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Charge-Exchange Neutral Particle Analyzer Diagnostic of TJ-II

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25 pp. 6 figs. 10 refs.

Abstract

A description of the Charge Exchange Neutral Particle Analyzers in operation in the heliac flexible TJ-II is reported. A description of the detectors, as well as the operation characteristics, hardware and software used in the control and analysis of the data obtained with the diagnostic is detailed.

Two NPAs are in operation in TJ-II. One of them is a 5-channel analyzer and another one is an Acord-12. The 5-channel analyzer provides measurements of charge exchange neutral fluxes at five energy channels, whereas the Acord-12 can measure simultaneously tvvo different hydrogen isotopes (H and D) at six energy channels. Their lines of sight can be varied poloidally in order to observe the different sections of the plasma.

Analizador de Partículas Neutras por Intercambio de Carga en el TJ-II

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Resumen

Se describe el diagnóstico Analizador de Partículas Neutras procedentes de la reacción de Intercambio de Carga que se encuentra en operación en el heliac flexible TJ-II. Se describen los detectores, sus características de operación, el hardware y el software utilizado para el control y análisis de los datos obtenidos con el diagnóstico. Hay dos analizadores de partículas neutras en TJ-II. Uno de ellos es un analizador de 5 canales y el otro es un Acord-12. El primero da la medida de flujos de neutros de intercambio de carga en 5 canales de energías y el segundo en 6 canales, pudiendo este último medir simultáneamente dos isótopos diferentes del hidrógeno (H y D). Las líneas de visión de ambos pueden ser variadas poloidalmente para que se puedan analizar diferentes secciones del plasma

1.- CX Analyzer

Charge exchange neutral particle analyzer diagnostic is operating in TJ-II stellarator (R0 = 1.5 m; a < 0.22 m; B < 1.2 T, iota = 0.9 –2.2) [1]. It consists of two different devices (neutral particle analyzer NPA) looking along two lines of sight. One of them is a 5-channel spectrometer [2] and another one is an Acord-12 [3] that can simultaneously measure hydrogen and deuterium atomic fluxes in six energies.

The spectrometers were designed and constructed in the Ioffe Physico-Technical Institute (Russian Academy of Sciences). There are many of similar analyzers in hot plasma laboratories worldwide: Russia, Germany, USA, Japan...

In a NPA, the neutrals escaping from the plasma with different energies are counted at each energy channel of the analyzer. These particles give information about the ions in the plasma because they are produced by a charge exchange reaction. In this reaction a slow neutral gives its electron to a fast ion from the center of the plasma, so the old ion is neutralized and escapes from the plasma without changing its previous velocity:

$$H_s^0 + H_f^+ \rightarrow H_s^+ + H_f^0.$$

The neutral flux leaving the plasma can be described by the following formula:

$$J(E,t) = \int n_i(r,t) n_0(r,t) \langle \sigma_{CX} v \rangle f_i(E,r,t) e^{-S(E,r,t)} \Omega A dr$$

Where $n_i(r,t)$ is the ion density; $n_0(r,t)$ is the neutral density; $<\sigma_{cx}v>$ is the charge exchange cross section: $f_i(E,r,t)$ is the ion energy distribution function; $e^{-S(E,r,t)}$ is the attenuation factor due to ionization by the following processes: electron ionization, proton ionization and charge-exchange; ΩA is the analyzer solid angle. This integral is performed along the view sight length in the plasma column.

As both analyzers are absolutely calibrated they provide the absolute values of the neutral fluxes.

2.- Purpose and operating principle of the apparatus (Acord12)

The Acord-12 is a device that allows to scan the energy and the mass distribution of a flux of fast atoms emitted by plasma. It separates two kinds of isotopes (namely hydrogen and deuterium) in six different energies each one. In this case the energy range varies from 100 eV up to 100 keV for hydrogen atoms and from 100 eV up to 50 keV for deuterium.

The operating principle is shown schematically in figure 1 [4]. First there is a slit with three different positions that separates the vacuum chamber from the analyzer. After that there is a cleaning condenser, which deflects the charged particles and only allows passing the neutral ones. After the cleaning condenser there is a stripping chamber where a gas (nitrogen) ionizes the entering neutral particles so the electric and magnetic analysis would be possible. The resulting ions pass through a gap of an electromagnet and the magnetic field deflects the ions proportionally to their momentum forming a broad fan of particles at the exit. After that the ions enter in a specially profiled condenser with its electric field parallel to the already passed magnetic field (E||B analysis). This electric field provides an equal deflection height for the ions of equal mass when they intersect a detector plane. The detector plane is formed by two rows of six detectors in each one. The mass suppression (H/D) of this analyzer is about 10^{-3}.

The electron multipliers (channeltrons) of type VEU-6 are used as the detectors in the Acord-12. These electron multipliers have an entrance gate of 8 mm of diameter and they provide a gain of 10^8 for particle intensity up to $5 \cdot 10^5$ particle/s in pulse counting mode [4].

The 5-channel analyzer is very similar to the Acord-12. The Acord-12 analyzer is an upgrade of 5-channel NPA. The main body of Acord analyzer is identical to the main body of 5-channel NPA and last one can be easy converted to Acord type. The main differences of the both devices are following:

a) different type of the analysing system: double electrical analysis in the 5-channel NPA (i.e. the mass separation is absent);
b) number of the energy channels: five in the 5-channel NPA;
c) different type of the detectors.

The open electron multipliers VEU-2 [6] are applied as the detectors in 5-channel analyzer. They have more larger entrance about 25 mm and exponential shape of the pulse height particle spectrum.

2.1.- *The analyzer energetic characteristics*

The energy assigned to each channel is determined by the current applied to the electromagnet. The energy relation between the channels is fixed. So it is only needed to fix the energy in one of the channels to define the energy of all of them. The channel used to fix the energy is the 7th, the lowest in the hydrogen row.

Table 1: Energy relation of the channels of the Acord-12. In the upper part are the deuterium channels and in the lower part the hydrogen ones.

