"Experimental Analysis On The Performance Of A Traction System"

BY

Dr. Mukhtar M. A. Murad, Dr. Jasem Alrajhi, Dr. Manzoor Ali

Department of automotive & Marine Engineering Technology
College of Technological Studies
P.O. Box 42325
70654 Shuwaikh - Kuwait

ABSTRACT

The performance analysis based on the experimental results has been carried out. The test rig comprised of a conventional internal combustion engine coupled with a hydraulic dynamometer, a D.C. series motor (torquer), an alternator and a battery pack. The rig was specially constructed so as to obtain purely mechanical, electrical and hybrid mode of operation. The engine overall performance map and transmission efficiency were obtained. The torquer, alternator, planetary gear train and battery performance have been determined. The tests were conducted under the hybrid mode whereby the engine fed both the dynamometer representing traction load and the alternator applied to charge the battery or to change the speed through the dynamometer.

1. INTRODUCTION

Hybrid vehicles, a possible combination of two or more sources of power for achieving better performance than the vehicles driven by conventional internal combustion engines, have been a promising possibility particularly for urban use. (1-4, 8-10).

The present work gives experimental results performed on a test rig representative of a hybrid system that could be run on purely mechanical, purely electrical and a hybrid mode (5). The engine overall performance map, transmission efficiency, performance of torquer, alternator, planetary gear train and battery have been determined.

2. EXPERIMENTAL APPARATUS

A conventional internal combustion engine was coupled to an automotive gear box. In the planetary gear train, the sun gear is driven from the engine, and the planetary carrier is coupled to the alternator. The annular gear coupled to the dynamometer was connected to the D.C. machine across step-down gear box, which could be used as a motor (purely electrical mode) or share in the load (hybrid drive). The lay-out of test rig is shown in Fig. (1), and is described in detail in Ref. (5).

3. EXPERIMENTAL RESULETS AND DISCUSSION

3.1 PURE MECHANICAL MODE

In this mode, the engine was run and loaded by the hydraulic dynamometer. The D.C. motor was disconnected from the dynamometer. For different throttle openings of the engine, the speed was changed within the working range by varying the dynamometer load.

The engine brake power, P_b, was obtained from the dynamometer relationship. This engine brake power was corrected for standard ambient temperature conditions (6). Also a correction factor for the drop in engine power taking place across the mechanical transmission of the test rig was applied. Thus the transmission efficiency of the rig, η_t, was determined.

Figure (2) is a typical representation of the variation of engine power and torque with engine speed whereas Fig. (3) shows the corresponding variation in engine brake mean effective pressure and brake specific fuel consumption with engine speed. Such variations with different parameters were obtained and applied to draw an overall performance map which is shown in Fig. (4). Figure (5) gives the variation of transmission efficiency with engine speed. A mean value of 90% was obtained.

The power from the engine to the dynamometer is transferred across four sets of transmission gears as shown in Fig. (1). The test rig transmission efficiency was obtained by dividing the value of experimental brake power with the power given by manufactures specifications corresponding to the test conditions.

3.2 PURE ELECTRICAL MODE

3.2.1 Performance Characteristics of Torquer

The torquer was tested at constant terminal D.C. voltages of 120 & 96 volts. These terminal voltages are equivalent to those prevailing when the system is working either in the pure electrical mode or in the hybrid mode and the torquer is fed from the batteries.

The torquer was fed from a 220 volt A.C. supply via a variable potentiometer to produce a voltage up to 96 volts and bridge connected rectifiers. The torquer was coupled to the dynamometer across the third gear box, as shown in Fig. 1, which was engaged in direct drive. The torquer load was varied by the hydraulic dynamometer. The torquer was first tested without any shunt resistance included in the field circuit. Afterwards the torquer was tested with different resistances connected in shunt with the field, in order to be able to cover the full torquer speed working area expected in urban pure electrical mode. A combination of six field shunt resistance three of which were 0.1 Ohm each and the rest were 0.05 Ohm each while the field resistance, R_f, was 0.0156 Ohm.

First set of results was obtained for a terminal D.C. voltage of 96 volts. Figure (6) gives the variation of torque against the speed for five different test configuration while Fig. (7) indicates the change of power with the speed. Figure (8), gives the associated variation of the motor efficiency with motor speed.

The second set of results was obtained for a D.C. voltage of 120 V and the Figure (9), (10), (11), represent the corresponding variations as mentioned above comparable to Figures (6), (7), & (8), respectively.

3.2.2 Performance Characteristics of Alternator

The alternator was driven by the D.C. motor across the dynamometer and gear boxes 9, 11, 13 as in Fig. (1). The speed relationship is then

$$\frac{NA}{N_r} = 1 + \frac{1}{K} \tag{1}$$

in which N_A and N_r are the speeds of alternator, respectively and K is the gear ratio.

The sun gear of the planetary gear train was braked. The alternator output D.C. voltage was adjusted by means of a voltage regulator fitted to the alternator. For each speed, the alternator load was varied from no load to full load by means of a series of load resistances. The values of test speeds and loads are intended to cover the expected range of hybrid operation.

A transmission efficiency of 95% was assumed across the three gear boxes during power transmission from the torquer to alternator.

Figures (12) and (13), give the alternator efficiency for terminal voltage 96 and 120 V respectively, and for constant speeds of 800, 1000 and 1500 R.P.M. across the working range of alternator output.

3.2.3 Performance Characteristics of Battery

The battery pack applied consisted of 10 lead acid batteries. The 12 Volt batteries were 120 Ampere-Hour capacity with 20 hour rating having outside dimensions of 514× 212 × 223 mm and a net weight of 36.5 kg having 21 plates per cell. The batteries performance was evaluated by testing one of the batteries chosen at random during charging and discharging with different discharge rates. The charging was done by means of a portable battery charger capable of supplying a maximum charging current of 100 Amps. The electrolyte density was measured by a hydrometer and corrected for variation in ambient condition. A variable resistance to the circuit was provided in order to maintain a constant discharge rate.

Figure (14) gives the change of battery voltage with capacity from the different discharge rates. Evidently the battery capacity decreases with increase of discharge rate. Figure (15) shows the variation of battery voltage, battery capacity and mean battery power obtained with different discharge currents.

5.7 Hybrid Mode Tests

The purpose of these test was to run the test rig under conditions similar to those existing on the road under hybrid mode of operation. The engine was run and was made to feed both the dynamometer which represented the traction load and the alternator which was applied to charge the batteries and in addition was used to change the dynamometer and hence the vehicle speed. Evidently the particular transmission containing both the planetary gear and alternator can be considered as a continuously variable transmission CVT, excluding both the classical manual or automatic gear boxes. The central system fitted in such a transmission should always be capable to select the alternator speed producing the optimum engine running conditions to mate the existing road conditions.

The tests were carried out in the following sequence:

The gear boxes between the planetary gear drive and both engine and dynamometer were engaged while the gear drive and both engine and dynamometer were engaged while the gear box between the dynamometer and torquer was disengaged. The alternator was first run at no load in case the dynamometer was stationary. The alternator was then loaded in steps from no load to full load by connecting the alternator load resistance in steps as in Fig. (1).

At each alternator load the engine throttle opening was gradually increased to produce a progressive increase in dynamometer speed associated with the decreasing alternator speed and constant engine speed. The dynamometer and alternator speed and load were then recorded. The following sample of experimental results obtained clarifies the method of computations adapted. Engine was working at part throttle opening.

Engine speed N_c = 2500 R.P.M.

Gear box between engine and planetary gear drive engaged on second speed i_{g2} = 2.246

Alternator speed NA = 720 R.P.M.

Alternator line voltage V_A = 96 volts

Alternator load I_A = 30.5 Amps.

Dynamometer speed N_d = 580 R.P.M

Dynamometer torque T_d = 29 Nm

Gearbox between dynamometer and planetary gear drive engaged on direct drive.

Considering the planetary gear drive:

The speed of the sun gear Ns can be obtained from the engine speed N_c by allowing for the stepping up of engine speed across the gear box between the engine and planetary gear drive, the relevant gear box was engaged on second speed. Allowance should also be made for the stepping down of speed across the bevel gear train in the planetary gear drive for which the gear ratio i_{gb}=1.735

Thus Ns = 3227 R.P.M.

But the speed of the planetary carrier is equal to the alternator speed, N_r = 720 R.P.M

Also the speed of the dynamometer N_d is equal to the speed of the annular gear N_A of the planetary gear train since the gearbox between the planetary gear drive and the dynamometer was engaged on direct drive. so N_A = 580 R.P.M.

