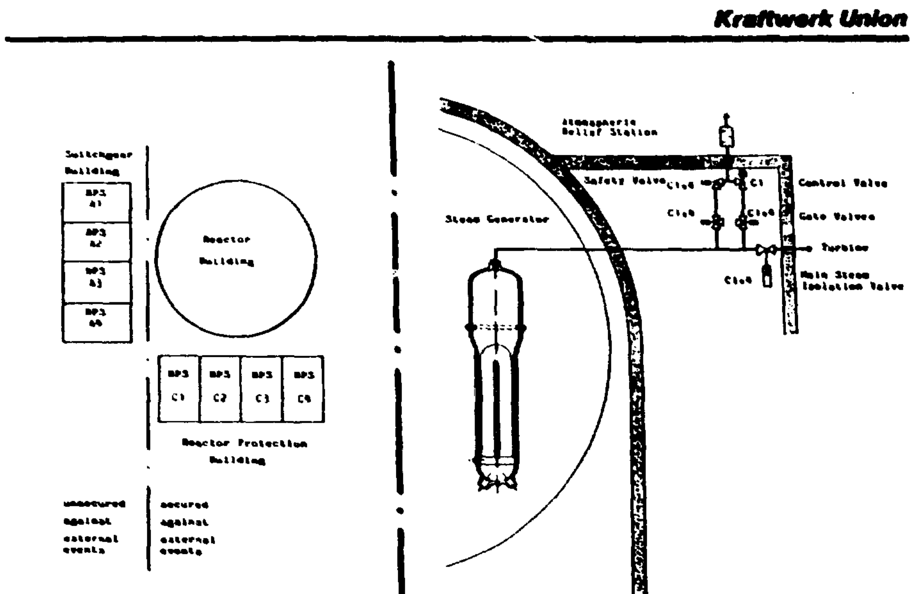
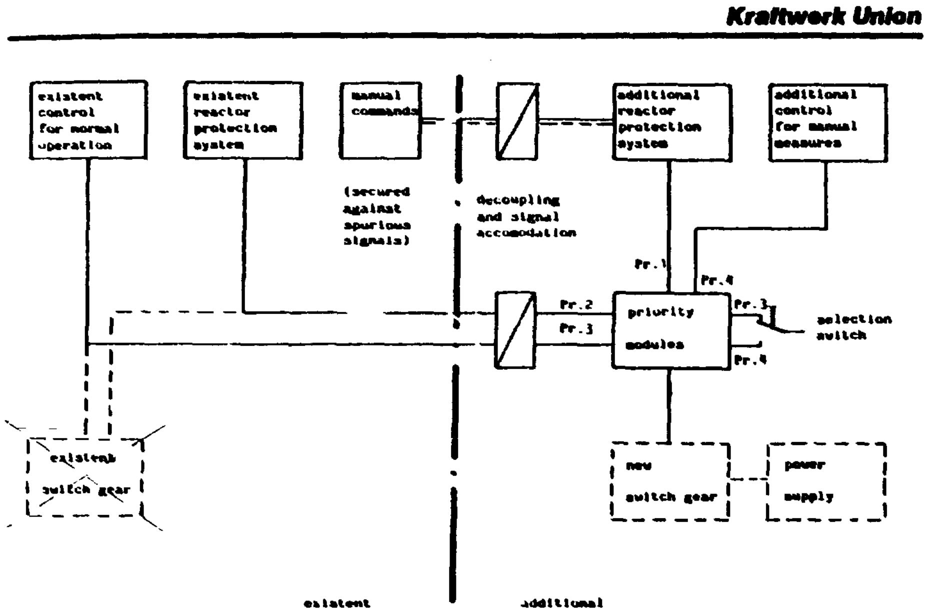


Atmospheric Relief Station
Variant 3

Fig. 8



Organization of additional safety related I + C

Fig. 9

AUTOMATIC DETECTION AND ANALYSIS OF NUCLEAR PLANT MALFUNCTIONS

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Abstract

In this paper a system is proposed, which performs dinamically the detection and analysis of malfunctions in a nuclear plant. The proposed method was developed and implemented on a Reactor Simulator, instead of on a real one, thus allowing a wide range of tests.

For all variables under control, a simulation module was identified and implemented on the reactor on-line computer. In the malfunction identification phase all module run separately, processing plant input variables and producing their output variable in Real-Time; continuous comparison of the computed variables with plant variables allows malfunction's detection. At this moment the second phase can occur: when a malfunction is detected, all modules are connected, except the module simulating the wrong variable, and a fast simulation is carried on, to analyse the consequences.

Introduction

The proposed techniques try to meet the growing demand of safety, especially after TMI accident. Generally in a traditionally built Control-Room, an abnormal condition or a malfunction is signaled by its consequences. By means of tresholds some important variables are supervised. When they are crossed, an automatic safety intervention may occur, or more frequently the operator is asked to take decisions. Often, important alarms may occur depending on trivial reasons and viceversa. Human factors techniques, synoptical and computer aided data presentation can aid operator in taking decisions. But in any case, what it is usually shown are the consequences and not the causes of "malfunctioning" conditions. For example the rise of temperature in the Fuel Core can be generated from loss of coolant, supply fault, pumps seizing etc. Operator must locate the right reason, evaluate consequences and take decisions on the base of its own experience and judgement.

