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NATIONAAL INSTITUUT VOOR KERNFYSICA EN HOGE-ENERGIEFYSICA

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THE VACUUM PROFILE OF THE ENERGY SPECTRUM COMPRESSOR

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(NIKHEF section K, dep. MTG)
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Abstract

A finite element model has been made of the vacuum system of the Energy Spectrum Compressor. It gives the possibility to calculate the average pressure profile of the system in a fast way. It is required that the average pressure in the system does not influence the present performance of the linac nor the performance of the beam switch yard. Calculations show that with standard pumps of 60 l/s an average pressure of $< 10^{-5}$ *Pa can be obtained.*

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A finite element model has been made of the vacuum system of the Energy Spectrum Compressor. It gives the possibility to calculate the average pressure profile of the system in a fast way. It is required that the average pressure in the system does not influence the present performance of the linac nor the performance of the beam switch yard. Calculations show that with standard pumps of 60 l/s an average pressure of < 10^{-5} Pa can be obtained.

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1. Summary.

This report deals with the pressure profile of the Energy Spectrum Compressor (ESC) vacuum line. A finite element model has been made of the vacuum system. This model gives the possibility to calculate the average pressure profile along the system in a fast way. It is important that the average pressure in the system does not influence the present performance of the linac, and that the pressure in the RF-cavities will not exceed 10^{-6} *Pa*. Using standard ion-getter pumps of 60 *l/s* it is shown that outgassing of the ESC system does not affect the pressure in the cavities of the linac and the pressure in the Beam Switch Yard (BSY). Furthermore, the pressure in the buncher section of the ESC can be kept in the 10^{-7} *Pa* range.
To obtain this the pumps have to be placed on the first and the last curved-section, the collimator, the Secondary Emission Monitor (SEM) and buncher section.
An average pressure of < 10^{-5} *Pa* in the curved-sections can be obtained

2. Introduction.

In 1992 the Amsterdam Pulse Stretcher (APS) should be operational. One of the requirements is an upgrade of the performance of the Medium Energy Accelerator (MEA).
In the table below main beam parameters are given for present and future operation of MEA.[1]

MEA beam parameters

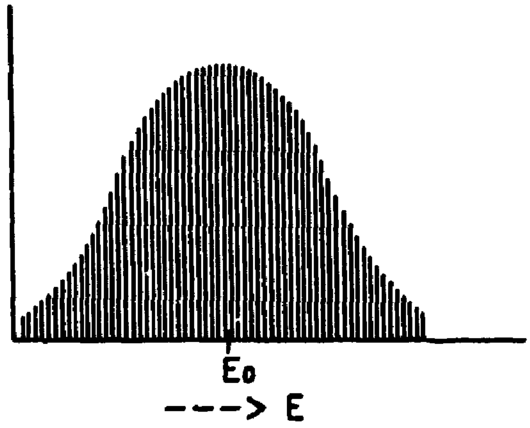
		Present Mea	Mea for PS-mode
E_{max}	$[MeV]$	500	900
Beam pulse length	$[\mu s]$	40	2.1
Repetition rate	$[Hz]$	500	365
Beam duty factor	[%]	2	0.1
$\hat{i}$	$[mA]$	10	60-80
$\bar{i}_{target}$	$[\mu A]$	100	40
$\delta E/E_0$	[%]	0.4	0.1

The increase of peak current ($\hat{i} = 10\,mA \rightarrow 80\,mA$) will result in a degradation of energy width $\delta E/E_0$ of the bunch. To keep the degradation within the acceptance range of the APS, the energy spread has to be reduced by means of an energy spectrum compressor.
An increase of pressure is also expected, because of the radiation on the first collimator and the photon/electron stimulated desorption in the curved-sections of the ESC. This pressure rise may not influence the pressure in the RF-accelerator sections in the linac. The pressure in those sections must be $< 10^{-6}\,Pa$. The buncher section of the ESC requires the same pressure as the RF-accelerator sections.
Also the BSY may not influence the pressure in the ESC, especially the pressure in the buncher section.