A) Checking of speed relationship

From Willi's Equation, (7),

$$\frac{N_s - N_r}{N_A - N_r} = -K$$

where K= planetary gear ratio = 1.941

Substituting for Ns, Nr & NA from previous calculated values taking into consideration that the annular gear rotates in opposite direction to both the sun gear and planetary carrier then, the gear ratio comes out to be 1.95 which is approximately equal the theoretical value of 1.941.

Figure (16) gives the theoretical relationship between N_A & N_r as calculated from Willi's Equation for a constant value of N_s = 3227 R.P.M. together with the test values of N_A & N_r obtained experimentally.

(B) Checking of power relationship

A similar analysis was done in order to check the power relationship. This analysis shows good coincidence between the experimental and theoretical values of the power ratio

$\frac{P_r}{P_A}$ of the planetary gear train.

The values of $\frac{N_r}{N_A}$ & $\frac{P_r}{P_A}$ as well as the corresponding experimental values are given in Fig. (17)

4. CONCLUSIONS

The performance of a hybrid system has been evaluated and it has been shown that field tests on an expensive hybrid car can be avoided and the performance analysis done on the test rig provides useful data for the interpretation of the optimum performance of a hybrid vehicle including the selection of optimum gear ratios between the power source and traction wheels.

In pure mechanical mode for the system, the variations of engine torque, power for different throttle openings with the engine speed and the variation in brake mean effective pressure, brake specific fuel consumption with speed have been obtained. An overall performance map has been drawn to obtain these parameters at any given conditions. The variation of transmission efficiency of test rig with engine speed has also been determined.

The performance characteristics of the torquer (D.C. Motor) involving parameters like power, torque, efficiency and speed have been obtained at two terminal voltages of 120 and 96 Volts. It can be concluded that the efficiency of the torquer decreases with the increase in torquer speed and also the efficiency is higher at low voltages. This would lead to a proper selection of a suitable torquer unit to suit the required conditions.

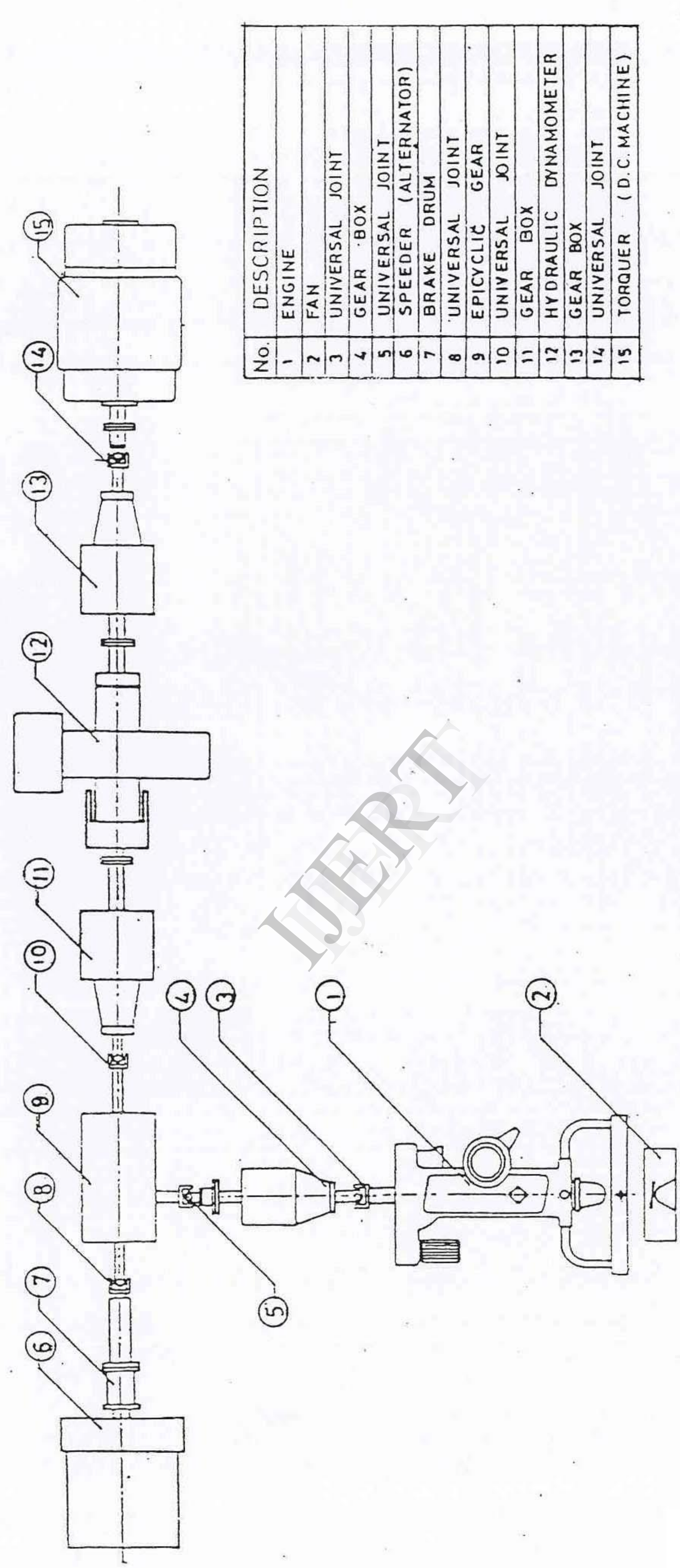
For alternator, the variations of efficiency with current at two different voltages and at speeds of 800, 1000 and 1500 R.P.M. have been determined. From the characteristics thus obtained, it can be seen that the efficiency of the alternator increases with the increase in current. For the two selected voltages of 96V and 120V, it is higher for low voltage of 96 V then that at 120V. Also the efficiency decreases with the increase in engine speed.

A 10 lead-acid battery pack was employed. The variation of electrolyte density, battery voltage, capacity and mean battery power at different discharge currents have been obtained. The battery capacity is shown to decrease with the increase in discharge rate.

The tests under hybrid mode were carried out. The speed and power relationships for the planetary gear train that was employed, showed a good coincidence between the theoretical and experimental values.

REFERENCES

1. G.H. GELB, N.A. RICHARDSON, T.C. WANG, B. BERMAN, "An Electromechanical Transmission for Hybrid Vehicle Power Testing", SAE Paper 710235, 1971.
2. A. BOLANDI, C.R. WEBB, "A Hybrid Passenger Car", Proc. I. Mech. E. No. C-205, London, 1979.
3. R. RILEY, M. DUVALL, R. CABENE II, G. Engg, K. KRUETZFELDT and A.A. FRANK, "Hybrid Electric Vehicle Development at Ground FX" SAE Paper 940340, 1994.
4. K.B WIPKE, N. HILL and R.P. LARSEN, "Analysis of Data from Electric and Hybrid Electric Vehicle Student Competitions", SAE Paper 940557, 1994.
5. M. MURAD, M. ALI, "Theoretical Analysis on the Performance of a Traction System". Accepted for publication.
6. E.F. OBERT, "Internal Combustion Engines", Harper and Bow, New York, 1973.
7. H.D. ARTAMOIVOV, V.A. ILARONOV, M.M. MORIN, "Motor Vehicles" MIR publications, Moscow, 1976.
8. URBON ELECTRIC VEHICLE (NEV) Technical specifications Electric Transportation Applications, March 2001.
9. ABE, S., Murata, M. "Development of IMA Motor for 2006 Civil Hybrid", SAE 2006-01-1505, 2006.
10. ABE, S., DAVE, H., "Hybrid Vehicles Lessons Learned and factor Prospects, "SAE 2006-21-0027".
11. Development of motor assisted hybrid traction system Hokkaido Kailway Company, Sapporo Japan 2008.
12. International AUL Conference, Engine & Environment Scp 2007.