This paper reports the results of a research to aid operator in finding the origin and evaluating the consequences of a malfunction. The plant is identified by a mathematical model and a modular numerical simulation is realized and implemented on the On-Line Computer. Each module is designed to furnish a variable , referring to a physically identifiable plant part.

In fig. 1 the whole scheme of the proposed system is shown. In normal operating conditions a program called " Diagnostic " runs, which continuously controls the plant. In malfunctioning conditions the " Previsional " program is automatically activated by " Diagnostic ", or manually by the operator. A more detailed description will follow.

Malfunction Detection "Diagnostic"

Each module runs in Real-Time, following the scheme of fig. 2. It works in a completely independent way, by processing only plant variables (with the exception of the output feedback). Malfunction fast detection is carried out by comparing plant variables with those computed by the model, following the scheme of fig. 3.

Modules and plant operate with the same input variables; for this reason a computed variable will disagree with the corresponding real variable when the plant transfer function is modified, that is when a malfunction occurs.

Several techniques have been tested to validate the difference between computed and real variables. The flow-chart of fig. 4 shows the selected method. With this method a malfunction is detected not only by observing the differences between computed and plant variables, but also by analysing their derivatives, in order to avoid false alarms. In Fig. 5 the flow-chart of Diagnostic is shown.

Malfunction Analysis "Previsional"

When a malfunction is detected through the difference between real and computed variables, as shown before, the "Previsional" phase can apply. It can run both automatically and under operator's request. In the predictive phase the same simulation modules, as in "Diagnostic", are used, but with two important differences.

- Modules are connected as shown in fig. 6. In this way, on the plant computer a Simulator is realized, wich starts from the Initial Conditions corresponding to the instant when the malfunction is detected; an extrapolation of the wrong variable is inserted.
- This new Simulator runs faster then Real-Time, to allow prevision of the consequences of the accident.

Flow-Chart of "Previsional" is shown in fig. 7. "Previsional" will furnish very rapidly the probable values reached by the controlled variables after a selected time (defined by PTIME). The reliability of the prevision will obviously depend on the validity of the choosen extrapolation methodfor the wrong variable, and it will decrease with the growth of requested prevision time.

Applications and Examples

Data will be presented as follows. In normal conditions - "Diagnostic" - all controlled variables are shown, with their plant and computed values, in blue colour. When a malfunction is detected by "Compare", the wrong variable values become green, and, after a confirmation time, they become red. At this moment "Previsional" start running. On the video +,- and = signs will appear under the controlled variables, as a first trend indication. On operator request PTIME prevision values will also be printed.

The proposed methods were implemented and tested on a Nuclear Reactor Simulator, instead then on a real plant; PEC Reactor Simulator was utilized. PEC (Prova Elementi di Combustibile - Test of Fuel Elements) is a 120 MWth experimental Fast Breeder Reactor under construction by the Italian Atomic Organization (ENEA).
The PEC Simulator is carachterized by:

- Principal Operator Console exact replica;
- Plant identified by a 400 differential equations, with 50 msec minimal integration step, mathematical model;
- Package implemented on SEL 32/77 system;
- Multipurpose instructor desk;
- Foxboro FOX 2/30 on-line computer.

Implementing and testing the proposed techniques on a Simulator instead then on a real plant, allows us to apply and verify them in any possible malfunction. Their validity on the real plant must obviously be verified, but it will depend essentially on reliability of the Simulator itself.

Let us conclude by presenting an example. Fig. 8 shows the controlled variables in a steady state condition, with the following meaning (see fig. 9):

WRI1	PRIMARY	INLET	FLOW	RATE	NORTH
WRI2	"		"		SOUTH

WR01	" OUTLET " NORTH
WR02	" " SOUTH
WWP1	IHX PRIMARY FLOW RATE NORTH
WXP2	" " SOUTH
WEP	EMERGENCY CIRCUIT PRIM. FLOW RATE
AHV	REACTOR VESSEL COOLANT LEVEL
AHCV	COMPONENTS VESSEL COOLANT LEVEL
AHX1	NORTH IHX COOLANT LEVEL
AHX2	SOUTH " "
VRP1	NORTH PRIMARY PUMP VELOCITY
VRP2	SOUTH " " "
ASS1	NORTH " " ABSORPTION
ASS2	SOUTH " " "
TCV	COMPONENTS VESSEL COOLANT TEMPERATURE
TXP01	NORTH IHX OUTLET COOLANT TEMP. PRIMARY
TXP02	SOUTH " " " "
TXS01	NORTH " " " SECONDARY
TXS02	SOUTH " " " "

Assume a supply fault in a primary cooling circuit pump (see fig.9). It will be detected by "Diagnostic" and signaled both by the difference between plant and computed variable of the pump velocity, and by a colour change in the screen. "Previsional" will then furnish data of fig. 10, which can be compared with those of fig. 8 to estimate consequences. Reliability of "Provisional" can be verified by comparison with the evolution of real variables recorded in fig. 11.

