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A determination of the steam consumption in the engines of the School of Mines power plant by means of a steam flow-meter

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A DETERMINATION OF THE STEAM CONSUMPTION IN THE ENGINES OF THE SCHOOL OF MINES POWER PLANT BY MEANS OF A STEAM FLOW-METER.

by

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C O N T E N T S .

DESCRIPTION AND OPERATION OF G. E. INDICATING FLOW-METER, TYPE "T S."

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The flow-meter as designed and built by the General electric Company consists primarily of a mercury U tube mounted on a stand, a steam nozzle in the pipe in which the steam flow is to be determined and the necessary piping to connect the two with an adjustable cylindrial scale mounted between the legs of the U tube used to determine the change in height of the mercury in the tube.

The U tube consists of an iron U connected to glass gage tubes of small diameter, these tubes being then connected to the piping system. This is shown in the drawing Plate I as B. B.

The nozzle shown in Plate II is nothing more than a bronze plug which screws into the steam pipe at right angles to the direction of flow of the steam, with a set of openings facing the flow of steam, and a set on the opposite side. The openings facing the flow of steam are connected through the nozzle to one leg of the U tube and give pressure head of the steam plus velocity head, while the other set, connected to the other leg of the U tube gives pressure head minus velocity head. The difference of elevation of the mercury in the tube is therefore due to a pressure equal to twice the velocity head of the steam.

The piping between the nozzle and the mercury is filled with water in order that the pressure may be transmitted without losses which might occur due to condensation of the steam, etc.

The indicator cylinder, A in Plate I, which is so adjusted that it may be revolved between the legs of the U tube, or moved parallel to the tube to accomodate the variation of the mercury level, is calibrated to read pounds of steam passing per hour when the observed reading is multiplied by a constant which depends upon the angle at which the tube is set, and the area of the steam pipe used in square inches. The constant referred to is stamped on the meter stand opposite the plug corresponding.

The method of setting and reading the instrument is as follows:- The meter is connected to the nozzle, the tube inclined to position desired, and controlling valves opened, being certain that the the zero reading checks. Next set the inside diameter of the pipe being tested, on scale D Plate I, opposite the arrow and clamp. Then knowing the gage pressure of the steam and the per cent. moisture or degree superheat, set the gage pressure on scale F opposite the known per cent. moisture or degree superheat, on scale E and clamp. Then adjust the indexes C at the levels of the mercury and read the indicated value. As was explained before, this value multiplied by the constant and the area of the steam pipe in square inches, gives the pounds of steam passing per hour.

In this test the per cent. moisture was used equal to four per cent., which was the average value for the steam. A small variation in the per cent. moisture made no appreciable difference in the flow-meter readings.

Before beginning the test it was the opinion of the writer that the flow-meter could not be used near the engines or compressors because of the pulsation of the steam in the pipes, but in order to test this idea out, nozzles were placed in both the steam line of the Ball Engine and of the Laidlow-Dunn compressor near the machines, in the horizontal line to the engine and the vertical line to the compressor. Upon trying the flow-meter in these positions it was found that the level of the mercury in the tubes was not affected by the pulsation of the steam and also not even by the vibration of the flow-meter itself due to the vibration of the steam line.

A nozzle was also placed in the main steam line of the plant near the boilers. This line is eight inches inside diameter. It was found that with all the units in the plant running at rated capacity the flow in the main was not suffcient to give readings on the flow-meter that could be determined with accuracy. The flow-meter is not calibrated for values less than one hundred, and with the nozzle in the eight inch line, the values were all below one hundred.

ARRANGEMENT FOR A VARIABLE LOAD ON ENGINE DURING TEST.

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The engines to be tested are each direct-connected to direct-current generators. The switch board arrangement is such that the two generators can take the load together, or each can furnish the amperage alone.

In order to have a load on the engines which could be regulated, a water rheostat was devised. During the test there was a load of from thirty to sixty amperes for supplying light and power around the plant. The rheostat furnished an additional means for bringing the engines up to one-half rated load, or full capacity, as was desired.

Connection to the busbars of the switchboard was made through an idle switch, by disconnecting the unused line on the side of the switch away from the bus-bars, and connecting in a line to the rheostat. The line from the switchboard to the rheostat consisted of No. 0000 copper wire, well insulated. Fuses of 300 ampere capacity were provided for the rheostat.

The rheostat is shown in Plate III. It consists of a jar of brine solution. The distance between the anode and cathode may be regulated by means of the hand set screw shown in sketch. One disadvantage of this type of rheostat is the fact that the operator cannot see how far apart the anode and cathode really are, nor can he know in just what stage of decomposition the terminals are.

In the first part of the test a cathode of copper was tried. The part of the cathode in contact with the electrolyte consisted of about two and a half pounds of copper. With an average current of one hundred and fifty amperes, it took three hours to cause the complete decomposition of the cathode, thereby causing the current to drop to zero. Then a substitute for copper in the cathode was used. A graphite cylinder four inches in diameter and eighteen inches long was trimmed down for five inches at one end to a diameter of an inch and a half, as shown in sketch. During the remainder of the test, or about fifteen hours, with a load of from 100 to 200 amperes, the graphite cathode was not materially disintegrated.

