THESIS

COMPARATIVE TESTS OF SMALL STEAM AND GASOLINE ENGINES

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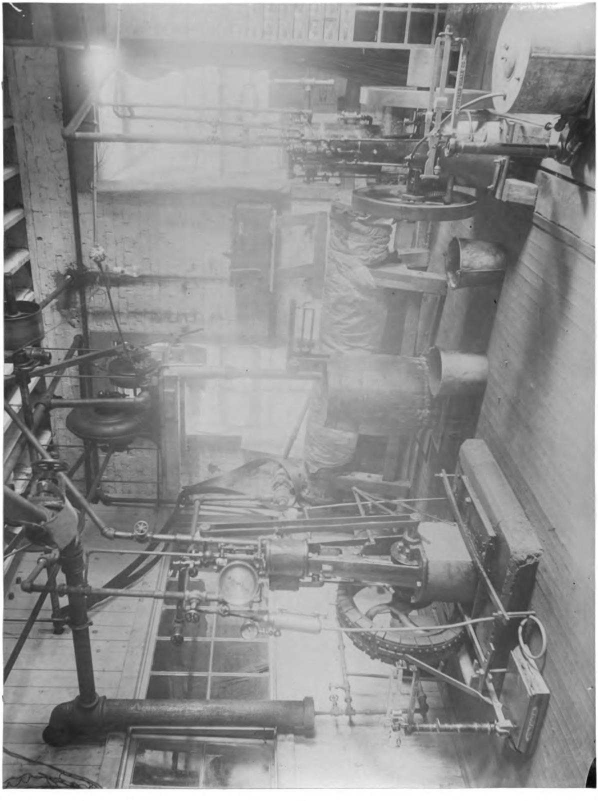
1902

This thesis is contributed by

Mr. E. D. Searing

under the date indicated by the department stamp, to replace the original which was destroyed in the fire of March 5, 1916.



T H E S I S

Comparative Tests of Small Steam and Gasoline Engines,

by

[illegible] F. Smith and E. [illegible] [illegible].

1903.

THESIS

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T H E S I S

Comparative Tests of Small Steam and Gasoline Engines.

Object of Tests:

The design of these tests was to determine, as a basis of comparison, the brake and indicated horsepower of the engine, their mechanical and thermal efficiencies and the steam and gasoline consumption per indicated and brake horse power per hour.

Engines:

Both engines are such as might be recommended for running light farm and dairy machinery, small pumps, forge blowers and light work of a similar kind.

The steam engine was manufactured by Olds and Son of Lansing, Michigan. It is of the vertical type, rated at five horse power by the manufacturers. The cylinder is four and one-half by five inches; the valve, plain D slide; the governor, throttling; the fly-wheel twenty-four inches in diameter. For a number of years the engine has been used intermittently in furnishing power for the cupola blower. By blocking the cross head the valve and piston were found to leak an inappreciable amount and, in general, the engine may be said to be in fair condition.

The gasoline engine was manufactured by Bates and Edmonds, Lansing, Michigan. It is also of the vertical type having a "four-stroke cycle" and rated at four horsepower. The cylinder is five and a half by five and a half inches and the fly wheel twenty-four inches in diameter. The charges are ignited by an electric spark, the explosions being governed on the "hit and miss" plan by a single [illegible] shaft governor. The condition of the engine is good, it having been purchased new previous to the tests.

Method of testing and apparatus:

The engines were allowed to run for nearly an hour preceding the tests so that the cylinder walls might become warmed, the brake expanded and all conditions equal to working obtained. The trials were each continued for an hour,- readings being taken every five minutes.

The indicated horsepower, in each case, was obtained from indicator diagrams taken every five minutes during the test,- the mean effective pressures were found with a Willis planimeter without getting the areas of the cards. On the steam engine, a Crosby indiother with forty pound spring was used; on the head end [illegible] a [illegible] indicator with a one hundred and twenty pound spring and a half size piston, making the spring equivalent to a two hundred and forty pound one. The reducing rig used on both engines is shown on plate 1, figure 2. It was of simple and original design and approximates very closely a straight line motion. Having the swinging end of the arm fixed to the crosshead, the other end slotted instead, the error of the arm swinging is compensated by its sliding in the slot.

