SMALL SCALE HYDROPOWER

PERFORMANCE AND EFFICIENCY DATA

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Introduction

Fossil fuels supplied the world with the cheapest source of power. Most of the machinery today was designed to use fossil fuels. However, from 1973 when the oil prices escalated, all nations feverishly began a search for other sources of power. However, hydropower had been used in the past, but lately has been forgotten or thought of in the form of huge dams which are very costly. Today, many developing nations are using minihydro or small scale hydropower which is badly needed for rural electrification.

Other nations like the USA make available facilities to upgrade the level of renewable energy technologies in developing countries. It is in this endeavor that we took up the testing of the Pelton turbine to acquaint ourselves with it.

Theory

In water turbines the kinetic energy of flowing or falling water is converted into mechanical rotary motion. This principle was used in the past in water-sheds. The Pelton turbine embodies the principle of the old water-shed.

Theoretical power is determined by head and mass flow rate. To calculate available power, head losses due to friction of flow in conduits and the conversion efficiency of machines employed must be also considered. The formula, thus, is the following:

$$P = H \times Q \times g \times \rho \times \eta = 9 \times 81 \times H \times Q \times \eta \times \rho$$

where P = output power in kilowatts (10^3 watts)

H = Net head = Grosshead - Losses (metres)

Q = Flow in m^3/sec

g = Specific gravity $9 \times 81\ m/s^2$

ρ = Density (for water $10^3 kg/m^3$)

η = Overall efficiency = $\eta_1 \cdot \eta_2 \cdot \eta_3 \ldots \eta_n$

The efficiency of a turbine can be broken down into three components: volumetric efficiency, the hydraulic efficiency, and the mechanical efficiency.

The overall efficiency η of a turbine is defined as:

$$\eta = \frac{\text{Power delivered to the shaft}}{\text{Power available in the water}} = \frac{T_w}{9 \times 81 \times H \times Q}$$

T = Torque and w angular velocity in radians. T is the torque delivered to the shaft by the turbine.

The volumetric efficiency η_V refers to possible loss of efficiency through leakage around the rotor. That is, not all the fluid flowing is effective in the energy transfer process.

Let Q_L represent this leakage while Q represents the net flow through the turbine. Then $Q - Q_L$ represents the flow that is effectively acting on the rotor.

Therefore volumetric efficiency $\eta_V \frac{Q - Q_L}{Q}$

The hydraulic efficiency η_H of a turbine is the ratio of $\gamma(Q - Q_L)\ H'$, the power transferred to the rotor, to $\gamma(Q - Q_L)H$, the availabile power in the water that effectively flows through the rotor. H' is the head utilized by the rotor which is equal to $H - H_f$, where H_f is the fluid friction head loss.

$$\eta_H = \frac{\gamma(Q - Q_L)(H - {}_f)}{\gamma(Q - Q_L)H} = \frac{H - H_f}{H}$$

Mechanical efficiency η_m of a turbine is the ratio of the power available at the shaft to that exerted by the water to the rotor.

$$\eta_m = \frac{T_w}{(T + T_f)w}$$

T_f represents the torque required to overcome mechanical friction. T is the torque available at the shaft of the machine. Friction is from the bearings, disk friction between the sides of the rotor, stuffing boxes, etc.

$w(T + T_f)$ can be represented as $(Q - Q_2)\gamma \times (H - H_f)$

$$\eta = \eta_V \cdot \eta_H \cdot \eta_M = \frac{Q - Q_L}{Q} \cdot \frac{H - H_f}{H} \cdot \frac{T_w}{\gamma(Q - Q_L)(H - H_f)}$$
$$= \frac{T_w}{\gamma QH}$$

Main characeristics of Pelton turbines (Fig. 1) are a jet of water from the nozzle strikes the buckets of the turbine which are divided into two parts by a vane. The jet is divided into two sections of the bucket. The buckets are placed at the periphery of the wheel. In this way the wheel is set into motion. The speed of rotation is a function of flow rate and the head. The flow of water is regulated by a needle in the nozzle. The wheel is attached to a horizontal shaft which leads to the generator at one end and to the governor at the other end. The governor is a regulating device.