Channel	#1	#2	#3	#4	#5	#6
E_k/E_7	0.5	0.69	1.01	1.39	2.2	4.03
Channel	#7	#8	#9	#10	#11	#12
E_k/E_7	1.0	1.42	2.04	2.94	4.82	8.74

Table 2: Energy relation of the channels of the 5-channel analyzer.

Channel	#1	#2	#3	#4	#5
E_n/E_1	1	1.34	1.92	2.63	3.95

2.2.- *NPA calibration*

The NPA is calibrated in Ioffe Physical Technical Institute, St. Petersburg, using hydrogen and deuterium neutral beams.

Also there is a built-in auxiliary ion source in the NPA for express checking of the detectors and analyzing system.

To operate the ion source a hollow made in nickel foil is filled with a mixture of equal gram-molecular portions SiO_2, Al_2O_3 and an alkali metal carbonate. Once the hollow is filled the mixture is welted with a drop of alcohol, then the source is inserted in the chamber and preheated in rough vacuum before alcohol has time to evaporate completely.

Heating of the ion source must be conducted gradually. The intensity of the ion beam becomes sufficiently stable in about 5 minutes after the final adjustment of the heating current [4].

Results of the calibration of the 5-channel analyzer are shown in table 3.

Table 3: Energy width of the channels in the 5-channel analyzer.

Channel	1	2	3	4
ΔE/E	11.25%	13.75%	18.75%	17.75%

3.- Mechanics

3.1.- *Supporting structure*

Both analyzers are mounted at the same support structure with the 5-channel analyzer in the upper part and the Acord-12 in the lower part. Figure 2 shows the diagnostic installed in the TJ-II.

3.2.- *Movement*

The supporting structure can be moved poloidally or toroidally. The poloidal movement can be remotely handed. With the supporting structure the analyzers are rotated around a fixed point, so the scanned poloidal line of sight can be varied. The angle between the line of sight of the two devices is fixed. The poloidal movement is performed by one screw moved by an electric motor. This screw varies the height of the analyzers and consequently the line of sight. This movement can be done remotely or locally and it has an accuracy of 0.1 mm with a maximum reachable length of the screw of 700 mm. It allows to scan the plasma inside the range of effective plasma radius $r_{eff} \sim\pm 0.5$. Later it is plannig to use a longer screw to increase the scan space to include the plasma periphery.

3.3.- *Line of sight*

The charge-exchange diagnostic gives information about the ions in its line of sight. The main purpose of this diagnostic is studying the ion distribution behavior and determination the ion temperature. The ion temperature of the hottest volume element along the line of sight of the analyser can be obtained from the slope of the tail of the flux spectrum if an ion Maxwell distribution is assumed [5] The hottest plasma volume is always the most central point viewed by the analyzers. So depending on the line of sight the measured temperature will refer to a different radial point of the plasma.

The line of sight viewed by the analyzer is controlled by the length of the screw. Thus the most central point of the plasma viewed by the analyzer varies with the magnetic configuration. Figure 3 presents the most central region of the plasma viewed for each analyzer versus the length of the screw for four different magnetic configurations.

3.4.- *Solid angle*

To get the absolute values of the fluxes it is necessary to calculate the solid angle subtended by the NPA. In order to calculate it the different slits between the vacuum vessel and the analyzers had to be taken into account. A scheme of the different slits from the plasma to the exit of the stripping cellis shown in figure 4. The dimensions of the different slits for both analyzers are summarized in table 4.

Table 4: Dimensions of the slits in both analyzers (w x h).

First slit	**Front aperture**	**Input slit of stripping chamber**		**Output slit of stripping chamber**	
Both NPA	Both NPA	5-Ch NPA	Acord-12	5-Ch NPA	Acord-12
30x5.5 mm^2	10x10 mm^2	2x15 mm^2	2x2 mm^2	3x15 mm^2	3x2 mm^2
20x4.0 mm^2	10x1 mm^2				
12x2.0 mm^2	10x0.1 mm^2				
25x2.5 mm^2					

The table 5 presents the values of the solid angle for various positions of the slits for both analyzers.

Table 5: Solid angle for front aperture = 10x10 mm^2

First slit	**Solid Angle** 5-channel ster· m^2	**Solid Angle** Acord-12 ster· m^2
30x5.5 mm^2	$5.51 \cdot 10^{-9}$	$1.58 \cdot 10^{-9}$
20x4.0 mm^2	$2.94 \cdot 10^{-9}$	$7.66 \cdot 10^{-10}$
12x2.0 mm^2	$8.82 \cdot 10^{-10}$	$2.30 \cdot 10^{-10}$
25x2.5 mm^2	$2.29 \cdot 10^{-9}$	$5.98 \cdot 10^{-10}$

5-channel:
If front aperture is 10x0.1 mm^2 then solid angle has to be divided by 100.
If front aperture is 10x1.0 mm^2 then solid angle has to be divided by 10.

Acord-12:
If front aperture is 10x0.1 mm^2 then solid angle has to be divided by 20.
If front aperture is 10x1.0 mm^2 then solid angle has to be divided by 2.

4.- Vacuum

4.1.- *Pumping*

In order to get the required vacuum several pumps are applied. In the Acord12 line there are 3 turbo molecular pumps. One of them pumping the flight-line-tube is located close to the TJ-II vacuum port to avoid the incoming of nitrogen from the stripping cell into the TJ-II vacuum vessel. The other two turbo molecular pumps are located at the beginning and at the end of the stripping cell (before and after the input and output slits) in order to determine exactly the length of the nitrogen stripping chamber where the neutrals are ionized.

The scheme in the 5 channel line is very similar to the Acord12 line. The only difference is that the two pumps in the stripping cell are changed by one turbo molecular pump with two entries before and after the stripping cell.

The pumps used in the diagnostic are listed in the table 6.

Table 6: Pumps operating in the CX diagnostic.

