TESTS OF A SMALL COMPRESSED AIR PLANT

BY

J. A. CORRELL & O. P. DRAKE.

DISCUSSION.

The following tests were made on the compressed air plant in the Engineering Laboratory of the Kansas State Agricultural College. The plant is equipped as follows: a vertical engine the make and rated horse power of which are unknown, belted, through a main shaft, to a double acting, horizontal, piston compressor manufactured by the Ingersoll-Sergeant Drill Company, and rated at from 8 to 13 horse power depending on the revolutions per minute and the receiver pressure. A Westinghouse engine with two 6 x 8 single acting cylinders was connected to the air receiver and used as an air motor.

The object of the tests was to determine 1st the efficiency of the plant, or the ratio of the developed brake horse power of the motor to the indicated horse power of the engine; 2nd the efficiency between the engine and compressor cylinders, and between the compressor cylinder and the brake on the motor; 3rd the horse power lost in heating the air and the cooling water.

A series of three tests was conducted, the duration of each of which was one hour. Indicator cards were taken on the engine and compressor every five minutes throughout the test; as there was no means of taking cards on the air motor, a rope brake was constructed and used instead. Every five minutes, at the same time that the indicator cards were taken, the speeds of the engine compressor and motor were noted, and at the same time, the initial and final temperatures of the air and cooling water, and the readings of the scale of the rope brake on the motor were taken. All water which passed through the water jacket of the compressor was carefully weighed and recorded, so that the total weight of water which passed through the jacket during the test was known.

The mean effective pressure for both the compressor and the engine was calculated as follows: The area of the card divided by the length of the card gave the average height of the card, and this multiplied by the scale of the indicator spring used, gave the mean effective pressure; or as a formula,

Let Pe = mean effective pressure.

a = area of card.

s = scale of indicator spring.

l = length of indicator card.

Then $Pe = \frac{a\ s}{l}$.

For the calculation of the indicated horse power from the indicator cards,

Let Pe = mean effective pressure.

L = length of stroke in feet.

A = area of piston in square inches

N = number of revolutions per minute.

Then $I.\ H.\ P. = \frac{Pe\ L\ A\ N}{33000}$

This will give the indicated horse power for one end of the cylinder. The area of the piston will be different for the two ends of the cylinder owing to the piston rod reducing the effective area for the crank end; since the mean effective pressure will be different for the two ends also, separate calculations will be required for the two ends. The total horse power developed will be the sum of the horse power developed by the two ends. Since in the formula the quantity $\frac{L\ A}{33000}$ is constant for the same engine, it is called the engine constant. Then I. H. P. = C Pe N where C is the engine constant. This must be calculated for both ends since A varies.

The brake horse power was calculated as follows:

Let w = weight of the brake.

W_o = weight on the scale pan of the brake.

W = effective weight on the brake.

S = scale reading.

r = radius of brake wheel of motor.

N = revolutions per minute.

Then $H. P. = \frac{2\pi r N W}{33000} = C N W$ where C = the brake constant or $\frac{2\pi r}{33000}$ and $W = W_o + w - S$

The efficiency of the whole plant then is;

$$E = \frac{B. H. P. \text{ of motor}}{I. H. P. \text{ of engine}}$$

The efficiency between the engine and compressor cylinders is;

$$E_1 = \frac{I. H. P. \text{ of compressor}}{I. H. P. \text{ of engine}}$$

and the efficiency between the compressor and the motor is;

$$E_2 = \frac{B. H. P. \text{ of motor}}{I. H. P. \text{ of compressor}}$$

To determine the horse power lost in heating the air and the cooling water,

Let t = rise in temperature of cooling water.

W = weight of cooling water used throughout the test.

Then the heat given to the cooling water expressed in B. T. U. is $Q = W t$.

$778Q = 778Wt$ = ft. lb. where 778 is the mechanical equivalent of heat.

$$H. P. = \frac{778Wt}{60 \times 33000}$$

To find the horse power lost in heating the air

Let t = rise in temperature of the air

W = weight of air compressed during the test.

