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A COMPUTER CONTROLLED ANALYSIS OF A POLARIZED ION SOURCE

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ABSTRACT

A method is described to analyse the operation and efficiency of the polarization determining components of a polarized ion source.

The method is discussed for a ground-state polarized ion source. Examples are given how to infer an insufficient vacuum or an insufficient function of 6-pole-magnets or transition units from a computerized measurement and analysis.

1. Introduction

For new developed polarized ion sources it is desireable to find out to which extend the various components limit the polarization. Since the polarized ion source developed at Bonn [1] comprises a Penning-type ioniser [2,3] with a superconducting magnet, interest arose to study the influence of the stray-field of the superconducting magnet on the operation of the 6-pole-magnets and transition units. For this reason a computer controls a dedicated measurement, the data acquisition, and uses for the interpretation of these data a linear model, by which the various components are described [4].

In the following, this linear model and measurements are discussed for a polarized proton beam of a ground-state polarized ion source.

2. The Method

One of the advantages of the Bonn Polarized Ion Source is that the 4 polarization generating components (two 6-pole-magnets and two transition units) can arbitrarily be put together. It turned out that for the intended kind of measurement the combinations S_1 or S_2 of Fig. 1 allows for a maximum of information. Since, for combination S_1 or S_2 both transition units are topped by a second (compressor) 6-pole-magnet, switching these transitions on and off, results in a loss of intensity and a change in polarization. Considering now that all 4 relevant components are allowed to be switched on and off, leads to 16 possible states of the combination of these components and to 32 measured quantities, because intensity and polarization are measured for each state.

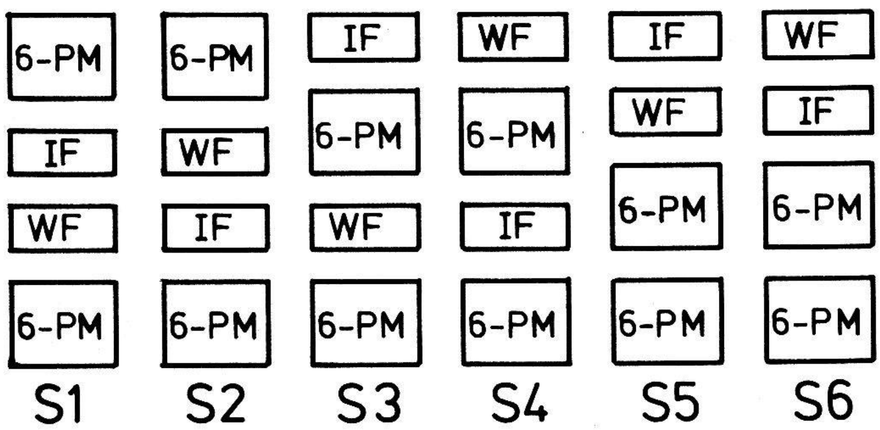

Fig. 1 Combinations of the polarization determining components. IF,WF: intermediate- and weak-field transition, 6-PM: 6-pole -magnet

In order to interprete and extract relevant quantities out of these measurements, the beam is described by a vector $\vec{I}$ built up by 4 components i_1-i_4 which stand for the intensities found in each of the hyperfine components, as shown in Fig. 2. The intensity I and polarization P_y can then be expressed by:

$$I = i_1 + i_2 + i_3 + i_4 \tag{1}$$

$$P_y = \frac{i_1 + i_4 - i_2 - i_3}{i_1 + i_2 + i_3 + i_4} \tag{2}$$

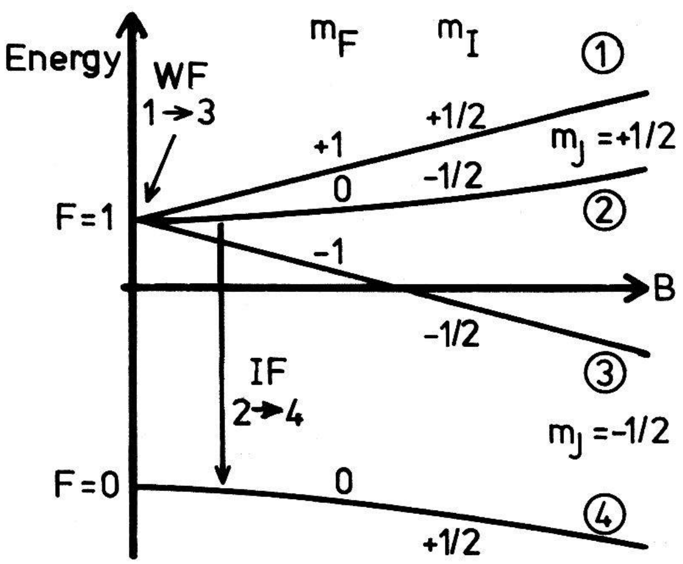

Fig. 2 Hyperfine structure splitting of hydrogen in a magnetic field B. The combined angular momentum of the nucleus(I) and electron(J) is indicated by F. The magnetic quantum number by m.

The beam transport through a polarization-changing element is described by a matrix. Within the frame of a linear model, the change in occupation of the hyperfine components, while passing various elements, is then described by a multiplication of the relevant matrices.

Up to now, nothing has been said about background. Since background is assumed to be unpolarized it is included in eq. (1,2) in the following way:

$$I = i_1 + i_2 + i_3 + i_4 + u \tag{3}$$

$$P_y = \frac{i_1 + i_4 - i_2 - i_3}{i_1 + i_2 + i_3 + i_4 + u} \tag{4}$$

The background u can be split up into two parts:

$$u = u_v + u_a \tag{5}$$

where u_v describes effects due to bad vacuum and u_a takes into account the fact that the ionizing condition and efficiency may change with a varied intensity of the atomic beam. The amount of u_v is tested by switching off the gas supply and the dissociator oscillator.

3. Description of the Components

The 4 polarization generating components of the polarized ion source are described by four types of 4x4 matrices with respect to the transfer of the intensities i_1-i_4. Two different matrices represent the weak-field(WF) transition and the intermediate-field(IF) transition and two types of matrices represent the on- and off-state of a 6-pole-magnet. Out of the 32 measured quantities only 15 turn out to be linearly independent and allow the calculation of the following 12 parameters:

$f_{1/2}$, $d_{1/2}$ are the factors by which the hyperfine structure components of Fig. 2 with respect to the quantum number m_J of the electron-spin are focused or defocused in the 6-pole-magnet 1 or 2.

$g_{1/2}$ stands for the fraction of beam that passes 6-pole-magnet 1 or 2 if it is switched off. Therefore, these factors depend only on the aperture and length of a 6-pole-magnet and its adjustment with respect to the atomic beam.

$I \cdot f_1 \cdot f_2$ is the part of the current that is focused by the 6-pole-magnets.

u_v is the background due to bad vacuum.

u_a reflects changed ionizing conditions when the intensity of the atomic beam is changed.

Z describes the transition probability ($2 \rightarrow 4$) of the IF.

Ω represents the probability of the wanted ($1 \rightarrow 3$) and Λ of an unwanted ($3 \rightarrow 2$) transition of the WF.

Figure 3 shows how the polarization depends on Ω and Λ if the background $u = 0$. Note, for $\Lambda > 0$ the polarization may even have the wrong sign!

4. Results and Discussion

Measurements showed that the operation of the 6-pole-magnets is not influenced by the superconducting magnet. The suppression factor (d/f) of the wrong components is 5% for each 6-pole-magnet. The transition probability Z of the IF is with $Z > 96\%$ satisfactory, if the stray-field of the supercon-

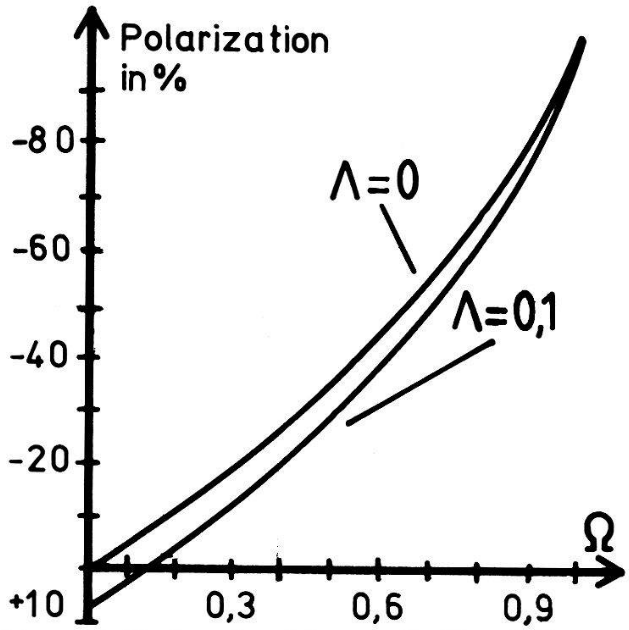

Fig. 3 Polarization of the WF calculated from the transition probabilities Ω (1→3) and Λ (3→2). Everything else is assumed to work perfectly.