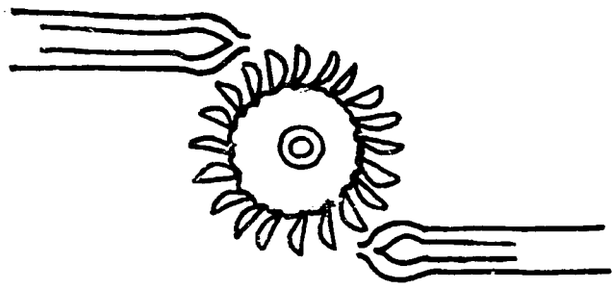
Pelton turbines are high head turbines. However, they can be designed to operat at lower heads.

Experimental

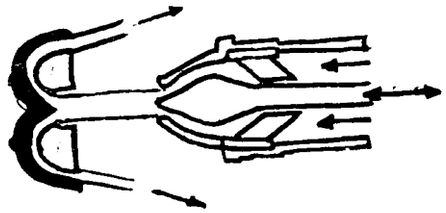
A small Pelton turbine was built in the workshop. The objective of our work is to find out how it operates, studying its performance and improving its efficiency.

The turbine has two nozzles one nearly on the top of the wheel and the other below the wheel. A shaft runs through the wheel and is attached at one end to a motor car alternator and the other end free mounted on a bearing with a small groove to facilitate the measurement of rpm's.

The circuit diagram, as shown in Fig. 2, contains a voltometer, an ammeter to measure the current from the alterantor and a second ameter to measure the current due to the load and/or current due to the load and alternator. A 12



Schematic of 2 nozzle Pelton-wheel



Jet Impinging Bucket

Figure 1.

volt battery is used for initial excitation of the field in the alternator. Water is led out of the system with a pipe.

Procedure

The source of water comes through a pipe from the water supply system with a press of 65 psi (equivalent to 47.7 m head). Hoses 1/2" in diameter, the pipe leading to the turbine 3/4" in diameter. A tachometer was procured for measuring the revolutions per minute.

Readings for voltage, current, flow rate, press and rpm were taken, without load, one, two, three loads. These were tabulated in Table 1. A graph of efficiency against rpm's was plotted in Graph 1 and 2. The flow rate was not used in the graph because it is constant.

It was found that the efficiency was very low, the power was also low. This was attributed mainly to the size of the pipes and the pressure (fluctuating) in the workshop because others were also using the water for their experiments.

The system was therefore moved to another site outside the workshop. This site has a pressure of about 70 psi (49.2 m head), 3/4" hoses were used. Here a variable resistance ws also used to give more readings than are given by the three lamps. The same readings were taken (Table 2), Graphs 3 and 4 were plotted.

Conclusion

From the graphs, although the point of maximum power was not caught, it can be concluded that efficiency achieved (highest 21.3%) is adequate. Pelton turbines efficiencies are usually in the order of 50-60% and considering the losses due to the shape of the buckets (not deep enough), losses in the pipes and the alternator, it is believed that their losses are considerable.

A gearing system was not introduced because this would not change the efficiency since rpm's up to 3,000 were obtained.

Looking through the graphs we can observe the following.

- From the efficiency rpm graph, it has been seen that the efficiency shows a smooth relation in increasing rate regarding the interval change due to load. But as soon as it reached the medium point the number of revolutions per minute as well as the efficiency drops a considerable amount.
- When it reached the lowest point, the efficiency and the revolutions are appreciably constant. For further work to improve the efficiency we can recommend the following.
  - Examine the size of the nozzle and their angle of attachment.
  - Increase the amount of water (Q) and head (H). Since they are the two parameters essential for more generation ($P = \eta QH$).
  - Study the efficiency of the alterantor.
  - Find the brake horsepower of the water shaft to find out the specific speed. (The rotation of the shaft should be equal to half of the water speed at the nozzle).
  - The size of the pipe. We are using 3/4" diameter hoses. So increasing the diameter will decrease the losses.
  - Since we are using this amount of water it is split into two jets instead of one.