C_p = specific heat of air at constant pressure.

C_v = specific heat of air at constant volume.

Now assume that the volume remains constant while the pressure increases, then;

$W_t C_v$ = heat given to the air during that stage.

Now assume that the pressure remains constant while the volume decreases, then;

$W_t C_p$ = heat given to the air during this stage.

Then the total heat given to the air during compression is;

$$Q = W_t C_v + W_t C_p$$

$$Q = W_t (C_v + C_p).$$

The ft. lb. of work expended during the hour to heat the air then is;

$$Q_2 = 778 W_t (C_v + C_p)$$

The horse power expended in heating the air then is;

$$H.\ P. = \frac{778 W_t (C_v + C_p)}{60 \times 33000}$$

In considering the results of these tests, we would like to call attention to relative sizes and horse-powers of the engine, compressor, and motor.

The maximum indicated horse-power which we were able to obtain from the engine was a little over eight. The compressor is rated in the maker's catalogue at, from eight to thirteen horse-power. A glance at the data will show that it was running at a little more than half its rated power.

There is no way of taking indicator cards on the motor, so we could not tell what its indicated horse-power was. We had to keep it throttled down very close, during every one of the tests, and for that reason we know that the brake horse-power of the motor was not as large as it would give with the throttle full open. Judging from the dimensions of the motor (length of stroke eight inches, diameter of cylinders six inches) its rated horse-power would be equal to, or greater than that of the engine, if it was not limited in the supply of air. These facts will partly explain why the efficiencies are so low.

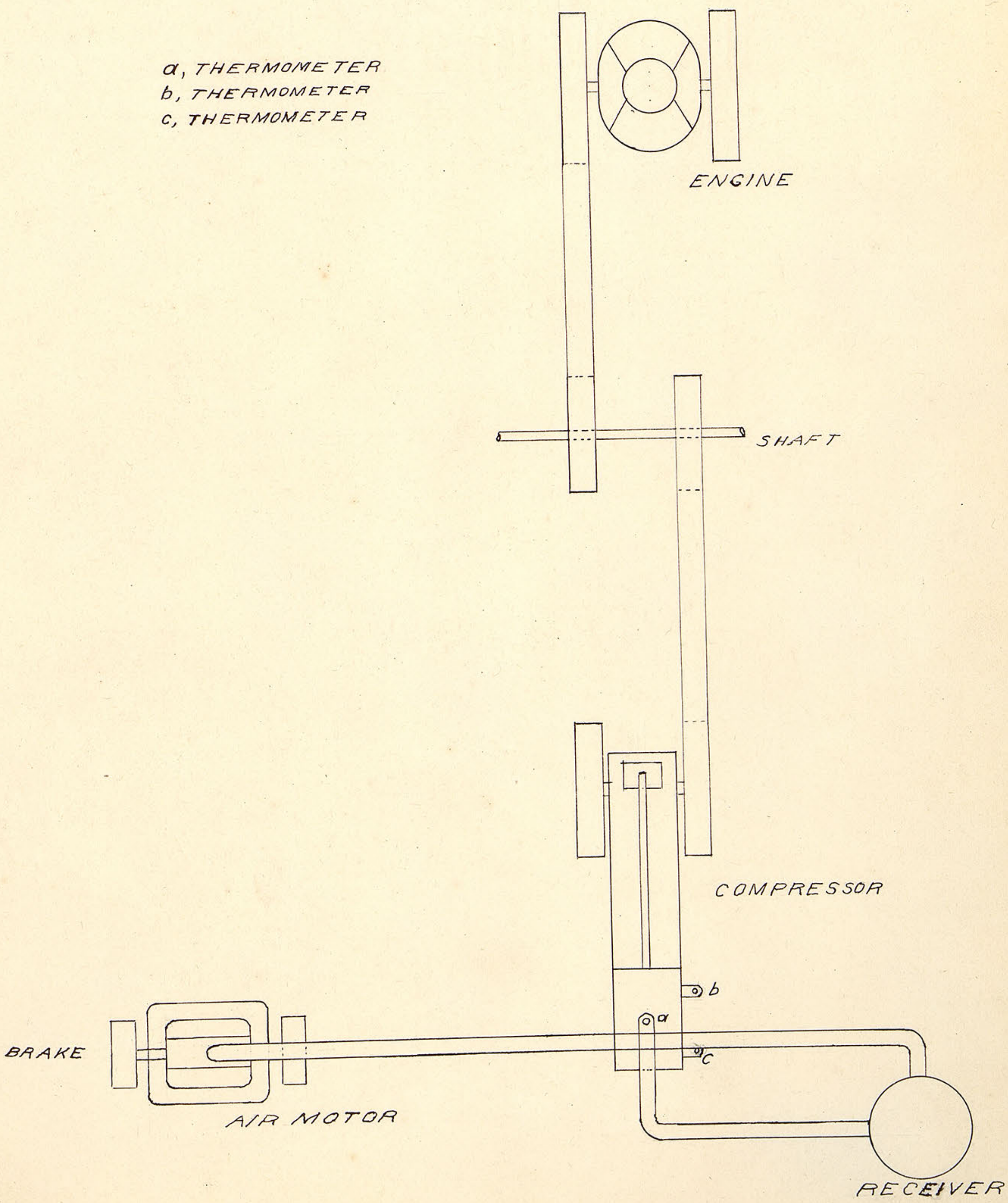
There is one loss which the tests show to be very great and which would be large in any plant; that is the heat loss. In this plant it is nearly two horse-power. Taking an average of all the tests, we find that 26.84% of the indicated power ofthe engine is used in heating the air and cooling water.