Pump	Model	Capacity
First slit CX12	Varian Turbo-V 300 HT	300 l/s
Beginning stripping cell CX12	Varian Turbo-V 300 HT	300 l/s
End stripping cell CX12	Varian Turbo-V 300 HT	300 l/s
First slit CX5	Varian Navigator TV 551	551 l/s
Stripping cell CX5	Pfeiffer-Balzers	400 l/s

4.2.- *Stripping chamber and feedback of nitrogen*

The stripping chamber is filled by nitrogen gas to produce the stripping of the neutrals by means of elastic collisions between the hydrogen atoms coming from the plasma and the nitrogen molecules. So the resulting ions would be deflected by the electric and magnetic fields to check their energy and mass.

The stripping cell must be at low pressure to ensure single collisions of the atoms. The amount of stripping reactions is linear with the pressure (for N_2 Pressure $< 8 \cdot 10^{-4}$ Torr), and thus the pressure in the stripping cell has to be taken into account during the analysis of the data.

5.- Electronics

5.1.- *Connection*

The scheme of the electric connections of the two lines of the diagnostic are shown in figure 5. The lists of the wires are presented in the tables 7 and 8.

Table 7: List of wires in 5 channel analyzer.

NUM.	DESCRIPTION	WIRE	DIM. (m)
72100	stripping pressure monitoring CX1	coaxial	7m
72101	power supply of detectors CX1, (4 kV, 5 mA)	coaxial	4m
72102	power supply of voltage dividers CX1, (2kV, 5mA)	coaxial	4m
72103	power supply of voltage dividers CX1, (2kV, 5mA)	coaxial	4m
72104	power supply of cleaning condenser CX1, (2kV, 5mA)	coaxial	4m
72105	power supply of counters CX1	expander	4m
72111	CX1 signal to CAMAC	coaxial	4m
72112	CX1 signal to CAMAC	coaxial	4m
72113	CX1 signal to CAMAC	coaxial	4m
72114	CX1 signal to CAMAC	coaxial	4m
72115	CX1 signal to CAMAC	coaxial	4m

Table 8: List of wires in Acord12.

NUM.	DESCRIPTION	WIRE	DIM. (m)
72200	stripping pressure monitoring CX2	coaxial	7m
72201	power supply of detectors CX2, (4kV, 5mA)	coaxial, high voltage	4m
72202	power supply of analyzing condenser CX2, (4kV, 5mA)	coaxial, high voltage	4m
72204	power supply of cleaning condenser CX2, (2kV,100mA)	coaxial, high voltage	4m
72205	power supply of preamplifiers CX2	expander	6m
72206	power supply of electromagnet CX2, (30 V, 5 A)	current	4m
72207	power supply of electromagnet CX2, (30 V, 5 A)	current	4m
72208	power supply of hall probe CX2, (2 V, 80 mA)	current	4m
72209	power supply of hall probe CX2, (2 V, 80 mA)	current	4m
72210	CX2 signal to CAMAC	coaxial	4m
72211	CX2 signal to CAMAC	coaxial	4m
72212	CX2 signal to CAMAC	coaxial	4m
72213	CX2 signal to CAMAC	coaxial	4m
72214	CX2 signal to CAMAC	coaxial	4m
72215	CX2 signal to CAMAC	coaxial	4m
72216	CX2 signal to CAMAC	coaxial	4m
72217	CX2 signal to CAMAC	coaxial	4m
72218	CX2 signal to CAMAC	coaxial	4m
72219	CX2 signal to CAMAC	coaxial	4m
72220	CX2 signal to CAMAC	coaxial	4m
72221	CX2 signal to CAMAC	coaxial	4m
72222	CX2 signal to CAMAC	coaxial	4m
72230	Hall probe signal to VXI	coaxial	4m

5.2.- *Power supply*

The voltage suppliers to the analyzers are following: 7 Standford Research Systems PS350 with a maximum applied supply of 5000V, 25W and 1 Tektronikx PS2521G.

The 4 the PS350 are applied in the 5 channel analyzers:

- One is to supply voltage to all the 5 electron multipliers (Ud, 4000V).
- Two others are for feeding the cylindrical condensers of the channels and the analyzing condenser (Ua, up to 2000 V).
- Last one for feeding the cleaning condenser (Ucc, 1500 V).

The following sources are used In the Acord12:

- One of them is to supply voltage to all the detectors (Ud, 2800 V).
- Second is to supply voltage to one plate of the analyzing condenser (Ua, up to 5000 V), another plate is grounded.
- The Tektronix module is applied to supply current to the electromagnet (Iem, up to 2 A) and Hall probe (80 mA, up to 2 V).
- Last one is for power supplying the cleaning condenser (Ucc, 1500 V).

A scheme of the power supply of both analyzers is shown in figure 6 [4,6].

6.- Magnetic fields screening

The magnetic fields in the vacuum vessel of the TJ-II could be varied if the diagnostics around it become magnetized. To avoid this problem one has to ensure that the magnetization of the diagnostic is under a certain value. The calculated value of the maximum magnetic volume allowable in the position of the CX is of 0.17 m^{-3} (if the value of the magnetic susceptibility is taken as 3) not to affect the magnetic field of TJ-II. The value of the magnetic volume of one of the spectrometers is of 0.006 m^{-3}. This value is well bellow under the maximum allowed value, so the diagnostic does not affect the magnetic field of TJ-II.

7.- CX control

7.1.- *Trigger*

A start signal is used to have the same time reference in all the channels of the CAMAC. To avoid electrical connections of the control room with the torus hall the trigger signal is an optical one. The trigger of the CX is in channel 25 of the panel 1 in the triggers sections of TJ-II [7].

The trigger is a light-darkness pulse (1-0 pulse). The signal starts with 400 ms of light (1), after 500 ms of darkness and then continuous light (1). When the second period of light begins the CAMAC starts the acquisition of data. The darkness period serves to reset all the counting channels to 0 and so not accumulate counts from one shot to another [8].

7.2.- *Vacuum protocol*

The vacuum at the TJ-II port is meassured by two vacuum gauges, one for each analyzer. The analyzers can be connected to the TJ-II vacuum chamber independently.

There is a maximun allowable pressure defined by the physicist in charge of the operation in agreement with the general TJ-II vacuum protocol. If for any reason the pressure is higher than the allowable value the conection valve will be automaticly closed by the system.