The greatest difficulty in operating the rheostat was in maintaining a constant load for the engines. There were three main causes for variation in load.

In the first place, as long as copper was used as a cathode, the cathode area was constantly decreasing. And this of necessity increased the resistance of the circuit, and caused a decrease in the load. However, as soon as carbon was substituted for copper, no more difficulty was encountered in this respect.

In the next place, a variation in temperature of the solution in the rheostat was found to materially alter the conductivity of the liquid, this of course causing the amount of current through the circuit to vary. However, this difficulty was also overcome. A small regulated stream of water was allowed to flow constantly into the rheostat. And the temperature of the brine solution could be kept at any desired temperature, by increasing or decreasing the flow of water into the rheostat. The surplus water overflowed at top.

The greatest difficulty was in keeping the solution at a constant degree of saturation in salt. Even though salt was added at very short intervals, in small handfuls, the current was found to vary widely. Besides, it took the constant attention of two men to tend the rheostat and watch the meter readings, while the load was on. As it was necessary to have a brine solution for the conductor, it became unavoidable to get some better way of adding the salt than by hand.

A tank of about ten gallons capacity was placed near the rheostat, and at an elevation slightly higher than the rheostat. This tank was nearly filled with water, and about one hundred pounds of salt was added.

A siphon connected the tank of brine solution and the rheostat. A cock was provided to regulate the amount of flow through the siphon. By this means the load was kept at a very uniform amount, and very little attention was required for the rheostat. The brine tank had to be filled with water every twenty minutes.

COMPARISON OF FLOW-METER AND WATER-METER READINGS.

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Average flow meter reading, 2:30 to 8:00 = 133.2

Average # steam per hour = 19.635 x 133.2 x 1.53 = #4001

Average # water per hour = 20,053 ÷ 5.5 = #3646

This makes a variation of .09 = 9%.

Average flow meter reading, 9:00 to 12:30 = 210.3

Average # steam per hour = 19.635 x 1.53 x 210.3 = #6270

Average # water per hour = 15,107 ÷ 3.5 = 4316.4

This makes an error of 31%.

Note:- Data for above calculations in Table I.

Note:- The boiler feed pump was not kept running at constant rate, and so the level in boilers varied, in addition the load was not constant, causing the elevation of water in the boilers to vary still more, so the pounds of water per hour to check flow-meter readings against, is not reliable and the results above are of little value. In the work following the flow-meter is used with no factor for error, assuming the Company's test before shipment as being accurate.

TABLE I.

Time.	Card No.	VM.	AM.	Watt.Hr. Meter.	Flow Meter.	Steam Gage.	Pounds Water.*	Steam per Hour.*	Table I.
2:15	1	220	200	74780	119	100		3600	
2:30	2	220	180	840	115	85		3460	
2:45		220	200	970	130	85		3920	
3:00		220	180	75080	120	80	3569	3610	
3:15		220	200	150	130	85		3920	
3:30		220	200	270	125	85	2249	3760	
3:45		220	170	420	120	85		3610	
4:00		220	200	500	140	85	1295	4200	
4:15		220	200	600	140	85		4220	
4:30		220	220	720	155	85	905	4660	
4:45		220	204	850	150	85		4500	
5:00		220	210	960	135	80	3237	4050	
5:15	3	220	245	76080	165	80		4960	
5:30		220	225	200	155	75	896	4660	
5:45		220	190	310	120	80		3610	
6:00		220	230	450	145	85	1975	4360	
6:15		220	195	550	130	95		3920	
6:30		220	205	620	135	100	1270	4050	
6:45		220	195	740	140	100		4200	
7:00		220	180	830	120	97	1652	3610	
7:15		Load off engine for ten minutes.							
7:30		220	175	77000	100	97	1428	3010	
7:45		220	230	110	140	100		4200	
8:00		220	200	250	130	90	1577	3920	
8:15		220	175	350	120	78		3610	
		Ball engine at full load.							
8:50	4	220	300			118			
9:00		220	270	77630	170	105		5105	
9:15	5	220	300	800	230	100		6930	
9:30		220	280	850	220	95	1202	6730	
9:45		220	275	78090	195	80		5870	
10:00	6	220	280	150	220	80	1643	6730	
10:15		220	280	310	205	75		6160	
10:30		228	260	490	300	70	2465	9030	
10:45		220	275	620	220	80		6730	
11:00	7	220	260	780	188	90	3403	5690	
11:15		220	275	930	200	100		6030	
11:30		220	270	79090	190	96	2241	5720	
11:45		215	300	240	210	85		6320	
12:00		220	280	410	210	80	1619	6320	
12:15	8	230	260	570	187	80		5670	
12.30		220	280	730	160	80	2034	4810	

* Pounds of water per half hour preceding specified time.

CONSTANTS USED IN CONNECTION WITH

TABLE I.

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Inside diameter of pipe in which meter was placed	= 8 in.
"K" for meter	= 1.53
Moisture in steam (average)	= 4%
Revolutions per minute of engine	= 260
Scale of spring in indicator	= 50# per in.
Length of indicator card	= 2.56 in.
Piston diameter	= 13 in.
Length piston stroke	= 14 in.
Piston rod diameter	= 2 in.