Circuit Diagram

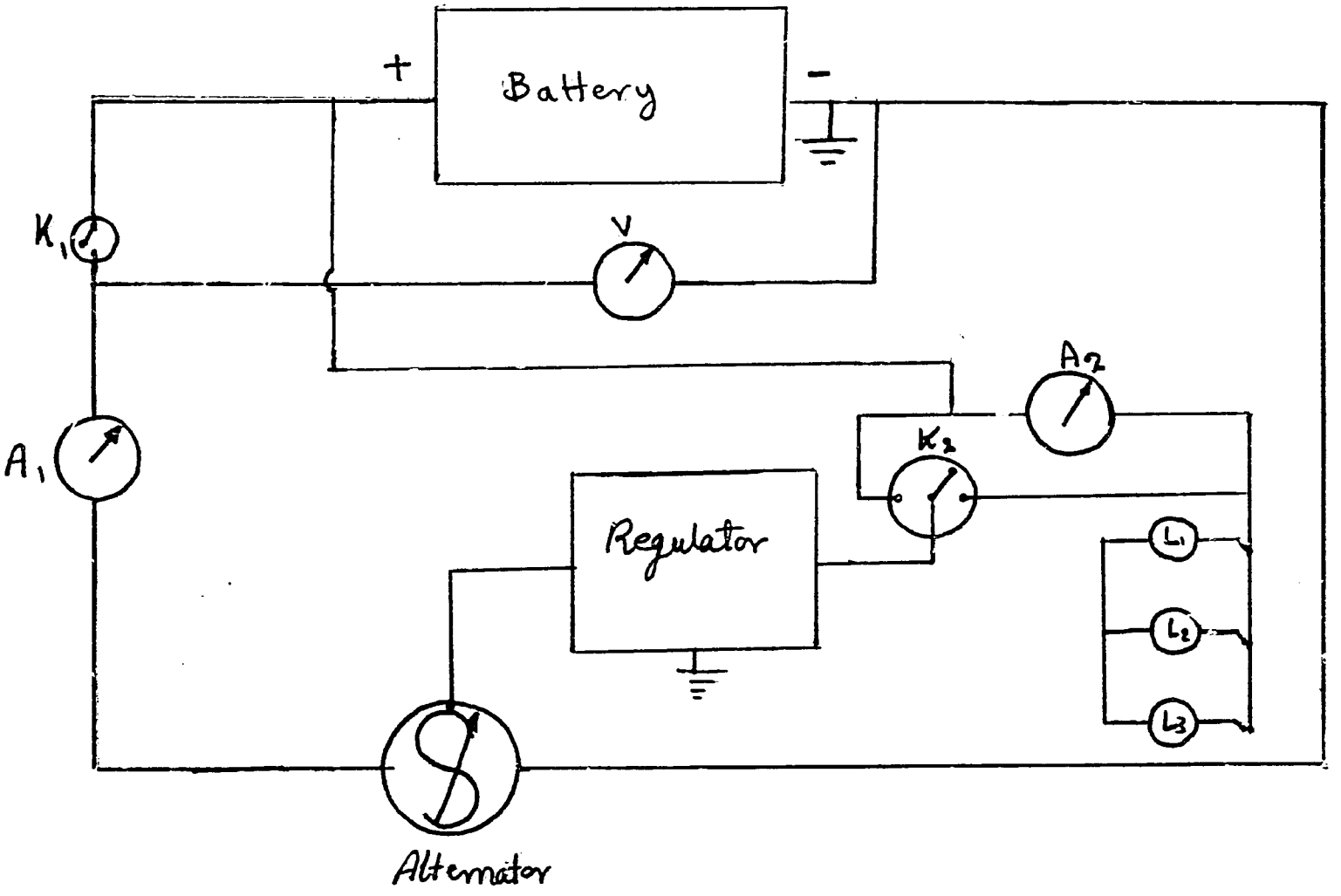


Figure 2.

Circuit Diagram Key

K_1 - Controls the battery only. Battery on-off key.

K_2 - When set to one direction it allows the ameter to measure the amount of current through the field of the alterantor. When set to other directions it allows the ameter to read the current passing through the field and the load.

The function of the regulator is to control the amount of current passing through the field of the alternator.

The voltage reads the volts coming through the battery as the voltage produced by the water shaft.

A_1 - Reads the current from the battery to the alternator field.

A_2 - Works according to the position of K_2 as mentioned above.

Table 1.