7.3.- *Remote control*

The position of the diagnostic and the valves control is done by means of a remote control system [9]. To realize the control requirements a PLC (Programmable Logic Controller) has been used. This PLC is connected with the PLC's of other diagnostics through a Profibus network (PROcess Field BUS) using an optic fiber.

The PLC assumes the control in real time and communicates with the other participants of the Profilbus network getting parameters and orders to change its state. Any wrong data that is not in the established limits of the controller will be refused by it and they will not be executed.

The integration of the Profibus network in the basic Ethernet network has been done through a PC with Windows NT server which plays the role of communication gateway between both networks.

To act remotely from any terminal connected to the Ethernet network of TJ-II the monitoring screens of the diagnostic have been programmed in the server. The application compiling all the information from the field network is BridgeView. It permits to program all screens for the diagnostic. Also this software has the possibility of publishing the control screens through HTML pages.

Three security levels have been established to guarantee the correct behavior of the diagnostics and to avoid wrong operations. The first level is established at the diagnostic place. It consists on the action over a mechanical switcher that annuls the possibility of remote controlling the system and only allows local manual control. To get access for the control using the net it is necessary to disconnect the switcher. Also to get the corresponding control screen it is necessary to give an username and password to the server. The third level is established from the control screen. To act over the diagnostic from outside of the Ciemat network the person who is responsible for the diagnostic gives permission. This permission can be given only to a computer whose IP address is previously accepted by the Ciemat network firewall and after introducing other username and password in the remote computer.

The access for the remote control can be done from any terminal connected to the Ciemat net with a web browser, which allows the diagnostic control from different computer platforms. To act over the diagnostic it is enough to introduce the value of the different variables that have to be modified [9].
The control of the power supply of the analyzer condenser of the 5 channel analyzer and the electromagnet of the Acord12 is done through a CAMAC- GPIB interface. The output signal of the CAMAC goes to a DAC (Digital-to-Analogue Converter). The output signal of this DAC is voltage in the range from –5V to +5V. This analogue signal goes directly to the high voltage power supply and control it. Input 5 V corresponds 5 kV. The control of the DAC module is performed by CAMAC commands.

The GPIB interface is installed in the CAMAC crate and it is controlled by the CAMAC controller. The CAMAC controller has a MicroVAX (fuexp6) that is connected to a VAX station (fuexp1), and it can be programmed from there. Because the power supply is controlled by the VAX fuexp1 any computer connected to the Ciemat net can be also connected to this VAX (fuexp1) and control it. Connection from outside of the Ciemat is done trough a firewall, so the computer must be previously identified.

8.- CX Data Acquisition System

8.1.- *Computer scheme*

Once the sources are controlled, the Preliminary Acquisitiòn System (PDA) is started from the external start signal. The output signal from the NPA's detectors goes to the preamplifiers. The preamplifiers are applied for converting short current pulses to the signals of the normalized duration and standard amplitude of NIM. These amplifiers include amplifier and integrated discriminator. The minimal threshold corresponds the input signal of $\sim 2\cdot 10^5$ e. Duration of the formed standard signals is 40 ns. [10]

In the Acord12 there are two 8-channel counters, each of them is used for one row of detectors (hydrogen and deuterium). The counters also have an input for the start signal given by a Time Intervals Generator (TIG). The data is stored in the buffer memory of the counters and after each shot is transferred to the CAMAC controller.

After each plasma discharge the CAMAC exports the information through an incorporated VAX (fuexp6) to the VAX fuexp1. The control program runs on fuexp1, and here the shots are also stored. Also there is a program for storing the experimental data in the TJ-II general data file. It is executed from FUSC computer where the general data from TJ-II are saved. This program retrieves via ftp the data from fuexp1 to FUSC.)

8.2.- Acquisition programs

There are two main programs in the acquisition system of TJ-II: npa12 and getcx2.

npa12:

The program NPA12 runs under VMS in the VAX fuexp1. It is placed in the directory 1DIA1:[CX.NPA] of user CX. The directory may be reached with the key word "NPA". The program is executed by the command "RUN NPA12"

The presentation screen has 6 options:
1 Change common parameters
2 Change 5-Ch NPA parameters
3 Change 12-Ch NPA parameters

4 Internal shot

This option allows to start the data acquisition without the TJ-II shot. It is used to check the status of the data acquisition program.

5 Waiting for shot

With using this option the program records all the parameters and it is waiting for the next shot to be done.

0 Exit

Change Common Parameters

When this option is chosen a new screen appears with some options:

1 Set Shot Number

It changes the number of the next shot.

2 Set Time Window

It sets the time interval in ms determinant time gate consequence for the counters. The data acquisition is possible only during the high level at the gate input. It is also the time interval of the signals stored in the TJ-II database. It is equivalent to the time resolution. Minimum allowed time window is 1 ms. This limit is determined by the CAMAC counters data transference rate.

3 Set Number of Windows

It sets the number of time windows to be stored, so the multiplication with the time windows gives the time interval along which the signal is recorded.

7 Start Time

It sets when the CX starts to record the signal. It has to be the same as the trigger. It only has storage purpose, the NPA will start always with the trigger signal. This parameter serves to write the time vector in the TJ-II data file.

9 Return to Main Menu

It returns to the previous screen.

There are some more options but they are not used.

Change 5-Ch NPA Parameters

In this option a screen appears with the following options:

1 Set energy

It sets the energy of the lowest energy channel. Fixing the energy of the first detector determines the energy of the other detectors. The possible programmed values of this parameter is from 100 eV to 500eV with steps of 25 eV, so the maximum energy reached is 1975 eV in the 5th channel when the energy in the first is set to 500 eV. This is the case of the TJ-II stellarator, but the 5-channel analyzer is capable to reach up to 20 keV in the 5th channel [5].

2 Set gas pressure

The pressure in the stripping cell is recorded with this option. It doesn't change anything in the CX because the change of the pressure in the CX is done manually. It is necessary to record it since the detection efficiency of the analyzer is normalized to the pressure $1\cdot10^{-4}$ Torr.

