
Ford	8N	1949	18	Gas	0.546	1.074	N.C.	OK	0.872	0.851	N.C.	0.851
Ford	8N	1950	38	Gas	0.546	0.727	N.C.	OK	0.733	0.664	N.C.	0.664
Ford	NAA	1953	7	Gas	0.564	0.739	N.C.	OK	0.785	0.609	N.C.	0.609
Ford	NAA	1953	5	Gas	0.564	0.673	N.C.	0.618	0.586	0.635	0.620	0.620
Ford	850	1955	8	Gas	0.547	1.017	N.C.	OK	0.945	0.642	N.C.	0.642
Ford	960	1956	4	Gas	0.540	0.740	N.C.	0.706	0.663	0.611	0.590	0.590
Ford	861	1958	20	Gas	0.547	0.633	N.C.	OK	0.599	0.555	0.533	0.533
AVERAGE					0.558	0.793						0.654
IHC	F-30	1938	28	Gas	0.625	1.133	N.C.	OK	0.674	0.615	N.C.	0.615
IHC	H	1941	50	Gas	0.502	0.597	N.C.	OK	N.C.	0.599	0.551	0.551
IHC	H	1942	51	Gas	0.532	0.616	N.C.	OK	0.616	N.C.	N.C.	0.616
IHC	H	1944	1	Gas	0.532	0.577	N.C.	OK	N.C.	N.C.	0.577	0.577
IHC	H	1950	48	Gas	0.532	0.877	0.818	OK	N.C.	N.C.	0.698	0.698
IHC	C	1950	30	Gas	0.551	0.791	N.C.	OK	0.685	N.C.	0.686	0.686
IHC	M	1950	34	Gas	0.502	0.581	N.C.	OK	0.551	0.580	0.574	0.574
IHC	H	1951	40	Gas	0.532	0.689	-	OK	0.666	N.C.	0.551	0.551
IHC	H	1952	24	Gas	0.532	0.710	N.C.	OK	N.C.	N.C.	0.590	0.590
IHC	Super M	1952	41	Gas	0.513	0.598	N.C.	OK	0.573	N.C.	0.599	0.599
IHC	Super M	1953	33	Gas	0.513	0.611	N.C.	OK	0.585	N.C.	0.549	0.549
IHC	MTA	1953	39	Gas	0.513	0.686	0.589	OK	0.596	N.C.	N.C.	0.596
IHC	Super H	1953	47	Gas	0.548	0.637	N.C.	OK	0.615	0.602	0.540	0.540
IHC	400	1955	10	LPG	0.472	0.604	N.C.	0.558	0.516	0.492	0.492	0.492
IHC	300	1956	53	Gas	0.535	0.741	N.C.	OK	0.642	N.C.	N.C.	0.642
IHC	300	1956	55	Gas	0.535	0.642	N.C.	OK	0.604	0.599	0.604	0.604
IHC	450	1947	3	Gas	0.528	0.609	N.C.	OK	N.C.	0.550	N.C.	0.550
AVERAGE					0.529	0.688						0.590

Table 18 -(Concl.).

