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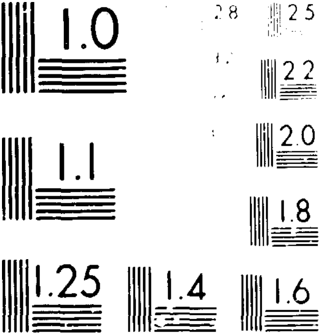

MICROCOPY RESOLUTION TEST CHART

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COMPUTER OPTIMIZATION OF HYDRO POWER STATION DESIGN AND RELIABILITY BY DYNAMIC SIMULATION*

by

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TABLE OF CONTENTS

1. INTRODUCTION

Mexico has an installed electric power generating capacity of nearly 22,000 MW. among them nearly 45% are hydro, 42% fossil fueled thermal and 3% Geothermal, gas turbines and diesels.

Due to its economic and population growth, the yearly increase of the electric power demand is in the order of 15%. Therefore, the growth in electric power supply is in the order of 3300 MW. To meet this demand Mexican engineers have to design and implement a large number of power station projects in a very short time.

Due to the large initial capital cost of hydro power stations as compared with thermal power stations or in the case of small hydro with gas turbines and diesels the need of a substantial cost reduction in the investment calls for sophisticated technologies in order to optimise, and speed up the design with enhanced reliability of Power Stations.

Towards this direction the IIE (Electric Power Research Institute) has developed computer software that enables the designer to analise and modify the system behaviour, to try alternatives to the basic design, and all this is done at a fraction of the time it would require a vast staff of engineers, and, with a lot more realistic picture of what will happen in the prototype installation.

2. PROGRAM DESCRIPTION

2.1 General

The computer program developed by the IIE was implemented in Pascal programming language. One of the main reasons to choose this language was its ability to create dynamic variables and thus stretch its memory allocation to the particular case is being currently analysed. Thus, the program has no restriction by itself on the number of pipes, water turbines, valves, surge tanks, etc., that can be analysed, the only restriction of size is thus due entirely to the hardware in which the program is run. The only software restriction is that can only be analysed water turbines with two different characteristics.

2.2 Mathematical Models

2.2.1 Pipes

Pipelines are considered elastic and their differential equations solved by the method of characteristics. However, when the transient is slow (i.e. the change in head or flow rate is slow) the program switches to rigid water column method in order to run faster and save computer time.

2.2.2 Water Turbines

The hydraullic QII vs Ku_1 and Mechanic Mu vs Ku_1 characteristics obtained from model test and scaled up to prototype dimensions are stored in the computer memory.

The head balance equation has to be solved together with the positive and negative characteristic of water hammer, and simultaneously with the swing equation of turbine-generator.

2.2.3 Surge tank

The program has models to simulate following types of surge tank:

a) Simple
b) Restricted orifice
c) Johnson differential
d) Expansion gallery differential
e) Closed type or accumulator

2.2.4 Inlet valves

The program has models to simulate almost all kinds of values found in hydro electric installations.

2.2.5 Other devices

The program can simulate the behaviour of the following surge control devices:

a) Relief valve
b) Air inlet valve

2.2.6 Governor:

The PID (proportional, integral and derivative) electro hydraulic governor is simulated with seven non linear differential equations. Dead times, saturation characteristics and non linearities are considered in the mathematical representation of the governor.

2.2.7 Generator and Voltage Control

The generator is simulated as a salient pole machine with transient and subtrainsient effects as well as saturation. The exciter or voltage regulator is modeled as IEEE type I static exciter.

2.2.8 Electric System

A small electric system represented by various kinds of load (including voltage dependent loads), electric motors and other generators tied to an infinite bus (in the case of non isolated systems) can be modeled to change the power flow in the hydro power station under consideration.

Thus, the simulation program model the three subsystems, namely, hydraulic, control, and generator network together in such a way that subsystem interaction can be seen and evaluated as a global hydropower station operational behaviour.

3. PROGRAM MODEL AND FIELD EXPERIENCE

No computer program can be regarded as a useful tool for design until its output has been compared with field experience. With this in mind, the program has been tested and its output compared with many existing power stations dynamic behaviour.

From this extensive testing, the validity of computer program output was confirmed to be realistic and accurate.

4. COMPUTER SIMULATION AND DESIGN OPTIMISATION

4.1 Pressure Rise vs Overspeed

It is well known that most of the cost of the civil work and mechanical design depends upon the impact of the transient behaviour on these structures, i.e. water hammer and thus overpressure define the design pressure of penstock and water turbine. On the other hand the fly wheel effect required by the unit is in inverse relation with the water hammer overpressure. Thus, these two conflicting parameters are best evaluated and modified by using computer simulation. In certain cases, the designer may seek in non- conventional closing modes in order to obtain an optimised water hammer and overspeed phenomena.

4.2 Surge Tank Design

The most important consideration in the surge tank design is its adoption. In many cases it has been proved that proper transient phenomena design by value stroking and/or location of the power house can entirely delete the requirement of the surge tank.

Second, there are many types of surge tanks ranging from simple to sophisticated differential. In many cases what seems to be cheap can be very expensive. i.e. the required tank diameter for stability can be too large in comparison with the differential. On the other hand, what seems to be a good design for large transients it is not for small ones. The experience shows that the energy dissipation for small load variations in the surge tank can be very small and thus there is almost no damping of the oscillation, the governor hunts and the complete hydro electric power station becomes unstable. It cannot be operated at all.

Sometimes the designer fear of a bad design lead him to adopt large safety factors, this translates of course in a very expensive design.

4.3 Control Design (Governor)

Due to unfavourable conditions that appear when the hydro power station is isolated from a large grid and/or when there exist a large local load which can be switched in a short time, frequency regulation and governor stability studies should be made for the sake of plant reliability. These studies will lead to the proper selection of flywheel effect, surge tank design and governor settings, that are all interrelated.

Besides the use of the program as a design tool, it can be very valuable during the commissioning of the power station since optimum control settings can be obtained before even the power station is constructed, thus saving time and money.

4.4 Generator, AVR, Transmission Line Design

The computer program scope is not limited to the hydraulic and governor system, but to the electric transient and dynamic stability can be simulated with great detail. Thus, the program is also useful in the design of transmission lines, short circuit analysis and so on.

5. CONCLUSION

A sophisticated computer simulation program of hydro power station dynamic behaviour was explained here.

Computer simulation allow the designer to evaluate the behaviour of thousands of alternatives and to select the one that is optimum.

Computer simulation with accurate and reliable models can lead to considerable savings by reduction of the labour cost of engineering design and the possibility to decrease the safety factor involved in the design due to the reduction of uncertainty on the behaviour of the variable involved.

6. COMPUTER OUTPUT EXAMPLES

To illustrate the output obtained by the computer program, several case studies of Bacurato P/S which is under design stage in Mexico are included.

Bacurato P/S has the following characteristics:

1. Civil

   a) low pressure concrete tunnel

      diamter 5.25 m
      length 1630 m

   b) Surge Tank
      Johnson differential

      tank diameter 18 m
      riser diameter 4.0 m

   c) Penstock

      diameter 4.6 m
      length 228.9 m

   d) manifold branch with two butterfly valves

2. Water Turbines (2 units)

Vertical Francis

Speed	276.9 rpm
Design Head	102.0 m
Flow rate	52.12 cms
Power output	48500 kw

3. Governor

PID type electro hydraulic

4. Generator

GD^2	1345 Ton-m^2
KVA	48500
p.t	0.95
voltage	13.8 KV
static exciter type I IEEE	

First example shows total load rejection condition of two units, (plates I and II).