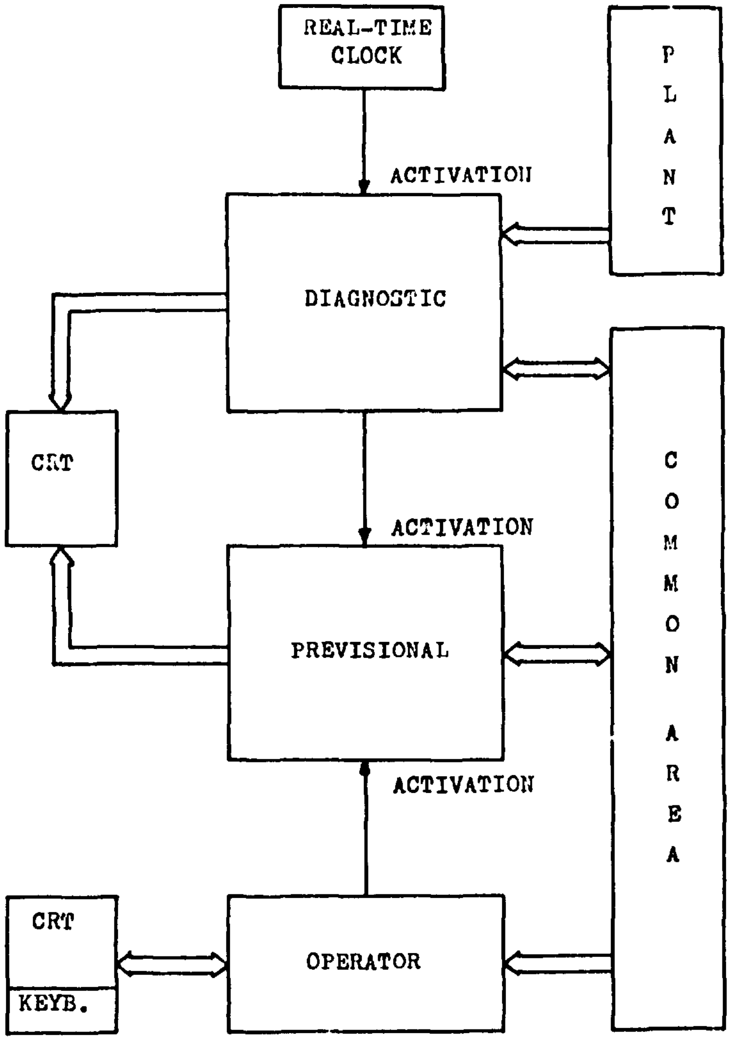

Fig.1

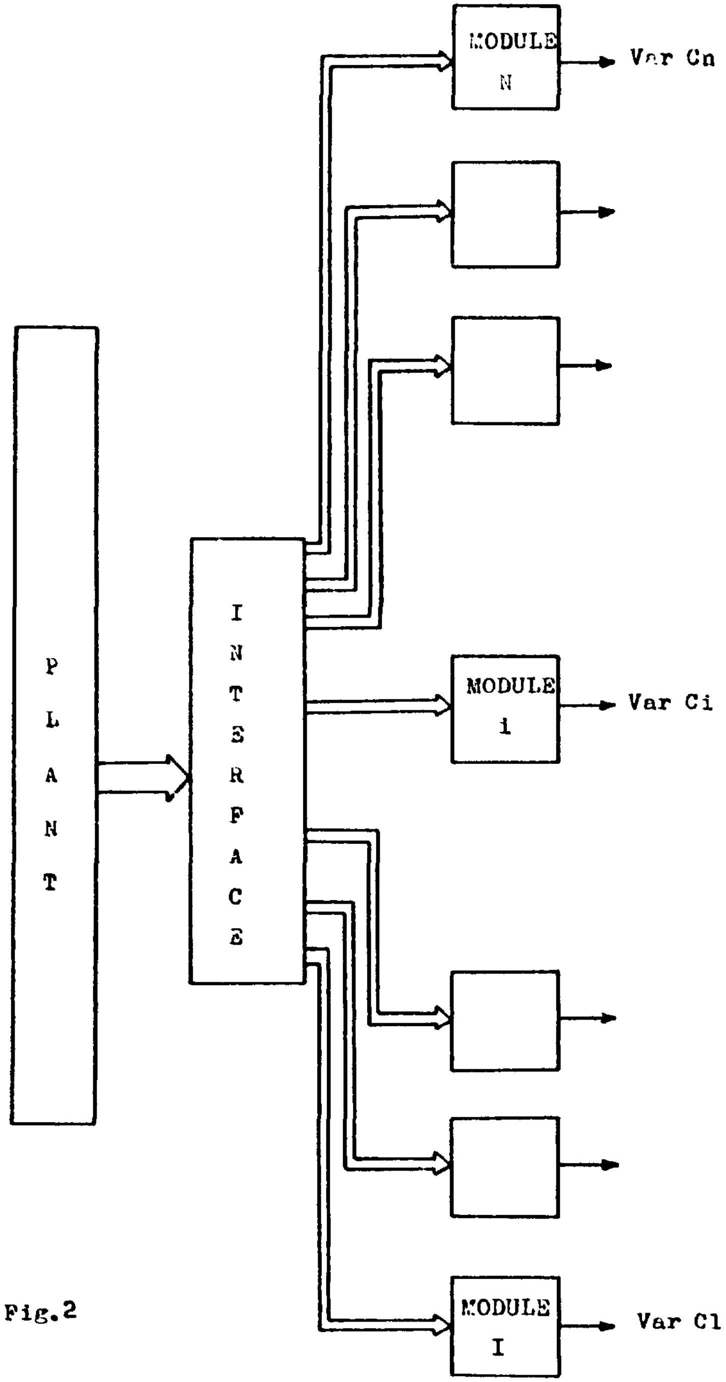
PLANT
INTERFACE
MODULE N
Var Cn
MODULE i
Var Ci
MODULE I
Var C1