						Observed Fuel Consumption, Max. Power (lb./H.P.-Hr.)						
							-- After --					
Make	Model	Year	Test No.	Fuel	Neb. Fuel Cons. Test B	Initial	Gov. Adj.	Air Cleaner	New Plugs	Carb. Adj.	Timed	Final
JD	B	1946	32	Gas	0.567	0.694	0.629	OK	0.631	0.647	N.C.	0.647
JD	B	1947	2	Gas	0.567	0.818	0.808	OK	0.782	0.737	0.703	0.703
JD	B	1947	44	Gas	0.567	0.932	N.C.	OK	0.910	0.772	N.C.	0.772
JD	A	1947	16	Gas	0.584	0.698	N.C.	OK	0.617	0.489	N.C.	0.489
JD	A	1949	21	Gas	0.584	0.664	N.C.	OK	0.635	0.646	N.C.	0.646
JD	A	1951	17	Gas	0.584	0.780	N.C.	OK	0.732	0.686	N.C.	0.686
JD	B	1952	26	LPG	not tested	0.670	0.665	OK	0.654	0.659	0.588	0.588
JD	60	1953	25	Gas	0.579	0.879	N.C.	OK	0.809	0.783	N.C.	0.783
JD	60	1955	27	Gas	0.579	0.735	0.723	OK	0.769	0.689	0.707	0.707
JD	70	1955	31	Gas	0.567	0.605	N.C.	OK	0.598	0.577	0.583	0.583
JD	60	1957	43	Gas	0.579	0.673	N.C.	OK	0.612	0.541	N.C.	0.541
AVERAGE					0.576	0.748						0.656
AC	WD	1949	54	Gas	0.565	0.758	N.C.	OK	0.641	0.709	0.653	0.653
AC	WD	1952	15	Gas	0.565	0.817	N.C.	0.633	0.623	0.611	N.C.	0.611
AC	WD	1952	52	Gas	0.565	0.713	0.697	0.615	0.615	N.C.	N.C.	0.615
AC	WD	1952	36	Gas	0.565	0.647	N.C.	OK	0.632	N.C.	0.626	0.626
AC	WD45	1954	37	Gas	0.535	0.663	0.652	OK	0.592	0.560	0.549	0.549
AVERAGE					0.559	0.720						0.611
Oliver	66	1952	49	Gas	0.521	0.811	0.765	OK	0.765	0.602	0.612	0.612
Oliv.	Sup 88	1956	45	Gas	0.495	0.635	0.603	OK	0.589	0.606	N.C.	0.606
AVERAGE					0.508	0.723						0.609
Case	SC	1944	42	Gas	not tested	0.645	N.C.	OK	0.664	0.692	0.591	0.591
Case	D	1952	12	LPG	not tested	0.508	N.C.	OK	0.508	N.C.	N.C.	0.508
Case	VAC	1954	13	Gas	0.592	0.676	N.C.	OK	0.691	0.714	N.C.	0.714
AVERAGE					0.592	0.676						0.714
M-M	UTA	1951	23	Gas	0.590	0.696	N.C.	OK	0.694	0.652	0.636	0.636
M-M	ZA	1952	19	Gas	0.591	0.870	N.C.	OK	0.778	0.736	0.661	0.661
M-M	ZA	1952	29	LPG	not tested	0.591	N.C.	OK	0.526	N.C.	0.485	0.485
AVERAGE					0.591	0.783						0.649

Table 19. Individual test results for engine governor condition.

					Spec. Engine Speed (RPM)		Obs. Engine Speed (RPM)		$r = N_h/N_L$		*R(%) (Avg.)		Deviation: Obs. from Specified		H.P.		Fuel Cons.	
Make	Model	Year	Test No.	Fuel	N_h No load	N_L Load	n_h No load	n_L Load	Spec.	Obs.	Spec.	Obs.	No Load	Load	Before Adj.	After Adj.	Before Adj.	After Adj.
Ford	2N	1943	6	G	2200	2000	1680	1500	1.10	1.12			-520	-500				
Ford	8N	1948	22	G	2200	2000	2090	1640	1.10	1.28			-110	-360				
Ford	8N	1949	18	G	2200	2000	2295	1760	1.10	1.30			+ 95	-240				
Ford	8N	1950	38	G	2200	2000	2110	1760	1.10	1.20			- 90	-240				
Ford	NAA	1953	7	G	2200	2000	1955	1430	1.10	1.37			-245	-570				
Ford	NAA	1953	5	G	2200	2000	2200	1815	1.10	1.21			0	-185				
Ford	850	1955	8	G	2400	2200	2290	2020	1.09	1.13			-110	-180				
Ford	960	1956	4	G	2400	2200	2275	1720	1.09	1.32			-125	-480				
Ford	861	1958	20	G	2400	2200	2315	1930	1.09	1.20			- 85	-270				
AVERAGE					2267	2067	2134	1731	1.10	1.23	9.23	20.9	-132	-336				
IHC	F-30	1938	28	G	1265	1150	1220	1120	1.10	1.09			- 45	- 30				
IHC	M	1941	50	G	1595	1450	1590	1360	1.10	1.17			- 5	- 90				
IHC	H	1942	51	G	1815	1650	1855	1280	1.10	1.45			+ 40	-370				
IHC	H	1944	1	G	1815	1650	1880	1650	1.10	1.14			+ 65	0				
IHC	H	1950	48	G	1815	1650	1660	1285	1.10	1.29			-155	-365				
IHC	C	1950	30	G	1875	1650	1595	1405	1.14	1.13			-280	-245				
IHC	M	1950	34	G	1595	1450	1585	1430	1.10	1.11			- 10	- 20				
IHC	H	1951	40	G	1815	1650	1860	1620	1.10	1.15			+ 45	- 30	22.6	21.8		
IHC	H	1952	24	G	1815	1650	1740	1560	1.10	1.12			- 75	- 90				
IHC	Sup M	1952	41	G	1600	1450	1660	1345	1.10	1.23			+ 60	-105				
IHC	Sup M	1953	33	G	1600	1450	1690	1450	1.10	1.17			+ 90	0				
IHC	MTA	1953	39	G	1600	1450	1480	1265	1.10	1.17			-120	-185	34.7	41.1	0.686	0.589
IHC	Sup H	1953	47	G	1815	1650	1870	1525	1.10	1.23			+ 55	-125				
IHC	400	1955	10	LPG	1600	1450	1600	1450	1.10	1.10			0	0				
IHC	300	1956	53	G	1925	1750	1955	1680	1.10	1.16			+ 30	- 70				
IHC	300	1956	55	G	1925	1750	1905	1730	1.10	1.10			- 20	- 20				
IHC	450	1957	3	G	1600	1450	1620	1450	1.10	1.12			+ 20	0				
AVERAGE					1710	1550	1692	1447	1.10	1.17	9.82	15.6	- 18	-103				