Servo motor stroke, spiral casing water hammer overpressure, draft tube head are shown on plate I.

Overspeed, generator and turbine torque and flow rate are shown on plate II.

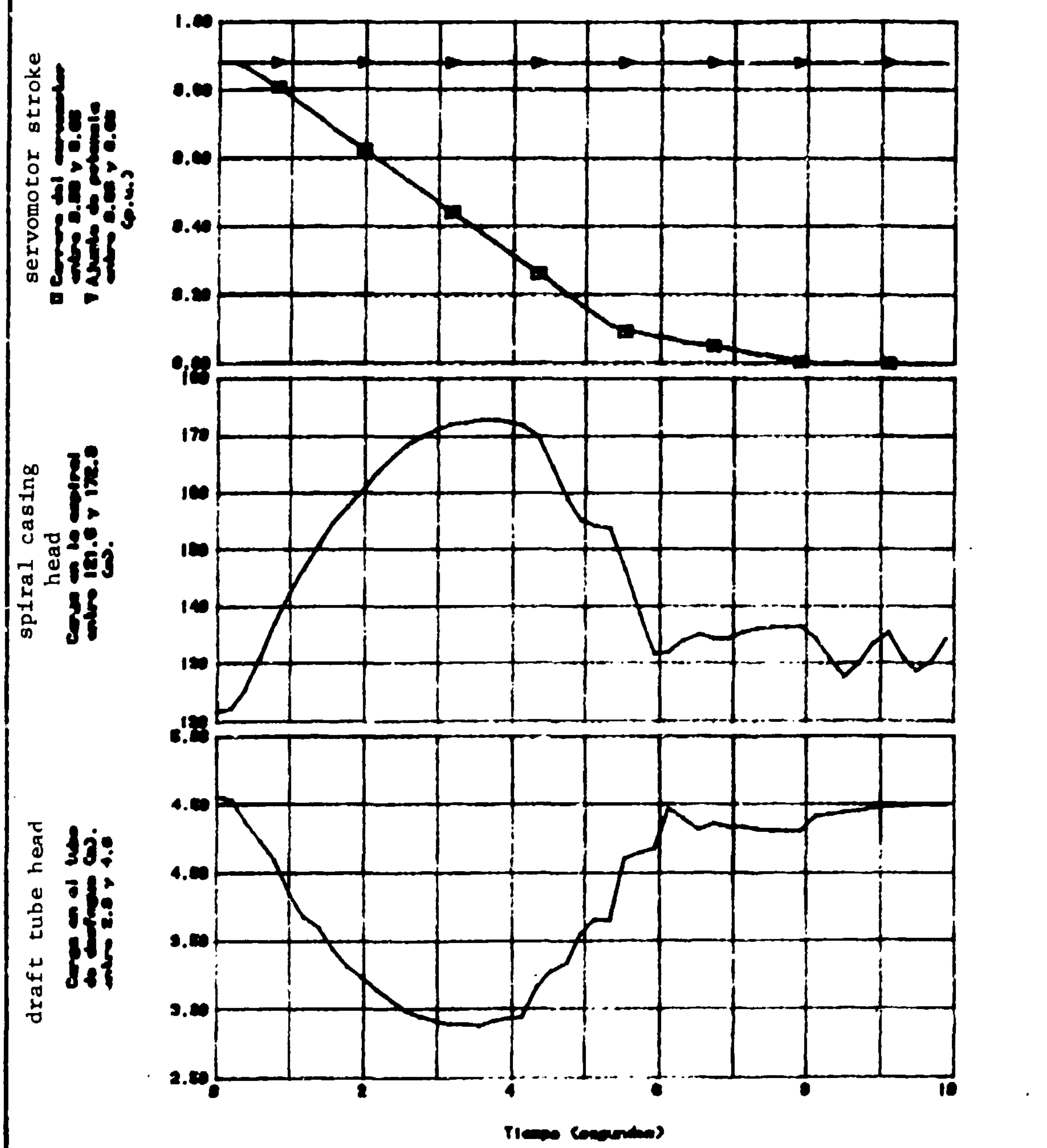
Plate III shows the water hammer phenomena along the penstock at six different locations.

Plates IV and V shows the subsequent pendulation of the surge tank for 300 sec. Plate IV shows the variation of water level in riser and main tank while plate V shows the flow rate in riser and main tank.

Second example shows a simulation of several variations in load in order to obtain the minimum possible surge in the surge tank. To accomplish this first we reject load slowly from full load to 'floating' no load condition. We keep the machines in this condition until the down surge produces a negative flow rate in the long low pressure tunnel when this negative flow rate is maximum and thus the inertia of the water is maximum too. We schedule a fast load demand. therefore, the surge tank faces the most unfavourable condition. As can be seen in plates VI to VIII the turbines reach the final power demand quickly and stably. In fact these simulations helped to decide upon the adoption of Johnson differential instead of restricted orifice. While the former requires 18 m diameter the latter required 25 m.

Third example shows a frequency regulation simulation. Here a step electric system rejection produces a frequency increase of 0.5 HZ. Plates show generator torque and turbine torque and generator angular speed and power angle.

Plate I



+++ Planta Hidroeléctrica BACURATO +++	
—— Rechazo total de carga a NAMOP 2 unid. ——	
Corrida : BACUR-163	Turbina No. 1
Fecha : 25-OCT-1982	Hoja No. 1

