A DIGITAL RECORDING DOUBLE FABRY-PEROT SPECTROMETER

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Abstract. — A simple and reliable recording double Fabry-Perot spectrometer is described. The linear increase in the first etalon was achieved as usual by means of a pressure reservoir of 200 atm. and a small glass capillary tube. With a second pressure reservoir and a needle valve, the flow rate of which could be changed by a servomotor, the pressure in the second Fabry-Perot was increased. The difference in pressure between the two systems was measured by a mercury manometer, into the limbs of which two 15 μ platinum wires are immersed. The deviation of the pressure difference changes the lengths of the wires not submerged in the mercury, which means a change of resistance. This variation was detected in a bridge and the amplified signal was used to drive the servomotor of the needle valve thereby increasing or lowering its flow rate. In this way the pressure difference could be kept constant to less than $\pm$ 0.03 mm Hg.

Résumé. — On décrit un spectromètre enregistreur à double étalon Fabry-Perot d'un fonctionnement simple et sûr. Dans le premier étalon on fait croître la pression linéairement à l'aide d'une bouteille à 200 atm. et d'un petit capillaire en verre suivant le procédé habituel. On augmente la pression dans le second étalon à l'aide d'une seconde bouteille et d'un robinet à pointeau asservi. La différence de pression entre les deux systèmes est mesurée par un manomètre à mercure dans les branches duquel sont immergés deux fils de platine de 15 μ. Un changement de la différence de pression modifie les longueurs de fil émergeant du mercure et par suite la résistance. Cette variation de résistance est mesurée avec un pont et le signal amplifié est utilisé pour commander le servomoteur du robinet à pointeau, ce qui modifie son débit. De cette façon la différence de pression peut être maintenue constante à moins de 0,03 mm Hg près.

I. **Introduction.** — Two or more Fabry-Perot interferometers in series are a well known spectrometer which combines high resolution with a large free spectral range. This combination advantageous for many spectroscopic investigations has been used very often until now. The first photoelectric recording spectrometer for two etalons in series was proposed and successfully used by Chantrel [1]. Later on also other devices have been reported [2].

The set up for two Fabry-Perot interferometers in series with a grating described in the following paper has been used so far for the measurements of the hyperfine structures of some Re *I*(*) and Eu *II* lines and has proved quite useful.

II. **Scanning of the first Fabry-Perot interferometer.** — The smaller spaced etalon is scanned as it is usually done in our laboratories in measurements with one Fabry-Perot interferometer. A pressure reservoir (volume 50 liters) filled with very pure nitrogen of 200 atm. is connected to the interferometer by a small capillary tube. The pressure in the Fabry-Perot is varied only in the range from several mm Hg to about 600-700 mm Hg ensuring an almost linear increase of the pressure. The outer dimensions of the glass capillary are : diameter 0.2 cm, length 5 cm. The capillary could be exchanged easily in order to change coarsely the recording speed. The different capillaries had an inner diameter of about 10^{-3} up to 10^{-1} mm. The fine variation of the recording speed was achieved by changing the volume of the apparatus by connecting additional glass vessels (Fig. 1). All connections of the apparatus also those to the Fabry-Perot interferometer are made of glass tubes [1].

(*) The first results of the measurements have been reported at the conference on « Atomic Spectra and Radiation Processes » Oxford April 1965.

(1) No rubber tubing has been used because even the thick wall quality changes its inner diameter if the pressure in the apparatus is going up ; this variation may produce a nonlinear increase, which is many times larger than that observed with rigid glass tubing. A similar effect can be observed if the flanges of the airtight Fabry-Perot housing are not tightened enough so that the O-rings used for sealing are able to expand when the pressure inside the housing increases.