The losses due to friction were very large compared with the power developed, because of the disproportion of the machines.

SUMMARY OF TESTS.

	I	II	III
Horse-power of the engine	7.25	7.17	6.9
Horse-power of the compressor	4.44	4.78	4.73
Horse-power of the motor	.4035	519	.4765
Pressure of air in receiver	37#	42#	45#
Total weight of cooling water used	300#	325#	237#
Increase in the temperature of the air, (F)	133.6°	127.9°	127.1°
Increase in the temperature of the cooling water (F)	21.2°	16.98°	22.4°
Horse-power used to raise the temperature of the cooling water	1.98	1.72	1.98
Horse-power used to raise the temperature of the air	.031	.028	.027
Horse-power lost between the engine and compressor	2.81	2.39	2.17
Horse-power lost between the compressor and motor	4.0365	4.261	4.2535
Efficiency of engine and compressor	61.24%	62.6-2/3%	68.55%
Efficiency of compressor and motor;(ratio of B. H. P. of the motor to the I. H. P. of the compressor)	9.08%	10.86%	10.07%
Efficiency of the whole plant	5.5%	7.25%	6.8%

SCHEME OF AIR PLANT



TEST No 1

DEPARTMENT OF MECHANICAL ENGINEERING, K. S. A. C.

LOG OF ENGINE TRIAL.

TEST MADE AT K.S.A.C. LABORATORY
MANHATTAN KANSAS
ON COMPRESSED AIR PLANT
DATE MAY 2 1903

CONSTANTS OF ENGINE.

Diameter of cylinder.... 6 in.
Diameter of piston rod.. $1\frac{1}{8}$ in.
Length of stroke .... $\frac{2}{3}$ ft.
Area of piston H. E...... 28.274 sq. in.
Area of piston C. E...... 27.28 sq. in.
Engine constant for H. E., .00057
Engine constant for C. E., .00055

OBSERVERS:
J. A. Correll
D. P. Drake

No. Card.	Time.	R. P. M.	M. E. P.		I. H. P.			Brake Load (Dynamo).		B. H. P.	Remarks.
			H. E.	C. E.	H. E.	C. E.	Total.	Volts.	Amperes.		
1		250	23.7	25.9	3.38	3.69	7.07				
2		250	24.5	25.9	3.49	3.69	7.18				
3		250	24.5	25.6	3.49	3.65	7.14				
4		248	24.5	25.9	3.46	3.66	7.12				
5		245	23.7	25.6	3.31	3.58	6.89				
6		250	23.7	25.9	3.38	3.69	7.07				
7		250	23.7	25.9	3.38	3.69	7.07				
8		250	23.3	25.9	3.32	3.69	7.01				
9		250	23.3	25.9	3.32	3.69	7.01				
10		252	25.1	25.9	3.6	3.78	7.38				
11		240	31.3	32.7	4.28	4.47	8.75				
12		250	24.7	26.9	3.52	3.83	7.35				
	Maximum,	252					8.75				
	Minimum,	240					6.89				
	Total,	14935									
	Average,	248.9					7.25				