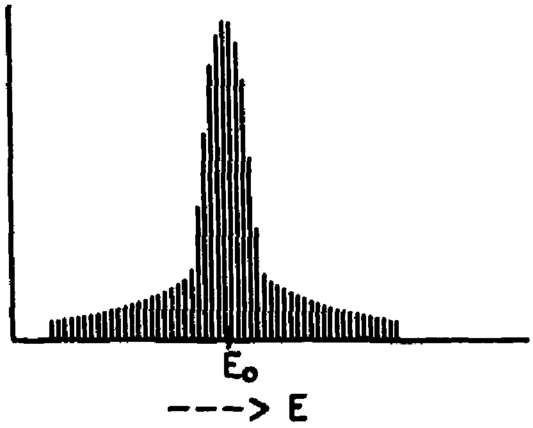
3. The Energy Spectrum Compressor.

At present $E_{max} = 500\,MeV$, $\hat{i} = 10\,mA$ the energy spectrum width $\delta E / E_0$ of MEA is $\approx 0.4\,\%$ In 'upgraded mode' $E_{max} = 900\,MeV$, $\hat{i} = 80\,mA$ a degradation of the energy spectrum width of $\delta E / E_0 \approx 1.0\,\%$ is expected.[1] The design of the APS is such that only a spectrum width up to 0.1 % can be accommodated. To realize this an ESC will be installed between the linac and APS. This is shown in figure A1.

The ESC consists of four magnets (curved sections) and a Radio Frequency bunching section (RF-cavity). In the curved sections path-length differences are created for particles with different energy. the RF-cavity, positioned at the end of the ESC, will increase the energy of particles of $E_0 - \delta E$, which arrived later than the 'reference' particle E_0. Particles of energy $\delta E + E_0$ will be slowed down, because they arrive to early.
Full details on the ESC are given in APS/88-05.[2]



Energy width before compression.



Energy width after compression.

4. The element configuration.

The ESC can be divided in several elements. Each element consists of several parameters and variables. A mathematical model can be formed by chaining the elements.

For the pressure calculations of the ESC every mechanical component is defined as a single element, with exception for the constructions with a strong change in aperture. e.g: the collimator is divided in three elements; front-section, where most of the degassing will occur due to beam radiation, middle-section and end-section where the beam position monitor is installed.

Generally we can define:

$$\sum_{i=1}^{n} Q_i = \sum_{i=1}^{n} p_i S_i \tag{4.0}$$

Where n is the total number of elements.

For each element, desorption can be defined as:

$$Q_i = -p_{i-1}C_{i-1} + p_i[C_{i-1} + C_i + S_i] - p_{i+1}C_i \tag{4.1}$$

and:

$$C_i = 4(W_i + W_{i+1})^{-1} \tag{4.2}$$

Where Q_i is the total desorption, p_i the pressure, S_i the effective pumping speed, C_i the conductance between element i and $i+1$ and W_i the molecular flow resistance (MFR) of element i.

The MFR depends on the geometry of the element and can be expressed as:

$$W = W_d + W_\infty \tag{4.3}$$

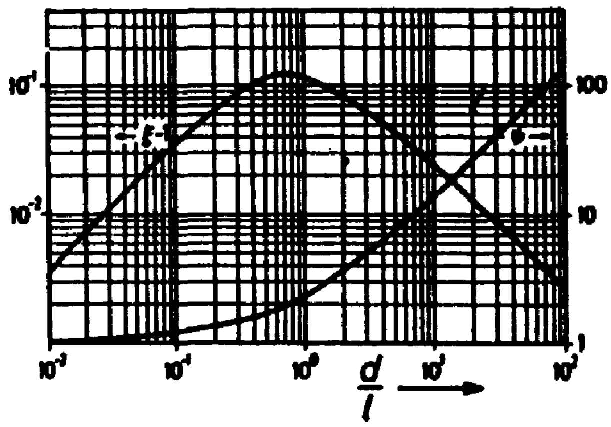
with:

$$W_\infty = \left[\frac{2\pi M_{molar}}{RT}\right]^{1/2} \frac{3Ul}{16A^2}\Phi \tag{4.4}$$

and:

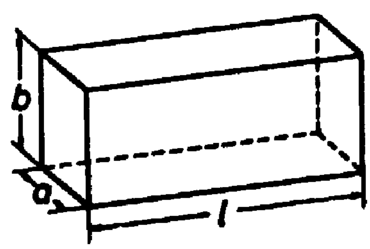
$$W_d = \left[\frac{2\pi M_{molar}}{RT}\right]^{1/2} \frac{1}{A} \tag{4.5}$$

Where W_∞ is the MFR of an infinitive long tube, W_d is the MFR of a orifice, A is the cross-section, l the length, U the circumference, M_{molar} the molecular weight of the residual gas, and Φ the form factor of the element.
The form factor Φ depend on the aperture of the element.
For a circular tube Φ can be expressed as $\Phi = \Psi\xi$. The factors Ψ and $\xi-1$ can be found in the graph below.



For a rectangular aperture, Φ is defined as below.

$\frac{b}{a}$	1	0,667	0,500	0,333	0,125	0,100
Φ	0,903	0,888	0,869	0,835	0,714	0,693



The gas-load Q depends on material, cleaning procedures, beam-load and time. The pumping speed depends on the resistance of the pump-out of the element and the capacity of the (supplied) pump, and can not exceed the reciprocal of the MFR.

The pressure is the only unknown value, and with n elements there are n equations with n unknown values. With computer calculations[3] a total element configuration is constructed and the pressure profile calculated.

5. Calculation.

Calculations have been made to determine the pressure profile of the ESC in 4 different pumping set-up's.
The three main values required to solve the equations are the MFR, the total desorption Q and the pumping speed of the element. The element configuration of the ESC is shown in figure A2.

The MFR is calculated with equations (4.3) (4.4) (4.5) using the dimensions of the element. Determination of the desorption Q is somewhat more complex than the MFR calculations. The total gas-load Q of an element is mainly a function of 2 contributions:

- Desorption in stationary situation after long time pumping with no beam.
- Photon/electron stimulated desorption (PSD) due to synchrotron radiation.

So we can say for each element:

$$Q = (q_{stat} + q_{PSD})A_{in} \tag{5.1}$$

Where Q is the total gas-load, q_{stat} the stationary desorption-rate, q_{PSD} the photon stimulated desorption-rate and A_{in} the internal area of the element. q_{stat} depend on material and cleaning procedures; in case of aluminium as material the initial desorption-rate is $< 10^{-7}$ $Pa\ l\ sec^{-1}m^{-2}$.
q_{PSD} depends on the photon flux due to synchrotron radiation. This can be expressed as:[4]

$$q_{PSD} = \frac{d\dot{N}}{ds}\frac{(DE)_m}{2.5\ 10^{17}}(QE)_e\ \pi D \qquad Pa\ l\ sec^{-1}m^{-2} \tag{5.2}$$

with:

$$\frac{d\dot{N}}{ds} = 1.28\ 10^{17}\frac{IE}{\rho} \qquad photons\ s^{-1}m^{-1} \tag{5.3}$$

Where $\bar{I}$ is the machine current, E the machine energy, ρ the bending radius, $(DE)_m$ the desorption efficiency, $(QE)_e$ the quantum efficiency and D the average diameter of the vacuum system.