Table 19. (Concl.)

Make	Model	Year	Test: No.	Fuel	Spec. Engine Speed (RPM) N_h	N_L	Obs. Engine Speed (RPM) n_h	n_L	$r = N_h/N_L$		*R(%) (Avg.)		Deviation: Obs. from Specified		H. P.		Fuel Cons.	
					No load	Load	No load	Load	Spec.	Obs.	Spec.	Obs.	No Load	Load				
JD	B	1946	32	G	1370	1250	1280	1180	1.09	1.09			- 90	- 70	17.3	18.0	0.694	0.628
JD	B	1947	2	G	1370	1250	1250	1120	1.09	1.10			-120	-130	16.3	18.1	0.818	0.809
JD	B	1947	44	G	1370	1250	1370	1250	1.09	1.10			0	0				
JD	A	1947	16	G	1080	975	1185	965	1.11	1.23			105	- 10				
JD	A	1949	21	G	1080	975	1075	955	1.11	1.13			- 5	- 20				
JD	A	1951	17	G	1080	975	1190	975	1.11	1.22			110	0				
JD	B	1952	26	LPG	1370	1250	1340	1260	1.09	1.07			- 30	10	14.8	14.8	0.670	0.665
JD	60	1953	25	G	1115	975	1185	1015	1.15	1.17			70	40				
JD	60	1955	27	G	1115	975	1050	940	1.15	1.12			- 65	- 35	27.2	28.6	0.735	0.723
JD	70	1955	31	G	1115	975	1125	985	1.15	1.14			10	10				
JD	60	1957	43	G	1115	975	1120	985	1.15	1.14			5	10				
AVERAGE					1198	1075	1197	1057	1.11	1.13	10.8	12.4	- 1	- 18				
AC	WD	1949	54	G	1720	1400	1715	1400	1.23	1.22			- 5	0				
AC	WD	1952	15	G	1720	1400	1720	1400	1.23	1.23			0	0				
AC	WD	1952	52	G	1720	1400	1995	1460	1.23	1.37			275	60	25.5	26.9	0.713	0.697
AC	WD	1952	36	G	1720	1400	1615	1380	1.23	1.17			-105	- 20				
AC	WD45	1954	37	G	1720	1400	1640	1360	1.23	1.21			- 80	- 40	34.8	36.5	0.663	0.652
AVERAGE					1720	1400	1737	1400	1.23	1.24	20.5	21.5	17	0				
Oliv.	66	1952	49	G	1750	1600	1695	1460	1.09	1.15			- 55	-140	18.5	20.1	0.811	0.765
Oliv.	Sup 88	1956	45	G	1750	1600	1690	1505	1.09	1.12			- 60	- 95	42.0	46.3	0.635	0.603
AVERAGE					1750	1600	1693	1483	1.09	1.14	8.96	13.22	- 57	-117				
Case	SC	1944	42	G	1680	1550	1840	1260	1.09	1.46			160	-290				
Case	D	1952	12	LPG	1390	1200	1510	1190	1.16	1.27			120	- 10				
Case	VAC	1954	13	G	1625	1425	1520	1425	1.14	1.07			-105	0				
AVERAGE					1565	1392	1623	1292	1.12	1.26	11.7	22.7	58	-100				
M-M	UTA	1951	23	G	1400	1275	1580	1275	1.10	1.24			180	0				
M-M	ZA	1952	19	G	1650	1500	1685	1405	1.10	1.20			35	- 95				
M-M	ZA	1952	29	LPG	1650	1500	1490	1365	1.10	1.09			-160	-135				
AVERAGE					1567	1425	1585	1348	1.10	1.18	9.49	16.2	18	-115				