Fig.2

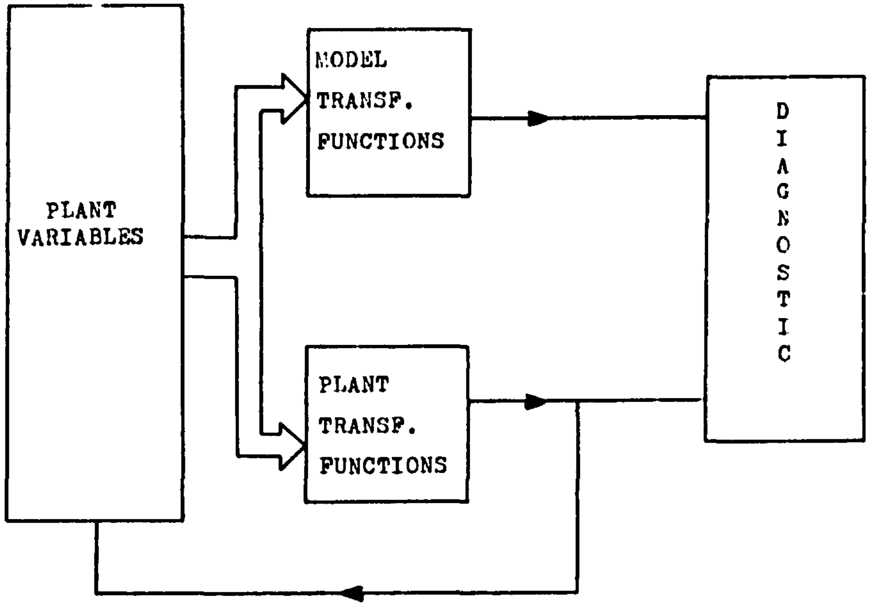
PLANT VARIABLES
MODEL TRANSF. FUNCTIONS
PLANT TRANSF. FUNCTIONS
DIAGNOSTIC

Fig.3

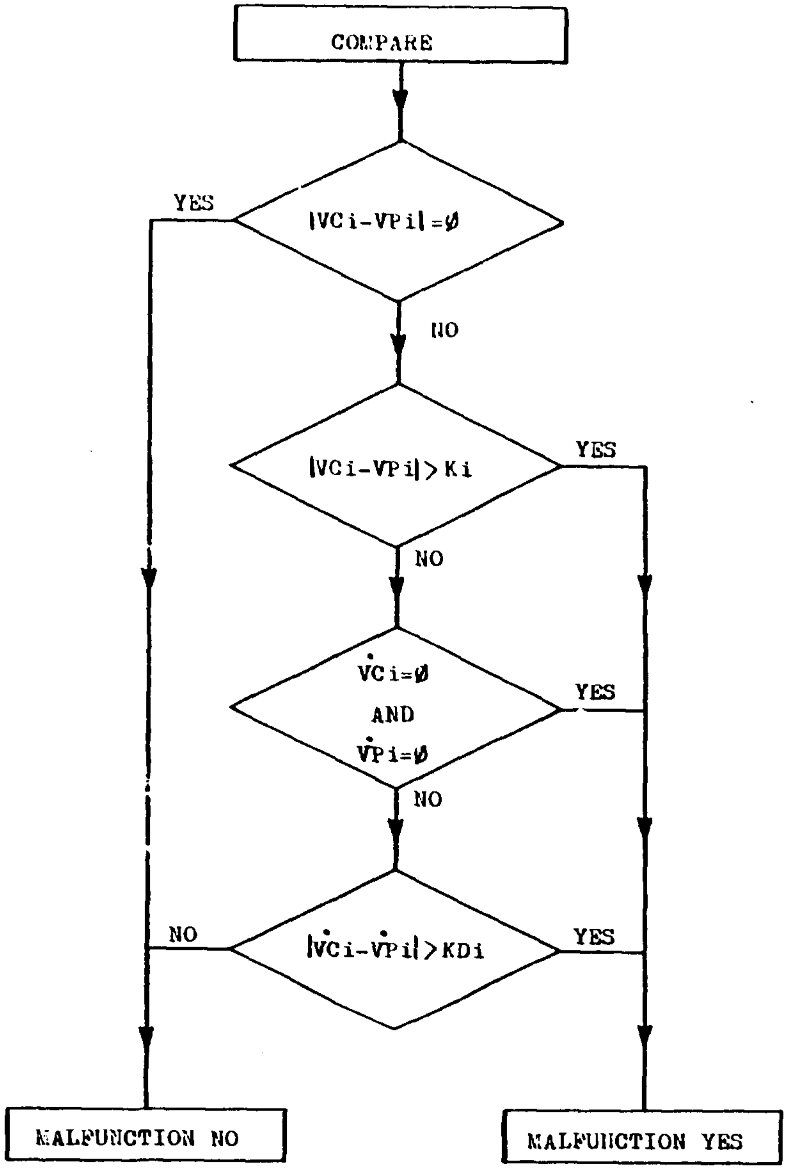
COMPARE
YES
$|VCi-VPi|=0$
NO
$|VCi-VPi|>Ki$
YES
NO
$\dot{V}Ci=0$
AND
$\dot{V}Pi=0$
YES
NO
NO
$|\dot{V}Ci-\dot{V}Pi|>KDi$
YES
MALFUNCTION NO
MALFUNCTION YES