3 Set Front Aperture of NPA

It records the value of the aperture of the NPA. As before, it doesn't change anything in the machine but only in the data file.

4 Set First Slit

It is the same as option 3 but for the first slit

9 Return to Main Menu

It returns to the previous screen.

Change 12-Ch NPA Parameters

This option has the same structure as the 5-Ch. The only difference is the energy settings. It changes the energy of the lowest hydrogen channel. In this case it varies from 100 eV (minimum in the first hydrogen channel) to 4370 eV (highest in the 6th hydrogen channel). In the deuterium channel the first energy is half of that of the hydrogen, and the other are in relation with this one. As the case of the 5-channel analyzer, these values are for TJ-II plasmas, in fact the maximum reachable energy with Acord-12 is up to 100 keV. [4]

getcx2

It is the program used to transfer the data from fuexp1 to FUSC. Data files in fuexp1 are stored in the 1DIA1:[CX.NPA.DATA] directory and they are named as ****.12 and ****.05, where **** is the number of the shot. The getcx2 command runs in the FUSC. It is invoked as "getcx2 ****". Due to security the program npa12 writes the number of the shot on the first line of the data file. Thus the program getcx2 checks the shot number written in the file with the name of the file. They must be the same, otherwise the transfer will not be allowed.

8.3.- Analysis programs

In order to deduce the ion temperature the raw data must be treated. To do it two programs are implemented, both for the 5-channel analyzer and the Acord-12 respectively: ti1 and ti2. Both programs are almost equals with slight differences in the menus that don't affect on the calculation method.

The first screen is a general one. It introduces the main parameters of the analysis.

1 Number of shots for the analysis
2 Shot numbers
3 Initial time (ms)
4 Final time (ms)
5 Detector efficiency
51 Detector energy width
6 Shift in energies (eV)
7 Minimum allowed signal to noise ratio
8 Number of time windows to accumulate

The options 5, 51 and 6 are only implemented in ti1. The program developed for Acord-12 analyzer contains these parameters as internal ones because these parameters don't change.

The option 8 is the time interval chosen to do the analisis.

After that screen there is the possibility of writing the fluxes on the terminal. If this option is chosen various tables (one for each time of analysis) will be written in the screen. In these tables the first row is the energy of the channel. The second one shows the flux as the function of the energy. The third row writes the logarithm of the flux. In the fourth row the counting rates are written. In the fifth row there is the noise signal (only if available). And in the last one the ratio between the signal and the noise are presented. The absolute fluxes can be also plotted on the screen.

To perform the analysis with a noise shot, it is only needed to introduce a shot number with the energies of the detectors decreased down to 0 in the list of shots given to analysis. Then the program will detect this as a noise shot and use it to do the following analysis.

Once the fluxes were calculated the program starts to calculate the ion temperature and asks if you want to plot the fits. If you don't want to plot them the program will calculate the temperature with the last settings saved. Otherwise for each temporal window the program will ask the settings for the fitting. These settings are the following:

1 Minimum regression factor

It allows a more or less accurate fitting of the line to the experimental values.

2 Number of energies to exclude

When this option is chosen the program shows the list of energies in order to facilitate the duty of excluding one of them.

3 Excluded energies

4 Excluded channels

This option allows to exckude the data from one energy channel.

5 Maximum energy to fit (only available in ti2)

This option disregards the data collected above this energy.

6 Factor of Ti for spectrum inflexion energy

This factor indicates the energy at which the program starts to fit the second linear fit of the data. It is necessary to do it for present of a non-maxwellian ion tail. This energy is equal the ion temperature calculated with the first linear fit multiplied by this factor.

After doing the fitting for each window time the program asks about writing the results in the TJ-II data file. The nomination of these files is done automatically: Ti1_ for one single shot with the 5-channel analyzer, Ti1serie_ for more than one shot and, correspondingly, Ti2_ and Ti2serie_ for the Acord-12.

Acknowledgment

We would like to thank A. López and his team for all the work done on the remote control of the system, B. v. Milligen for the system management of the FUEXP1 and CAMAC, F. Aragón and the vacuum team for the maintenance work done and J. López for his help with electronics in general.

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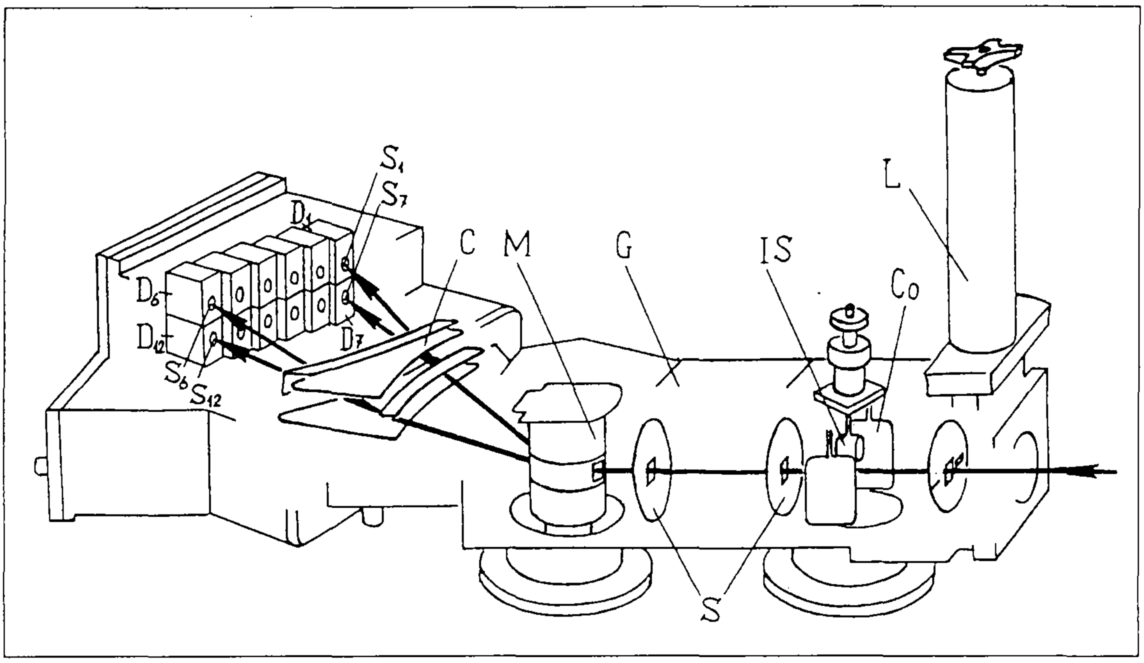