For the case of $E_{max} = 0.9\ GeV$, $\hat{i} = 80\ mA$, beam duty factor = 0.1%, $\rho = 2.5\ m$ and $D = 0.4\ m$ the total photon flux is $\approx 6.10^{16}\ photons\ s^{-1} m^{-2}$. With a quantum efficiency[5] $(QE)_e$ of 0.1 and a molecular desorption efficiency[6] $(DE)_m$ of 10^{-4} $mol\ e^{-1}$ the desorption-rate becomes $2\ 10^{-5}\ Pa\ l\ sec^{-1} m^{-2}$.
Due to the uncertainty in determining the desorption-rate in the bellows, collimator and beam position monitor, a safety factor of 4 is used. So the initial desorption becomes about $10^{-4}\ Pa\ l\ sec^{-1} m^{-2}$. This value will decrease gradually to $10^{-5}\ Pa\ l\ sec^{-1} m^{-2}$ after a beam dose of 10–100 $A.h.$[7]
Effective pumping speeds based on installation of 60 l/s ion-getter pumps are:

- 15 l/s on the first and last curved-section.
- 10 l/s on the buncher section.
- 48 l/s on the SEM section.

The results of the calculation are shown in figure A3 and A4. In figure A3 the results of three calculations are shown.
The first calculation is made with the configuration of pumps as marked above (continuous line). The desorption of the collimator is estimated to be $10^{-2}\ Pa\ l\ sec^{-1} m^{-2}$ due to beam-heating. The rest of the ESC delivers a desorption-rate of $10^{-4}\ Pa.l\ sec^{-1} m^{-2}$.
In the second calculation a pump (eff. 25 l/s) is added at the collimator (8) (dotted line). The front and back-end of the collimator are joined by a vacuum-bypass.
In the third calculation additional pumps are added: the second and third curved-section are equipped with 15 l/s (eff.) pumps (dashed line).
The fourth calculation is shown in figure A4; where the pump is disconnected from the first curved-section.
Both calculations 2 (dotted line) and 4 are shown.

The table below summarizes the different computer runs with respect to the pump distribution. The numbers enclosed in brackets are standing for the element numbers. (Figure A2)

Table of pumping distribution.

Run	1	2	3	4
PS(1)	30	30	30	30
M1(5)	15	15	15	-
Coll(8)	-	25	25	25
M2(11)	-	-	15	-
SEM(14)	48	48	48	48
M3(16)	-	-	15	-
M4(20)	15	15	15	15
RF(27)	10	10	10	10
PS(29)	48	48	48	48

6. Discussion.

From the second calculation is obvious that it is useful to connect a pump to the collimator. The front-end of the ESC will not put any 'pressure strain' on the linac or BSY. Locating pumps at the second and third curved-section makes, economically speaking, no sense, the changes in pressure profile are very small with respect to the second calculation.

In figure A4 we can see the result of disconnecting the pump from the first curved-section in addition to the second calculation. The pressure load on the linac will increase 2.5 times.

Owing to the high field strength in the buncher section the pressure in this section must be as low as in the linac ($< 10^{-6}\,Pa$).
In both figures we can see that there is no influence on the pressure in the buncher. Only on the entrance of the ESC the pressure depends strongly on the pump distribution. It is therefore important that there will be enough pump speed available to keep the linac pressure below $10^{-6}\,Pa$.

7. Conclusion.

The conclusions, based on the results of the calculations, are:

- Pumps have to be positioned at the entrance of the first magnet and at the exit of the last magnet, at the collimator (element 8) and at the SEM section. The collimator has to be connected with a vacuum bypass to insure effective pumping at both sides.

- It is also necessary to position pumps directly after the last linac RF-section and buncher section of the ESC. These pumps will act as a buffer on pressure variations in the BSY or ESC, and will protect the linac vacuum from pressure rise.

- All the pumps to be used must be standard ion-getter pumps of 60 l/s.

With this proposed pump distribution, the linac will still be able to operate with a pressure $< 10^{-6}\ Pa$, and the the pressure in the buncher section of the ESC will be $< 10^{-6}\ Pa$.
The average pressure in the ESC will be in the $10^{-5}\ Pa$ range.