DEPARTMENT OF MECHANICAL ENGINEERING, K. S. A. C.

LOG OF COMPRESSOR TRIAL.

TEST MADE AT K. S. A. C. LABORATORY
MANHATTAN KANSAS

ON AIR COMPRESSOR

DATE MAY 2, 1903

CONSTANTS OF ENGINE.

Diam. of cylinder... 8 in.
Diam. of piston rod, $1\frac{3}{8}$ in.
Length of stroke .... $\frac{2}{3}$ ft.
Air per revolution .. .46 cu. ft.

Area of piston H. E. 50.26 sq. in
Area of piston C. E. 48.78 sq. in
Comp. constant for H. E. .001015
Comp. constant for C. E. .000985

OBSERVERS:

O. P. Sieake
J. A. Correll

No. of card.	Time.	R. P. M.	Area.		M. E. P.		I. H. P.			Temperature of Air.			Temperature Cooling Water.			H. P. Dissipated in heat.	Remarks.
			H. E.	C. E.	H. E.	C. E.	H. E.	C. E.	Total.	Initial.	Final.	Rise.	Initial.	Final.	Rise.		
1		110	1.69	1.67	20.18	20.24	2.25	2.19	4.44	59	189	130	58	79	21		TOTAL WEIGHT OF
2		110	1.71	1.67	20.52	20.24	2.28	2.19	4.47	56.3	190	133.7	58	77	19		COOLING WATER = 300#
3		110	1.77	1.65	20.66	20	2.36	2.17	4.53	56.3	190	133.7	58	76	18		
4		110	1.71	1.7	20.53	20.61	2.28	2.23	4.51	55.4	190	134.6	59	77	18		PRESSURE IN
5		106	1.73	1.69	20.90	20.49	2.22	2.14	4.36	55.4	189	133.6	58	78	20		RECIEVER = 37#
6		110	1.72	1.64	20.78	19.88	2.30	2.13	4.45	54.5	189.5	135	58	79	21		
7		106	1.75	1.68	20.3	20.36	2.25	2.15	4.38	53.6	189.5	135.9	58	79	21		
8		110	1.74	1.68	21.13	20.36	2.32	2.22	4.54	55.4	190	134.6	59	80	21		
9		110	1.7	1.67	20.3	20.24	2.27	2.19	4.46	57.2	191	133.8	59	82	23		
10		112	1.77	1.66	20.78	20.12	2.41	2.22	4.63	57.2	192	134.8	60	84	24		
11		102	1.70	1.65	21.13	20	2.1	2.01	4.11	59	192	133	61	86	25		
12		110	1.74	1.65	20.52	20	2.32	2.17	4.49	60.8	192	131.2	57	71	24		
	Maximum,	112										135.9			25		
	Minimum,	102										130			18		
	Total,	65.30															
	Average,	108.8										133.6			21.2		

TEST № 1

DEPARTMENT OF MECHANICAL ENGINEERING, K. S. A. C.

LOG OF ROPE BRAKE.

Test made at K.S.A.C. LABORATORY
MANHATTAN KANSAS
On COMPRESSED AIR PLANT
Date MAY 2 1903

CONSTANTS OF BRAKE.