For graph (1) and (2)

No.	Q Kg/sec	(m)	Q·H	RPM	A_1	A_2	V	VA_1	R Ω	η %
7	0.82	47.7	388.4	2740	1.7	1.75	15.5	26.4	9.1	7
2	0.82	47.7	388.4	2340	4.8	5	15	72	3.1	18
3	0.82	47.7	388.4	1000	7	7	9	63	1.3	16
4	0.82	47.7	388.4	1100	8	8.2	7.5	60	0.94	15

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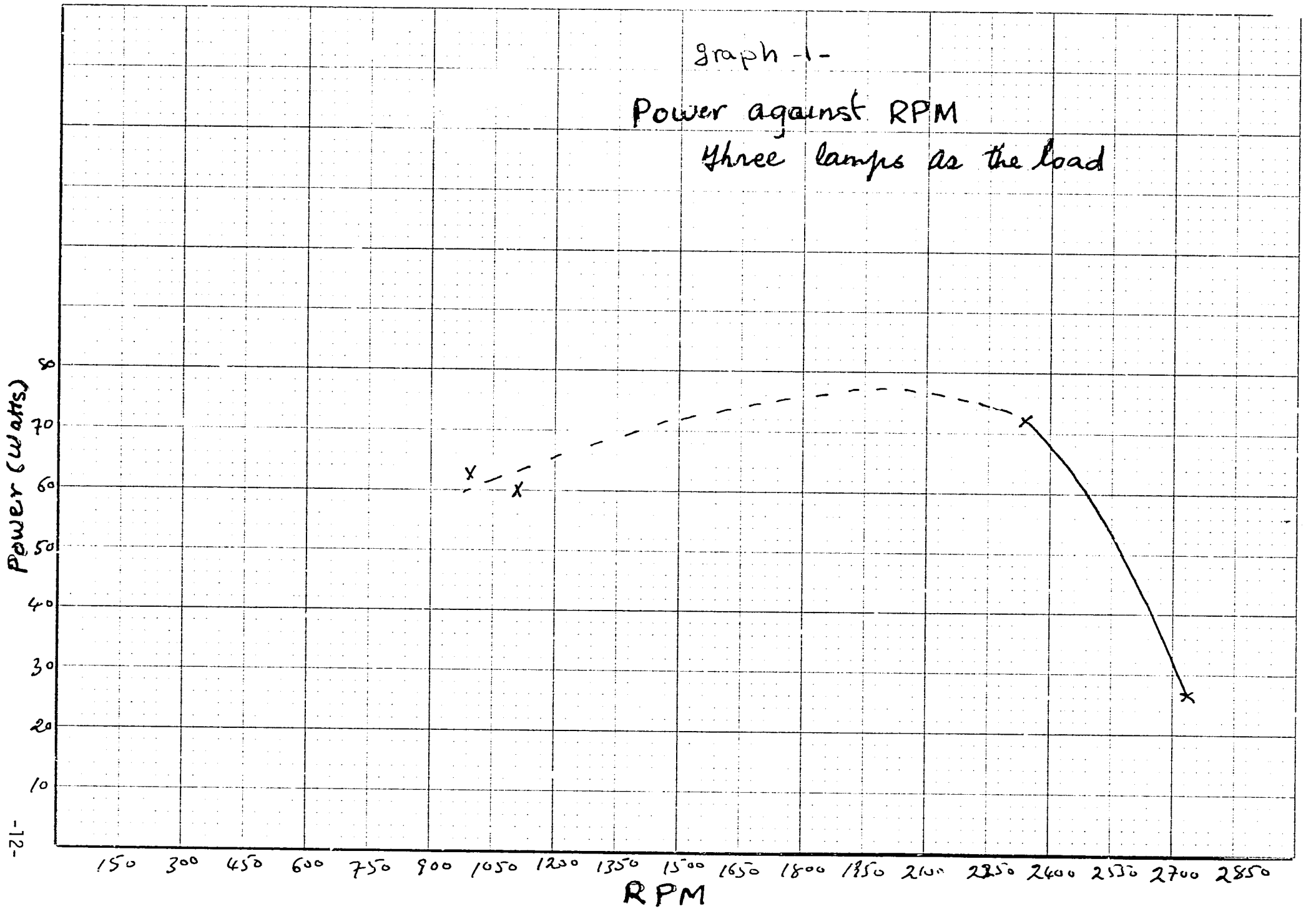