Plate II

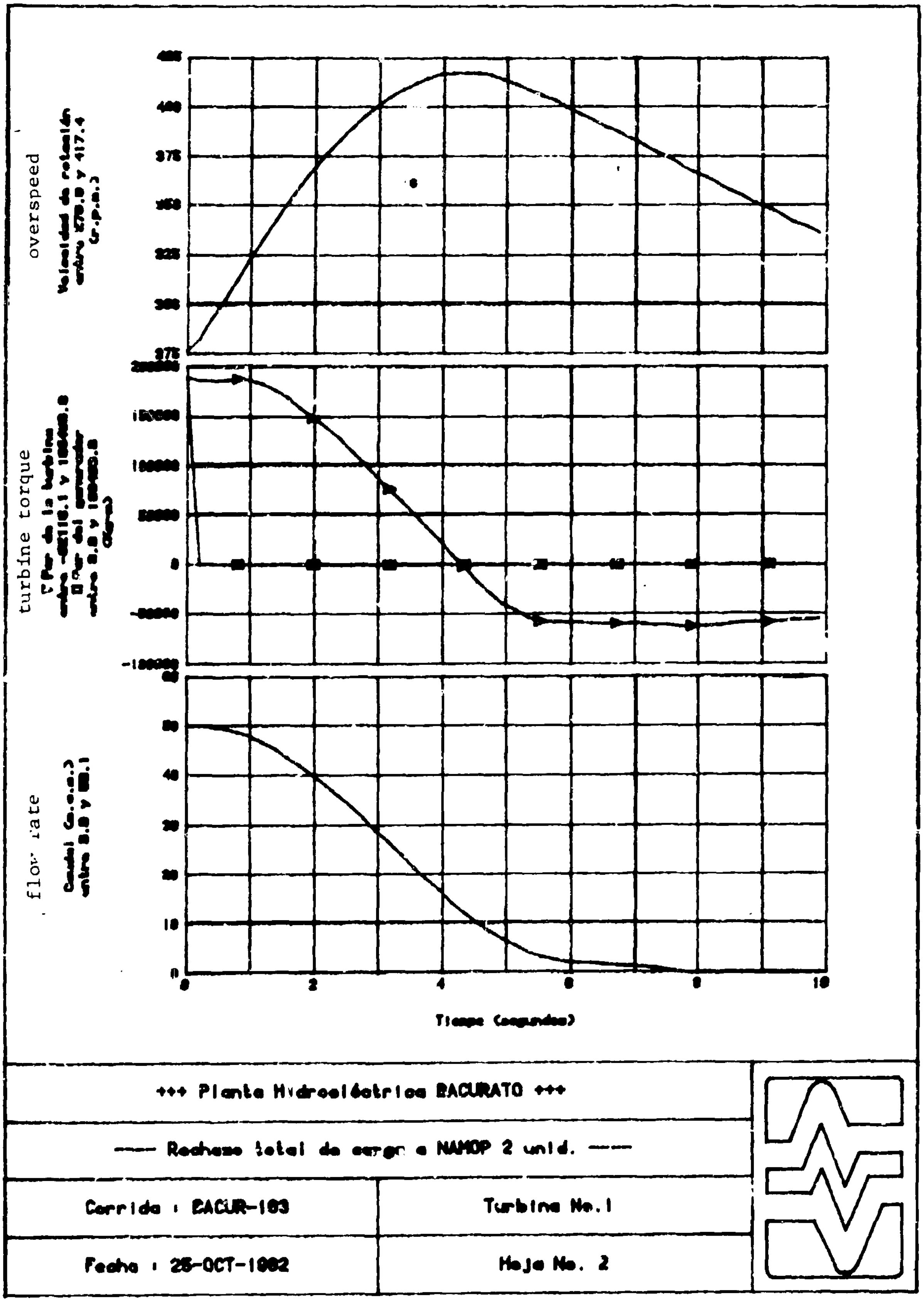
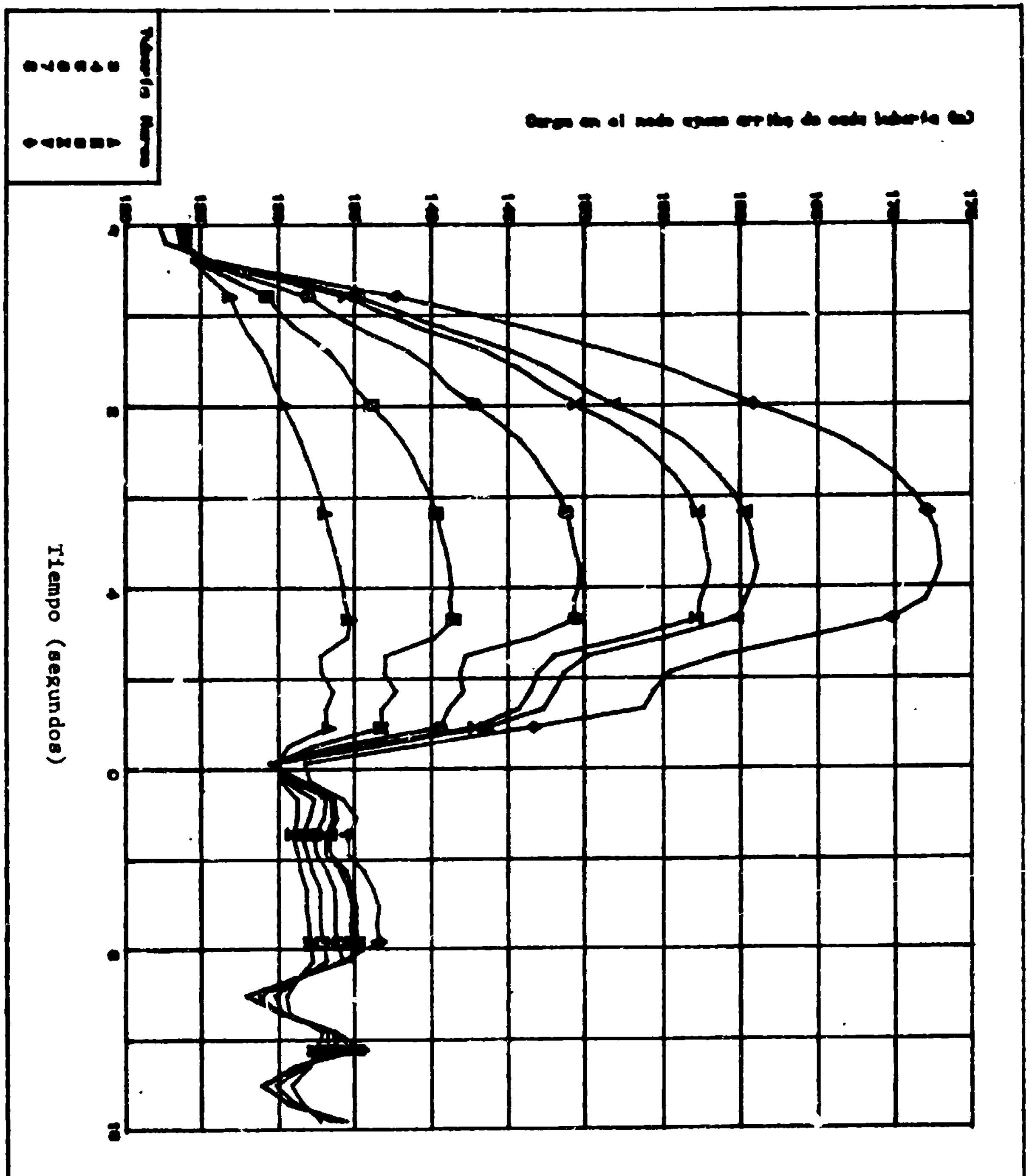

overspeed
turbine torque
flow rate
Tiempo (segundos)
0
2
4
6
8
10
+++ Planta Hidroeléctrica BACURATO +++
---- Rechazo total de carga a NAMOP 2 unid. ----
Corrida : BACUR-103
Turbina No.1
Fecha : 25-OCT-1982
Hoja No. 2