$$*R = \frac{2\ (N_h - N_L)}{N_h + N_L} \times 100$$

Table 20. Individual test results for spark plug conditions.

Make	Model	Year	Test No.	Fuel	Observed Horsepower		Observed Fuel Consumption (lb./H.P.-Hr.)		Misfire under full load?
					Before New Plugs	After New Plugs	Before New Plugs	After New Plugs	
Ford	2N	1943	6	G	14.2	15.4	0.854	0.787	Yes
Ford	8N	1948	22	G	16.7	18.0	0.684	0.629	No
Ford	8N	1949	18	G	15.1	16.2	1.074	0.872	No
Ford	8N	1950	38	G	17.2	18.6	0.727	0.733	No
Ford	NAA	1953	7	G	19.1	19.1	0.739	0.785	No
Ford	NAA	1953	5	G	22.3	22.5	0.618	0.586	No
Ford	850	1955	8	G	31.9	34.3	1.017	0.945	No
Ford	960	1956	4	G	29.8	30.7	0.706	0.663	No
Ford	861	1958	20	G	37.9	38.5	0.633	0.599	No
AVERAGE					22.69	23.70	0.784	0.733	
IHC	F-30	1938	28	G	15.8	31.8	1.133	0.674	Yes
IHC	M-	1941	50	G	Not changed	--	--	--	No
IHC	H	1942	51	G	19.1	19.1	0.616	0.616	No
IHC	H	1944	1	G	Not changed	--	--	--	No
IHC	H	1950	48	G	Not changed	--	--	--	No
IHC	C	1950	30	G	13.9	15.1	0.791	0.685	Yes
IHC	M	1950	34	G	33.3	35.1	0.581	0.551	No
IHC	H	1951	40	G	21.8	23.7	0.689	0.666	Yes
IHC	H	1952	24	G	Not changed	--	--	--	No
IHC	Sup M	1952	41	G	36.5	37.4	0.598	0.573	No
IHC	Sup M	1953	33	G	42.7	44.6	0.611	0.585	No
IHC	MTA	1953	39	G	41.1	41.1	0.589	0.596	No
IHC	Sup H	1953	47	G	25.8	25.8	0.637	0.615	No
IHC	400	1955	10	LPG	39.8	42.3	0.558	0.516	No
IHC	300	1956	53	G	25.3	27.5	0.741	0.642	No
IHC	300	1956	55	G	31.7	33.1	0.642	0.604	Yes
IHC	450	1957	3	G	Not changed	--	--	--	No
AVERAGE					28.90	31.38	0.682	0.610	

Table 20 (concl.).