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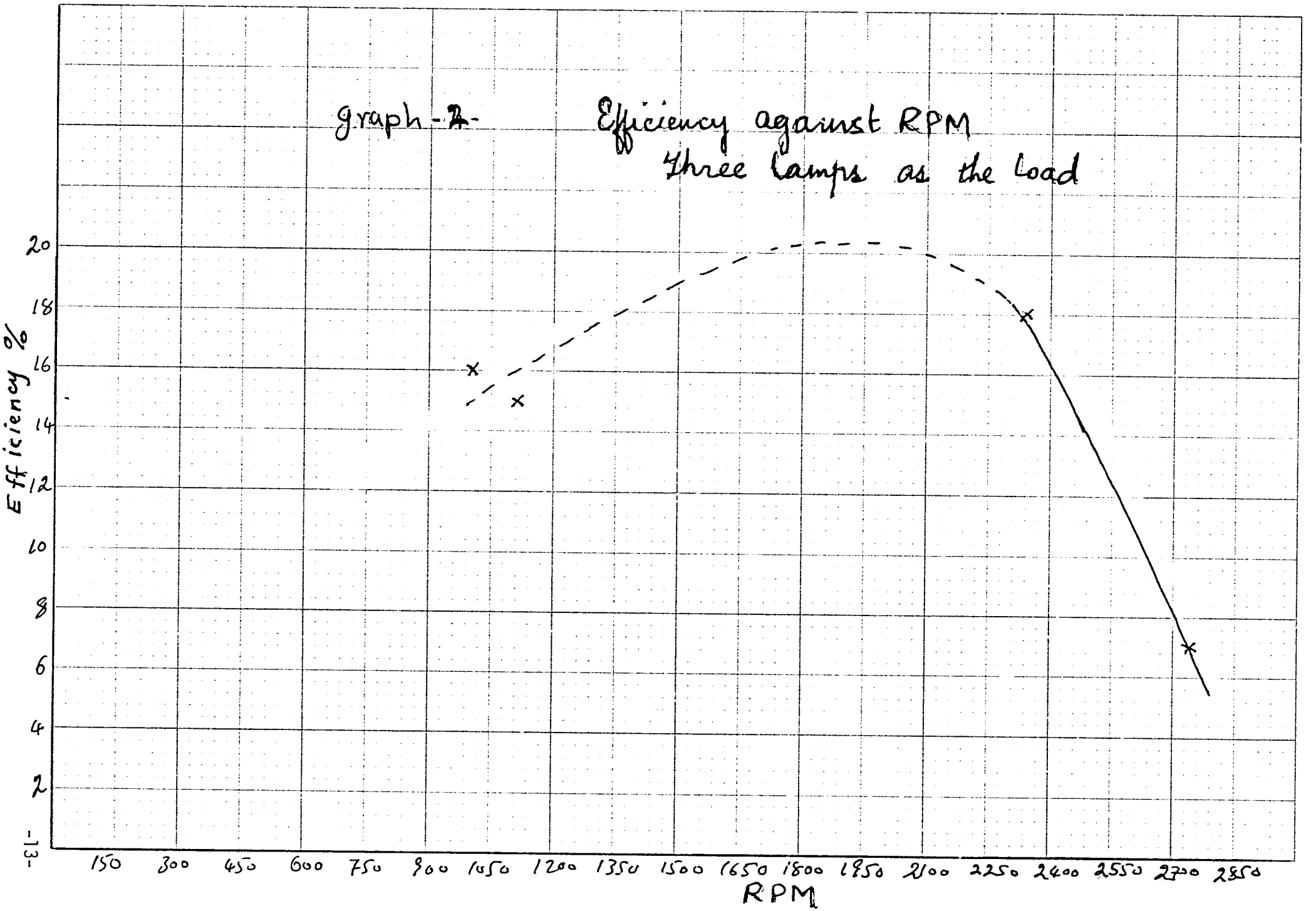

Table 2
For graphs (3) and (4)