No.	DESCRIPTION
1	ENGINE
2	FAN
3	UNIVERSAL JOINT
4	GEAR BOX
5	UNIVERSAL JOINT
6	SPEEDER (ALTERNATOR)
7	BRAKE DRUM
8	UNIVERSAL JOINT
9	EPICYCLIC GEAR
10	UNIVERSAL JOINT
11	GEAR BOX
12	HYDRAULIC DYNAMOMETER
13	GEAR BOX
14	UNIVERSAL JOINT
15	TORQUER (D.C. MACHINE)

FIG. (1) TEST RIG LAYOUT

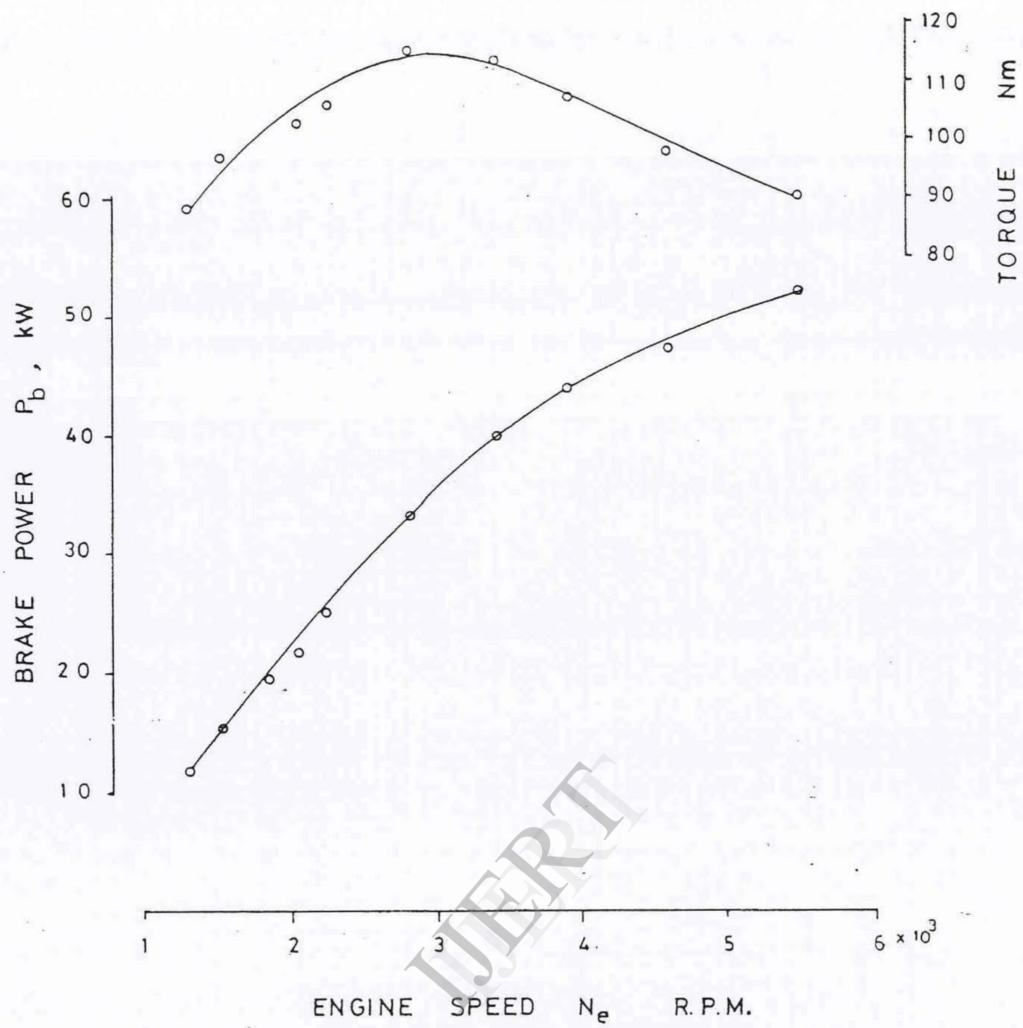


FIG (2) VARIATION OF BRAKE POWER AND TORQUE WITH ENGINE SPEED

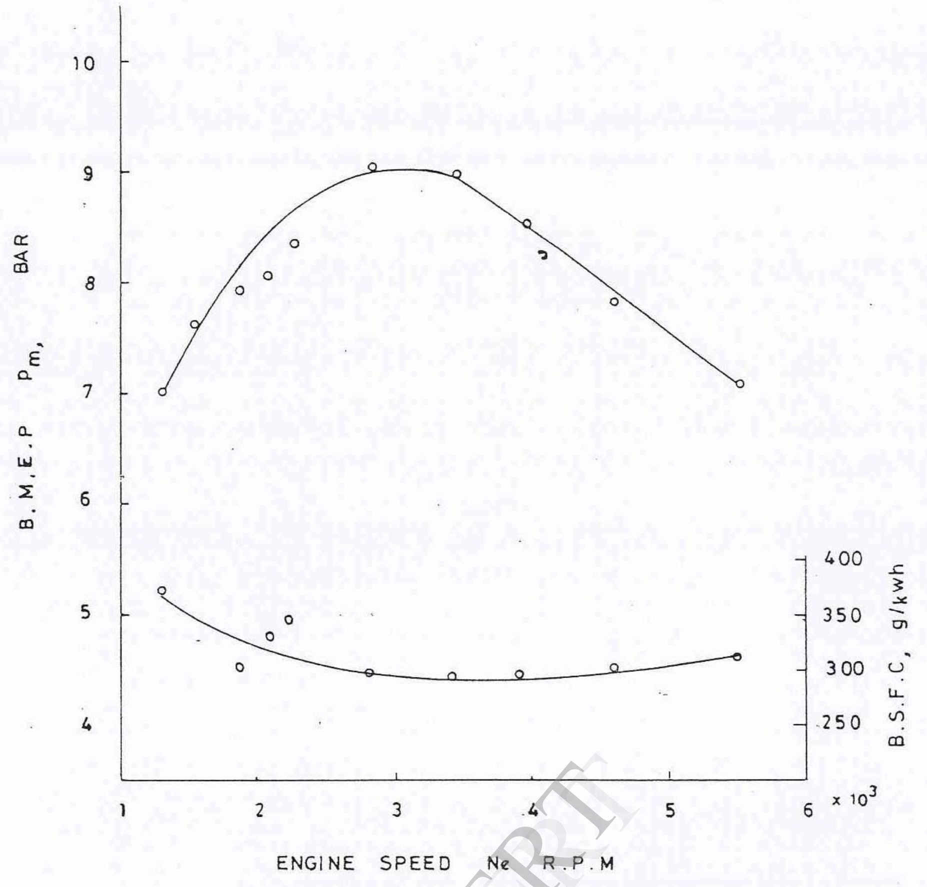


FIG. (3) VARIATION OF BRAKE MEAN EFFECTIVE PRESSURE AND BRAKE SPECIFIC FUEL CONSUMPTION WITH ENGINE SPEED.

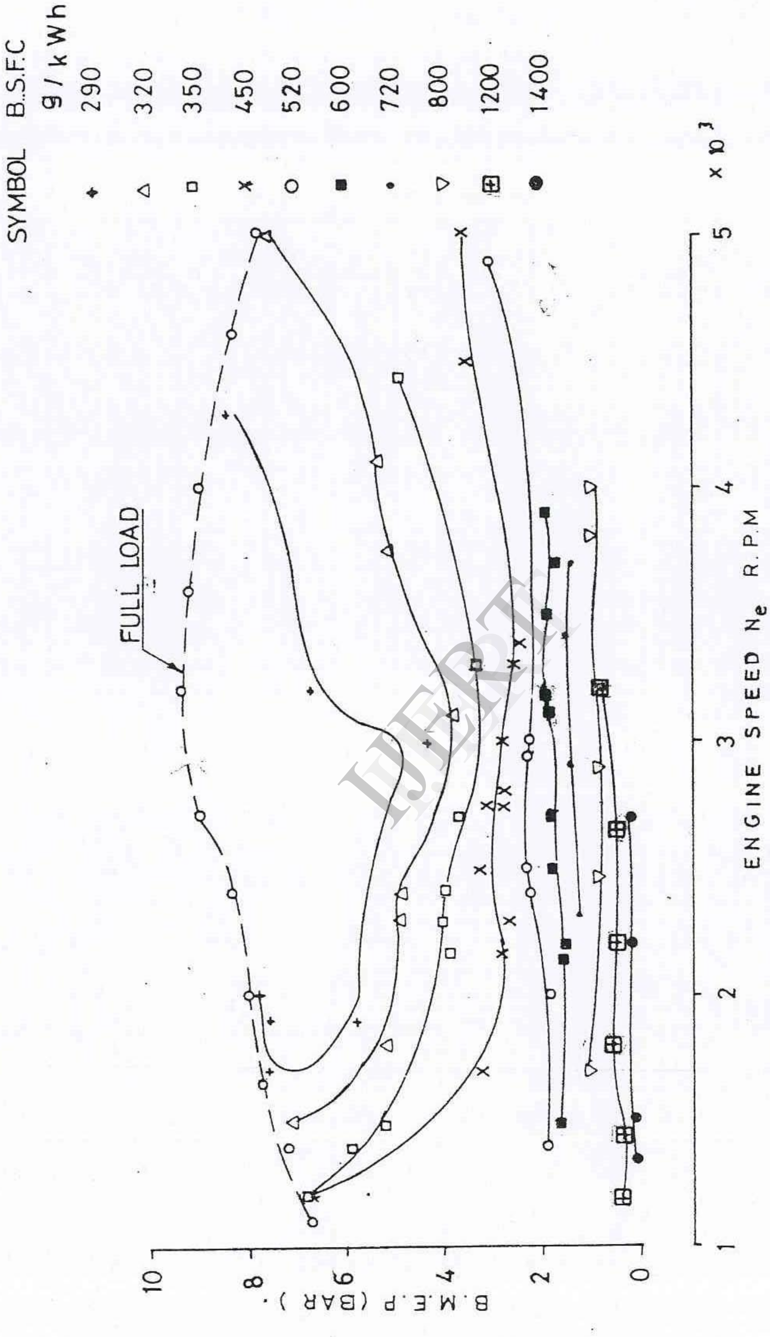


FIG. (4) PERFORMANCE MAP SHOWING VARIATIONS OF BRAKE MEAN EFFECTIVE PRESSURE & BRAKE SPECIFIC FUEL CONSUMPTION WITH ENGINE SPEED.

