X International Meeting on Reduced Enrichment for Research and Test Reactors, Buenos Aires, September 1987

PERFORMANCE OF A DIGITAL REACTIVITY-METER (009-NC/1-IPEN) IN INITIAL TEST PROGRAMS FOR RESEARCH AND POWER REACTOR

by

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ABSTRACT

This paper describes the digital reactivity-meter (009-NC/1-IPEN) built at the IPEN/CNEN-SP for the start-up tests of Angra-I power station. It is also being used in the IEA-R1 research reactor for evaluating control rod worth and the various reactivity coefficients. The equipament is composed of two main parts: an electronic module with 12 bit A/D and D/A interfaces, an picoamperimeter and several microprocessors; and the micro-computer in which is solved the inverse kinetics equation to obtain the reactivity as a function of time. The results obtained demonstrate the accuracy and the practicability of the reactivity meter.

1. INTRODUCTION

Reactivity is a fundamental physical variable for safe operation of Nuclear Reactor. At each new start-up or refueling of Nuclear reactors it is necessary to measure several reactivity parameters such as Critical Boron Concentration, Control Rod Worth, Temperature Coefficients, etc,as part of a Initial Test Programs usually demanded by the license authority [1].

There are several techniques for reactivity measurements [2,3] most which requiring sophisticate equipments, and theoretical bases which demands long time for analysis. For practical, or routine, measurements the best technique involves the solution of the inverse kinetics equation allowing reactivity results in real time. In this technique a signal from out of core instrumentation is used to feed a reactivity computer, which solves the inverse kinetic equation [4]. In the past, the solution of inverse kinetics equation was carried out in an analogue computer. However, with the recent development of digital microcomputers, the solution, of the inverse kinetic equation can be obtained in real time.

In this paper, a digital reactivity-meter developed by the Reactor Technology Department of IPEN-CNEN-SP is described, as well as the results of a test of performance made at the Brazilian Nuclear Power Station, Angra I.

2. REACTIVITY-METER (DESCRIPTION)

The reactivity-meter (009-NC/1-IPEN) is composed of an interface A/D of 12 bits which conects the signals from the out of core instrumentation to a digital microcomputer. In Figure 1 is illustrated a schematic operation of the reactivity-meter. This electronics module is composed by:

i) picoamperimeter of automatic scale;
ii) 12 bit A/D converter;

iii) multiplexer with flying capacitor

iv) 10 bit A/D converter;

v) microprocessor

vi) RS 232 C Interface

A block diagram of the electronics module is show in figure 2. The equipment uses a current signal from a ionization chamber ($3x10^{-10}$ to 10^{-6}A) to feed a picoamperimeter which gives an out put of 0 to 10 volts. All the control is made by a internal microprocessor. Through a signal from an external microcomputer the internal microprocessor decodifyies this instruction and starts the data aquisition from the pico amperimeter. A multiplexer sorts the desired information, temperature signal or power channel signal. The total number of analogue input is 3 to the multiplexer, and 2 to picoamperimeter. Once the data aquisiction is made the microprocessor provides signals in 4096 channels to an external microcomputer through in RS232C interface for real time digital computation of reactivity . The reactivity obtained is made available through a D/A converter, for x-t/x-y register. The front and back views of the eletronics module, are shown in figure 3.

The reactivity is obtained through the solution of the inverse kinetic equation,

$$\rho(t)=\overline{\beta}+\Lambda \frac{\dot{n}(t)}{n(t)} - \frac{1}{n(t)} \sum \lambda_i \beta_i \int_{-\infty}^{t} dt' n(t') e^{\lambda_i (t'-t)} , \quad (1)$$

where $\rho(t)$ is the reactivity; $\overline{\beta}$ is the total efective delayed neutron **fraction**; n(t) is the neutron amplitude function(power); λ_i and $\overline{\beta}_i$ are the radioactive decay constant and a efective delayed neutron fraction of percursor i and Λ is the prompt neutron generation time. The solution of equation (1) [5] is obtained through a numerical scheme which assumes that n(t) or the digital signal coming from the electronic module, can be linearly interpolated between two successive measured points, and that the integral in eq.(1) can be solved in a time instant using the results obtained in the previous time. The software were made in FORTRAN-80 CP/M, and instaled in a