Plate III

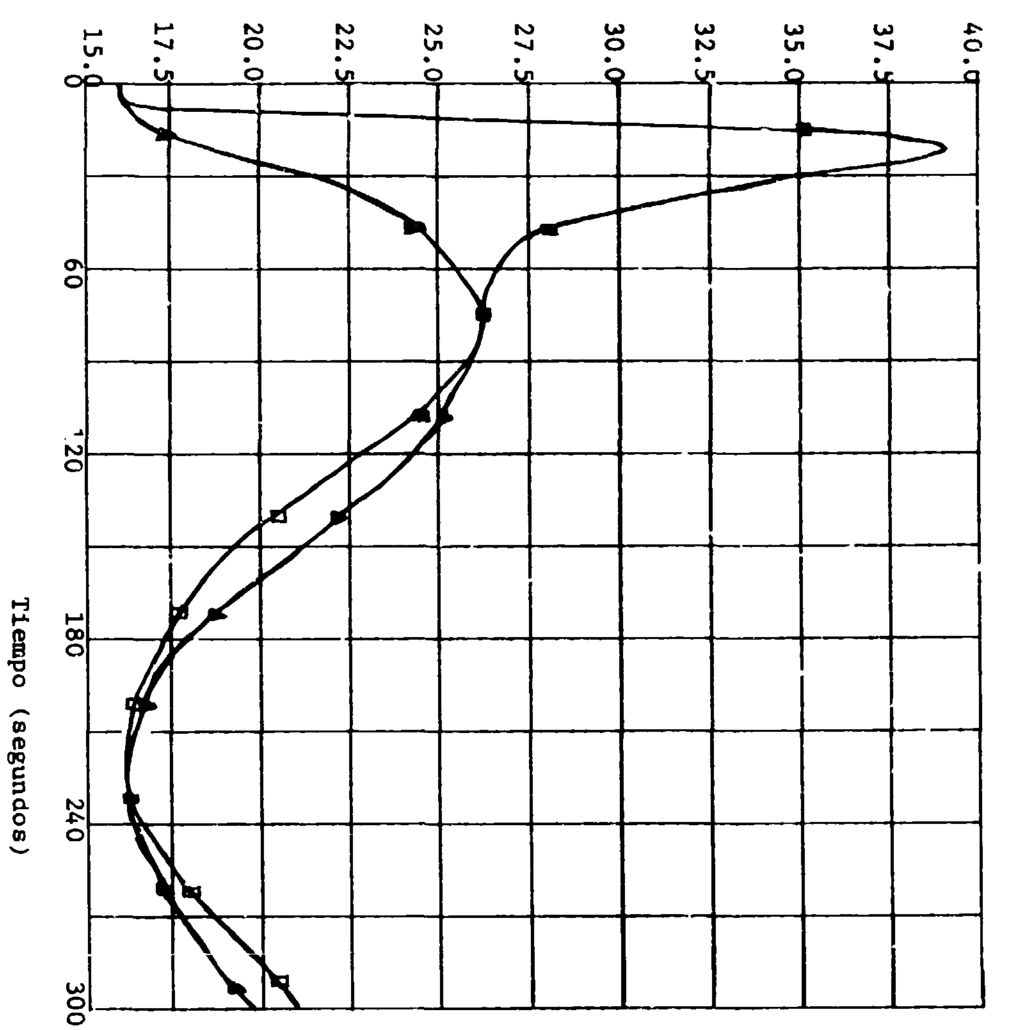


+++ Planta Hidroeléctrica BACURATO +++

—— Rechazo total de carga a NAMOP 2 unid. ——

Corrida : BACUR-163	Tuberías
Fecha : 25-OCT-1982	Hoja No. 4A

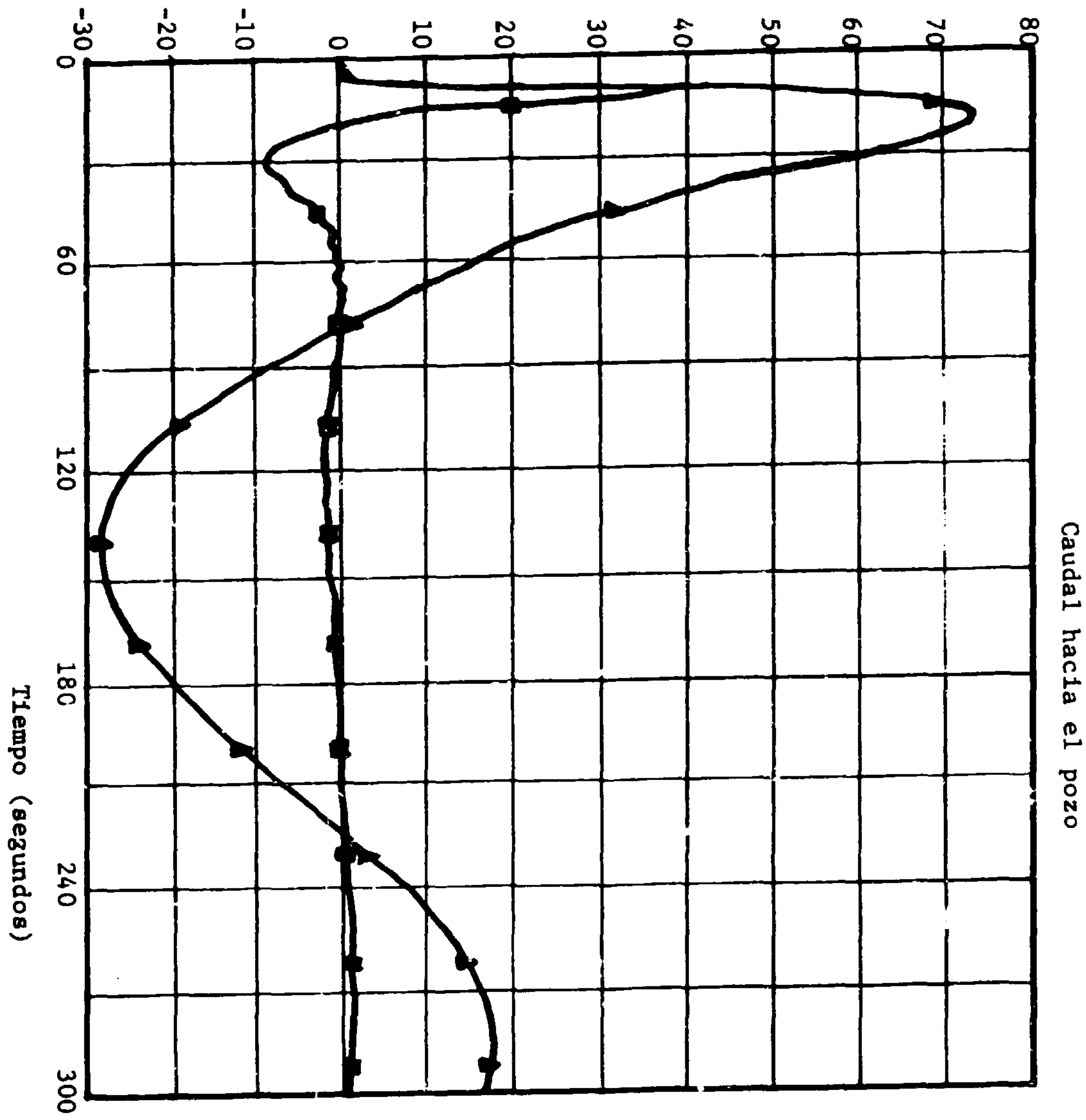
Plate IV water level



+++ Planta Hidroeléctrica BACURATO +++	
Rechazo de Carga Pozo Johnson Namino = 213.5	
Corrida : BACUR-213	Pozo No.1
Fecha : 15-DIC-1982	

Plate V

flow rate



+++ Planta Hidroeléctrico BACURATO +++
Rechazo de Carga Pozo Johnson Namino = 213.5
Corrida : BACUR-213 Pozo No.1
Fecha : 15-DIC-1982