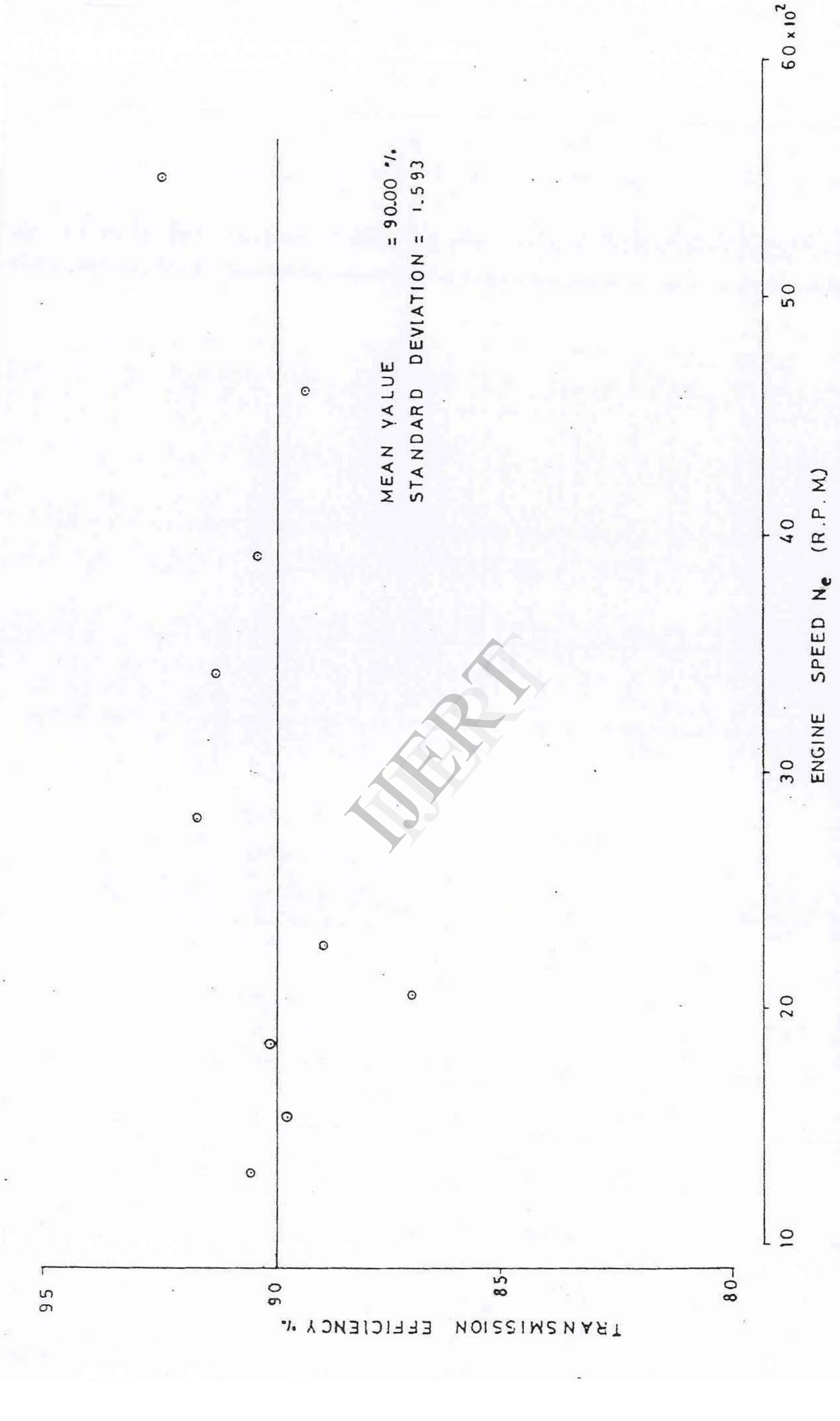


FIG.(5) VARIATION OF TRANSMISSION EFFICIENCY WITH ENGINE SPEED

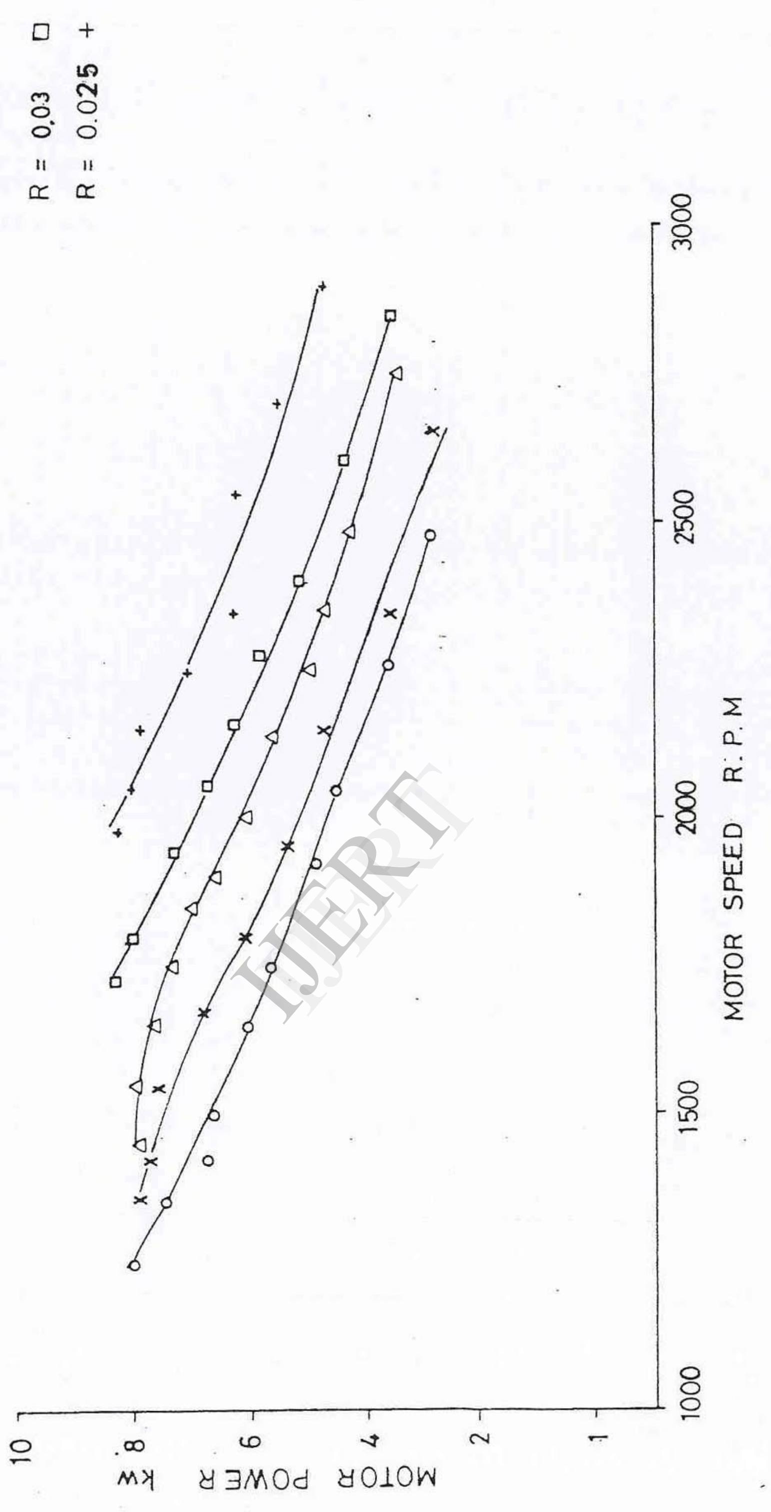


FIG. (6) VARIATION OF MOTOR POWER WITH MOTOR SPEED