Make	Model	Year	Test No.	Fuel	Observed Horsepower		Observed Fuel Consumption (Lb./H.P.-Hr.)		Misfire under full load?
					Before New Plugs	After New Plugs	Before New Plugs	After New Plugs	
JD	B	1946	32	G	18.0	18.3	0.629	0.631	No
JD	B	1947	2	G	18.1	20.2	0.808	0.782	Yes
JD	B	1947	44	G	16.1	16.9	0.932	0.910	No
JD	A	1947	16	G	24.2	30.4	0.698	0.617	Yes
JD	A	1949	21	G	25.1	28.2	0.664	0.635	No
JD	A	1951	17	G	28.5	30.7	0.780	0.732	No
JD	B	1952	26	LPG	14.8	14.8	0.665	0.654	No
JD	60	1953	25	G	27.3	29.1	0.879	0.809	No
JD	60	1955	27	G	28.6	28.9	0.723	0.769	No
JD	70	1955	31	G	38.0	39.1	0.605	0.598	No
JD	60	1957	43	G	31.5	32.1	0.673	0.612	No
AVERAGE					24.56	26.25	0.732	0.704	
AC	WD	1949	54	G	23.7	24.0	0.758	0.641	No
AC	WD	1952	15	G	28.7	29.2	0.633	0.623	No
AC	WD	1952	52	G	28.7	28.7	0.615	0.615	No
AC	WD	1952	36	G	26.5	27.9	0.647	0.632	No
AC	WD45	1954	37	G	36.5	36.2	0.652	0.592	No
AVERAGE					28.82	29.20	0.661	0.620	
Oliv.	66	1952	49	G	20.1	20.1	0.765	0.765	No
Oliv.	Sup 88	1956	45	G	46.3	46.3	0.603	0.589	No
AVERAGE					33.20	33.20	0.684	0.677	
Case	SC	1944	42	G	17.5	17.7	0.645	0.664	No
Case	D	1952	12	LPG	38.7	38.7	0.508	0.508	No
Case	VAC	1954	13	G	15.3	14.7	0.676	0.691	No
AVERAGE					23.83	23.70	0.610	0.621	
M-M	UTA	1951	23	G	36.2	36.8	0.696	0.694	No
M-M	2A	1952	19	G	20.9	22.7	0.870	0.778	No
M-M	2A	1952	29	LPG	27.0	28.5	0.591	0.526	No
AVERAGE					28.03	29.33	0.719	0.666	

Table 21. Individual test results for carburetor adjustment.

Make	Model	Year	Test No.	Fuel	Observed Horsepower Before Adjust	Observed Horsepower After Adjust	Observed Fuel Consumption (Lb./H.P.-Hr.) Before Adjust	Observed Fuel Consumption (Lb./H.P.-Hr.) After Adjust	Combustion Meter Reading Before Adjust	Combustion Meter Reading After Adjust	Initial Carb. Setting Rich	Initial Carb. Setting Lean	Initial Carb. Setting No Change Needed
Ford	2N	1943	6	G	15.4	15.7	0.737	0.689	12.8	13.8	x		
Ford	8N	1948	22	G	18.0	19.3	0.629	0.691	14.4	13.6		x	
Ford	8N	1949	18	G	16.2	15.6	0.872	0.851	11.8	13.0	x		
Ford	8N	1950	38	G	18.6	17.7	0.733	0.664	12.2	13.4	x		
Ford	NAA	1953	7	G	19.1	18.6	0.785	0.609	12.0	13.5	x		
Ford	NAA	1953	5	G	22.5	22.5	0.586	0.635	14.5	14.0		x	
Ford	850	1955	8	G	34.3	34.6	0.945	0.642	<10.0	13.4	x		
Ford	960	1956	4	G	30.7	30.7	0.663	0.611	12.0	13.3	x		
Ford	861	1958	20	G	38.5	37.9	0.599	0.555	13.0	13.3	x		
AVERAGE					23.7	23.6	0.733	0.661	12.5	13.5			
IHC	F-30	1938	28	G	31.8	32.0	0.674	0.615	13.0	13.7	x		
IHC	M	1941	50	G	33.5	35.8	0.597	0.599	14.5	13.8		x	
IHC	H	1942	51	G	--	--	N.C.	--	13.8				x
IHC	H	1944	1	G	--	--	N.C.	--	--				x
IHC	H	1950	48	G	--	--	N.C.	--	13.4				x
IHC	C	1950	30	G	--	--	N.C.	--	13.3				x
IHC	M	1950	34	G	35.1	35.7	0.551	0.580	14.1	13.5		x	
IHC	H	1951	40	G	--	--	N.C.	--	13.6				x
IHC	H	1952	24	G	--	--	N.C.	--	14.4				x
IHC	Sup M	1952	41	G	--	--	N.C.	--	13.4				x
IHC	Sup M	1953	33	G	--	--	N.C.	--	13.5				x
IHC	MTA	1953	39	G	--	--	N.C.	--	13.4				x
IHC	Sup H	1953	47	G	25.8	25.8	0.615	0.602	13.0	13.7	x		
IHC	400	1955	10	LPG	42.3	42.8	0.516	0.492	14.3	14.9	x		
IHC	300	1956	53	G	--	--	N.C.	--	13.5				x
IHC	300	1956	55	G	33.1	33.4	0.604	0.599	13.0	13.4	x		
IHC	450	1957	3	G	43.8	43.6	0.609	0.550	12.8	13.5	x		
AVERAGE					35.1	35.6	0.595	0.577					