No.	Q Kg/sec	H(m)	Q-H	RPM	A_1	A_2	V	VA_1	R_Ω	η%
1	0.83	48.16	400.3	2785	1.8	0	15.4	27.7		6.9
2	0.83	49.16	400.3	2766	2	0.5	15.4	30.8	30	7.7
3	0.83	49.16	400.3	2719	2.5	1.0	15.4	38.5	15.4	9.6
4	0.83	49.16	400.3	2670	3.0	1.5	15.4	45.9	10.27	11.5
5	0.83	49.16	400.3	2590	3.6	200	15.4	55.4	7.7	13.9
6	0.83	49.16	400.3	2550	3.9	2.5	15.4	60.1	6.16	15.0
7	0.83	49.16	400.3	2448	4.43	3.0	15.0	66.5	5	16.6
8	0.83	49.16	400.3	2426	5.0	3.5	14.25	71.3	4.1	17.8
9	0.83	49.16	400.3	2348	5.4	4.0	14.0	75.6	3.5	18.9
10	0.83	49.16	400.3	2207	6.0	4.5	14.2	85.2	3.16	21.3
11	0.83	49.16	400.3	1007	7.0	5	9.0	63	1.8	15.7
12	0.83	49.16	400.3	1040	7.5	5.5	8.5	63.3	1.6	15.8
13	0.83	49.16	400.3	1096	7.75	6.5	8.1	62.8	1.3	15.7
14	0.83	49.16	400.3	1190	9.0	7.5	7.0	63.2	0.94	15.8
15	0.83	49.16	400.3	1240	9.3	8.0	6.8	63.3	0.85	15.8