Figure 1. Scheme of the Acord12. L is the vacuum valve; IS is the alkali ion source; C_0 is the cleaning condenser; G is the stripping chamber; S are the stripping chamber slits; M is electromagnet; C is analysing condenser; S_1-S_{12} are input channel slits; D_1-D_{12} are detectors.

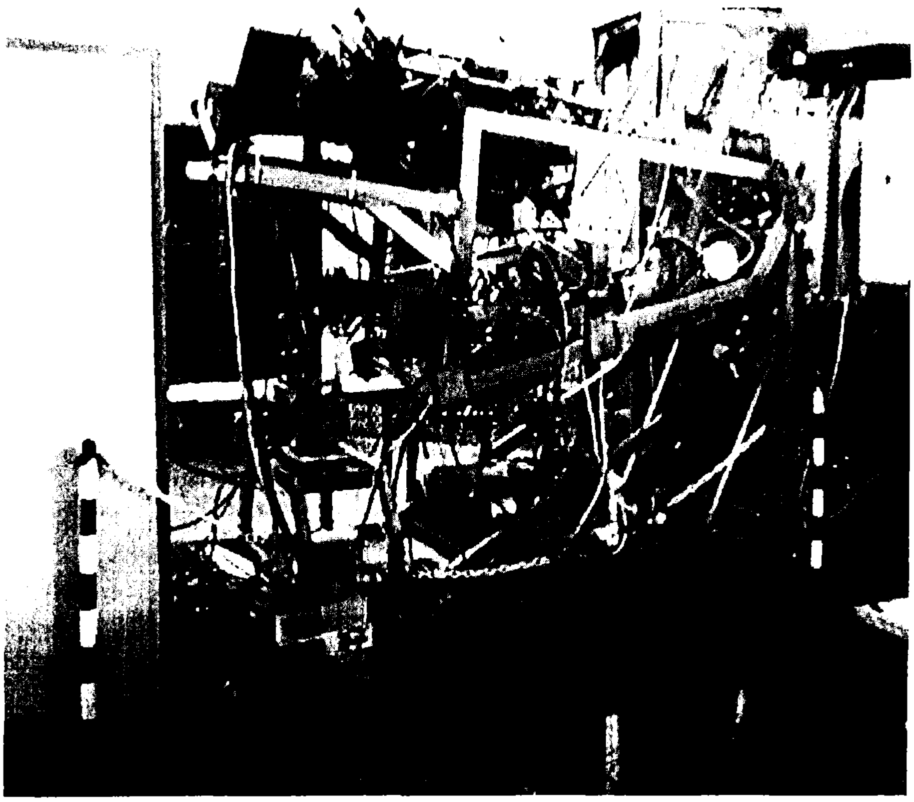

Figure 2. The charge-exchange neutral particle analyser diagnostic in TJ-II.

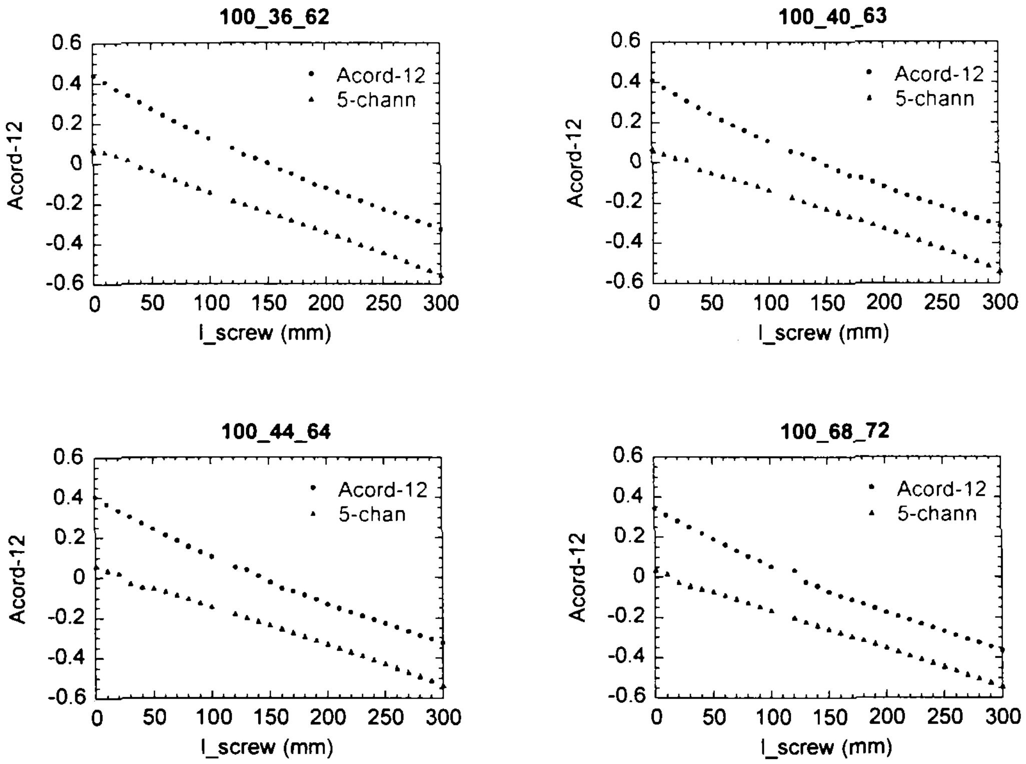

Figure 3 Effective radius scanned as a function of the length of the screw (parameter in the remote control screen), for the two neutral particle analyser for different magnetic configurations of TJ-II. The three numbers in the name (i.e. 100_44_64) refer to the different currents in the TJ-II coils that determine the configuration.