Table 21 (concl.).

Make	Model	Year	Test No.	Fuel	Observed Horsepower Before Adjust	Observed Horsepower After Adjust	Observed Fuel Consumption (Lb./H.P.-Hr.) Before Adjust	Observed Fuel Consumption (Lb./H.P.-Hr.) After Adjust	Combustion Meter Reading Before Adjust	Combustion Meter Reading After Adjust	Initial Carb. Setting Rich	Initial Carb. Setting Lean	Initial Carb. Setting No change needed
JD	B	1946	32	G	18.3	19.0	0.631	0.647	14.0	13.5		x	
JD	B	1947	2	G	20.2	19.9	0.782	0.737	13.0	13.4	x		
JD	B	1947	44	G	16.9	16.9	0.910	0.772	11.8	12.5	x		
JD	A	1947	16	G	30.4	30.7	0.617	0.489	14.6	13.4		x	
JD	A	1949	21	G	28.2	29.5	0.635	0.646	14.5	13.5		x	
JD	A	1951	17	G	30.7	30.7	0.732	0.686	12.7	13.5	x		
JD	B	1952	26	LPG	14.8	16.4	0.654	0.659	14.9	14.7		x	
JD	60	1953	25	G	29.1	29.7	0.809	0.783	12.1	12.3	x		
JD	60	1955	27	G	28.9	29.8	0.769	0.689	12.5	12.9	x		
JD	70	1955	31	G	39.1	39.1	0.598	0.577	13.4	13.5	x		
JD	60	1957	43	G	32.1	32.6	0.612	0.541	14.0	13.5		x	
AVERAGE					26.2	26.8	0.704	0.657					
AC	WD	1949	54	G	24.0	24.9	0.641	0.709	13.8	13.5		x	
AC	WD	1952	15	G	29.2	28.9	0.623	0.611	12.5	13.1	x		
AC	WD	1952	52	G					13.0				x
AC	WD	1952	36	G					13.4				x
AC	WD 45	1954	37	G	36.2	35.7	0.592	0.560	12.8	13.5	x		
AVERAGE					29.8	29.8	0.619	0.627					
Oliv.	66	1952	49	G	20.1	20.4	0.765	0.602	11.7	13.5	x		
Oliv.	Sup 88	1956	45	G	46.3	46.3	0.589	0.606	14.0	13.5		x	
AVERAGE					33.2	33.4	0.677	0.604					
Case	SC	1944	42	G	17.7	17.7	0.664	0.692	14.1	13.5		x	
Case	D	1952	12	LPG					14.6				x
Case	VAC	1954	13	G	14.7	15.0	0.691	0.714	14.0	13.4		x	
AVERAGE					16.2	16.4	0.678	0.703					
M-M	UTA	1951	23	G	36.8	36.8	0.694	0.652	12.8	13.8	x		
M-M	ZA	1952	19	G	22.7	23.3	0.778	0.736	13.0	13.5	x		
M-M	ZA	1952	29	LPG					14.8				x
AVERAGE					29.8	30.1	0.736	0.694					

Table 22. Individual test results for ignition timing.