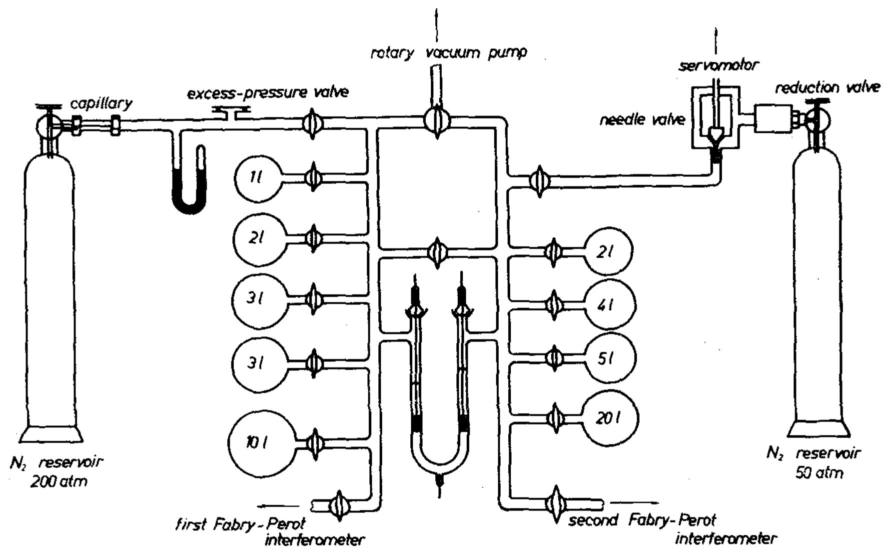

FIG. 1. — Pressure control system for the two Fabry-Perot interferometers. The reduction valve in the system of the second Fabry-Perot reduces the pressure of 50 atm in the N_2 reservoir to about 2 atm. For most of the recordings the vessels with a volume of two or three liters have been connected to the first and all vessels available to the second Fabry-Perot. The electric control system for the pressure difference between the two Fabry-Perot interferometers is shown in figure 3.

There are essentially three effects which prevent ideal linear increase of the refractive index with time :

1) the small quadratic term in the pressure dependence of the refractive index,

2) the small nonlinearity in the pressure change caused by the increase of the pressure in the Fabry-Perot and the simultaneous decrease of the pressure in the nitrogen reservoir, and.

3) the influence of the temperature variation of the surroundings.

One finds that the effects (1) and (2) nearly cancel each other, leaving a deviation from linearity of about 0.06 % for the set-up described above assuming a total volume of 5 liters. The temperature dependence will be discussed below.

The deviation from the linear increase of the refractive index can be experimentally verified by comparing the free spectral range measured for succeeding orders of the Fabry-Perot. A typical result from a measurement of an argon line is shown in figure 2. The maximum deviation over 24 orders is about 0.3 %. Most of this deviation is supposed to be caused by the influence of the temperature variations of the room where the Fabry-Perot and the pressure control system are installed. Although the room is temperature stabilized to about 0.1 °C (measured over one day) and the Fabry-Perot is moreover surrounded by a water

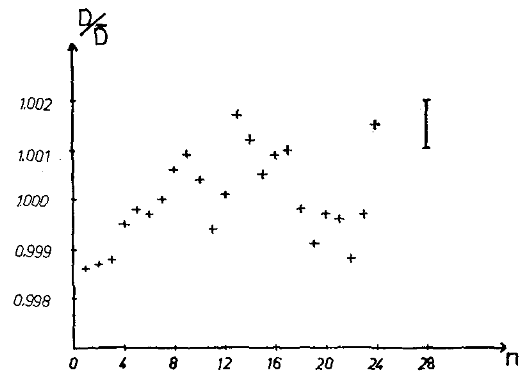

FIG. 2. — Variation of the free spectral range (D) measured with an Argon line (without isotope shift) for 24 orders (n), corresponding to a total pressure variation of about 500 mm Hg. The spacer used in the Fabry-Perot was 36.514 50 mm. Plotted are the ratios of D to their mean value $\bar{D}$. The bar at the right represents the variation of $D/\bar{D}$ caused by a change of temperature of the invar spacer of 0.005 °C. The recording speed was 1 order per 5 minutes.

jacket increasing the heat capacity of the housing in order to dampen its temperature changes, the temperature influence is still observed because the free spectral range depends on it very sensitively. This is shown by the bar at the right of figure 2 which indicates the change of the free spectral range due to a change of the temperature of the invar spacer of 0.005 °C.