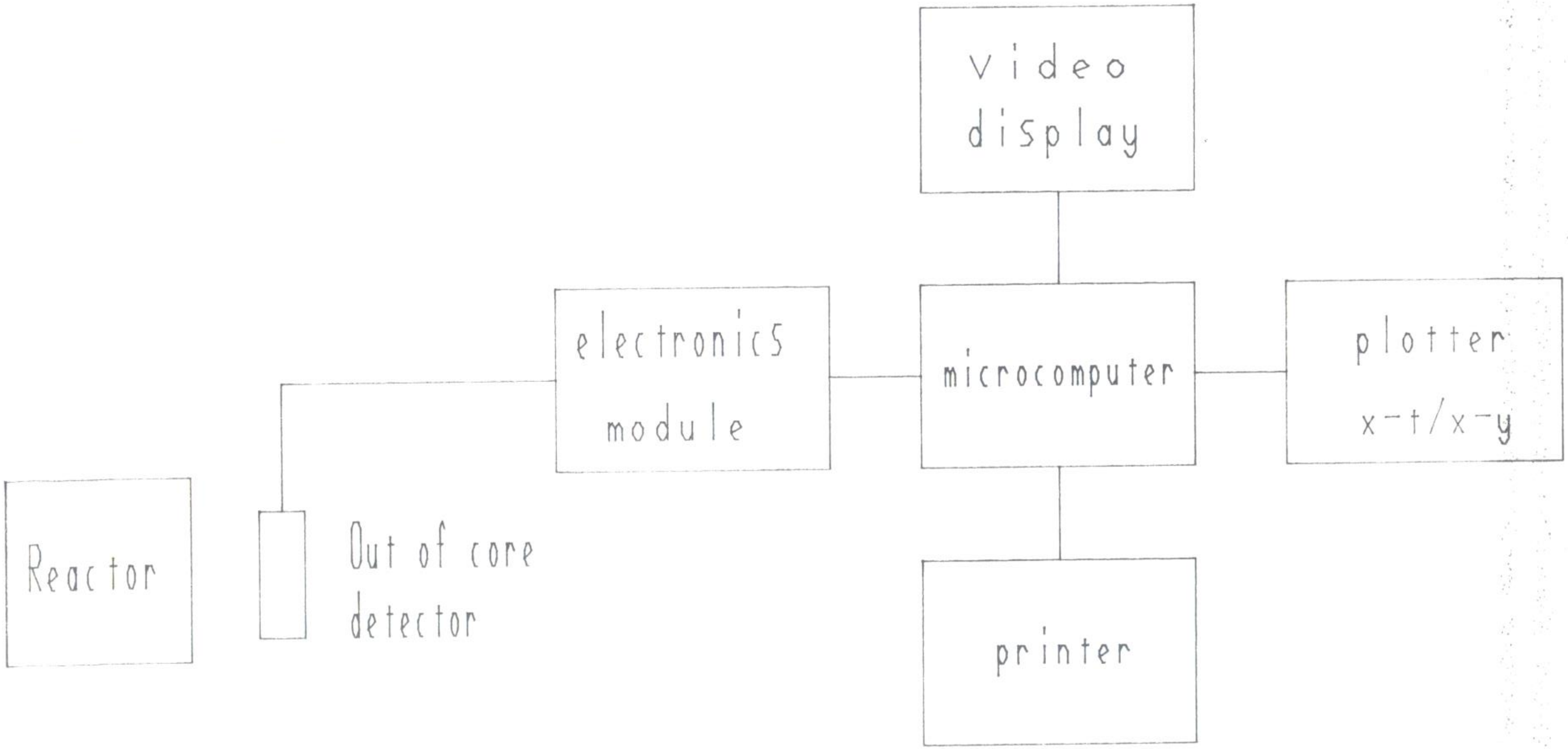


Figure 1: Schematic Operation of the Digital Reactivity-Meter