Make	Model	Year	Test No.	Fuel	Observed Horsepower Before Timing	Observed Horsepower After Timing	Observed Fuel Consumption (Lb./H.P.-Hr.) Before Timing	Observed Fuel Consumption (Lb./H.P.-Hr.) After Timing	Method of Changing Time: Adjust Points	Method of Changing Time: Adj. Dist.	Method of Changing Time: Adjust both pts. and dist.	Spark Advance Deg. BTDC: *R	**O_i	***O_F	R-O_i	R-O_F	O_i-O_F
Ford	NAA	1953	5	G	22.5	23.6	0.635	0.620			x	30	22	30	+ 8	0	-8
Ford	960	1956	4	G	30.7	31.8	0.611	0.590	x			27	17	23	+10	+ 4	-6
Ford	860	1958	20	G	37.9	38.8	0.555	0.533	x			27	16	21	+11	+ 6	-5
AVERAGE					30.4	31.4	0.600	0.581									
IHC	M	1941	50	G	35.8	39.6	0.599	0.551		x		35	45	35	-10	0	+10
IHC	H	1944	1	G	21.9	23.5	0.577	0.577			x	35	30	35	+ 5	0	-5
IHC	H	1950	48	G	19.5	21.5	0.818	0.698		x		35	12	32	+23	+ 3	-20
IHC	C	1950	30	G	15.1	15.3	0.685	0.686			x	35	28	31	+ 7	+ 4	-3
IHC	M	1950	34	G	35.7	36.7	0.580	0.574		x		35	29	32	+ 6	+ 3	-3
IHC	H	1951	40	G	23.7	27.2	0.666	0.551		x		35	45	35	-10	0	+10
IHC	H	1952	24	G	19.9	23.1	0.710	0.590	x			35	50	35	-15	0	+15
IHC	Sup M	1952	41	G	37.4	38.5	0.573	0.599			x	35	38	32	- 3	3	+6
IHC	Sup M	1953	33	G	44.6	44.6	0.585	0.549		x		35	26	33	+ 9	+ 2	-7
IHC	Sup H	1953	47	G	25.8	27.8	0.602	0.540	x			35	40	35	- 5	0	+5
IHC	400	1955	10	LPG	42.8	42.8	0.492	0.492	x			27	26	27	+ 1	0	-1
IHC	300	1956	55	G	33.4	33.1	0.599	0.604	x			22	28	22	- 6	0	+6
AVERAGE					29.6	31.1	0.624	0.584									
JD	B	1947	2	G	19.9	20.8	0.737	0.703			x	25	26	14	- 1	+11	+12
JD	B	1952	26	LPG	16.4	18.2	0.659	0.588	x			25	30	23	- 5	+ 2	+7
JD	60	1955	27	G	29.7	30.3	0.699	0.707		x		20	16	15	+ 4	+ 5	+1
JD	70	1955	31	G	39.1	40.2	0.577	0.583		x		15	18	15	- 3	0	+3
AVERAGE					26.3	27.4	0.666	0.645									
AC	WD	1949	54	G	24.9	26.7	0.709	0.653			x	30	17	22	+13	+ 8	-5
AC	WD	1952	36	G	27.9	28.2	0.632	0.626		x		30	33	30	- 3	0	+3
AC	WD 45	1954	37	G	35.7	39.0	0.560	0.549		x		30	35	30	- 5	0	+5
AVERAGE					29.5	31.3	0.634	0.609									

Table 22 (concl.).

					Observed Horsepower		Observed Fuel Consumption (Lb./H.P.-Hr.)		Method of Changing Time			Spark Advance Deg. BTDC					
Make	Model	Year	Test No.	Fuel	Before Timing	After Timing	Before Timing	After Timing	Adjust Points	Adj. Dist.	Adjust both pts. and dist.	*R	**O_1	***O_F	R-O_1	R-O_F	O_1-O_F
Oliv.	66	1952	49	G	20.4	20.4	0.602	0.612		x		22	20	22	+ 2	0	-2
AVERAGE					20.4	20.4	0.602	0.612									
Case	SC	1944	42	G	17.7	18.8	0.692	0.591	x			25	40	25	-15	0	+15
AVERAGE					17.7	18.8	0.692	0.591									
M-M	UTA	1951	23	G	36.8	38.5	0.652	0.636	x			25	40	25	-15	0	+15
M-M	ZA	1952	19	G	23.3	26.7	0.736	0.661	x			17	23	16	- 6	+ 1	+7
M-M	ZA	1952	29	LPG	28.5	31.7	0.526	0.485			x	17	21	17	- 4	0	+4
AVERAGE					29.5	32.3	0.638	0.594									

R* Recommended Spark Advance.