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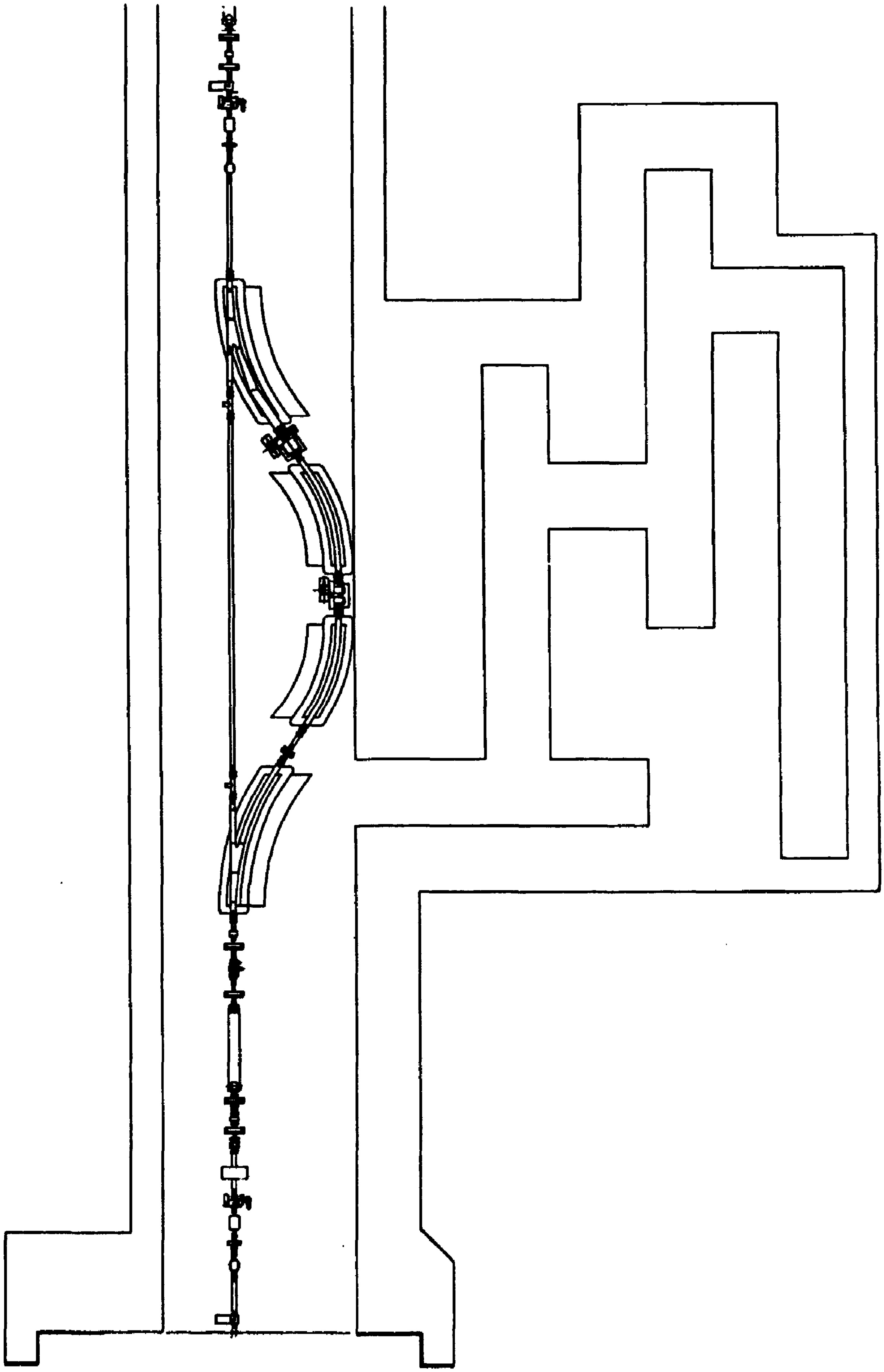