Fig.4

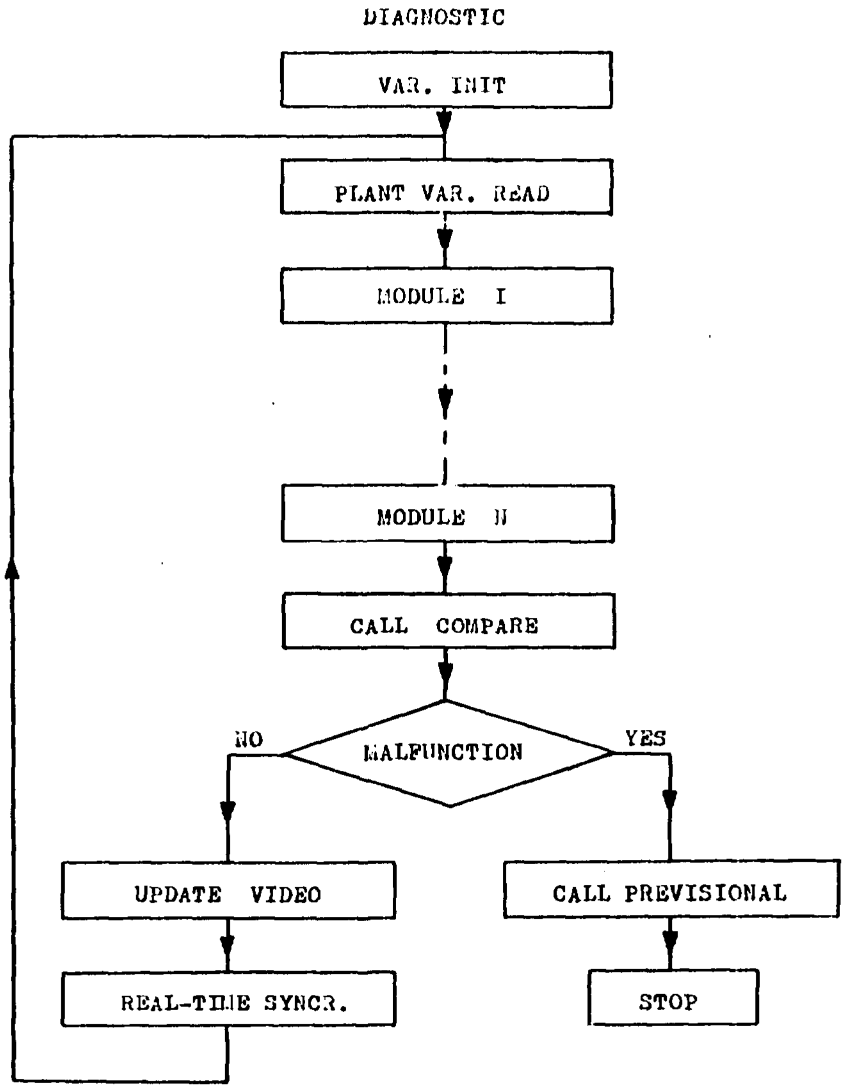
DIAGNOSTIC
VAR. INIT
PLANT VAR. READ
MODULE I
MODULE N
CALL COMPARE
NO
MALFUNCTION
YES
UPDATE VIDEO
CALL PREVISIONAL
REAL-TIME SYNCR.
STOP