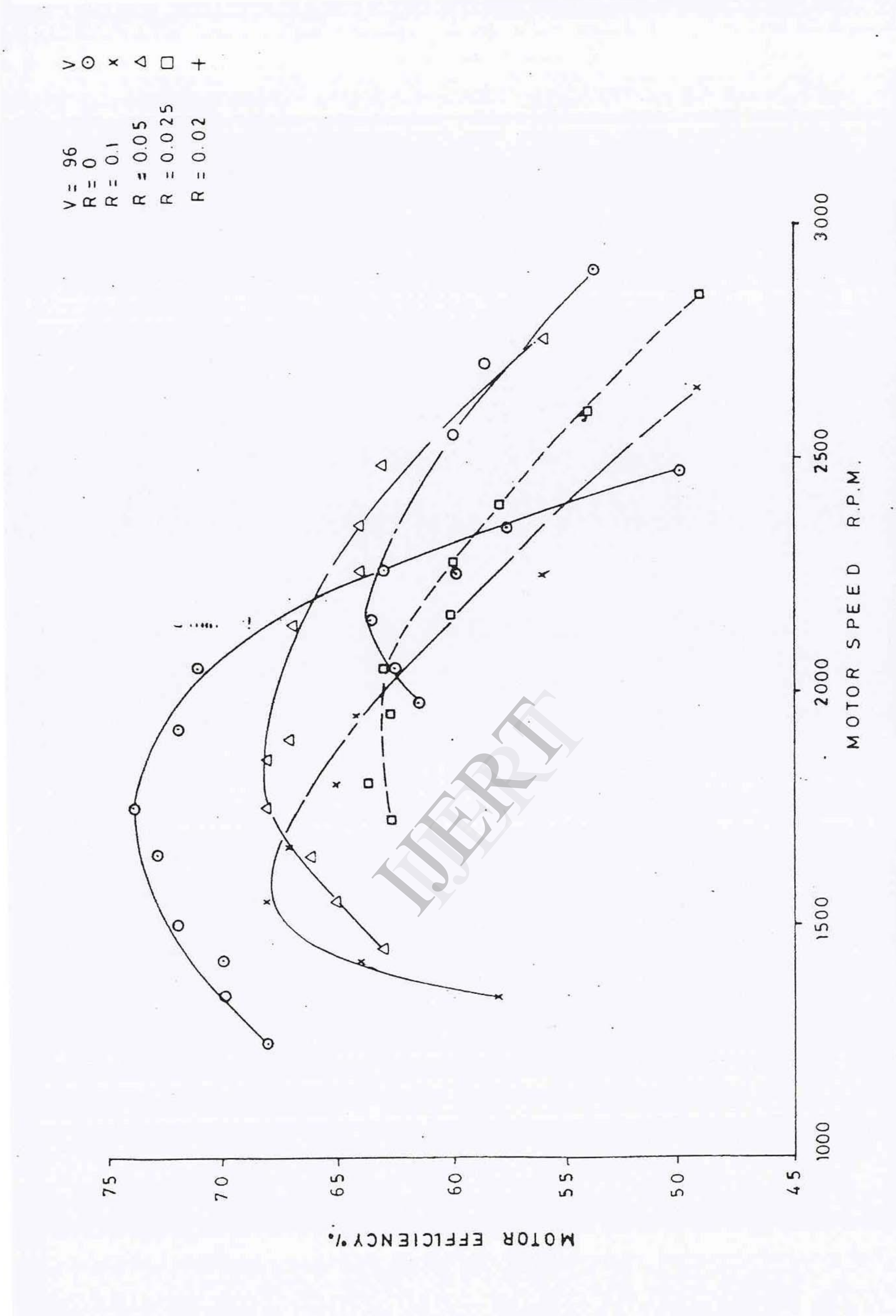


FIG.(7) VARIATION OF MOTOR EFFICIENCY WITH MOTOR SPEED.

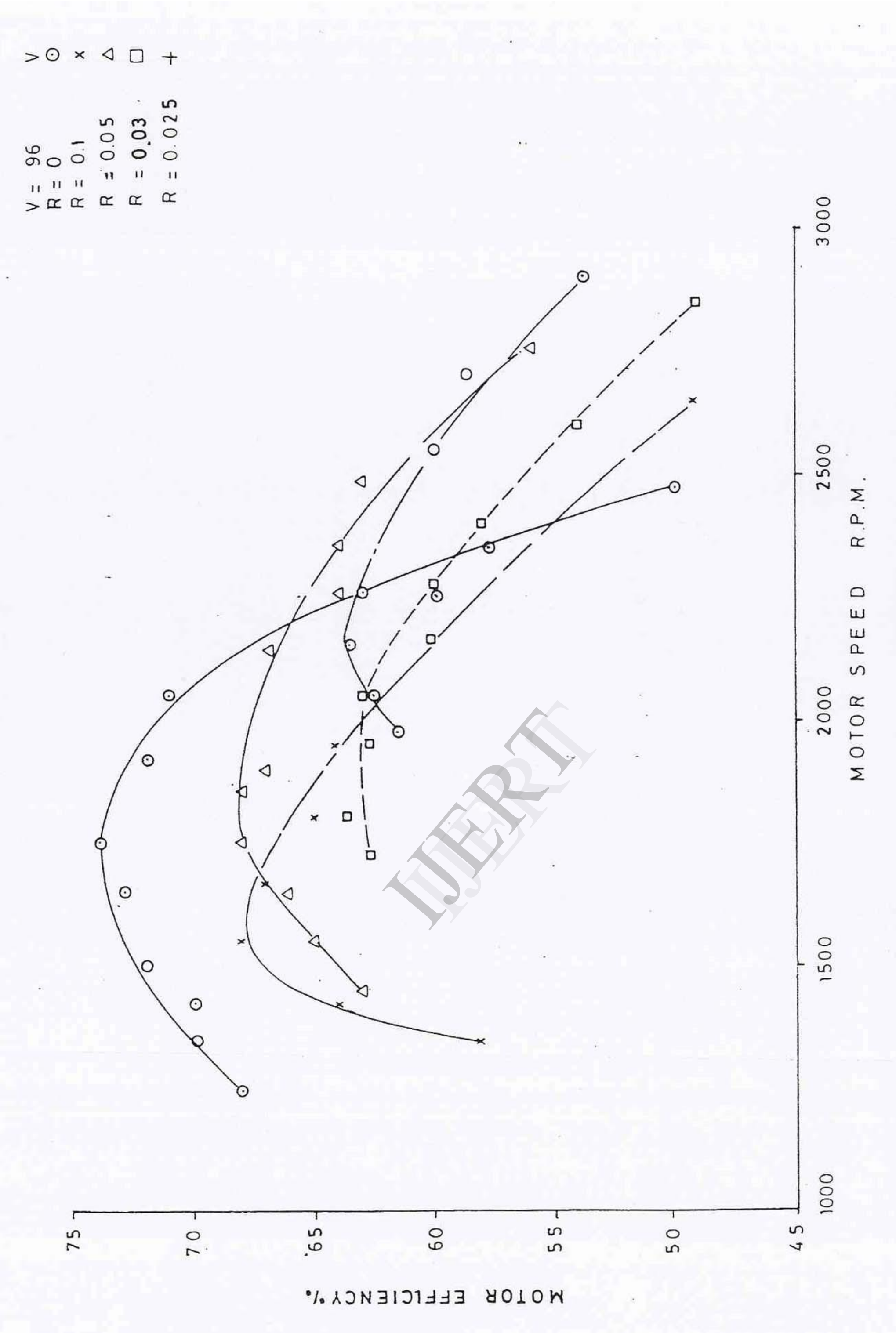


FIG. (8) VARIATION OF MOTOR EFFICIENCY WITH MOTOR SPEED.

