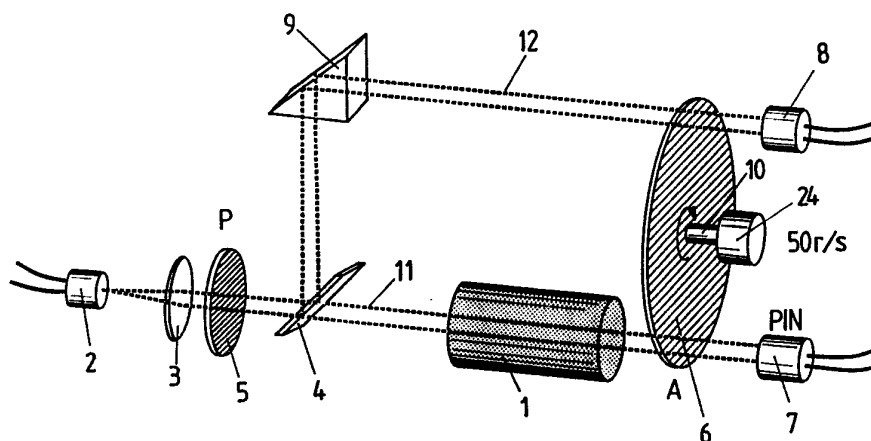




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(54) Title: A METHOD AND A POLARIMETER FOR MEASURING OPTICAL ROTATION OF SUGAR AND OTHER OPTICALLY ACTIVE SOLUTIONS



(57) Abstract

The invention relates to a method and a polarimeter to measure optical rotation of a sugar or other optically active solution by producing a monochromatic and collimated light beam, which is split into a measuring beam (11) and into a reference beam (12), directing the measuring beam (11) through the optically active solution (1) and by making reference beam (12) to pass the solution cell, directing the original light beam first through a fixed polarizer (5) and then directing each split beam through an analyzer (6), which is rotated at constant speed hence producing a cosine squared waveform for each beam, measuring the phase difference between the cross-polarization positions of the analyzer (6) for the measuring beam (11) and for the reference beam (12) thus allowing for measuring the absolute angle of optical rotation. According to the invention constant triggering pulses are generated by using the steep rising/falling parts of the periodical waves to generate pulses to start and to stop counting procedure on a crystal oscillator counter, and that a first time delay between the consecutive triggering pulses is measured for the measuring (11) and the reference beams (12) and a second time delay for the full half period of one beam, wherein the said phase difference is counted from the said first and second time delays.

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A Method and a Polarimeter for Measuring Optical Rotation of Sugar and Other Optically Active Solutions

The method described below is intended for measuring optical rotation of sugar and other optically active solutions by -
5 producing a monochromatic and collimated light beam, which is split into a measuring beam and into a reference beam,

- directing the measuring beam through the optically active
10 solution and by making reference beam to pass the solution cell,
- directing the original light beam first through a fixed polarizer and then directing each split beam through a analyzer, which is rotated at constant speed hence pro-
15 ducing a cosine squared waveform for each beam,
- measuring the phase difference between the cross-polarization positions of the analyzer for the measuring beam and for the reference beam thus allowing for measuring the absolute angle of optical rotation.

20

A polarimeter measures the optical rotation angle of the plane of polarization of a light beam as it travels through an optically active sample solution, most often a sugar solution. The angle of rotation is directly proportional to the sugar
25 concentration in solution. At specified conditions (temperature, concentration and cell length) each optically active compound has its characteristic specific angle of rotation. The angle of rotation may be positive or negative.

30 In the manufacture of sugars polarimetry is widely used method to control sugar contents of process solutions at factory sites. Also research and control laboratories use polarimeters. All known commercial polarimeters use incoherent, filtered light sources (lamps) with relatively low intensity. Their spectral
35 band width is normally of the order of a few nanometers. Measuring dark solutions in this conventional manner is limited to very thin path lengths. Using coherent, high intensity, narrow-band laser light allows for adequate penetration through dark solutions in cells of even 5 cm of length increasing the

accurate of measuring optical rotation of dark solutions. There are few reports of using lasers as light sources in polarimeters.