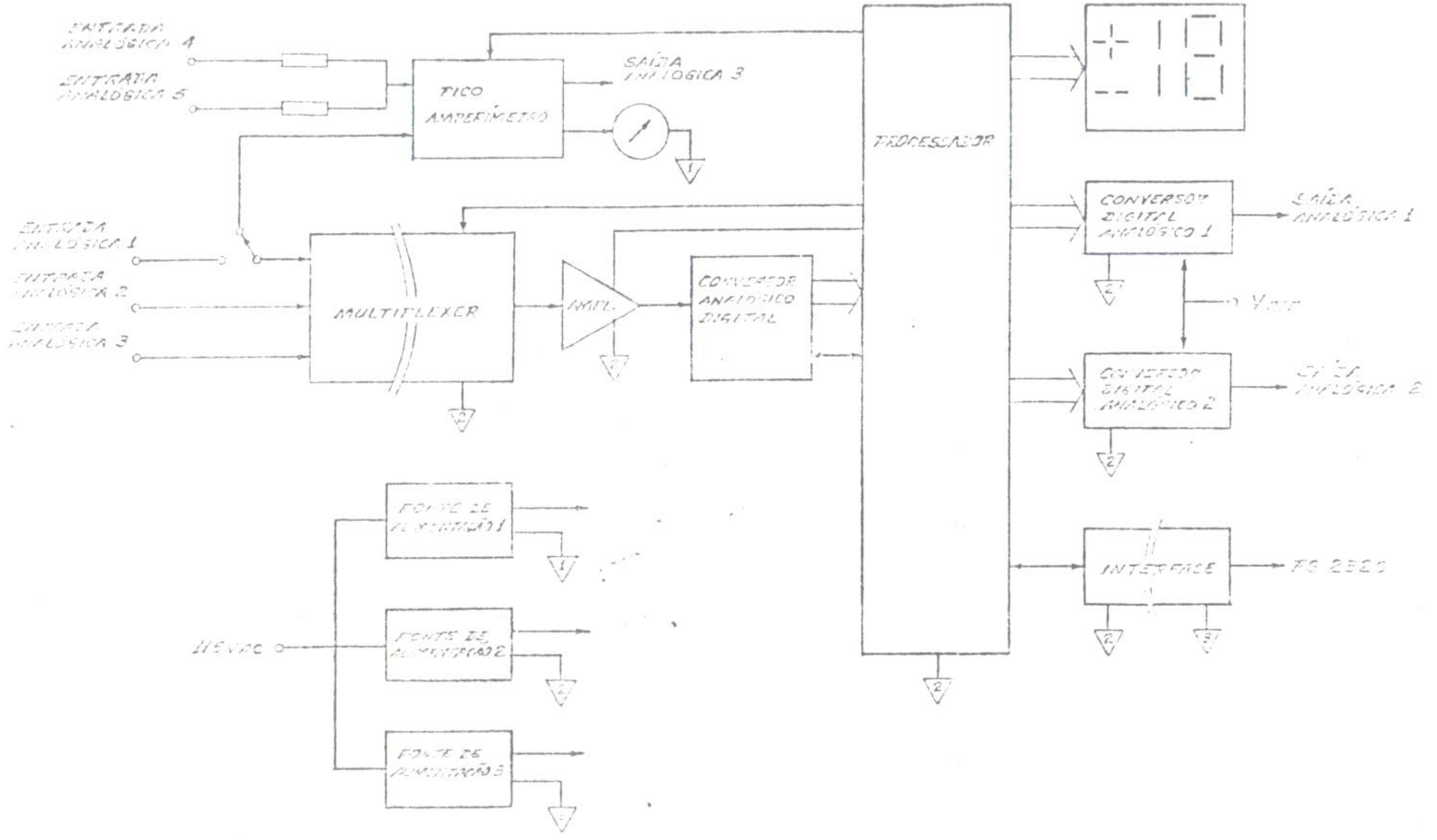
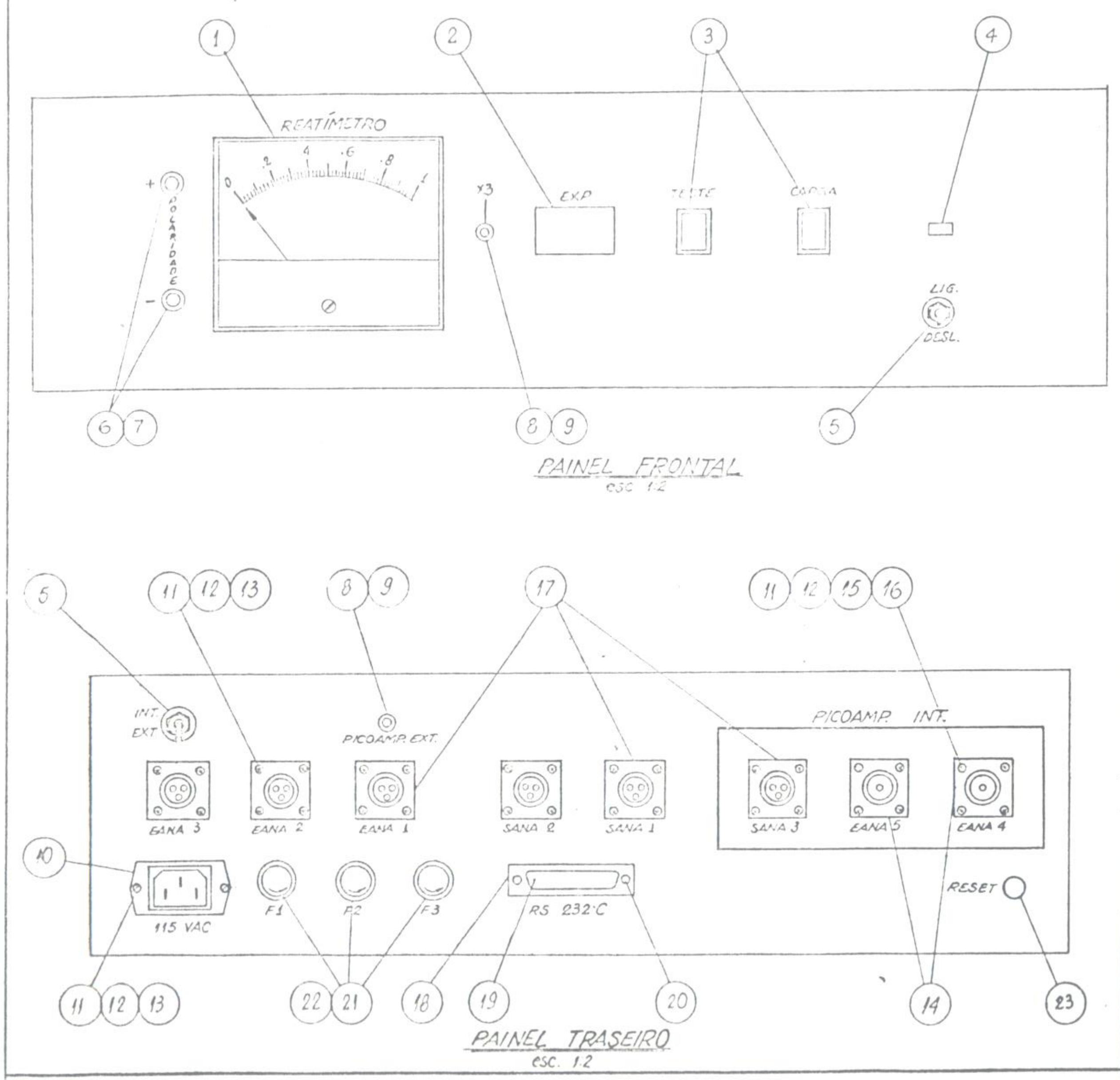