Plate VI

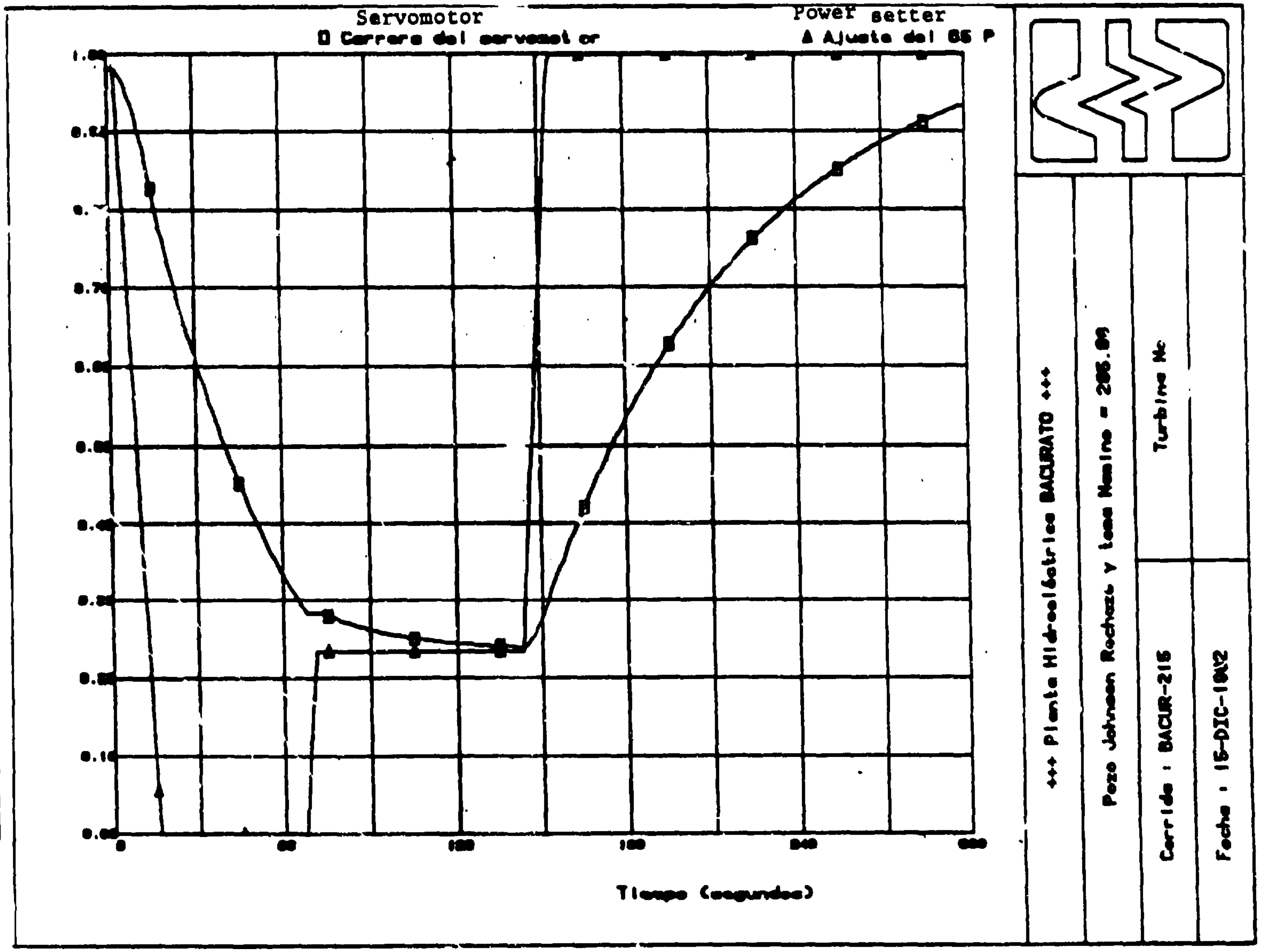
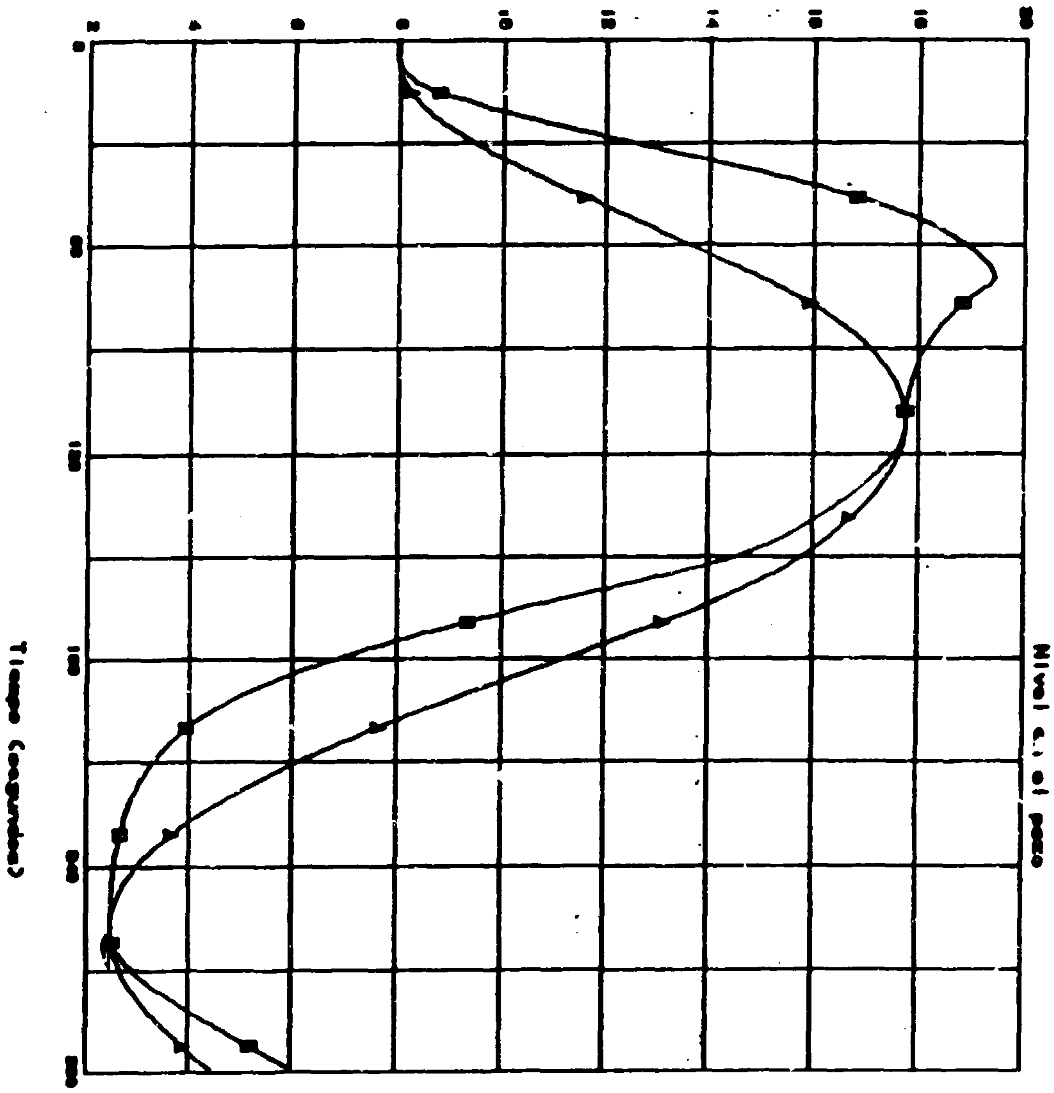
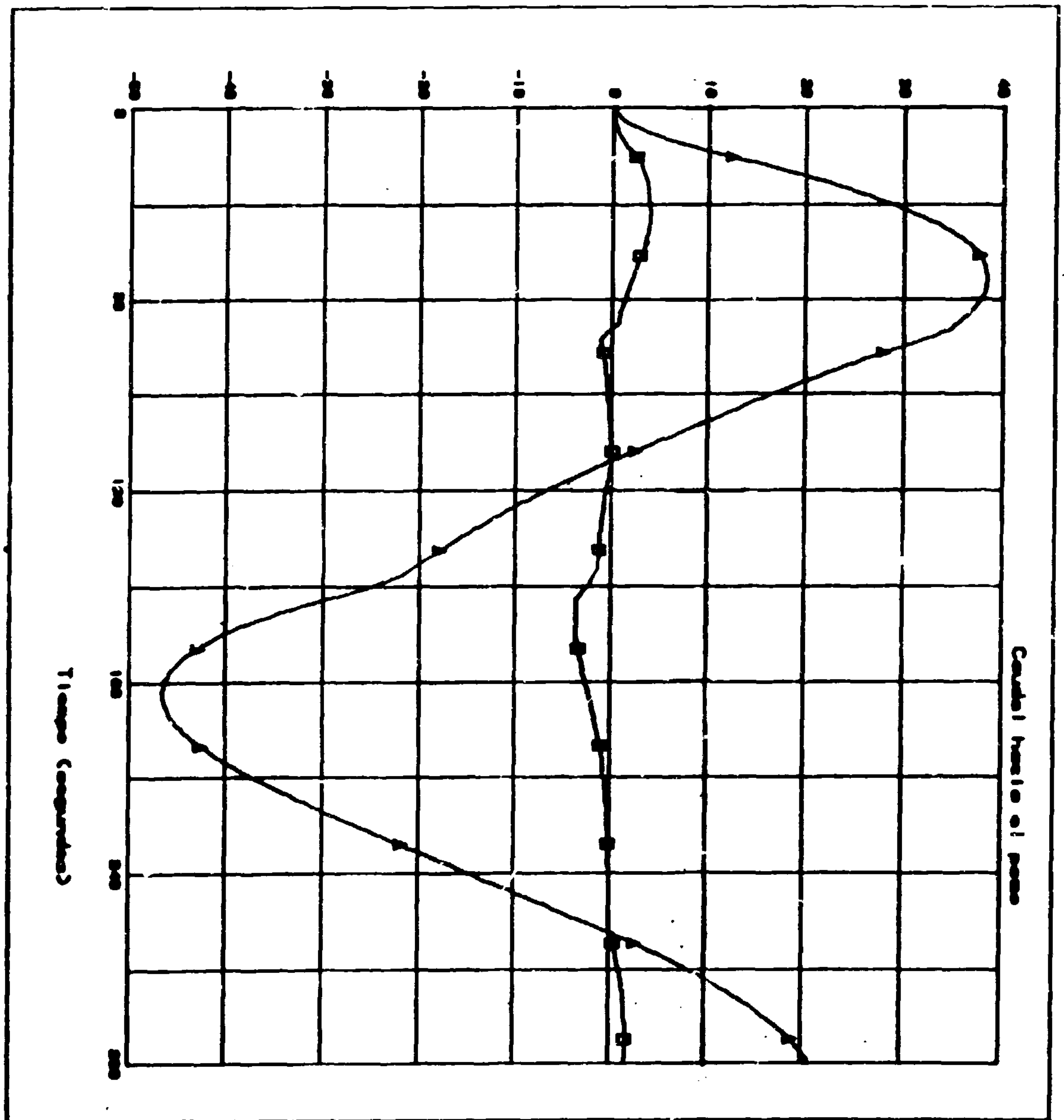