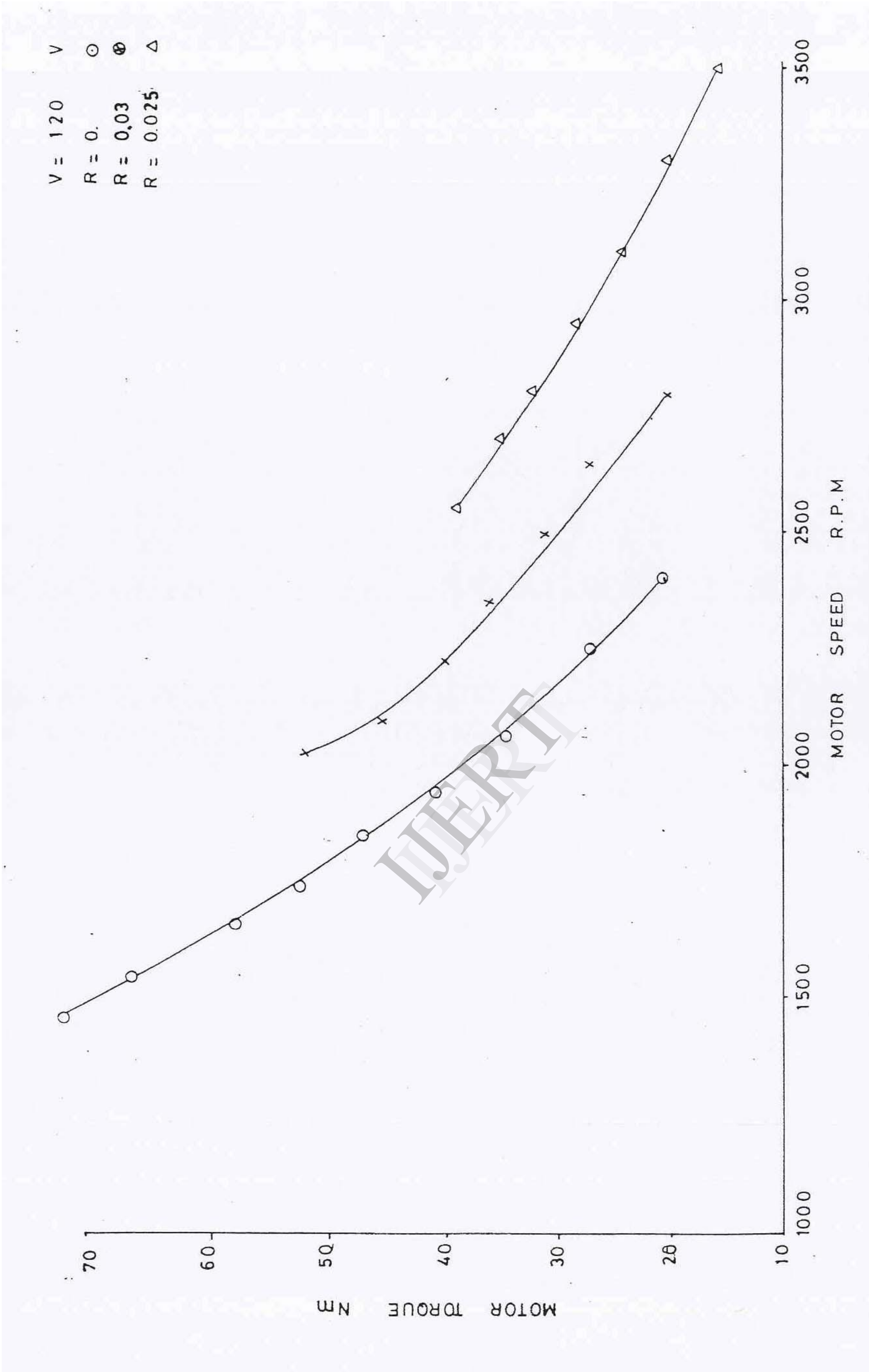


FIG. (9) VARIATION OF MOTOR TORQUE WITH MOTOR SPEED

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 2 Issue 8, August - 2013

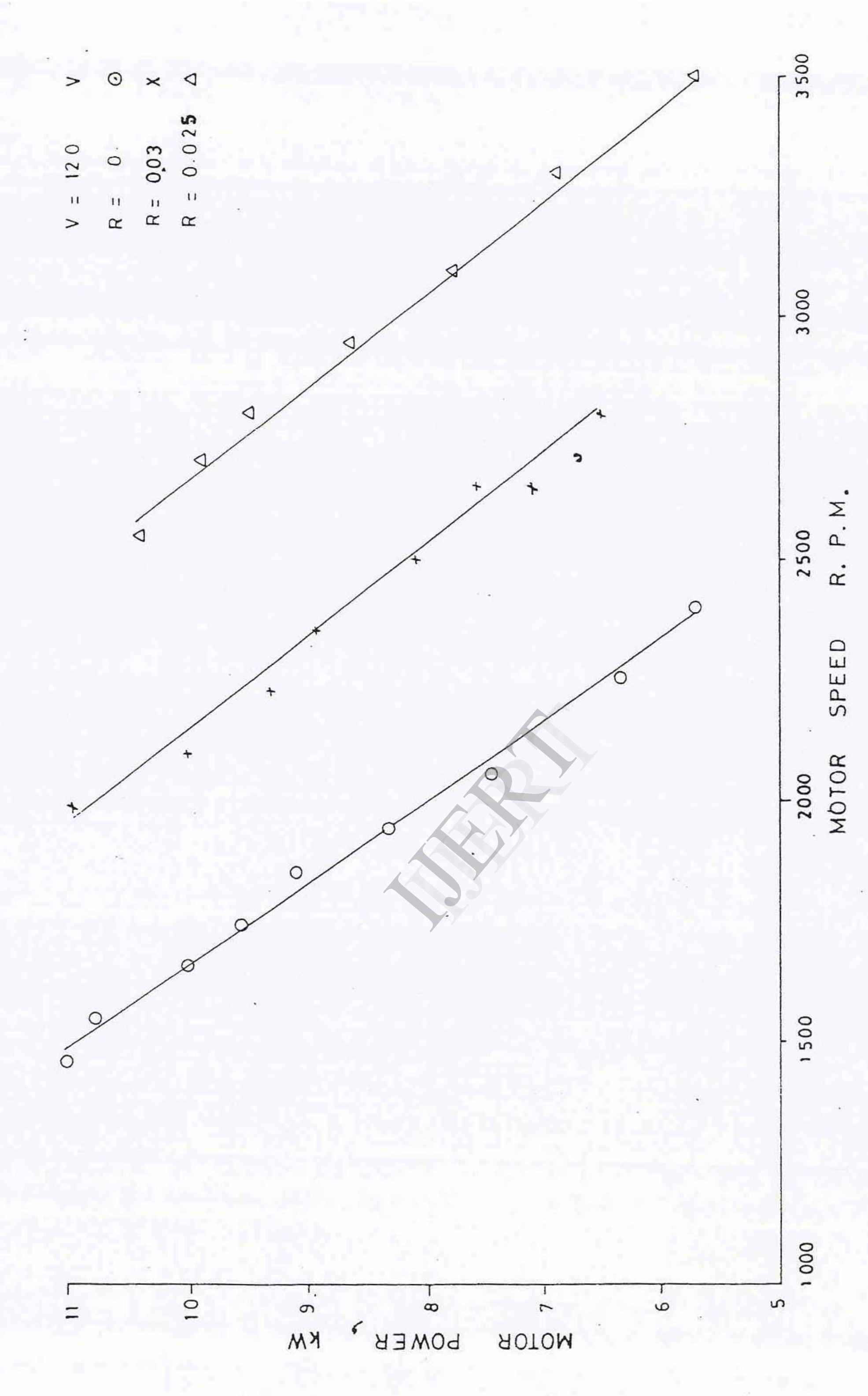


FIG. (10) VARIATION OF MOTOR POWER WITH MOTOR SPEED