5 Most commonly used polarimeters use Faraday compensation to measure optical rotation (Nature 178, Dec 22nd, 1956). The polarized light is directed through a sample cell and the rotation of the polarization of light is compensated by using a magneto-optical cell, where alternating current produces a
10 compensating magnetic field bringing the direction of polarization of the light beam back to its original value. Compensation current is directly proportional to the angle of rotation. Compensation is limited to a few degrees. Compensation method is sensitive to any magnetic changes of the measuring environment, f.e. latitude. The instruments have to be calibrated at
15 each location by using standard solutions.

Known approaches of polarimetric technology are presented in the following publications: Hans Wenking, Göttingen, 'Zeitschrift
20 fur Instrumentenkunde', 66. Jahrgang, Heft 1. January 1958 and K. Zander et al. 'Zucker', 27, 642 (1974). Known commercial polarimeters use photomultiplier tubes to monitor light intensity variations of the polarized light. These devices need high-voltage power supplies and special care has to be taken in
25 industrial environments to meet safety requirements.

Using lasers as light sources in polarimeters has been described in the following publications: in A.L. Cummins et al., 'Lasers and Analytical Polarimetry' , pp. 291 - 302, in the 17th ICUMSA
30 proceedings, Montreal, pp. 56 - 57, in a french patent publication No 2.393 296 and in a brazilian patent application PI 7803313. In these studies improved transmission of the light beam through solutions and slightly improved measuring accuracy due to the narrower band width have been reported.

35

A US-patent No 2,861,493 (Landgren) describes a polarimeter, where a filtered incoherent light beam is directed through a rotating polarizing component, which also causes the plane of polarization of the transmitted light to rotate. The light beam

is then split into two beams, one going through a sample solution and the other that passes the solution. Both beams are then directed through separate polarizing devices onto photosensitive detectors. The angle of rotation is obtained by using an analog phase-shift meter. Measuring the phase shift in this device, however, is inaccurate and does not meet the accuracy requirements of the present day polarimetry. It is impossible to use the described optical arrangement in the time-delay based polarimeter to be described below.

10

The purpose of the present invention is to allow construction of a new polarimeter that will give the absolute angle of rotation of an optically active material or solution with an accuracy of one thousandth of a degree in the angle region from -180° to +180°. The device allows for measuring dark solutions in reasonably long sample cells. The method used is insensitive to the magnetic field of the measuring environment. Characteristic features of the method are presented in the patent claim 1 and characteristic features of a polarimeter using the above method is presented in the claim 5.

The method differs from all of the previous methods in the way cross-polarization positions of the first polarizer and the rotating analyzer with respect to each other are obtained. Here we use the rising part of the oscillating signal for triggering and we measure the time delay between the cross-polarization positions between the measuring and the reference beams and simultaneously the time span of the two consecutive cross-polarization positions of the reference beam. In most earlier methods the minimum light intensity as cross-polarization position indicator of the analyzer has been used. For measuring time differences a crystal oscillator and an electronic counter is used. The present method allows using simple low voltage PIN photodiodes as light detectors. A considerable advantage is also obtained by using a temperature stabilized, single mode diode laser as the light source of the polarimeter. The theoretical measuring accuracy is increased because of the extreme small band width (0.02 nm) and wavelength stability (0.01 nm) of the temperature stabilized laser. Laser transmission is superior to

lamp transmission when measuring dark solutions. All crucial components of the device are made of light weight materials, they have long lifetime and small size of the components allows for compact and durable design of the polarimeter. The
5 polarimeter needs only low voltages to be operated.

In the following a functional performance of the polarimeter is described. The preferred embodiment and most important principles are shown in Figures 1 - 3.