O_1** Observed Spark Advance before timing.

O_F*** Observed Spark Advance after timing.

AN INVESTIGATION OF FARM TRACTOR PERFORMANCE

by

FLOYD NORMAN REECE

B. S., Kansas State College
of Agriculture and Applied Science, 1952

AN ABSTRACT OF A THESIS

submitted in partial fulfillment of the
requirements for the degree

MASTER OF SCIENCE

Department of Agricultural Engineering

KANSAS STATE COLLEGE
OF AGRICULTURE AND APPLIED SCIENCE

1959

It is an established fact that Kansas agriculture is highly mechanized. The farm tractor is the most important single item of mechanized equipment on Kansas farms since the tractor is used in practically every farming operation involving mechanized equipment. There are about 165,000 tractors on Kansas farms, or an average of 1.38 tractors per farm.

The cost of operating the tractor is an important part of farm expense. On the 1,007 farms in the Kansas Farm Management Association in 1956, the average cost of fuel and oil was $1,018.

It is known that the maintenance and adjustment of the farm tractor have a direct effect upon tractor power output and fuel efficiency. The power output and fuel efficiency capabilities of practically all tractors when new and in best possible adjustment can be determined by the Nebraska Tractor Tests. However, very little information is available on the operating characteristics and efficiency of tractors as they are being operated on the farm.

The objectives of this study were:

1. To obtain information on power output and fuel consumption of farm tractors as they are being operated on the farm.
2. To make a comparison of the power output and fuel consumption of the tractors on Kansas farms to their capabilities as determined from the Nebraska Tractor Tests.
3. To determine the extent of improper maintenance practices and adjustment, and the resulting effect on tractor power and fuel consumption.

Portable test equipment was devised which made it possible to test tractors on the farm for power output, fuel consumption, and engine condition.

A total of 50 tractors in Riley and Wilson counties in Kansas were tested for power output and fuel consumption. The tractors were tested under the condition at which they were being operated, and again after each of a series of simple adjustments and maintenance on the tractor engine were made to correct the results of improper maintenance.

It was found that, on the average, the 50 tractors were capable of developing, as they were being operated, 74.9 per cent of their maximum horsepower as determined from the Nebraska Tractor Tests, and the specific fuel consumption at maximum power was 32 per cent greater than that determined from the Nebraska tests.

After simple adjustment and service of the engine governor, air cleaner, spark plugs, carburetor, and ignition timing, the tractors were capable of developing an average of 83.3 per cent of their maximum power as determined from the Nebraska tests. The specific fuel consumption was only 13 per cent greater than that determined from the Nebraska Tests after the adjustments were made. This resulted in an average increase of 3.07 horsepower, or 11.1 per cent, per tractor in maximum power, and a decrease of 0.105 lb./h.p.-hr., or 14.4 per cent, in specific fuel consumption.

It was determined that the engine governor did not maintain the correct engine speed on 80 per cent of the tractors tested. Simple repair and adjustment was possible on 20 per cent of the tractors, which gave an average increase of 9.1 per cent in power and a 4.8 per cent decrease in specific fuel consumption. Major repair of the engine governor was needed on 60 per cent of the tractors.

The air cleaner was found to be choked with dirt and chaff on 10 per cent of the tractors. Service of the air cleaner on these tractors resulted in a 7.6 per cent increase in power and a 11.4 per cent decrease in fuel consumption.

New spark plugs were installed in 90 per cent of the tractors, which resulted in an average increase of 5.3 per cent in power, and a decrease of 6.1 per cent in specific fuel consumption.

Adjustment of the carburetor was needed on 72 per cent of the tractors. This adjustment resulted in an average decrease of 5.9 per cent in fuel consumption.

Adjustment of the ignition timing was done on 54 per cent of the tractors, which resulted in an average increase of 5.3 per cent in power and a decrease of 5.3 per cent in specific fuel consumption.

From the results obtained from this study, it is possible to estimate that improper maintenance of the farm tractor is costing the Kansas farmer, collectively, up to $8,390,000 annually in wasted fuel. On individual farms, such as those represented by the average farm in the Kansas Farm Management Association, up to $146 may be wasted annually due to improper maintenance of the tractors on these farms.