Radius of pulley .... $10\frac{3}{4}$ in.
Weight of brake .... $8\frac{1}{2}$ lbs.
Weight on brake .... $20\frac{1}{2}$ lbs
Brake constant .... .0001666

OBSERVERS:
J. A. Correll
O. P. Drake

Number of Reading.	R. P. M.	Balance Reading.	B. H. P.	Remarks.
1	110	7	.4034	
2	106	7	.3887	
3	90	7	.33	
4	110	7	.4034	
5	110	7	4034	
6	110	7	.4034	
7	105	7	.3851	
8	112	6.5	.421	
9	110	6	.4217	
10	110	6	.4217	
11	112	6	.4294	
12	110	5.5	.431	

DEPARTMENT OF MECHANICAL ENGINEERING, K. S. A. C.

LOG OF ENGINE TRIAL.

TEST MADE AT K. S. A. C. LABORATORY
MANHATTAN KANSAS
ON UPRIGHT ENGINE
DATE MAY, 2, 1903

CONSTANTS OF ENGINE.

Diameter of cylinder.... 6 in. Area of piston H. E..... 28.27 sq. in.
Diameter of piston rod.. 1 1/8 in. Area of piston C. E..... 27.28 sq. in.
Length of stroke .... 2/3 ft. Engine constant for H. E., .00057
Engine constant for C. E., .00055

OBSERVERS:
O. P. Drake
J. A. Correll

No. Card.	Time.	R. P. M.	M. E. P.		I. H. P.			Brake Load (Dynamo).		B. H. P.	Remarks.
			H. E.	C. E.	H. E.	C. E.	Total.	Volts.	Amperes.		
1		250	24.71	27.45	3.40	3.82	7.22				
2		250	25.43	27.45	3.50	3.82	7.32				
3		250	24.71	27.45	3.40	3.82	7.22				
4		240	25.43	27.45	3.36	3.756	7.116				
5		246	23.53	26.67	3.18	3.74	6.92				
6		250	25.82	27.25	3.56	3.88	7.44				
7		250	25.82	27.45	3.56	3.82	7.38				
8		250	25.82	26.27	3.56	3.74	7.30				
9		250	22.16	25.49	3.05	3.64	6.69				
10		250	24.71	27.45	3.40	3.82	7.22				
11		240	25.10	27.45	3.32	3.756	7.076				
12		240	25.43	27.45	3.36	3.756	7.116				
	Maximum,	250					7.44				
	Minimum,	240					6.69				
	Total,	13846									
	Average,	247					7.168				

DEPARTMENT OF MECHANICAL ENGINEERING, K. S. A. C.

LOG OF COMPRESSOR TRIAL.

TEST MADE AT K.S.A.C. LABORATORY
MANHATTAN KANSAS
ON AIR COMPRESSOR
DATE MAY 2, 1903

CONSTANTS OF ~~ENGINE~~. COMPRESSOR

Diam. of cylinder... 8 in. Area of piston H. E. 50.26 sq. in
Diam. of piston rod, 1 3/8 in. Area of piston C. E. 48.78 sq. in
Length of stroke .... 2/3 ft. Comp. constant for H. E. .001015
Air per revolution .. .46 cu. ft. Comp. constant for C. E. .000985

OBSERVERS:

O. P. Drake
J. A. Correll

No. of card.	Time.	R. P. M.	Area.		M. E. P.		I. H. P.			Temperature of Air.			Temperature Cooling Water.			H. P. Dissipated in heat.	Remarks.
			H. E.	C. E.	H. E.	C. E.	H. E.	C. E.	Total.	Initial.	Final.	Rise.	Initial.	Final.	Rise.		
1		110	1.92	1.8	22.92	21.82	2.56	2.36	4.92	58.1	177	118.9	57.2	66.2	9		TOTAL WEIGHT OF
2		110	1.87	1.82	22.33	22.06	2.49	2.39	4.88	59.9	181	121.1	57.2	67.1	9.9		COOLING WATER = 325#
3		112	1.8	1.82	21.49	22.06	2.44	2.43	4.87	60.8	185	124.2	57.2	68	10.8		
4		110	1.84	1.79	21.97	21.69	2.45	2.35	4.80	60.8	180.5	119.7	59	74.3	15.3		PRESSURE IN
5		110	1.84	1.78	21.97	21.55	2.45	2.34	4.89	61.7	190	128.3	64.4	84.2	19.8		RECIEVER = 42#
6		108	1.86	1.79	22.21	21.69	2.43	2.31	4.74	62.6	194	121.4	63.1	84.2	21.1		
7		108	1.84	1.77	21.97	21.45	2.41	2.28	4.69	62.6	196	133.4	60.8	80.6	19.8		
8		108	1.88	1.78	22.45	21.55	2.46	2.30	4.76	63.5	197	133.5	58.1	73.4	15.3		
9		108	1.84	1.79	21.97	21.69	2.41	2.31	4.72	65.3	198	132.7	60.8	79.7	18.9		
10		108	1.84	1.82	21.97	21.06	2.41	2.36	4.77	66.2	199	132.8	61.7	81.5	19.8		
11		104	1.84	1.79	21.97	21.69	2.32	2.22	4.54	68	201	133	62.6	84.2	21.6		
12		110	1.84	1.77	21.97	21.45	2.45	2.32	4.77	66.2	202	135.8	62.6	85.1	22.5		
	Maximum,	112							4.92			135.8			22.5		
	Minimum,	104							4.54			118.9			9		
	Total,	6530															
	Average,	108.8							4.78			127.9			16.98		

TEST No 2

DEPARTMENT OF MECHANICAL ENGINEERING, K. S. A. C.

LOG OF ROPE BRAKE.

CONSTANTS OF BRAKE.

Test made at K.S.A.C. LABORATORY
MANHATTAN KANSAS
On COMPRESSED AIR PLANT
Date MAY 2 1903

Radius of pulley .... $10\frac{3}{4}$ in.
Weight of brake .... $8\frac{1}{2}$ lbs.
Weight on brake .... $30\frac{1}{4}$ lbs
Brake constant .... .0001666

OBSERVERS:

J. J. Cottrell.
O. P. Drake

Number of Reading.	R. P. M.	Balance Reading.	B. H. P.	Remarks.
1	100	6	.546	
2	100	6.5	.538	
3	104	7.	.55	
4	110	7.5	.573	
5	106	8	.543	
6	102	8	.523	
7	102	8	.523	
8	106	8	.543	
9	104	8.5	.466	
10	104	8.5	.466	
11	100	9	.496	
12	96	10	.46	

DEPARTMENT OF MECHANICAL ENGINEERING, K. S. A. C.

LOG OF ENGINE TRIAL.

TEST MADE AT K.S.A.C. Laboratory
Manhattan Kansas
ON Upright Engine
DATE May 8, 1903

CONSTANTS OF ENGINE.

Diameter of cylinder.... 6 in.
Diameter of piston rod.. 1 1/8 in.
Length of stroke .... 2/3 ft.
Area of piston H. E. 28.274 sq. in.
Area of piston C. E.... 27.28 sq. in.
Engine constant for H. E., .00057
Engine constant for C. E., .00055

OBSERVERS:
O. P. Drake
J. A. Correll

No. Card.	Time.	R. P. M.	M. E. P. H. E.	M. E. P. C. E.	I. H. P. H. E.	I. H. P. C. E.	I. H. P. Total.	Brake Load (Dynamo). Volts.	Brake Load (Dynamo). Amperes.	B. H. P.	Remarks.
1		242	26.68	22.9	3.68	3.05	6.73				
2		235	27.1	23.32	3.63	3.01	6.64				
3		240	27.73	22.27	3.79	2.94	6.73				
4		245	26.89	21.22	3.75	2.86	6.61				
5		245	27.52	24.37	3.84	3.28	7.12				
6		235	28.99	23.11	3.88	2.99	6.87				
7		240	28.99	24.79	3.96	3.27	7.23				
8		240	26.89	22.06	3.68	2.91	6.59				
9		240	27.73	23.53	3.79	3.1	6.89				
10		245	29.42	25	4.11	3.37	7.48				
11		240	27.73	25	3.79	3.30	7.09				
12		240	28.15	23.74	3.85	3.13	6.98				
	Maximum,	245					7.48				
	Minimum,	235					6.59				
	Total,	14135									
	Average,	240.5					6.9				

TEST № 3

DEPARTMENT OF MECHANICAL ENGINEERING, K. S. A. C.