10

Fig. 1. shows the principal optical structure of the polarimeter

Fig. 2. shows the periodical signals falling on the light detectors as a function of rotation angle and as a
15 function of time

Fig. 3. shows the schematic diagram of the device including optical and electronic layout

The laser diode (Melles Griot 56 DLD 403) is temperature stabilized to keep it running in the TEM_{00} single mode and to
20 guarantee maximum absolute wavelength stability. Laser light obtained in this manner is coherent, polarized and highly monochromatic. To improve the polarization properties of the light beam an additional polarizing element (a disk made out of
25 polaroid material) is used to improve the polarization ratio to 10,000 : 1. The band width of the laser is 0.02 nm and the absolute wavelength stability is 0.01 nm.

The operational wavelength of the laserdiode is appr. 780 nm
30 allowing excellent transmission in dark molasses solution.

The sample will be located in the cell 1 and the measuring beam 11 will be directed through the sample solution. The measuring beam is obtained from a laser diode 2. The beam is collimated
35 by using the lens 3 and is then polarized parallel to the natural laser polarization further by using the polarizator 5. The beam is the split into two components by using an angled beam splitter 4, which leaves some 4% of the light intensity for the reflected and about 96% of the light intensity for the

transmitted beam. High intensity of the transmitted beam is reduced to the intensity level of the reflected beam by using a neutral density filter for transparent sample solutions while for darker solutions attenuation will be diminished accordingly.

- 5 The reference beam is reflected onto a aluminium coated mirror 11 (or a prism) to make the beam parallel to the sample beam. The polarizing and optical components may be made of same materials described in the above mentioned US-publication No 2,861,493.

10

- By using the laser beam to measure the optical rotation of dark solutions relatively normal path lengths up to 5 cm may be used. This is an significant improvement as compared to the conventional polarimeters where path lengths of some 2 mm may be used
- 15 because of low intensities of the incoherent light sources. Path length is directly proportional to the optical rotation angle and hence we estimate that about 20 fold measuring accuracy is gained for dark solutions. This improvement is significant for the control of the sugar contents of dark molasses solutions at
- 20 process sites.

- The two beams have parallel polarizations before the sample cell. The sample will rotate the plane of polarization of the measuring beam, the angle of rotation being directly proportional to the concentration of the optically active compound in
- 25 solution. Both sample 11 and reference 12 beams (after sample cell 1) are directed through a rotating analyzing polarizer, called analyzer 6.

- 30 The analyzer is rotated at constant speed via an axis 10 connected to the electrical motor 24. Both beams then arrive to two identical photodiodes 7 and 8 (Telefunken S153P silicon photodiodes).

- 35 In the present arrangement the rotation speed of the analyzer is about 50 Hz. Absolute rotation speed is not important but it is advantageous to have the rotation speed constant. This speed allows fast enough rise times of the oscillating signals at the photodiodes to be used for triggering purposes. The signals at

both photodiodes are known to obey Malus' periodical law. During one full turn of the analyzer both beams come to cross-polarization position two times giving the effective measuring frequency of about 100 Hz. A crystal oscillator and pulse counting electronics is used to measure the time delay (t_x , shift) between the cross-polarization positions of the measuring and the reference beams respectively. The time duration of each half turn (t_d , period) is measured simultaneously from the reference beam by using a second channel of the pulse counting electronics. The absolute angle of rotation is then given by $180^\circ * (t_x/t_d)$.

Fig. 2. shows the periodical signals observed at the photodiodes. The measuring signal may be automatically amplified (up to a factor of 20) to the same intensity level as the reference signal to compensate possible transmission changes taking place in the sample cell. This arrangement guarantees proper triggering of the sample and reference channels. The measuring techniques is completely insensitive to local magnetic fields. The polarimeter compares the time delay between the measuring and the reference signals to the time duration for each half turn giving an internal calibration for each measurement. Effective signal averaging is then used to improve the raw data and statistical error analysis is carried out as further criteria of the quality of the data. To trigger pulse counting electronics old invention of constant fraction discrimination (CDF) techniques is used. Triggering of the timer clocks is accomplished by using the rising parts of the oscillating signals arriving at the photodetectors. The signal is inverted at quarter height and added to the original signal making a very sharp and intensity independent triggering possible. The sum signal is then converted into a triggering pulse, which starts or stops the pulse counting electronics. The triggering pulse from the reference signal starts two independent counting channels, the stop signals from the rising part of the delayed measuring signal and the stop signal obtained from the next rising part of the reference signal both stop their own pulse counting channels. Number of pulses for both events is then stored into the CPU unit 18 of the device. The number of pulses