Servomotor
Power setter
Tiempo (segundos)
+++ Planta Hidroeléctrica BACURATO +++
Turbine No
Corrida : BACUR-215

Plate VII

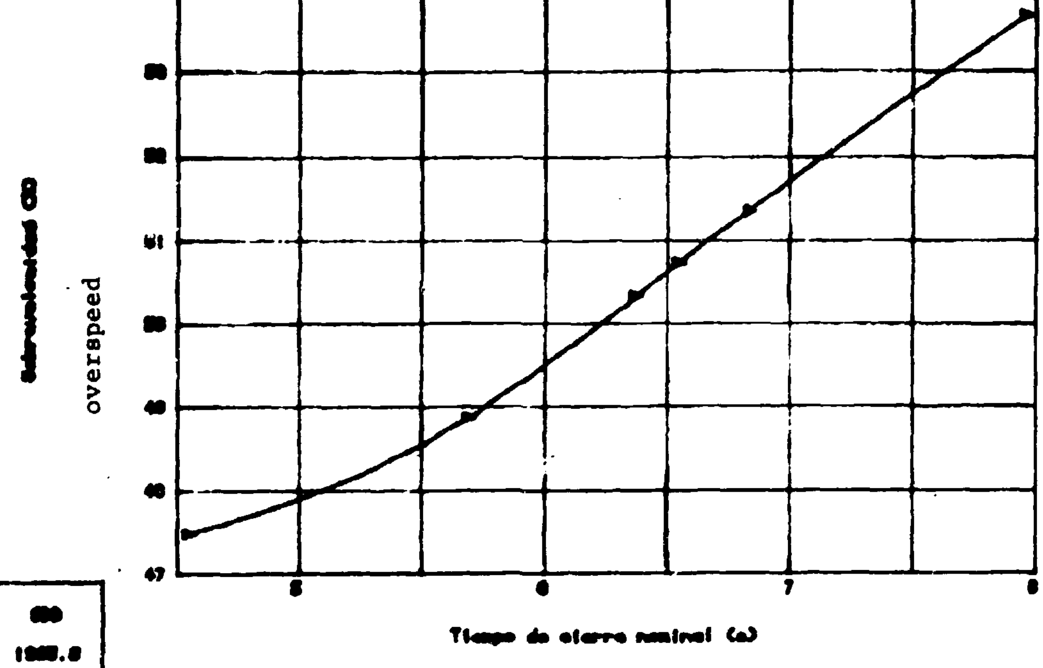


+++ Planta Hidroeléctrica BACURATO +++	
Pozo Johnson Rechazo y toma Máxima = 285.00	
Corrida : BACUR-215	Pozo No.
Fecha : 15-DIC-1982	

Plate VIII



+++ Planta Hidroeléctrica BACURATO +++	
Pozo Johnson Rechazo y toma Nomina = 285.00	
Corrida : BACUR-215	Pozo No.1
Fecha : 15-DIC-1982	