Figure 2 - Block Diagram of Electronic Module.



POS.	QT.	DESCRIÇÃO	CÓDIGO
[illegible]	[illegible]	[illegible]	[illegible]
23	01	Chave pushbutton (JOTO)	[illegible]
22	0	Fusível 5 x 20 mm de 200 mA	
21	03	Porta fusível tipo rosca p/ fusível 5x20mm (JOTO)	[illegible]
20	01	Conj. de retenção fêmea p/conector HD20 (AMP)	[illegible]
19	25	Soquete p/ conector fêmea HD 20 (AMP)	[illegible]
18	01	Conector fêmea 25 pinos HD 20 (AMP)	[illegible]
17	06	Conector série 8400 fêmea (WHINNER)	[illegible] -3F
16	08	Arruela lisa de Teflon Ø3 mm	
15	08	Arruela isoladora de Teflon Ø3 mm	
14	02	Conector UHF fêmea (WHINNER)	QF-3
13	26	Arruela de pressão Ø3 mm	
12	34	Porca sextavada Ø3 mm	
11	34	Parafuso Ø 3 x 15 mm	
10	01	Conector 2P+T 10A-250V IEC 320 (Steck)	S-1320
09	02	Suporte para LED Ø 3mm cromado (JOTO)	
08	02	Diodo emissor de luz (LED) Ø 3 mm (Vermelho)	SLR-34 UT [illegible]
07	02	Suporte p/ LED Ø 5 mm cromado (JOTO)	Cat. 8352
06	02	Diodo emissor de luz (LED) Ø 5mm (Vermelho)	FLV 110
05	02	Chave Liga-Desliga-Strap 3 vias	
04	01	Lâmpada de Neon	LP 14
03	02	Chave pushbutton (C&K)	J 51
02	03	Display - 7 segmentos - anodo comum	MAN 4710
01	01	Galvanômetro 0-1mA (Kyoritsu)	KM 06

NOTAS

Figure 3 - Backand Front View of the Electronic Module.