Fig.5

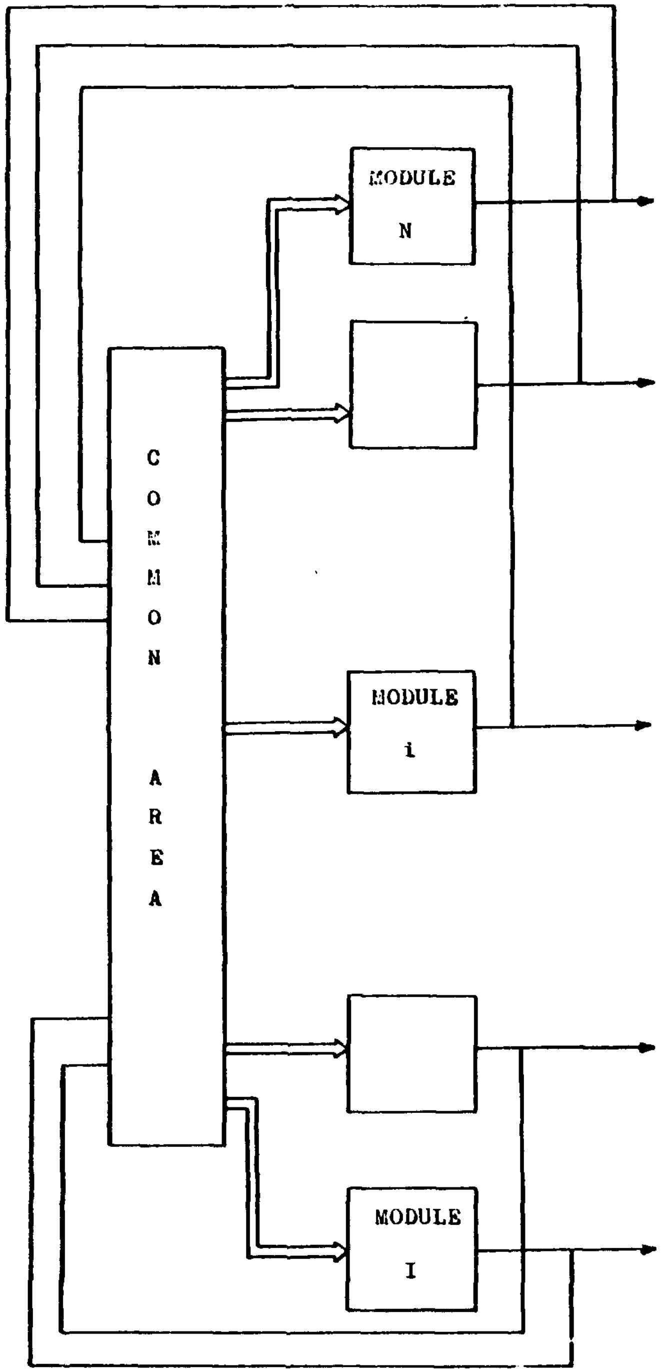
MODULE
N
C O M M O N
A R E A
MODULE
i
MODULE
I

Fig.6

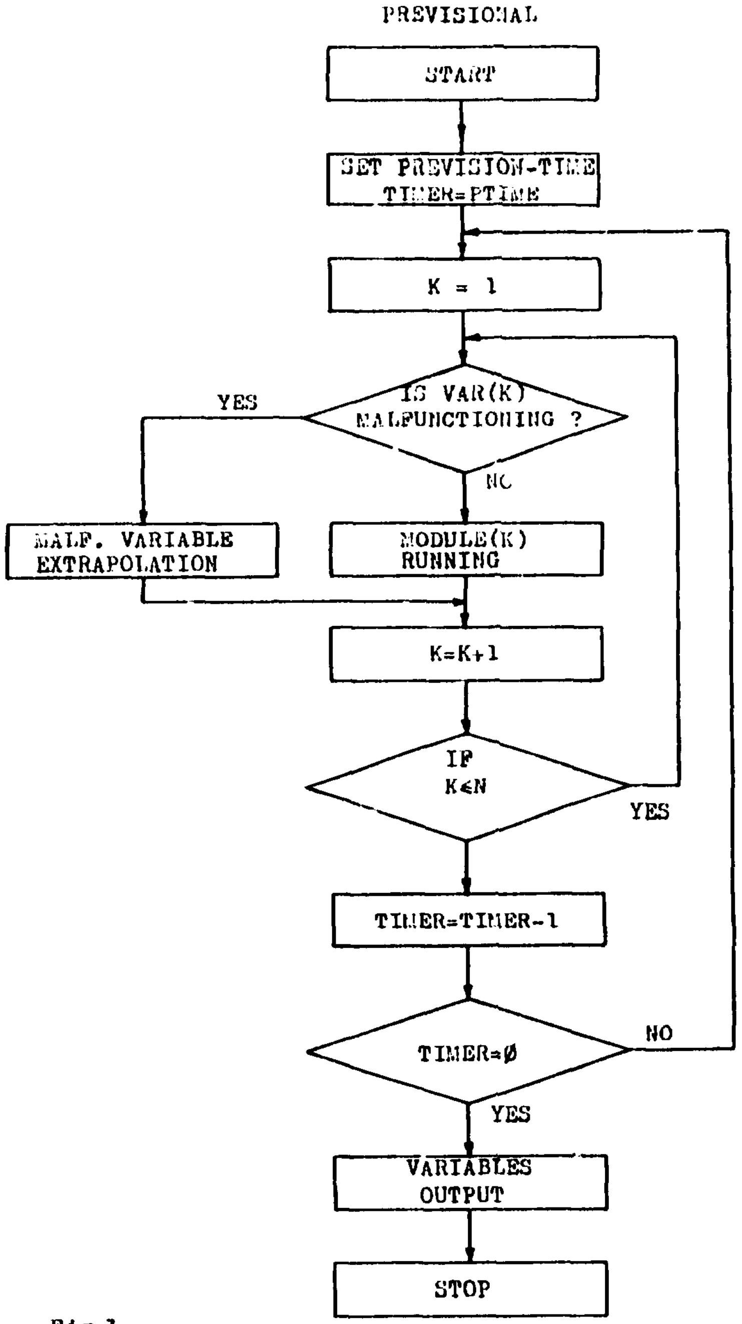
PREVISIONAL
START
SET PREVISION-TIME
TIMER=PTIME
K = 1
IS VAR(K)
MALFUNCTIONING ?
YES
NO
MALF. VARIABLE
EXTRAPOLATION
MODULE(K)
RUNNING
K=K+1
IF
K≤N
YES
TIMER=TIMER-1
TIMER=0
NO
YES
VARIABLES
OUTPUT
STOP