-+-+ Planta Hidroeléctrica < BACURATO > +-+-	
Pruebas de sobrevelocidad y sobrepresión	
N.A.M.Op.	n = 278.98 rpm
Fecha : 26-OCT-1982	Ho = 121.92 m

Plate IX Summary of total load rejection simulations

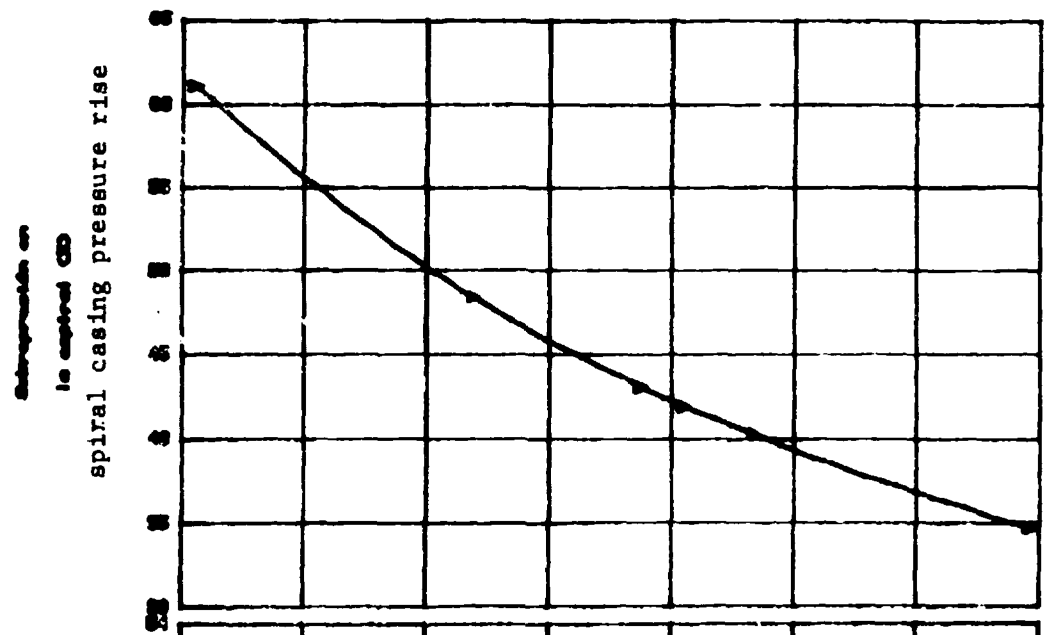
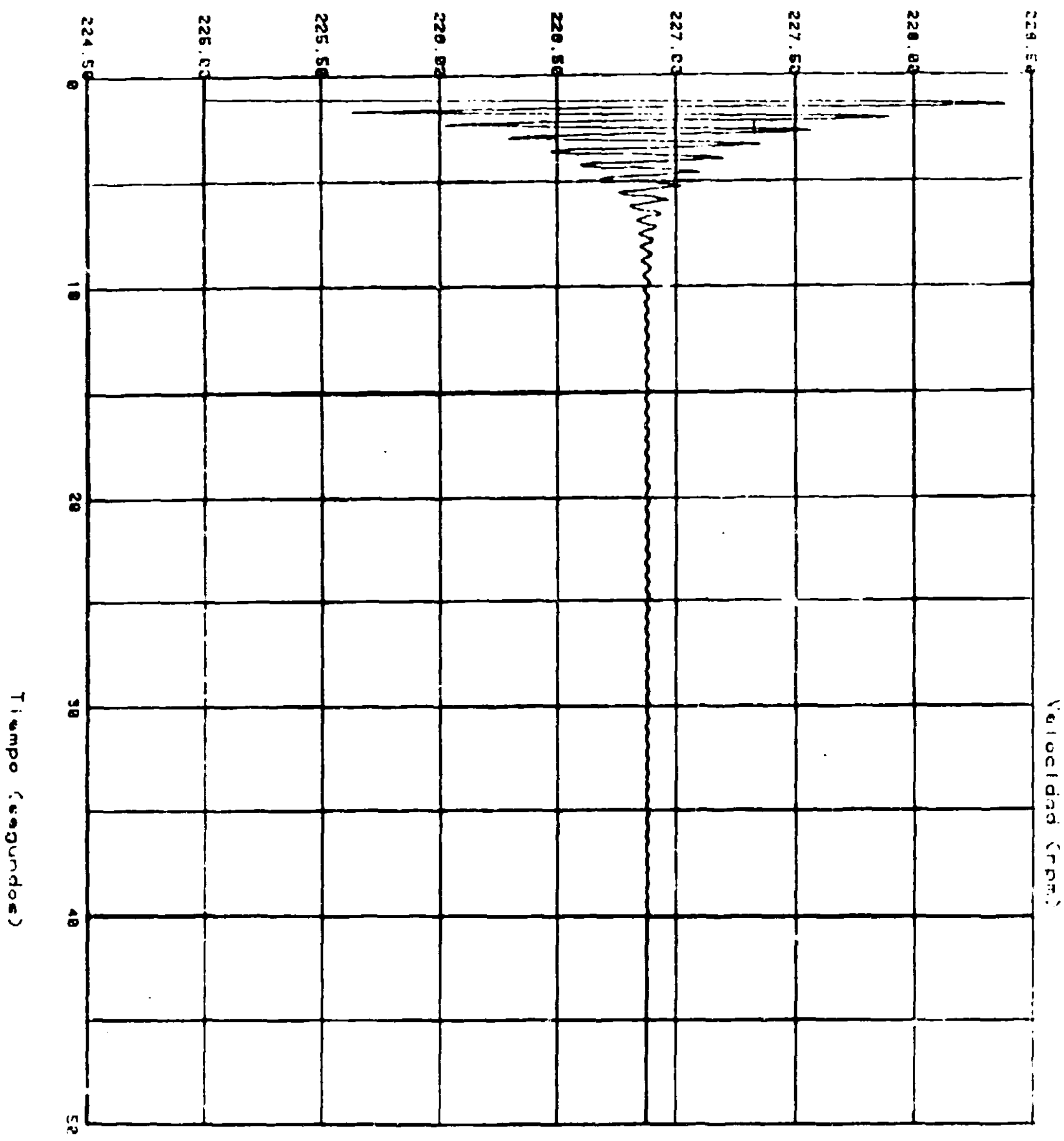
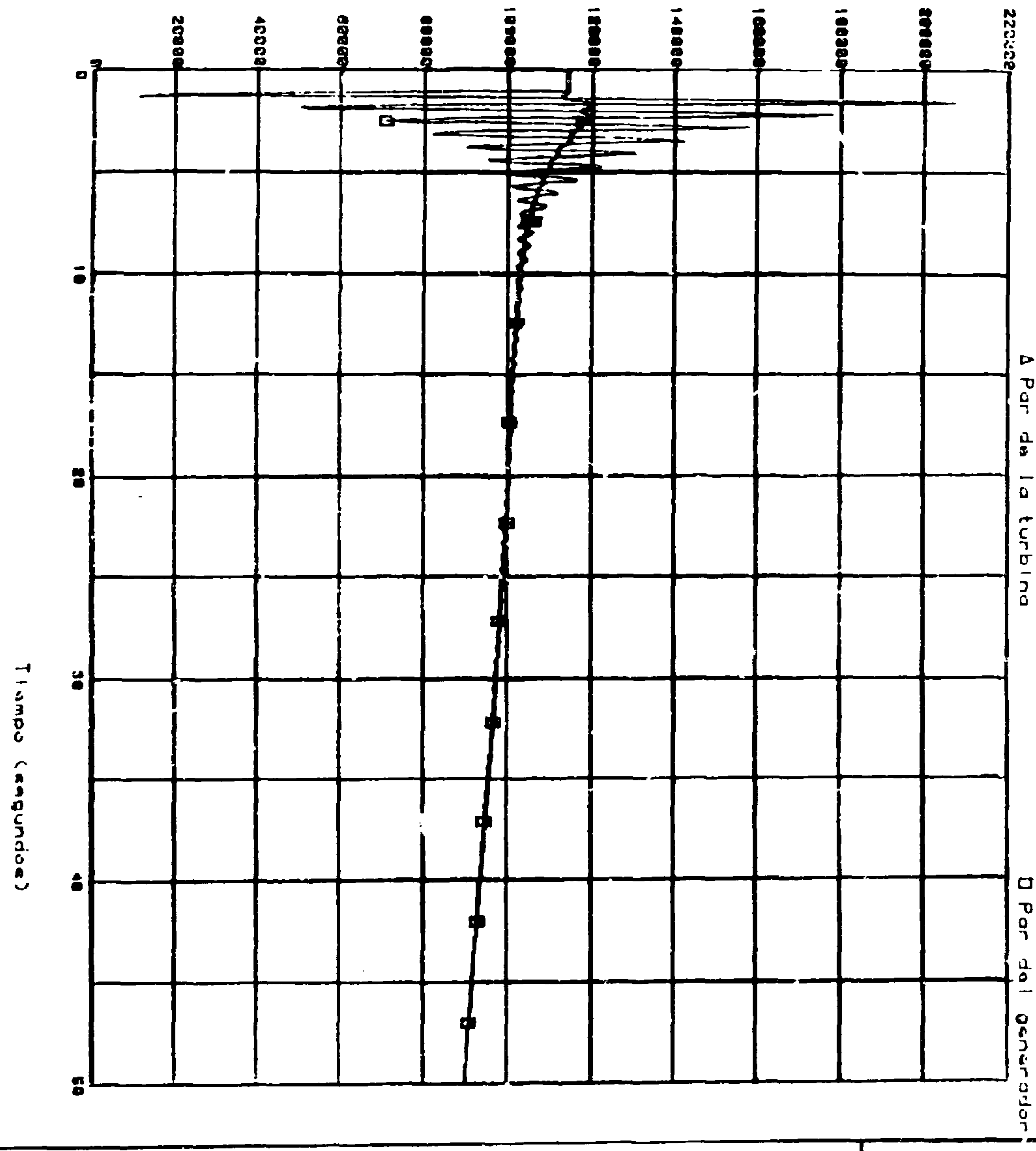