III. **The Scanning of the second Fabry-Perot interferometer.** — The variation of the pressure for the scanning of the second Fabry-Perot is achieved by a pressure reservoir of about 50 atm., a reduction valve reducing this pressure to 2 atm., and a needle valve (Fig. 1), the flow rate of which can be changed by a servomotor. The pressure systems for the first and the second Fabry-Perot are separated by a mercury manometer made of glass. Two platinum wires of 15 μ diameter fixed at the spherical joints immerse into the mercury (Fig. 3). In order to stretch the wires

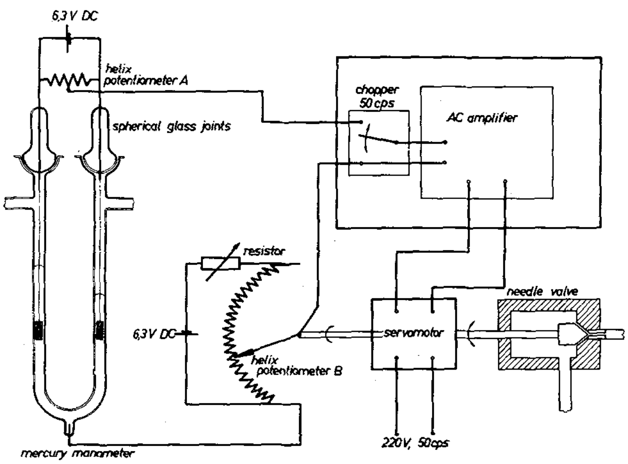

FIG. 3. — Electric control system for the pressure difference between the two Fabry-Perot interferometers. The helix potentiometer A has 10 turns, 300 kΩ, and a linearity tolerance of ± 0.05 %, B has 3 turns, 5 Ω and a linearity tolerance of ± 0.5 %. The total voltage at potentiometer B is 50 mV. The shaft of B is connected to the axis of the servomotor by a gear (omitted in this figure), the slide being in upper position, if the needle valve is opened completely. The chopper is driven by AC 50 cps, so is the exciting winding of the servomotor. The gain of the AC amplifier is about 5×10^5.

they are weighted by small pieces of gold. By means of the spherical joints the wires can be adjusted in such a way that they hit the center of the surface of the mercury whereby highest sensitivity is achieved. A change of the pressure difference between the first and the second Fabry-Perot changes the length of the wires not submerged in the mercury. This change is measured in a bridge (Fig. 3). Deviations from the bridge balance result in a voltage difference at the chopper proportional to the deviation from the set point of the pressure difference and a 50 cps. signal at the input of the amplifier is produced. The output signal is used to drive the servomotor, which either closes or opens the needle valve according to the sign of the voltage difference between the slide of the helix potentiometer A and the lower contact of the mercury manometer. A change of sign of this voltage changes the phase difference between the amplified signal and the alternating current used for the exciting winding of the servomotor by 180°.

In order to prohibit hunting around the set point the following circuit is used to dampen the regulation action.

The servomotor also moves the shaft of the helix potentiometer B (Fig. 3). The voltage difference of the bridge is reduced by the voltage produced by potentiometer B, which is proportional to the opening of the needle valve and is fed into the amplifier. The motor operates until this input signal is zero. Therefore the deviation of the opening of the needle valve from the rest position is proportional to the deviation of the pressure difference from its set point ([2]).

The set point of the pressure difference can easily be changed by turning the slide of potentiometer A. The shaft of this potentiometer was connected to a turns-counting dial, which proved very useful in finding the right pressure difference or in resetting a certain pressure difference used before.