ducting magnet is compensated for. This is better demonstrated for the WF by Fig. 4. For a compensating current of 3 A Ω is sufficiently high, whereas Λ could be smaller. A better screening of the superconducting magnet will improve the conditions for the transition units.

With this method even other qualities may be examined. Figure 5 shows how the polarization, Ω, and Λ of the WF depend on the applied RF-amplitude. Compared to Fig. 3 the Ω and Λ values of Fig. 5 result in a polarization being too small. Recalling that Fig. 3 was calculated without taking into account any background implies that the vacuum is too bad. Improving the vacuum by a factor of 3 increases

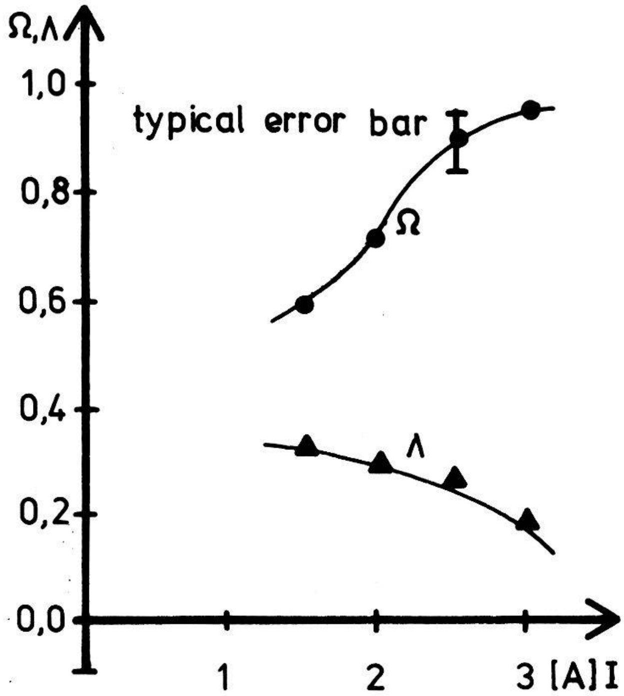

Fig. 4 The transition probabilities Ω and Λ are influenced by a current I, compensating a stray-field.

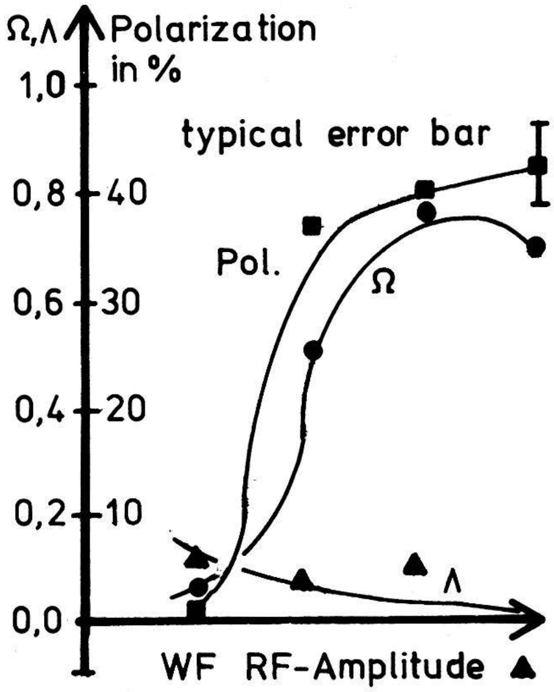

Fig. 5 The transition probabilities Ω, Λ and the polarization depend on the RF-amplitude applied to the WF.

the polarization by 20-30%!

These results show that the method developed is an adequate tool to analyse polarized ion sources. Moreover, the method as such is not limited to the conditions, the examples and discussion in this paper refer to.

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