Figure A1. General layout of the ESC

element no.	name.	
1	Pump-section	
2	PM-section	
3	SM-section	
4	Tube	
5	Curved-section	Start ESC.
6	Connection	
7	Bypass	
8	Collimator	
9	Bypass	
10	Connection	
11	Curved-section	
12	Connection	
13	SEM	
14	Pump-section	
15	Connection	
16	Curved-section	
17	Connection	
18	XY monitor	
19	Connection	
20	Curved-section	
21	Connection	
22	Valve section	
23	RM-section	
24	XY monitor	
25	Collimator	
26	RM-section	
27	Buncher	End ESC.
28	RM-section	
29	Pump-section	
30	Valve-section	

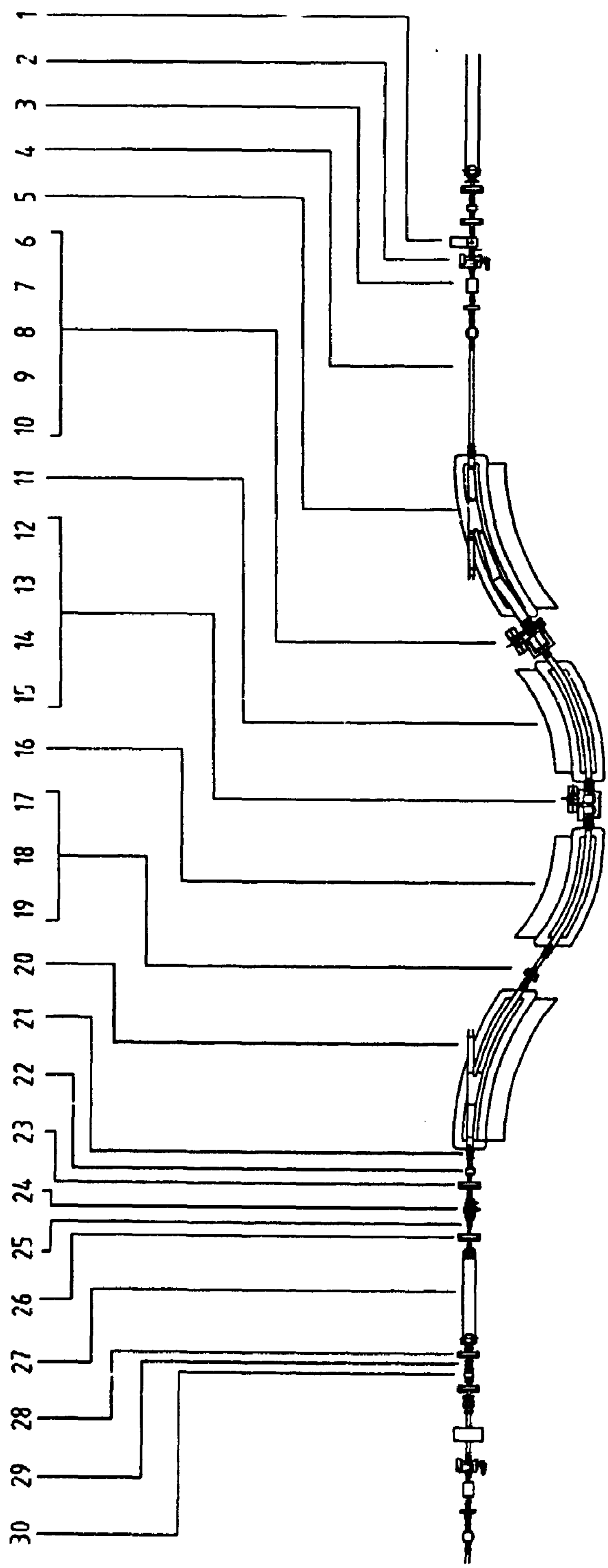

Figure A2. The element configuration of the ESC

Figure A3

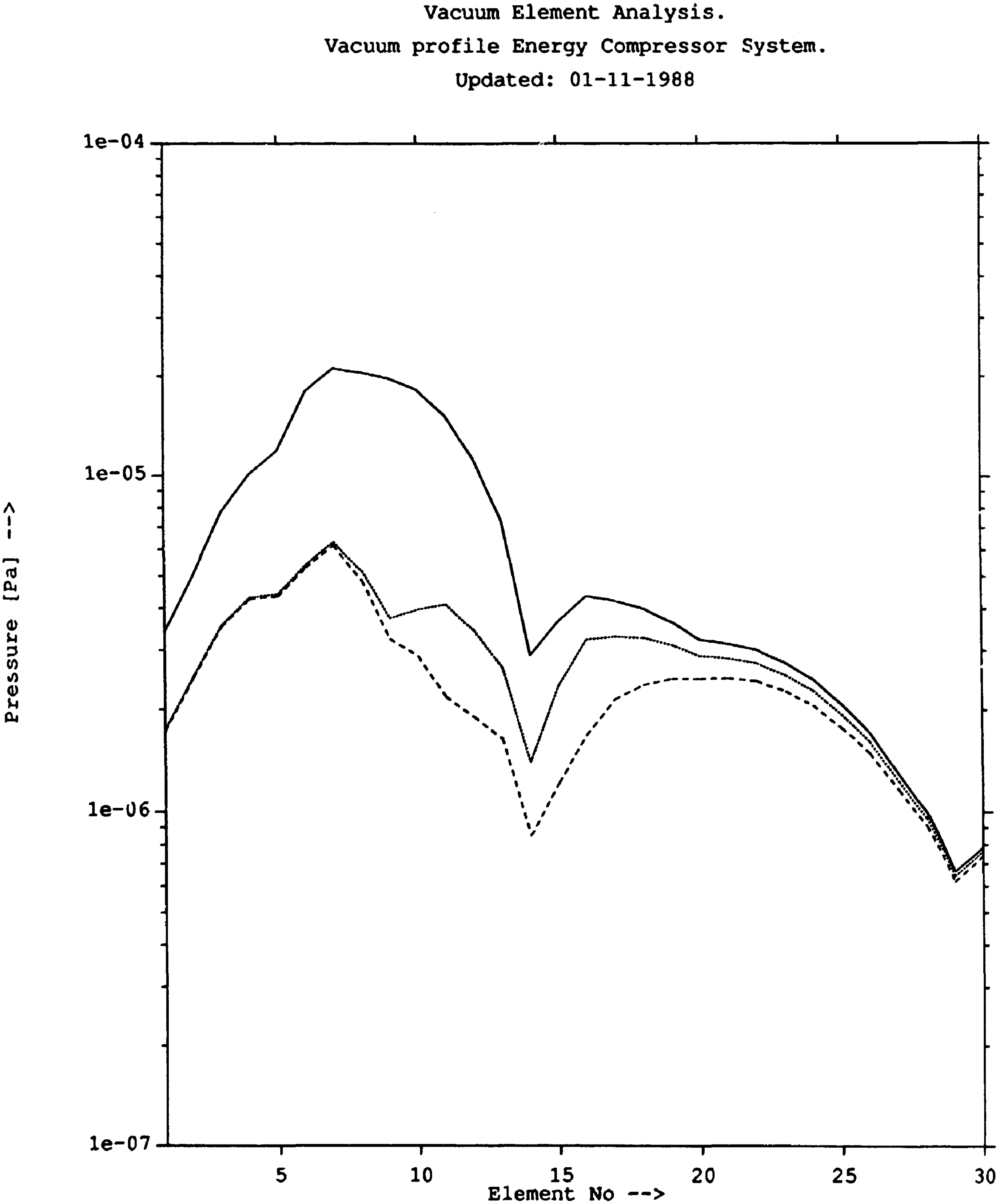

Figure A3. Results of run 1, 2 and 3

Figure A4

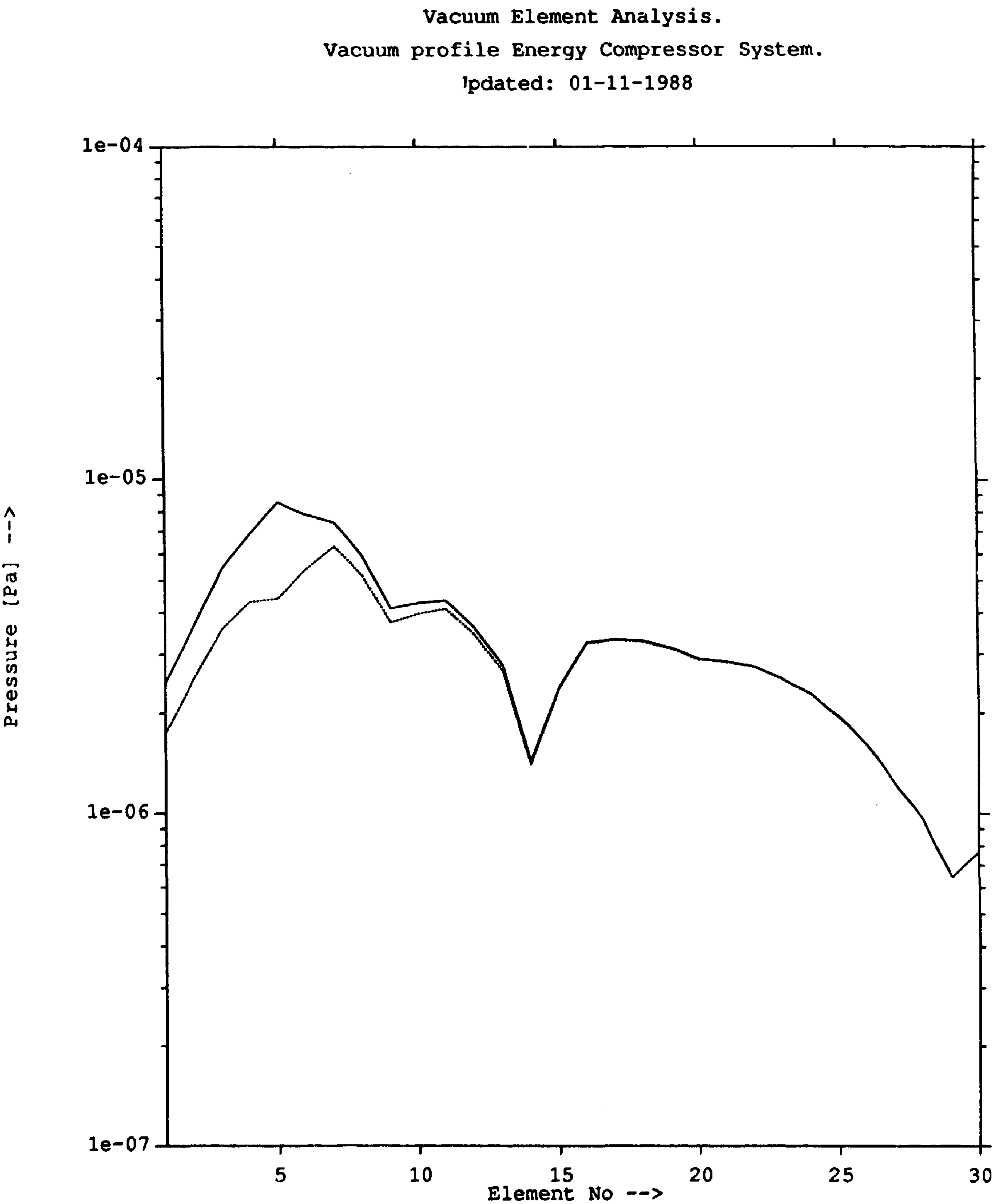

Figure A4. Results of run 2 and 4