IV. **Test of the constancy of the pressure difference control system.** — To check the control circuit a Fabry-Perot interferometer was connected to the pressure control system at the place of the second Fabry-Perot without the first Fabry-Perot being present, but with the whole pressure control system for both Fabry-Perot interferometers in action. With this set-up recordings were made of an Argon line and the free spectral range D was evaluated for the different orders. The results obtained for a typical recording are plotted in figure 4. The variations of $D/\bar{D}$ ($\bar{D}$ is the average of the different values of D) observed in the recording are the result of the variations, which are due to the system of the first Fabry-Perot (Fig. 2) and of the regulation errors of the constant pressure difference control. The maximum deviation observed is 0.6 % ([3]). To get an approximate value for the

([2]) If the pressure in the second Fabry-Perot is going up the needle valve has to open a little bit more to maintain a linear pressure increase, because of the lowering of the pressure difference between both sides of the needle valve. Therefore the slide of the helix potentiometer B changes its rest position a little bit during the measurement. This changes slightly the set point for the pressure difference between the first and second Fabry-Perot. For our arrangement described above this variation was calculated to be less than 0.02 mm Hg and was therefore smaller than the other regulation errors. It can be further reduced if a higher pressure is applied to the needle valve.

([3]) Difference between the highest and lowest value for D.

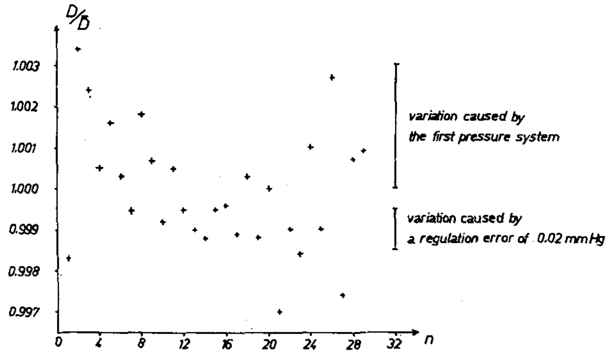

FIG. 4. — Test of the regulation error. The diagram is similiar to figure 2. The spacer used in the Fabry-Perot was 36.514 50 mm. For this measurement the Fabry-Perot was connected to the pressure control system (Fig. 1) at the place of the second Fabry-Perot with no first Fabry-Perot present but with the whole control system in action. The maximum deviation observed is 0.6 %. About 0.3 % are due to the first pressure system (see Fig. 2) witch means that the pressure control system increases the deviation by 0.3 % corresponding to a maximum regulation error of ± 0.03 mm Hg. The recording speed was 1 order per 5 minutes.

maximum regulation error, 0.3 %, which are due to the first pressure system must be subtracted. From the remainder of 0.3 % it follows that the pressure difference was constant during the recording to less than ± 0.03 mm Hg. Other recordings which have been made in the same way and also the actual measurements with both Fabry-Perot interferometers confirm this result.

V. **Optical arrangement and the digital recording of the photomultiplier signals.** — The optical arrangement of the two Fabry-Perot interferometers used for our measurements is shown in figure 5. There is

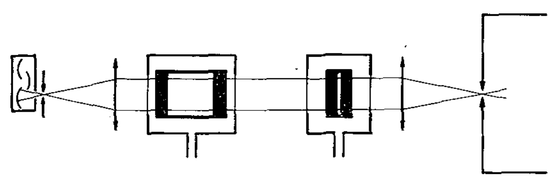

FIG. 5. — The arrangement of the two Fabry-Perot interferometers.

no intermediate image of the interference fringes between the Fabry-Perot interferometers. The maximum ratio of the two spacers used for our measurements was 15 : 1. An example of our results is shown in figure 6 (4). A recording with one Fabry-Perot is compared to another made with two Fabry-Perot

(4) The complete results of our investigations of the hyperfine structure of some Re I lines will be reported at the Colloquium on « Hyperfine Structure of Atoms and Molecules », Paris June 1966.