Plate X



Varacion de frecuencia del sistema de 60 a 60.5 Hz f_1 f_0	
Corrida : GENER-012	Turbina No.1
Fecha : 26-OCT-1982	

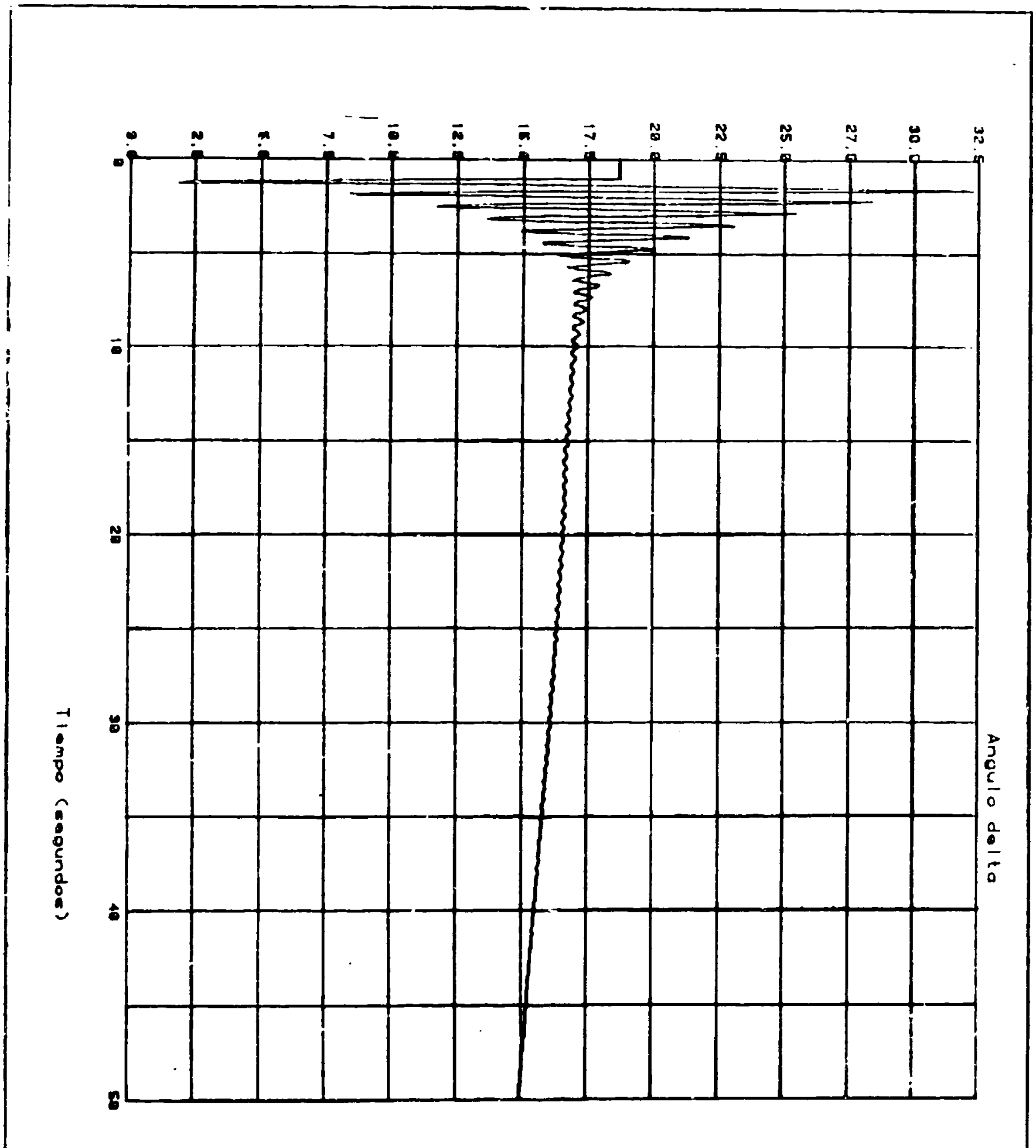
Plate XI



Variacion de frecuencia del sistema de 60 a 60.5 Hz

Corrida : GENER-012	Turbina No. 1
Fecha : 26-OCT-1982	

Plate XII



Varacion de frecuencia del sistema de 60 a 60.5 Hz

Corrida : GENER-012	Generador No.1
Fecha : 26-OCT-1982