RESULTS AND CONCLUSIONS.

I. Variation of steam consumption to generator load on Ball engine.

Following table shows the amount of steam, in pounds per hour at various loads, per kilowatt generated.

Time.	K. W. Delivered.	K.W. For excitation.	K. W. Generated.	Steam pounds per hr.	Steam lbs. per K. W. hour.	Steam Pressure Gage.
2:30	39.6	1.8	41.4	3460	83.5	85
2:45	44.0	1.8	45.8	3920	85.5	85
5:30	49.6	1.8	51.4	4660	90.0	75
6:00	50.6	1.8	52.4	4360	83.2	85
9:00	59.4	1.8	61.2	5105	84.2	105
11:15	60.5	1.8	62.3	6030	97.0	100
9:30	61.6	1.8	63.4	6730	106.0	95
9:15	66.0	1.8	67.8	6930	103.5	100

From the above table it is found that the amount of steam per K. W. Hour increases with the load and also with the pressure of the steam. The observations seem to show that the steam flow meter readings are not reliable when the flow of steam per unit area of cross section is small.

II. Variation of steam consumption to the indicated horse power of Ball Engine.

The following table shows the relation between the pounds of steam recorded by steam flow meter and the horse-power-hours as indicated by the engine cards.

Note:- For areas and Properties of cards, see Plate IX.

Card No.	Area Card (head end)	Area Card (Crank end)	*Indicated Horse power.	Lb.Steam per Hr.	Lb.Steam per H.P. hour.	Pres.
1	1.64	1.87	82.5	3600	43.6	100
2	1.32	1.51	66.4	3460	52.0	85
3	1.83	2.11	92.6	4960	53.5	80
4	2.22	2.63				
5	2.24	2.58	113.0	6930	61.3	100
6	2.10	2.47	107.5	6730	62.5	80
7	1.91	2.22	92.0	5690	61.8	90
8	2.30	1.98	100.8	5670	56.4	80

* The indicated horsepower includes the friction load of engine and the excitation of field of generator.

The table shows considerable variation in the amount of steam used by the engine, the cause of which we were unable to determine to our satisfaction.

III. Relation between steam consumption of Laidlow-Dunn air compressor and the indicated horse power in the steam end of the compressor.

The cards of the steam end are shown in Plate VIII.

Card No.	Card Area Crank end.	Card Area Head end.	R.P.M. Compr.	Indicated H.P.	Steam Flow lbs. per hr.	Lbs. Steam per H.P.Hr.	Steam Press. gage.
1	.81 sq. in.	.86sq. in.	106	95.0	2350	24.75	100
2	.81 "	.86 "	106	95.2	2360	24.79	100
-	---	---	131	117.0	2940	25.10	94
3	.85 "	.90 "	139	130.3	3223	24.70	101
4	.81 "	.86 "	103	92.4	2260	24.49	94

The table shows a uniform consumption of about twenty-five pounds of steam per H. P. hour by the compressor.

Suggestion:-

The writers would suggest that in the future any tests made with the steam flow meter be made in small pipe, with corresponding high steam velocity, even if necessary to place a section of smaller pipe in the larger lines being tested, as the results shown in the Compressor test seem much more reasonable than those in the Engine test.

STANDARDIZATION OF INSTRUMENTS USED.

STEAM GAGES.

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Gage #1.	**Gage #2.**	**Gage #3.**
West Boiler.	**Middle Boiler.**	**East Boiler.**

Standard	No. 1.	No. 2.	No. 3.
5	10.5	13.0	5.0
10	15.5	17.5	11.0
15	20.5	22.0	16.0
20	25.0	26.0	21.5
25	29.0	32.0	27.0
30	34.0	37.5	32.0
35	39.5	43.0	37.0
40	44.5	47.0	42.0
45	49.5	52.0	47.0
50	53.5	57.0	52.5
55	58.0	62.0	57.5
60	63.0	67.5	62.5
65	68.0	71.5	67.5
70	73.0	76.0	72.5
75	77.5	81.5	77.5
80	82.0	87.0	83.0
85	87.5	91.0	88.0
90	92.5	96.5	92.5
95	97.5	102.5	98.0
100	102.0	106.5	103.0
105	107.0	112.0	108.0
110	112.0	117.0	113.0
115	117.0	121.0	117.0
120	121.0	125.0	122.0
125	127.0	131.0	127.0

STANDARDIZATION OF INSTRUMENTS.

Voltmeter	Style No. 6464 A.
	Serial No. 21059.

Stand..V. M.	Lab. V. M.
95.6	96.5
108.0	109.0
120.6	120.5
128.8	129.5
137.8	138.0
149.8	149.5
155.6	155.0
162.6	162.0
169.6	169.5
176.0	175.5
185.6	185.0
194.6	193.5
205.8	204.5
210.8	209.5
212.6	211.5
214.4	213.5
216.0	215.5
217.6	215.5
219.4	218.5
221.0	220.0

The voltmeter and ammeter checked very closely the watt-hour-meter readings.