The brake horsepower was determined by the pull delivered to a pair of small scales by the Prony brake shown on plate 1, figure 1. The brake consists of segments of wood bolted to two strips of hoop-iron arranged so as to extend around the face of the fly-wheel, the ends having a clamping screw to tighten the brake. Water was conveyed through the top of the brake to the face of the wheel from the [illegible] which kept the brake evenly wet and the friction constant. No trouble was experienced from heating of the fly wheel and consequently unsteadiness of the brake. With the high speed maintained and the pull delivered, the above items recommend this style of brake is a [illegible].

The steam consumption of the steam engine was measured by conducting the exhaust steam into a fifty horsepower Wheeler surface condenser,- the condensed steam being weighed in a barrel resting on scales. From this data the steam consumption per indicated horse power per hour is obtained.

The gasoline, in case of the gasoline engine, was pumped from a a galvanized supply tank resting on scales by a pump operated automatically. The weight of gasoline used was obtained from successive weights of supply.

The total explosions as well as those for each interval were read from an explosion counter. The device consists of a vertical pipe connected with the exhaust pipe and regulated by a globe valve. A close fitting copper cap fits over the top of the pipe and is connected with the arm of the counter which it operates by impulses from the explosions and its own weight.

The quality of the steam used was obtained from readings on a Carpenter's separating calorimeter connected to the supply pipe near the engine and the boiler pressure from a pressure gauge similarly connected. The revolutions per minute were read by applying a speed counter to the fly wheel shaft for each successive reading.

Trial test of steam engine:

Everything was put in readiness for the steam engine test and a few indicator cards were taken, card 1, plate 2 is a sample of these cards obtained. The shape of the cards and the fact that the engine required so much "cranking", in starting, as a gasoline engine caused the results to be unsatisfactory. The steam chest was then opened and the lead of the valve was seen to be three-eighths of an inch. The eccentric was next looked to and found to have lost one set screw; the other was loose and allowed the eccentric to shift a slight amount on the shaft causing a variable lead and angle of advance. A lead of one-sixteenth of an inch being considered right for an engine of this type and size, the valve was set thus. A card such as card 2, plate 2 was obtained. An examination shows the card to be as bad or worse than card 1. Again the lead was changed, this time to one-eighth of an inch, Card 3, plate 2, shows an improvement over card 3 and so a lead of one-fourth inch was tried. Card 4, plate 5, with this lead, shows a fair steam distribution for an engine with throttling governor and the final test was made with the valve in this condition. The reason so large a lead is required, is on account of too small outside lap of the valve for its travel.

Formulas,-

Steam engine:

$$\text{I. H. P.} = \frac{2\,P\,L\,A\,N}{33000}, \text{ where (1)}$$

I. H. P. = indicated horse power

P = average mean effective pressure

L = length of stroke in feet

A = area of piston in square inches

N = number of revolutions per minute.

$$\text{B. H. P.} = \frac{2\,R\,P\,N}{33000}, \text{ where} \quad (2)$$

B. H. P. = Brake horse power

R = Length of brake arm in feet

P = pull on scales in pounds

N = number of revolutions per minute.

$$\text{Mechanical efficiency} = E = \frac{\text{B. H. P.}}{\text{I. H. P.}} \quad (3)$$

$$\text{Quality of steam} = X = \frac{A}{A+B} \text{ where (4)}$$

A = pounds of steam which will pass through orific

B = pounds of steam which will pass through the " with the steam in the same time.

Water consumption per I. H. P. per hour.

$$W = \frac{\text{Weight of condenser water per hour}}{\text{I. H. P.}} \quad (5)$$

Steam consumption per I. H. P. per hour

$$W' = W \times X \quad (6)$$

Steam consumption per B. H. P. per hour

$$W'' = W' \div E \quad (7)$$

B. T. U. supplied per I. H. P. per hour $= W(XR+Q-Q_1)$ (8)

B. T. U. = British thermal units.

W = water consumption per I. H. P. per hour.

X = Quality of steam

R = Latent heat corresponding to lbs. admission pressure

Q = Heat of liquid corresponding to lbs. admission pressure

Q_1 = Heat of liquid corresponding to lbs. back pressure.

B. T. U. delivered I. H. P. per hour $= \frac{60 \times 33000}{778} = 2545$ (9)

Thermal efficiency $= T = \frac{\text{B. T. U. delivered}}{\text{B. T. U. supplied}}$ (10)

Gasoline Engine.

I. H. P. = indicated horse power $\quad I.H.P. = \frac{PLAN}{33000}$,

P = average mean effective pressure.

L = length of stroke in feet

A = area of piston in square inches.

N = number of explosions.

The horse power and mechanical efficiency same as Form (3) and

(3) For steam engine.