LOG OF COMPRESSOR TRIAL.

TEST MADE AT K.S.A.C. LABORATORY
MANHATTAN KANSAS
ON COMPRESSED AIR PLANT
DATE MAY 8 1903.

CONSTANTS OF ENGINE.

Diam. of cylinder... 8 in.
Diam. of piston rod, 1 3/8 in.
Length of stroke .... 2/3 ft.
Air per revolution .. .46 cu. ft.

Area of piston H. E 50.26 sq. in
Area of piston C. E 48.78 sq. in
Comp. constant for H. E .001015
Comp. constant for C. E .000985

OBSERVERS:

J. A. Correll
C. P. Drake

No. of card.	Time.	R. P. M.	Area.		M. E. P.		I. H. P.			Temperature of Air.			Temperature Cooling Water.			H. P. Dissipated in heat.	Remarks.
			H. E.	C. E.	H. E.	C. E.	H. E.	C. E.	Total.	Initial.	Final.	Rise.	Initial.	Final.	Rise.		
1		105	1.8	1.6	21.17	19.4	2.25	2.01	4.26	85.1	202	116.9	64.4	86.9	22.5		
2		100	1.89	1.82	22.24	22.6	2.25	2.18	4.43	83.3	204	120.7	65.3	86.9	21.6		Total weight of water
3		105	1.93	1.85	22.7	22.42	2.42	2.32	4.74	83.3	207	123.7	66.2	86.9	20.7		used in test 237#
4		108	1.97	1.93	23.18	23.4	2.54	2.49	5.03	83.3	209	125.7	66.2	86.9	20.7		
5		105	1.9	1.85	22.35	22.42	2.38	2.32	4.70	84.2	210	125.8	66.2	87.8	21.6		Receiver Pressure 45#
6		100	1.93	1.85	22.7	22.42	2.31	2.21	4.52	83.3	210	126.7	68	70.5	2.5		
7		104	1.94	1.89	22.82	23	2.41	2.35	4.76	83.3	210.5	127.2	70.7	94.1	23.4		
8		105	1.94	1.89	22.82	23	2.44	2.37	4.81	84.2	214	129.8	69.8	95	25.2		
9		110	1.98	1.89	23.3	23	2.6	2.48	5.08	84.2	216	131.8	69.8	96.8	25.		
10		106	1.89	1.85	22.24	22.42	2.39	2.34	4.73	84.2	216	131.8	68.9	96.8	27.9		
11		108	1.89	1.85	24.38	22.42	2.44	2.39	4.83	84.2	216	131.8	70.7	98.6	27.9		
12		105	1.95	1.96	24.45	24.44	2.45	2.46	4.91	84.2	216	133.6	69.8	99.5	29.7		
	Maximum,	110							5.08			1336			29.7		
	Minimum,	100							4.26			116.9			2.5		
	Total,	6305							56.80			1525.5			268.7		
	Average,	105							4.73			127.1			22.4		

TEST №3

DEPARTMENT OF MECHANICAL ENGINEERING, K. S. A. C.

LOG OF ROPE BRAKE.

Test made at K.S.A.C. LABORATORY
MANHATTAN KANSAS
On COMPRESSED AIR PLANT
Date MAY 8 1903

CONSTANTS OF BRAKE.

Radius of pulley 10 3/4 in.
Weight of brake 8 1/2 lbs.
Weight on brake 30 1/4 lbs
Brake constant .0001666

OBSERVERS:

J. A. Correll
O. P. Drake

Number of Reading.	R. P. M.	Balance Reading.	B. H. P.	Remarks.
1	100	9	.496	
2	95	9	.470	
3	95	9	.470	
4	100	9	.496	
5	104	9.5	.507	
6	98	9	.486	
7	99	9	.491	
8	90	9	.446	
9	95	9	.470	
10	95	9	.470	
11	95	9	.470	
12	90	9	.446	