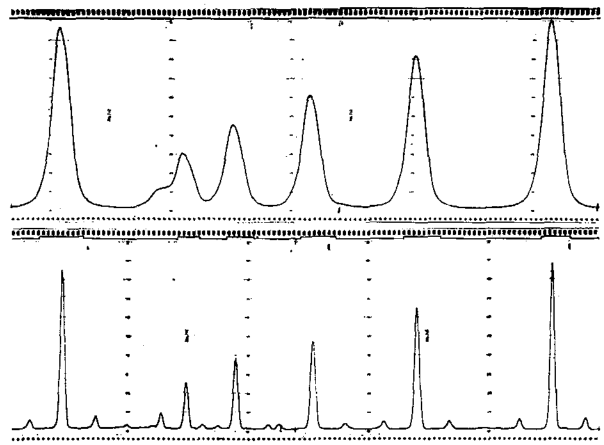

FIG. 6. — Hyperfine structure of ^{187}Re in the Re I-line $\lambda = 5\,275$ Å $(5d^5\,6s\,6p\,z\,^8P_{5/2} - 5d^5\,6s^2\,a\,^6S_{5/2})$. The wave number increases from left to right. The upper recording was made with a Fabry-Perot interferometer with a free spectral range of 1.875 54 cm^{-1}, the lower with two Fabry-Perot interferometers in series with free spectral ranges of 1.875 54 cm^{-1} and 125.02 × 10^{-3} cm^{-1}. At both sides of every hyperfine structure component of the lower recording there is one satellite because the basis of the profile measured with the smaller etalon is larger than three orders of the larger etalon.

The electronic set-up for the processing of the signals interferometers showing the gain of resolution by the second Fabry-Perot of the double Fabry-Perot spec-

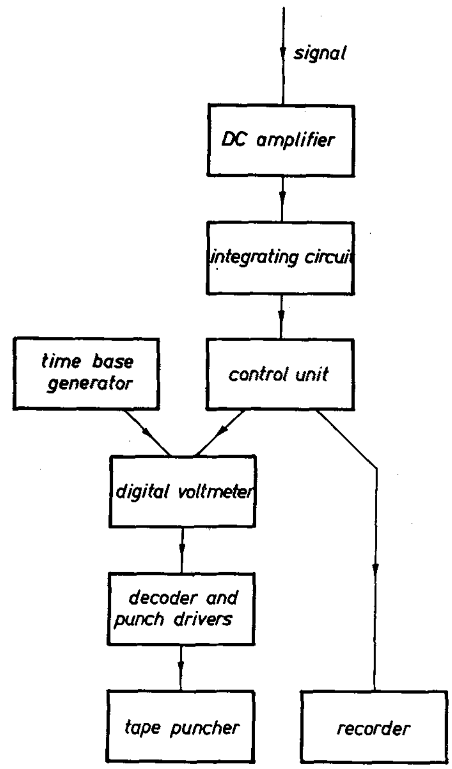

FIG. 7. — Block diagram of the electronic set-up for the recording of the light signals.

trometer is shown in figure 7. The signal of the photomultiplier was fed into a DC amplifier, averaged in a RC circuit, and recorded. Besides this the signal was measured by a digital voltmeter in time intervals identical with the time constant of the RC circuit (for most of our recordings 2.9 or 4.6 s) and punched into paper tape. The advantage of the digital output is that the evaluation can be done quickly and accurately by a computer.

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Bibliographie

[1] Chantrel (H.), *J. Phys. Rad.*, 1958, **19**, 366.
[2] See for instance : Mack (J. E.), Mc Nutt (D. P.), Roesler (F. L.), and Chabbal (R.), *Appl. Opt.*, 1963, **2**, 873 and Krause (H.), and Krebs (K.), *Optik*, 1963, **20**, 471.

INTERVENTIONS

Mertz. — Do you have any trouble with phasel shifts in the RC integrator which can distort the line profiles ?

A. Steudel. — If the wavenumber range corresponding to the half width of the lines is recorded in a time which is at least 10 times larger than the time constant of the RC integrator (Fig. 7) the distortion of the lines can be neglected for all pratical purposes.

Stroke. — Could you elaborate on the role of the helical resistor in your servo ?

A. Steudel. — The function of helical resistor B is to dampen the regulation action of the servo system. The voltage difference Δu produced by the deviation from the bridge balance is reduced by the voltage u_B between the slide and the lower end of potentiometer B (Fig. 3). Potentiometer B is connected to the servomotor so that u_B is proportional to the opening of the needle valve. The servo system causes that the input of the AC amplifier is zero, that means that $\Delta u = u_B$ or that the opening of the needle valve is proportional to the deviation of the pressure difference from a set point.