Gasoline consumption per I. H. P. per hour =

$$G = \frac{\text{gasoline used per hour}}{\text{I. H. P.}} \qquad (13)$$

Gasoline consumption per B. H. P. per hour =

$$G' = G \div E \qquad (15)$$

E = mechanical efficiency

B. T. U. supplied per I. H. P. per hour (Prof. [illegible]'s chemistry

with corrections for water formed in combustion) =

$$G \times 1.8\ (8000\ C + 33000H) \qquad (14)$$

G = gasoline used per I. H. P. per hour.

C = carbon in gasoline expressed in hundredths.

H = hydrogen in gasoline expressed in hundr[illegible].

One calorie = 1.8 B. T. U.

B. T. U. delivered per I. H. P. per hour as in form (9) =

2545.

The thermal efficiency found as in form (10)

Log of Results:

Steam engine.

Time	Gauge pressure	R. P. M.	Condensed steam	M. E. P.
3:50	--	--	--	--
3:55	63 lbs.	470	3[illegible].70 lbs.	37.0 lbs.
4:00	60	4[illegible]8	30.[illegible]5	3[illegible].3
4:05	61	470	[illegible]0.50	37.0
4:10	64	472	31.0[illegible]	[illegible]7.5
4:15	67	475	31.00	38.0
4:20	[illegible]2	470	[illegible]0.50	3[illegible].5
4:25	[illegible]6	4[illegible]	3[illegible]	3[illegible].0
4:30	57	4[illegible]5	2[illegible].50	[illegible]5.0
4:35	65	472	2[illegible].75	36.5
4:40	[illegible]	4[illegible]	3[illegible]	[illegible]6.3
4:45	57	4[illegible]4	30.[illegible]	35.[illegible]
4:50	55	460	[illegible]8.50	3[illegible].0

Average gauge pressure = 61.[illegible] # = 7[illegible].[illegible] # absolute

Average R. P. M. = 4[illegible].5

Total steam = 3[illegible].5 #

Average M. E. P. = 3[illegible].4 #

Brake arm = 30"

Brake pull = [illegible]9#

Lead = $\frac{1}{[illegible]}$"

Average back pressure = 6# = 20.5 # absolute

This unusually high back pressure measured from the cards and undoubtedly due to too small an exhaust pipe and the turns in it, is unfavorable for a fair test of the steam engine.

Calorimeter readings:

Time	Cal. gauge	Steam pass in 10 min.	Water
3:50			0
3:55	[illegible]	2.80	.04
4:00	65	2.[illegible]	.05
4:05	[illegible]	2.64	.05
4:10	69	2.85	.04
4:15	73	2.90	.04
4:20	[illegible]7	2.65	.06
4:35	65	[illegible]	.05
4:30	62	2.55	.06
4:35	70	2.[illegible]	.05
4:40	[illegible]	2.60	.05
4:55	62	2.55	.05
4:50	60	2.50	.05

Steam passed through in 120 minutes = 32.04 #

Water passed through in 60 minutes = .60 #

Calculations:

Steam engine,

$$I.H.P. = \frac{2 \times 36.4 \times 5 \times 15.9 \times 4[illegible]3.5}{12 \times 33000} = 6.85$$

$$B.H.P. = \frac{2 \times 22 \times 5 \times 29 \times 482.5}{7 \times [illegible] \times 33000} = 6.34$$

$$\text{Mechanical efficiency} = \frac{6.34}{6.85} = 92.5\ \%$$

$$\text{Quality of steam} = \left(\frac{33.04}{2}\right) + \left(\frac{32.04}{2} + .60\right) = [illegible]\ \%$$

$$\text{Water consumption per I. H. P. per hour} = \frac{362.5}{6.85} = 52.9\#$$

Steam consumption per I. H. P. per hour = 52.9 x .963 = 50.94#

Steam consumption per B. H. P. per hour = 50.94 ÷ .925 = 55.0#

B. T. U. supplied = 53.9 (.963 x 888 + 278.1 - 198.2) = 4[illegible],97[illegible].6

$$\text{Thermal efficiency} = \frac{2545.0}{43,974.6} = .0579 \text{ or } 5.79\ \%$$

Gasoline engine:

Time	Gasoline weight	Explosions	R. P. M.	M. E. P. Pl.
4:4[illegible]	.37	00	00	00
[illegible]:5[illegible]	.3[illegible]	2[illegible]5	3[illegible]	81
[illegible]:55	.[illegible]	[illegible]	[illegible]	78
4:[illegible]	.[illegible]	[illegible]	[illegible]	7[illegible]
[illegible]	.[illegible]	[illegible]	3[illegible]	7[illegible]
[illegible]:10	.3[illegible]	[illegible]	3[illegible]	7[illegible]
4:15	.3[illegible]	[illegible]4	[illegible]	[illegible]2
4:[illegible]	.33	[illegible]	[illegible]	[illegible]1
[illegible]	.[illegible]	[illegible]	35[illegible]	[illegible].5
4:[illegible]	.[illegible]	[illegible]	3[illegible]	7[illegible].5
4:[illegible]5	.[illegible]	[illegible]75	[illegible]	[illegible].5
4:40	.2[illegible]	[illegible]	[illegible]	7[illegible]
[illegible]:45	.2[illegible]	[illegible]	[illegible]	75

Total weight of gasoline = 3.4[illegible]

Average explosions per minute = 17[illegible].[illegible]

Average R. P. M. = [illegible]

Average M. E. P. = 7[illegible].[illegible] #

Stroke arm = 3[illegible]"

Brake pull = 25 #

Sp. gravity of gasoline = .70[illegible]

From a combustion test of a sample of the gasoline used, the chemical department found it to be

Carbon = 84.1%

Hydrogen = 15.9%

100.0% Specific gravity .7005

Calculations:

Gasoline engine,

$$\text{I. H. P.} = \frac{[illegible]}{19 \times 33000} = 4.57$$

$$\text{B. H. P.} = \frac{2 \times 22 \times 7 \times 25 \times 332}{7 \times 2 \times 33000} = 4.31$$

$$\text{Mechanical efficiency} = \frac{4.31}{4.57} = 94\%$$

$$\text{Gasoline per I. H. P. per hour} = \frac{3.42}{4.57} = .748\#$$

$$\text{Gasoline per B. H. P. per hour} = \frac{.748}{.94} = .796\#$$

$$\text{B. T. U. supplied} = .796 \times 1.[illegible]\ ((8000 \times .84) + (29000 \times .159))$$

$$= 17,[illegible].8 \text{ B. T. U.}$$

$$\text{Thermal efficiency} = \frac{2545.0}{17,[illegible].8} = .1[illegible]75 \text{ or } 1[illegible].75\%$$

Comparisons and conclusions:

The mechanical efficiencies of the two engines give nearly the same showing, but a small loss in friction and making a comparison of the power delivered at the fly wheel possible, without giving either engine an appreciable advantage over the other. On the other hand, the thermal efficiencies differ widely,— the steam engine being onethird as useful of heat energy as the gasoline engine.

The only mutual basis suggested of itself in comparing the gasoline and steam consumptions is through the cost of gasoline and cost of producing steam. If we consider a ton of coal delivered to the grate to cost three dollars ($3.00) and that a pound of coal will evaporate seven pounds of water, one pound of steam will cost $.000214. Applying this to the steam consumption per brake horse power per hour we have the cost of a brake horse power as $.0119 per hour. The cost of gasoline is twelve cents ($.12) per gallon and since its specific gravity is .7006, a gallon will weigh 5.604 pounds, making the cost per pound $.0214. This applied to the gasoline used per brake horse power causes a brake horse power to cost $.0170 per hour. So far in these calculations no account has been taken of the cost of installing a boiler house, engine house, boilers, piping, foundations, cost of engines, etc. In the ultimate cost of power, these items will surely enter. Considering the total cost of engines and piping for each, engine house, foundations, and items common to both engines, to be the same per horse power, [illegible]

each other. [illegible] the relative [illegible] found [illegible]

that of [illegible] engines [illegible] nearly [illegible]

the [illegible] power of [illegible] increased, the [illegible] approximate

costs per horse power must be [illegible] of the steam engine:

boiler, feed pump, etc., $16.00; boiler house [illegible]; chimney and

[illegible]; repairs, taxation and insurance $4.00; site [illegible], mak-

ing a total cost of [illegible] per horse power. Also [illegible] eight

hours per day and three hundred days per year [illegible]

[illegible] per year of [illegible]

[illegible] in the [illegible]