TÍTULO: REATÍMETRO DE 12 BITS - DISPOSIÇÃO DOS COMPONENTES NOS PAINÉIS TRASEIRO E FRONTAL	FOLHA 04 DE 04
DOCUMENTO Nº: R43-IP7-009.NC-3DE-009	REV. 01

microcomputer.

3. REACTIVITY METER PERFORMANCE

The digital reactivity-meter, 009-NC/1-IPEN, was developed by the IPEN-CNEN-SP mainly to be a tool in Reactor Physics Measurements in the IEA-R1 Research Reactor. It has been used in reactivity assessment (control rod worth; reactivity coefficients) to qualify the computer codes used in research reactor design(6,7), mainly in view of the Institute goal to change the core by using a low enrichment uranium fuel (20%).

Furnas, the brazilian utility responsible for the operation of Angra -I Nuclear power plant, had been using a Westinghouse rented analogue reactivity computer to conduct the necessary low power physics tests. With the development of IPEN'S digital reactivity computer, Furnas demonstrated interest in utilizing it in the low power physics tests of Angra-I. A series of tests, comparing the IPEN's reactivity meter results to the Westinghouse's, was performed in order to qualify the IPEN's instrument for utilization in a nuclear power plant.

The reactivity-meter was used in the low power physics test in the refuelling cycle 3, having performed the following measurements(8,9):

i) Low-Power Range of Conduct the Physics Tests by measuring the Nuclear Addition Heat Point

ii) Boron End Point, or Critical Boron Concentration

iii) Control Rod Worth

iv) Temperature Coefficients.

In Table 1 the definition of the physics test power range is ilustrated by reporting the Heat Addition Point i.e., the power level below which the nuclear heat feedback has no effect.

TABLE 1 - POWER RANGE TO CONDUCT THE PHYSICAL TEST

	WESTINGHOUSE (AMP.)	009-NC/1-IPEN (AMP.)
RANGE	$7x10^{-9}$ - $3,5x10^{-7}$	$8x10^{-9}$ - $4x10^{-7}$
HEAT ADDITION POINT	7×10^{-7}	8×10^{-7}

In Table 2 the critical boron concentration (ppm) is reported for several conditions of control rod banks insertions. The experimental values measured by the two reactivity-meters are compared with those calculated by FURNAS.

TABLE 2 - BORON END POINT (ppm)

CONTROL ROD BANK CONDITIONS	WESTINGHOUSE	009-NC/1-IPEN	CALCULATED
All Rods With drawn	1488	1488	1515
D-IN	1409	1409	1431
D+C-IN	1276	1276	1279
D+C+B-IN	1165	1165	1166
D+C+B+A-IN	962	962	947

In Table 3 the control rod worth, in pcm, for A,B,C and D banks is reported, and in table 4, the isothermal and moderator reactivity temperature coefficients are reported. In both cases, the experimental results measured by the reactivity-meters are compared with those calculated by

FURNAS and KWU/NUKEN (an architect engineering company).

TABLE 3 - CONTROL ROD WORTH (pcm)

BANK	CALCULATED		EXPERIMENTAL		DEVIATION(%)	
	KWU/NUKEN	FURNAS	WEST.	IPEN	WEST.	IPEN
D	670	676	674.3	677.8	+0,6	+1,2
C	1240	1266	1255.1	1264.0	+1,2	+1,9
B	920	905	916.9	898.7	-0,3	-2,3
A	1790	1838	1840.9	1837.3	+2,8	+2,6
SUM	4620	4685	4687.1	4677.8	-	-

TABLE 4 - TEMPERATURE COEFFICIENTS (pcm/$^{\circ}$C)

COEFFICIENT	CALCULATED		EXPERIMENTAL		DEVIATION(%)	
	KWU/NUKEN	FURNAS	WEST.	IPEN	WEST.	IPEN
Isothermal	-9.45	-9.80	-10.1	-10.2	-6.9	-7.9
Moderator	-5.95	-5.85	-6.6	-6.7	-10.9	-12.6

4. CONCLUSION

In all tests the measurements obtained by the digital reactivity meter were in good agreement with those obtained by the Westinghouse analogue reactivity meter, as well as the results calculated by the utility.

The good performance of 009-NC/1-IPEN demonstrates that it is appropriate in reactivity measurements in nuclear reactors. Due its good performance, FURNAS has decided to use the digital reactivity meter in the next refueling low power test. This decision will save the utility US$ 50.000 yearly.

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AKNOWLEDGES

The authors wish to express their gratitute to FURNAS Centrais Elétricas.