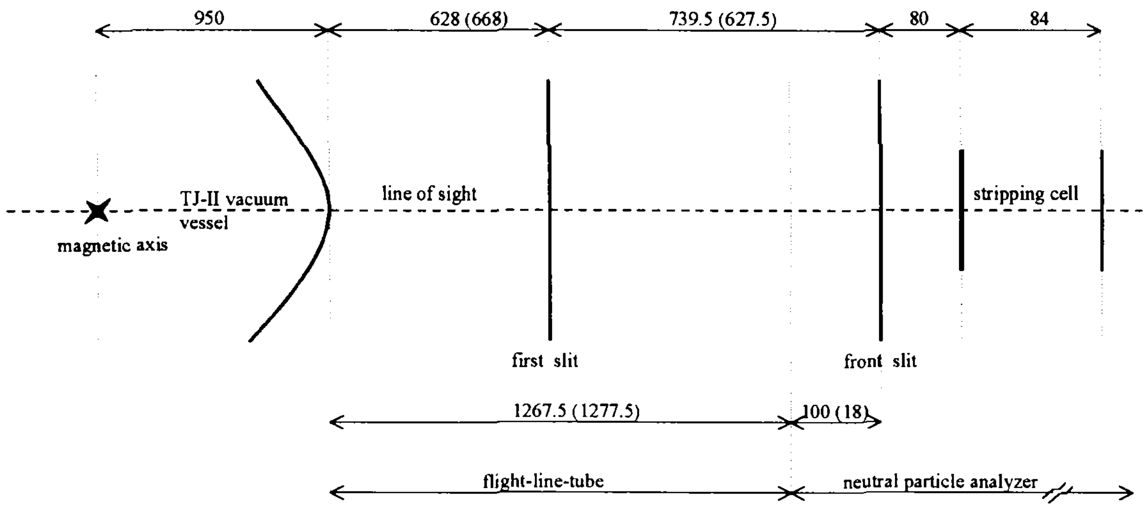

Figure 4. Scheme of the slits in the analysers and the different slits in the path of the neutrals, from left (vacuum vessel) to right (exit of the stripping cell). The numbers are the distance in milimeters in the Acord12, in brackets those corresponding to the 5 channel analyzer when different of Acord12.

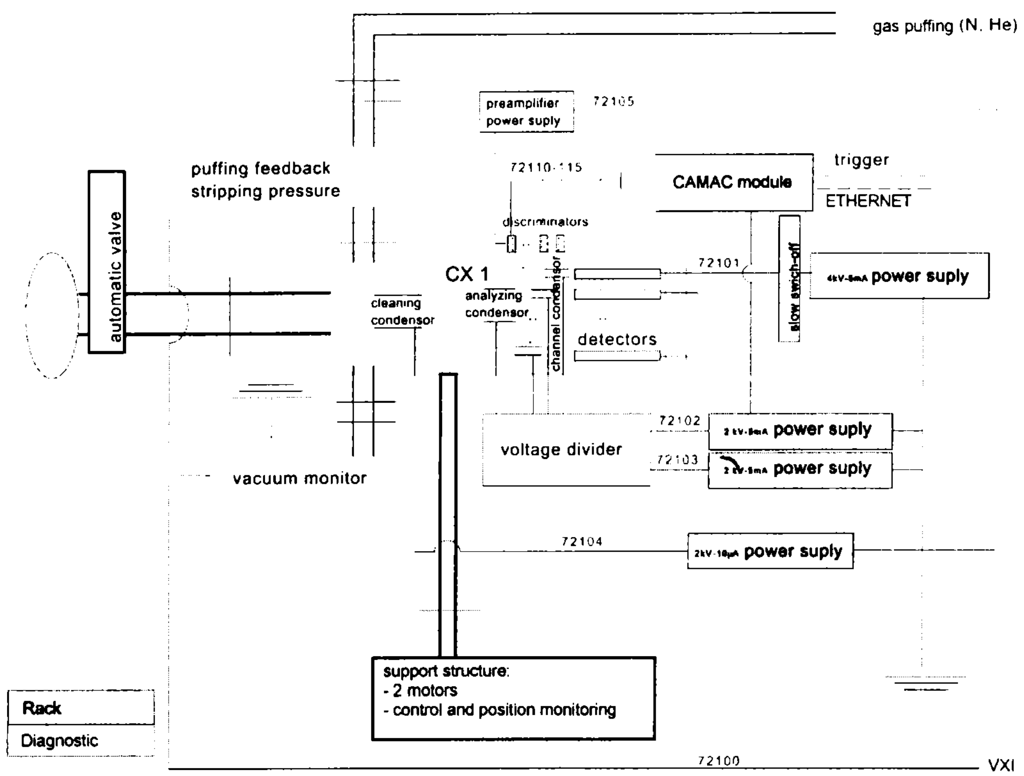

Figure 5a. Scheme of the electric connections for the 5- channel analyser.