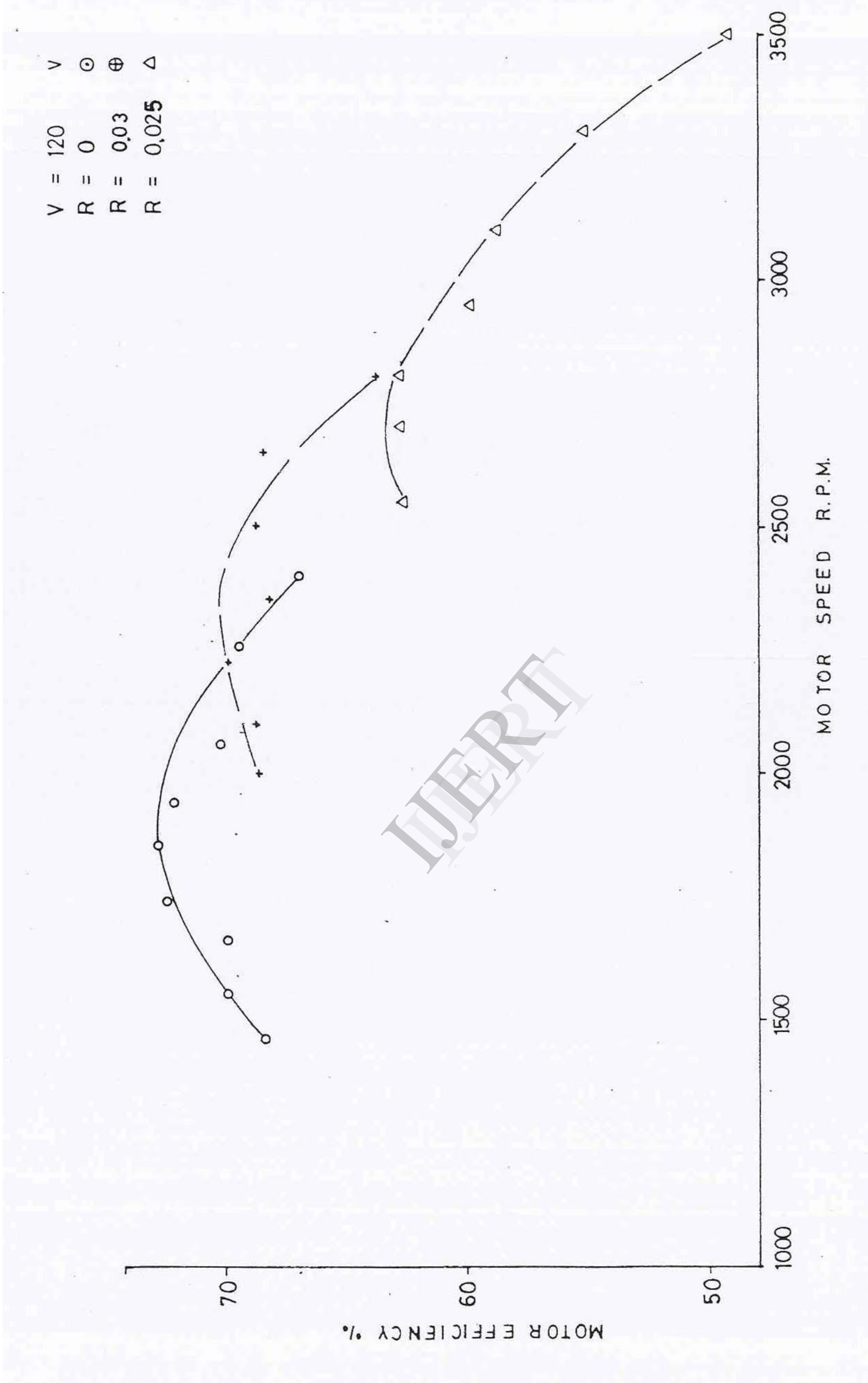


FIG. (11) VARIATION OF MOTOR EFFICIENCY WITH MOTOR SPEED.

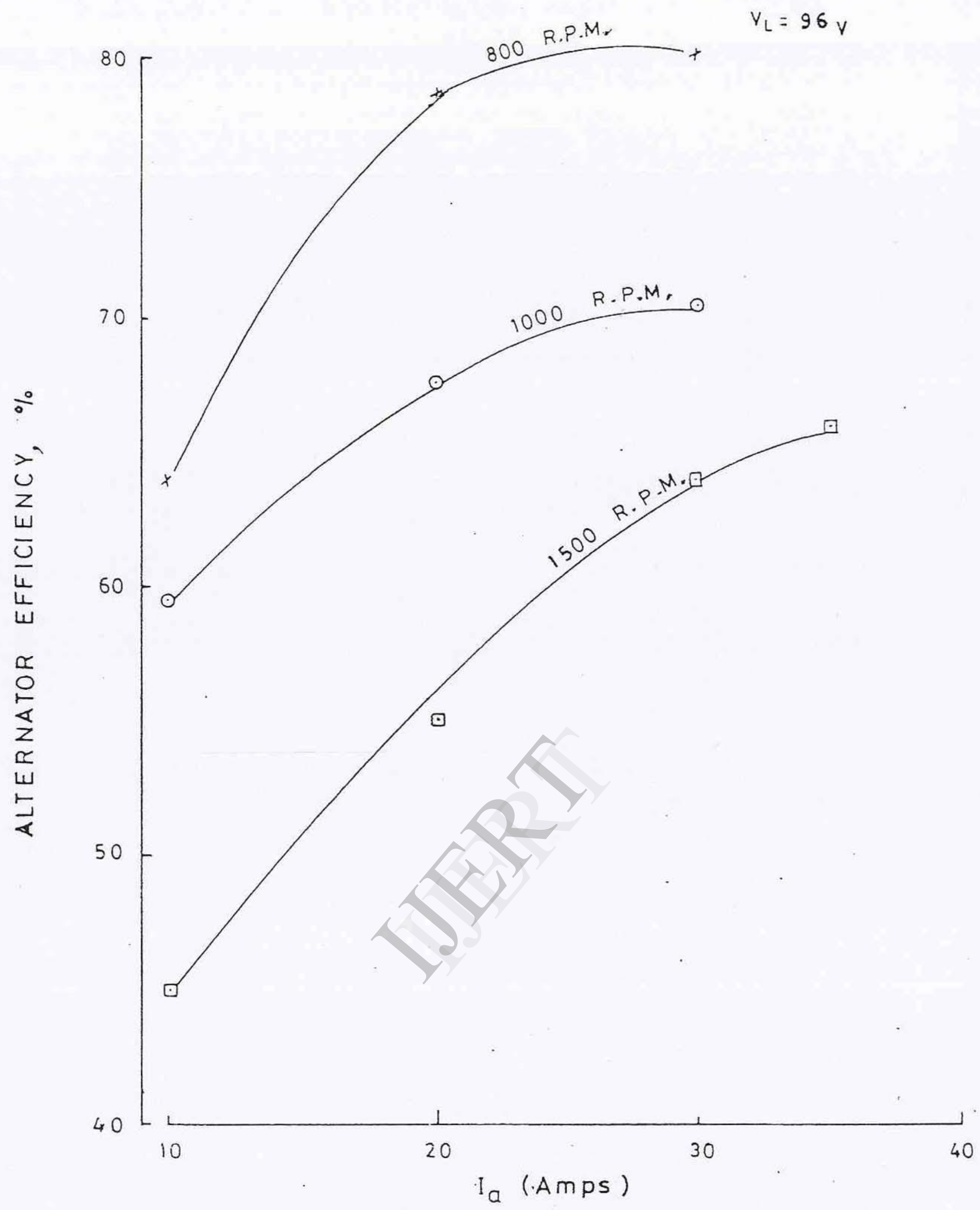


FIG. (12) VARIATION OF ALTERNATOR EFFICIENCY WITH CURRENT FOR DIFFERNT SPEEDS.