[illegible] engines running under [illegible] the [illegible] of

steam for the steam engine would be sufficient to pay [illegible]

installation of the steam plant in thirty-[illegible] months,

or less than three years. From these calculations it appears that

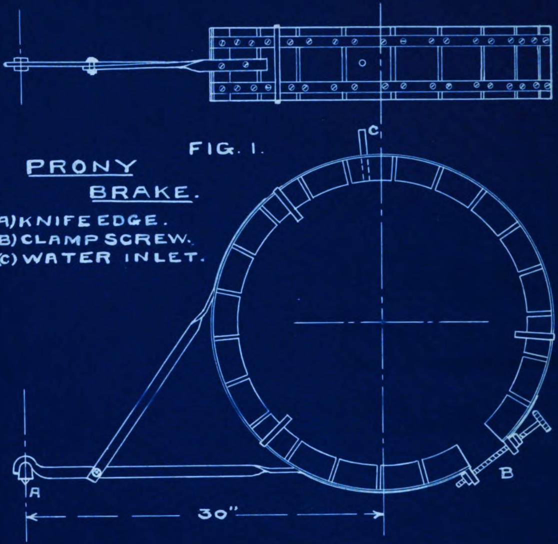
where any considerable amount of power is desired for any number of

years, the steam engine would be the more economical one to install.

However, if a small amount of power is desired, especially to be used

automatically [illegible] not [illegible] steam plant, [illegible] installation [illegible] of [illegible], [illegible] the professions.

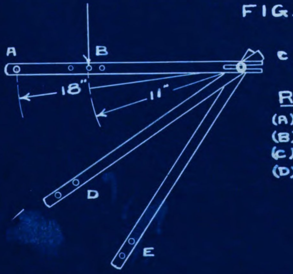
FIG. I.



PRONY BRAKE.

(A) KNIFE EDGE.
(B) CLAMP SCREW.
(C) WATER INLET.

FIG. II.



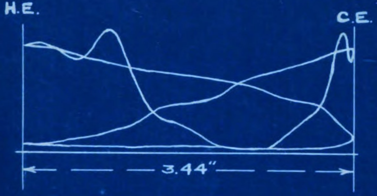
REDUCING RIG.

(A) FIXED TO CROSSHEAD.
(B) CORD TO INDICATOR.
(C) STATIONARY.
(D) AND (E) FIXED TO BASE.

PLATE I.

E.D.S

SAMPLE CARDS.



(1).

STEAM ENGINE.

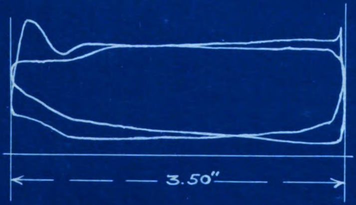
LEAD — — — 3/8".

R.P.M. — — — 460.

AVG. M.E.P. — 16#.

SPRING — — 50#.

TIME — — 10:50.



(2).

STEAM ENGINE.

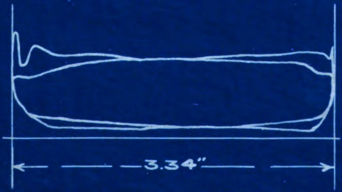
LEAD — — 1/16"

R.P.M. — — 450.

AVG. M.E.P. — 44#

SPRING — — 50#

TIME — — 3:50



(3).

STEAM ENGINE.

LEAD — — 1/8".

R.P.M. — — 425.

AVG. M.E.P. — 33#

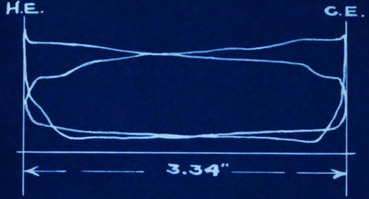
SPRING — — 50#

TIME — — 3:20.

PLATE II.

E.D.S.

SAMPLE CARDS.



(4).

STEAM ENGINE.

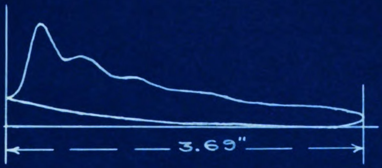
LEAD — — 1/4".

R.P.M. — — 468.

AVG. M.E.P. — 36.3#

SPRING — 50#

TIME — — 4:40.



(5).

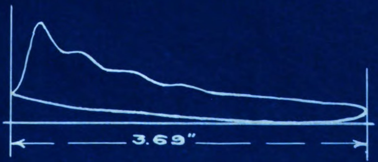
GASOLINE ENGINE.

R.P.M. — — 363.

AVG. M.E.P. — 81#

SPRING — 240#

TIME — — 4:20



(6)

GASOLINE ENGINE.

R.P.M. — — 366.

AVG. M.E.P. — 79.5#

SPRING — 240#

TIME — — 4:30.

PLATE III.

E.D.S.

KW 2/3/14