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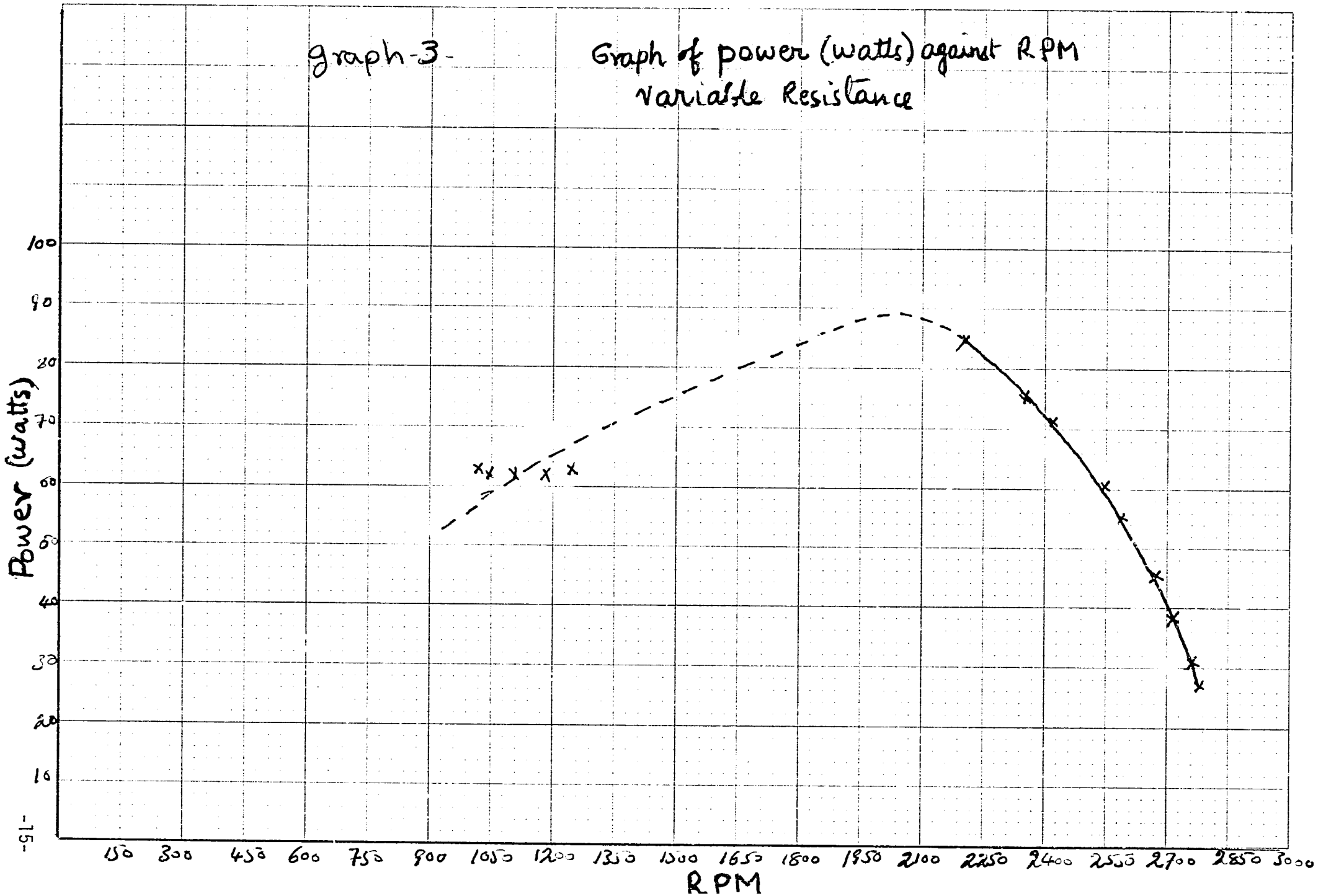
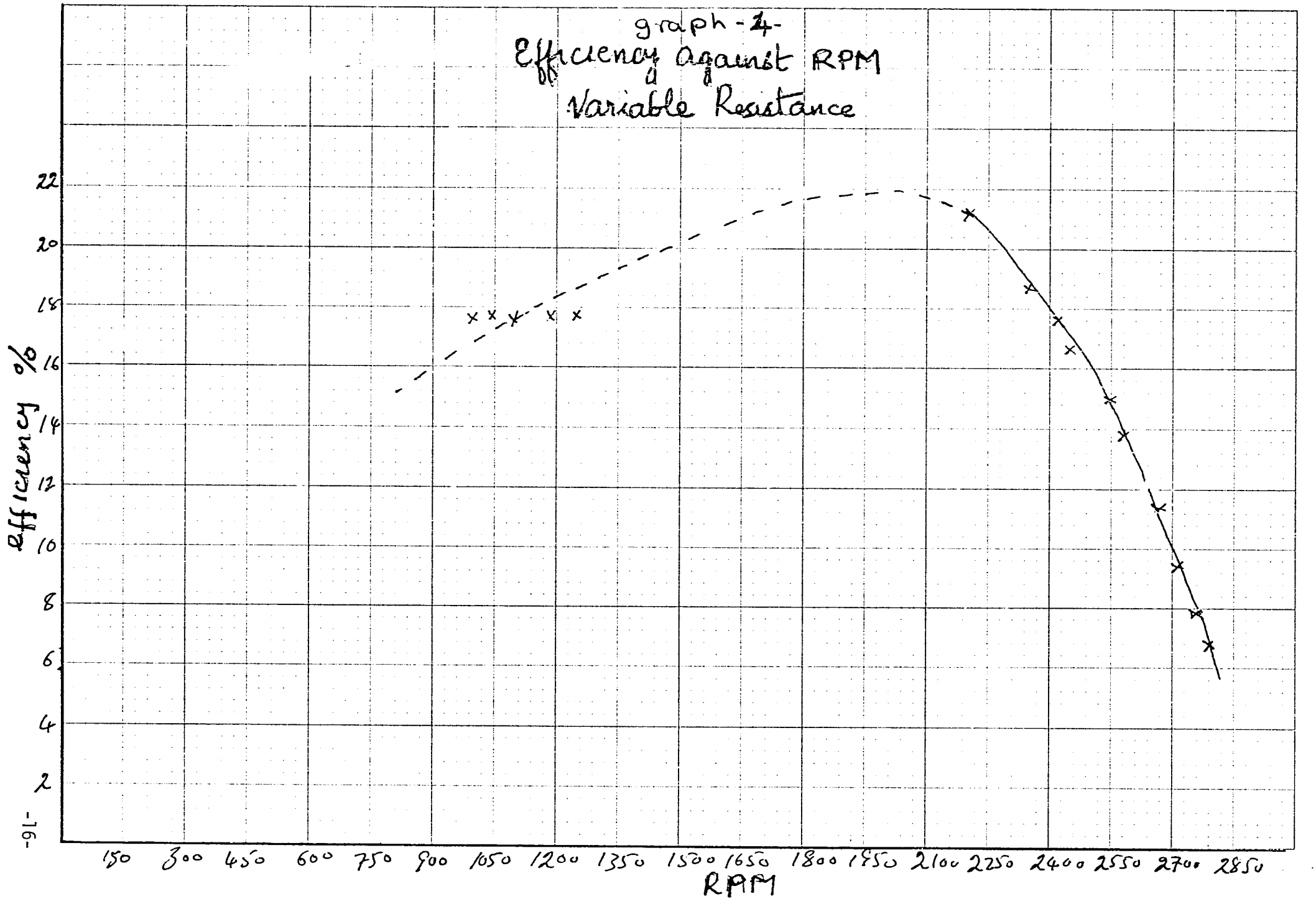
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