Fig.7

STEADY STATE VALUES

WRI1	WRI2	WRO1	WRO2	WXP1	WXP2	WEP
314.4	314.4	314.4	314.4	314.4	314.4	20.2

AHV	AHCV	AHX1	AHX2
-3.213	-3.970	-3.556	-3.556

VRP1	VRP2	ASS1	ASS2
117.0	117.0	250.0	250.0

TCV	TXPO1	TXPO2	TXSO1	TXSO2
399.4	399.2	399.7	495.7	495.9

Fig. 8

PREVISION FOR 2 MIN.
REQUESTED BY DIAGNOSTIC

WRI1	WRI2	WRO1	WRO2	WXP1	WXP2	WEP
289.7	327.0	308.5	308.5	308.6	308.6	20.3

AHV	AHCV	AHX1	AHX2
-3.222	-3.963	-3.557	-3.557

VRP1	VRP2	ASS1	ASS2
112.9	116.9	231.8	250.1

TCV	TXPO1	TXPO2	TXSO1	TXSO2
398.5	397.8	398.4	495.5	495.7

Fig. 10

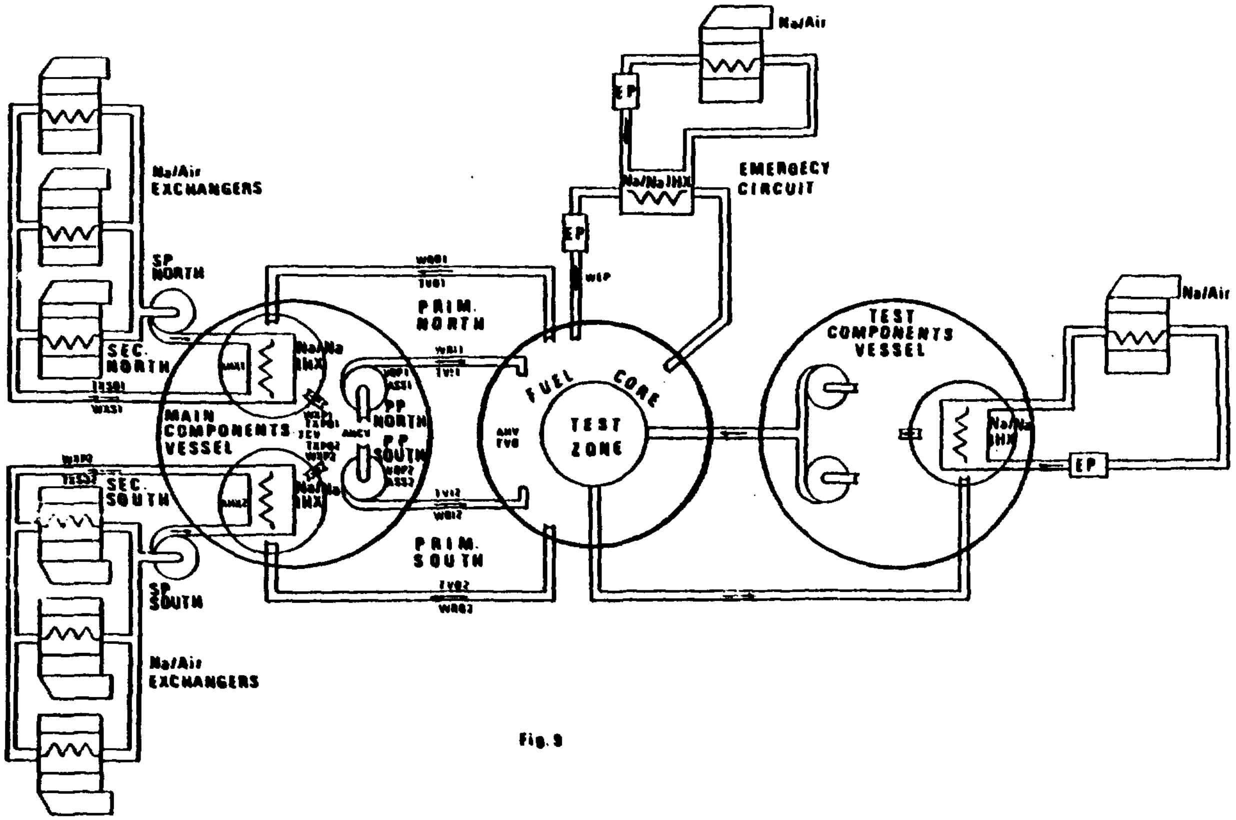

Fig. 9

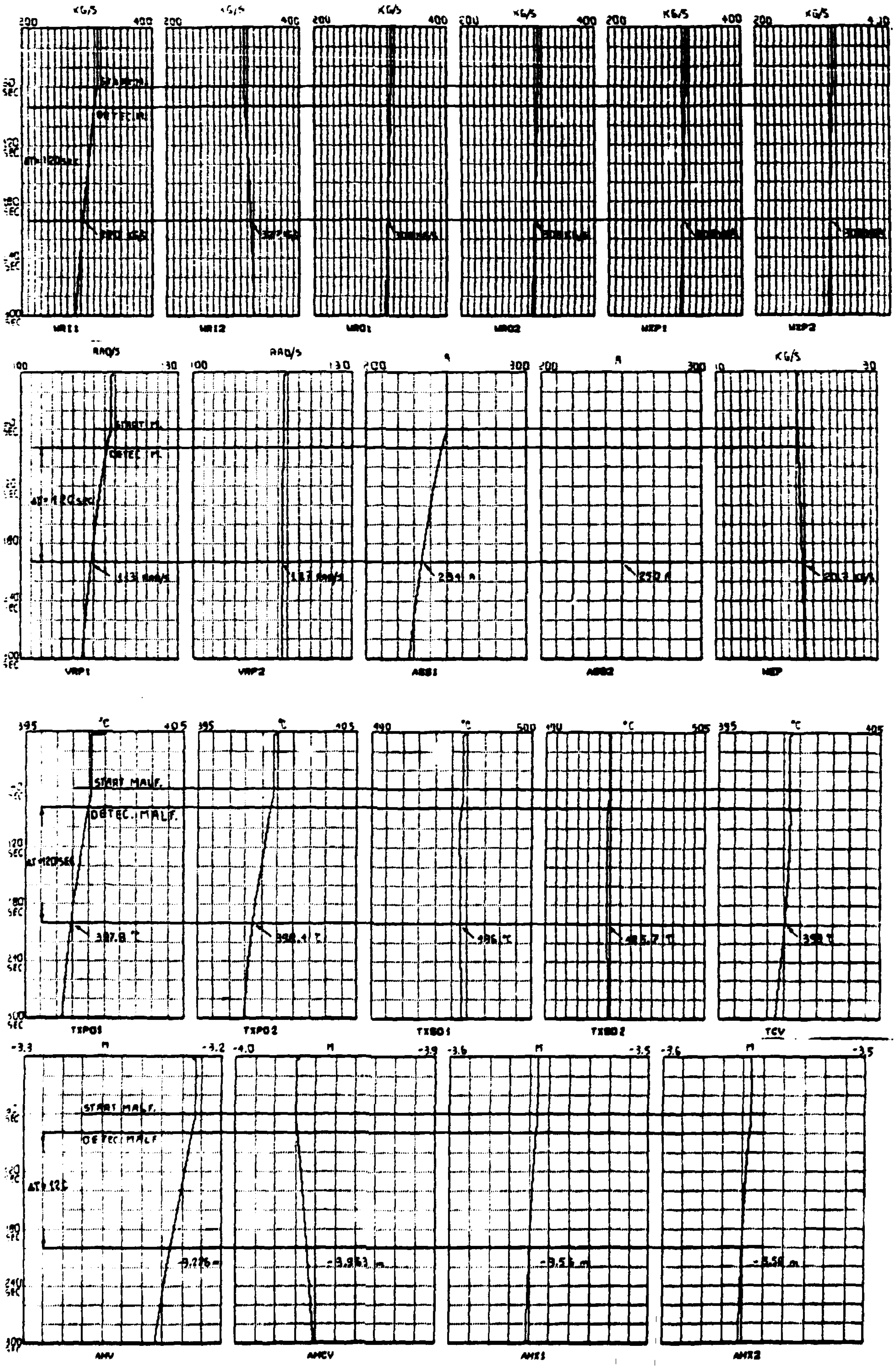KG/S
200
400
START M.
DETEC M.
ΔT=120 SEC
60 SEC
120 SEC
180 SEC
240 SEC
300 SEC
WRI1
WRI2
WRO1
WRO2
WXP1
WXP2
RAD/S
100
130
A
200
300
KG/S
10
30
START M.
DETEC. M.
ΔT=120 SEC
131 RAD/S
127 RAD/S
254 A
250 A
20.3 KG/S
VRP1
VRP2
ABS1
ABS2
WEP
°C
395
405
490
500
505
START MALF.
DETEC. MALF.
ΔT=120 SEC
397.8 °C
398.4 °C
496 °C
TXPO1
TXPO2
TXBO1
TXBO2
TCV
M
-3.3
-3.2
-4.0
-3.9
-3.6
-3.5
START MALF.
DETEC. MALF.
ΔT=120
-3.226 m
-3.953 m
-3.53 m
AMV
AMCV
AMX1
AMX2

Fig. 11