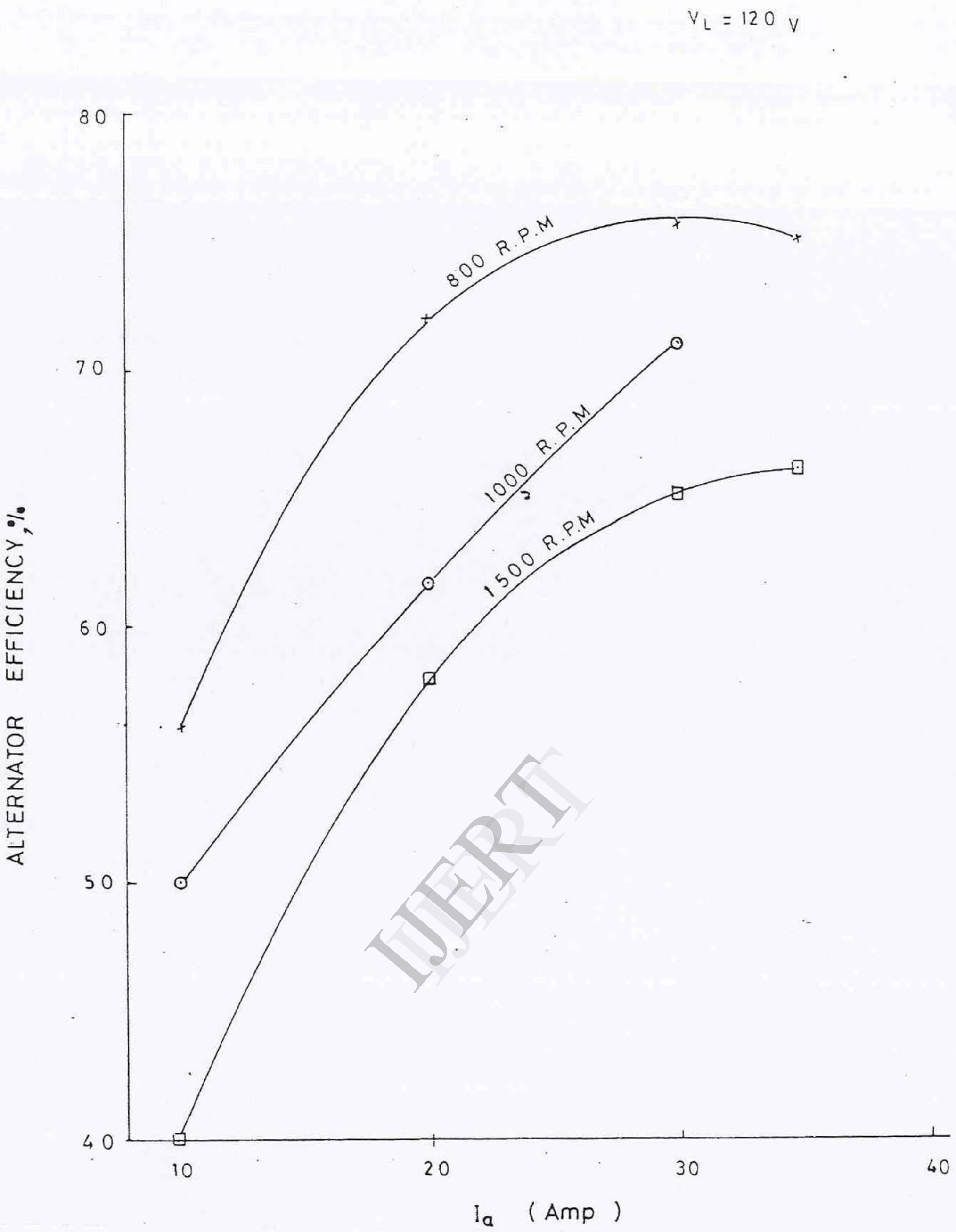


FIG. (13). VARIATION OF ALTERNATOR EFFICIENCY WITH CURRENT FOR DIFFERENT SPEEDS

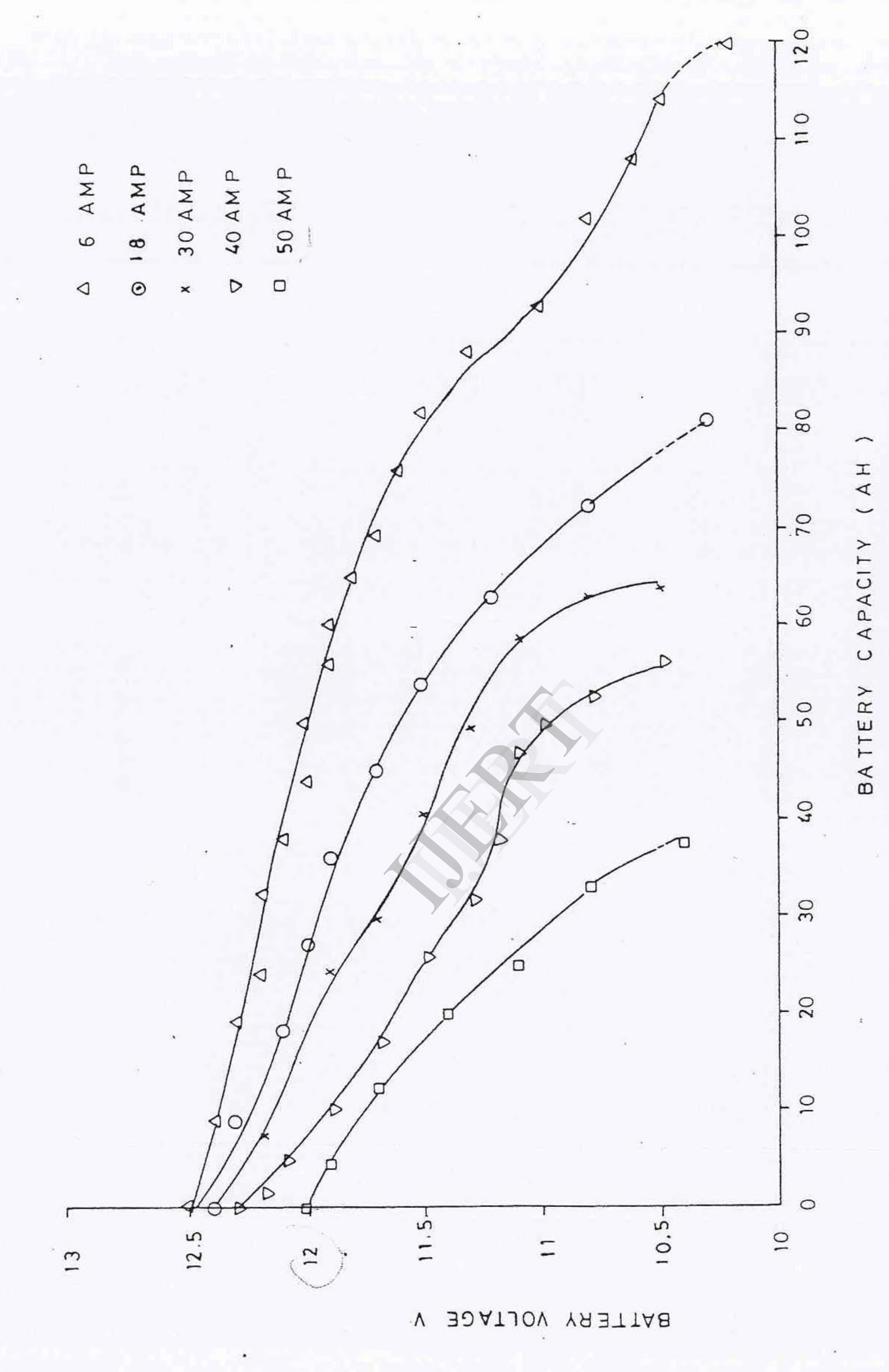


FIG. (14) VARIATION OF BATTERY VOLTAGE WITH BATTERY CAPACITY

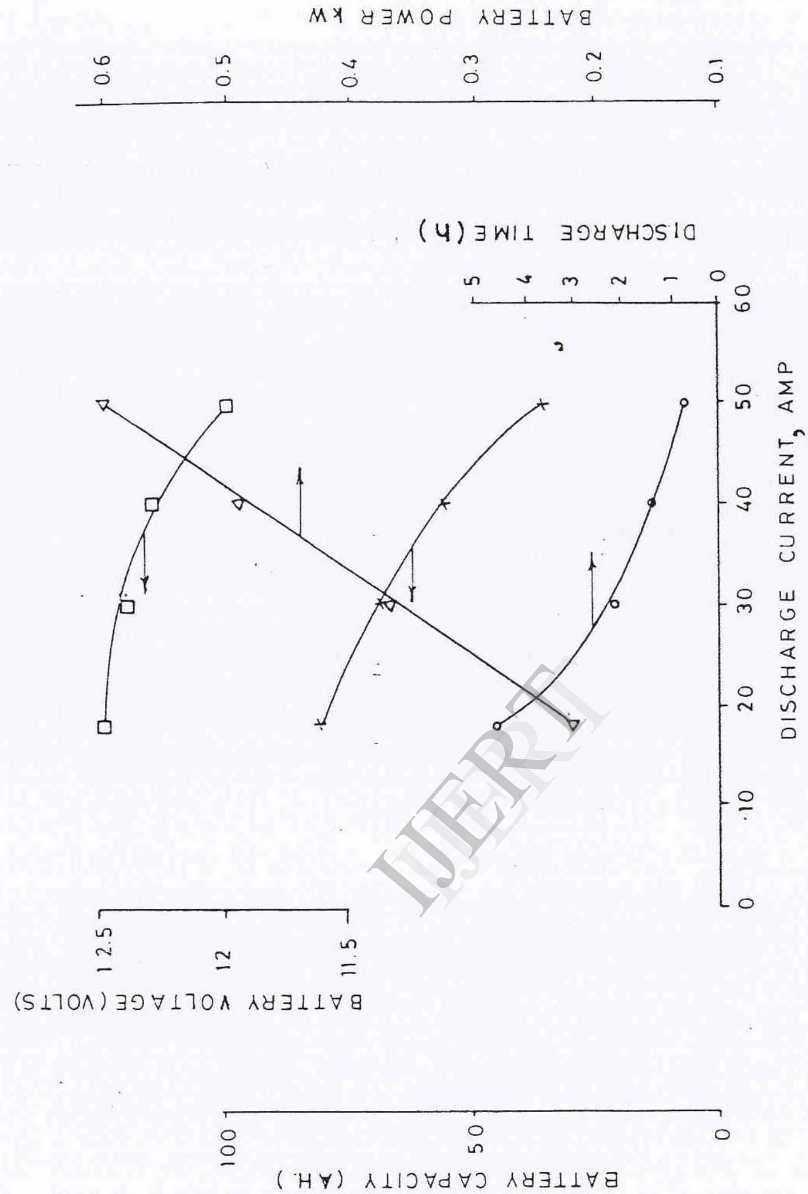


FIG. (15) VARIATION OF BATTERY VOLTAGE CAPACITY AND MEAN BATTERY POWER WITH DISCHARGE CURRENT.