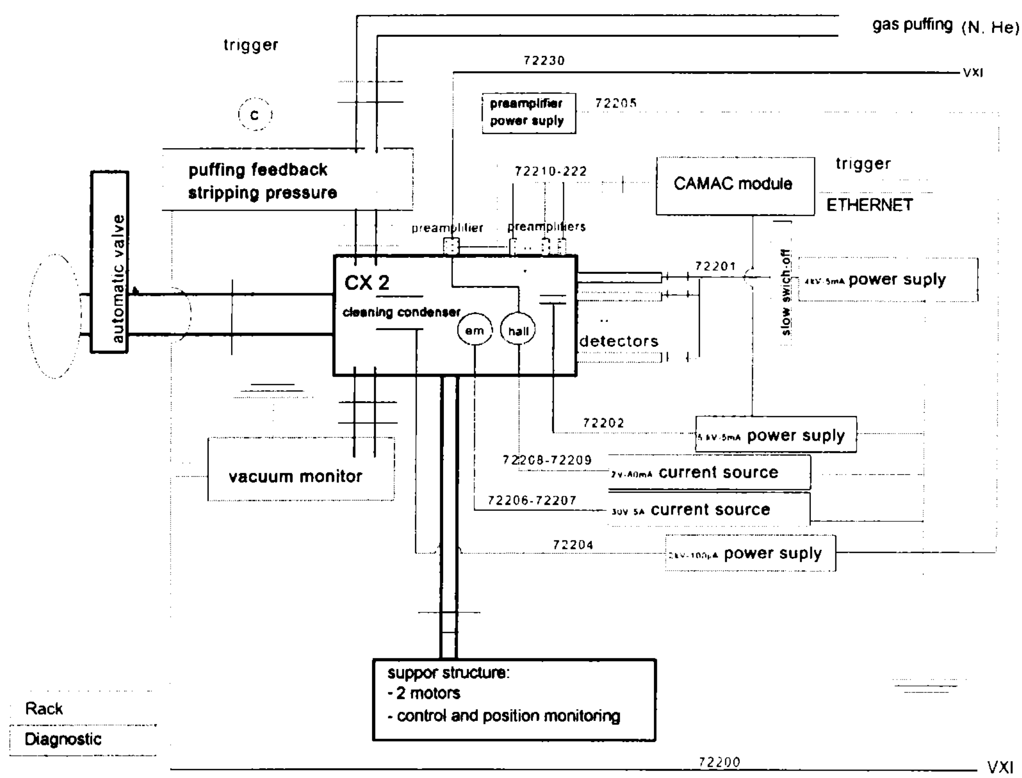

Figure 5b. Scheme of the electric connections for the Acord12.

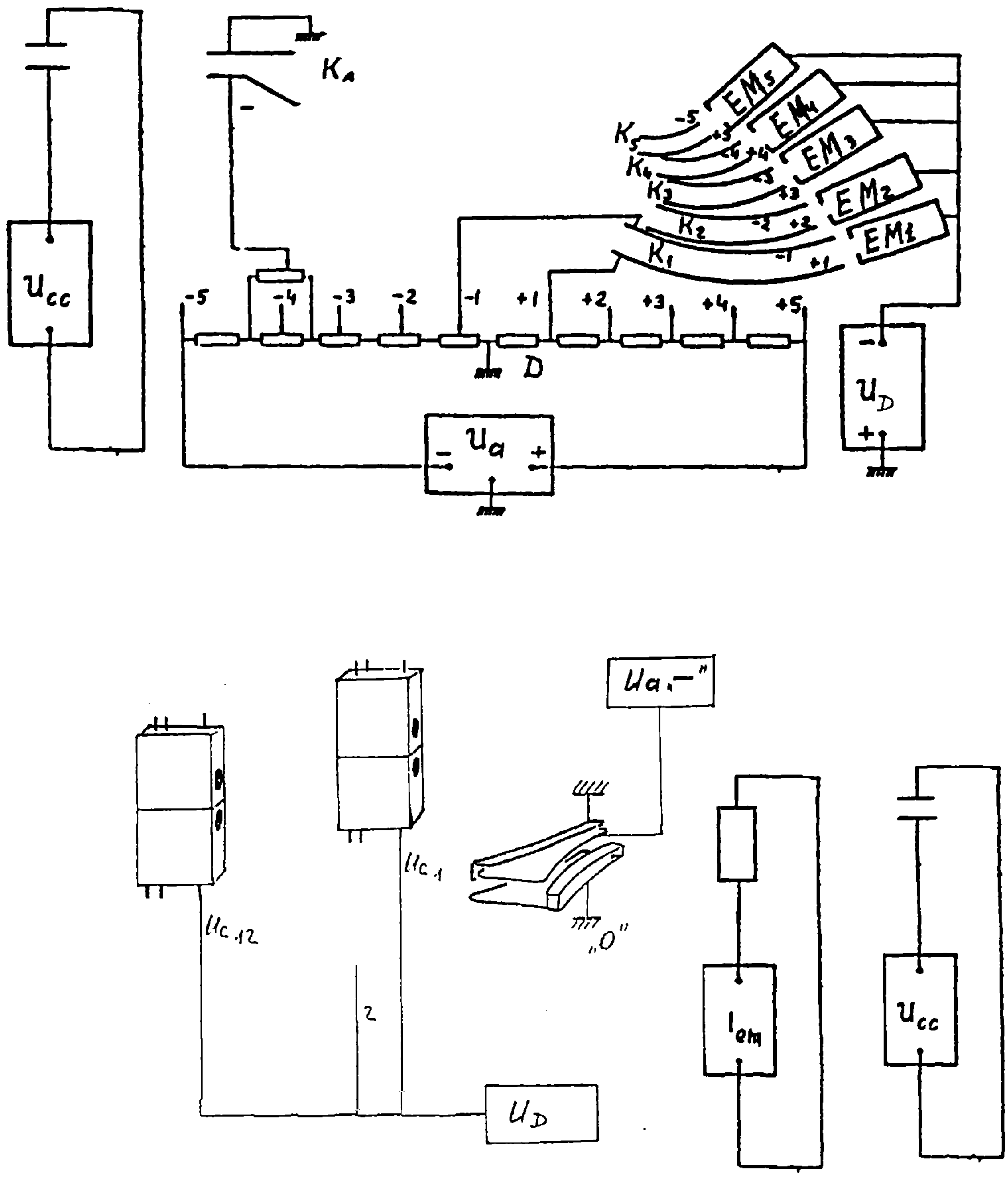

Figure 6. Scheme of the power supply of both analysers, 5-channel analyser (up) and Acord12 (down). U_{cc} is the voltage to the claening condenser; U_a is the voltage to the analyser condenser (in 5-channel analyser also to the condensers of the channels), in the 5 channel analysers the U_a is supplied by two power supply; U_D is the voltage applied to the detectors; and I_{em} is the current source applied to the electromagnet.