(nx) obtained for the start and stop signals of the reference and the measuring beams, respectively, is directly proportional to the time delay between the cross-polarization positions of the two beams seen by the detectors 7 and 8. The number of
5 pulses obtained between the consecutive rising parts of the reference signals at diode 8 is proportional to the half turn rotation time of the analyzer (np). The absolute angle of rotation is accordingly $180^\circ * (nx/np)$. Principally falling parts of the wave may also be used to generate start and stop
10 pulses.

To complete one measuring cycle 20 millisecond time period will be used. This comprises of a 10 ms measuring time and a 10 ms counter reading time. In this manner we can use effective signal
15 averaging, a measuring period of 10 seconds will improve the original measuring accuracy roughly by a factor of 20. Standard statistics is calculated at later phases of data acquisition allowing for efficient control of the quality of the data.

20 The device shown in Fig. 3. may be divided into functional parts. Laser diode 2 and its temperature stabilizing electronics is assembled into one unit 13. Optics, polarizing components, the rotating motor, NTC- resistor and the PIN diodes are fixed to the optical bench 14 of the device. The rest of the
25 instrumentation is CFD-, pulse counting, data acquisition and communication electronics.

The signals from PIN photodiodes are directed onto the constant fraction discriminators 16, where constant voltage triggering
30 pulses are generated. These pulses are directed to the pulse counting card 4, which gives two pulse numbers for each half rotation of the analyzer 6. One number is proportional to the time duration of the half rotation time of the analyzer and the other is proportional to the time delay between the cross-
35 polarization positions of the measuring and reference signals. The CPU unit 18 sends both numbers in serial form to an external microcomputer. Averaging and statistics will be done on the microcomputer. The device has a set of push buttons and a LED display for internal control of the device. The temperature of

the sample cell will be measured continuously by using a Pt-100 temperature sensing element. Temperatures are digitized and also directed via serial interface 20 into the external microcomputer. The CPU-unit may be interfaces also to an external
5 process computer 22.

The PIN photodiodes use low voltages on the contrary to photomultiplier tubes used in conventional commercial polarimeters. Since all other electronics of the device uses low voltages as
10 well the design offers fewer safety risks when used in industrial environments.

Using a single polarizing analyzer allows for simple construction and gives following advantages in the optical design: 1)
15 The optical alignment of the two beams is not a critical factor for the functioning of the device 2) Simultaneous multi-colour analysis of concentrations of various sugar components in solution becomes possible. The latter option is based on the fact that the wavelength dependence of the specific rotation
20 angle is characteristic to each optically active compound. This kind of multiplexing is not possible in any of the known conventional and formerly reported polarimeters.

Patent Claims

1. A method to measure optical rotation of sugar or other optically active solution by

- 5 - producing a monochromatic and collimated light beam, which is split into a measuring beam (11) and into a reference beam (12),
- directing the measuring beam (11) through the optically active solution (1) and by making reference beam (12) to
10 pass the solution cell,
- directing the original light beam first through a fixed polarizer (5) and then directing each split beam through a analyzer (6), which is rotated at constant speed hence producing a cosine squared waveform for each beam,
- 15 - measuring the phase difference between the cross-polarization positions of the analyzer (6) for the measuring beam (11) and for the reference beam (12) thus allowing for measuring the absolute angle of optical rotation,
characterized in that
- 20 - constant triggering pulses are generated by using the steep rising/falling parts of the periodical waves to generate pulses to start and to stop counting procedure on a crystal oscillator counter, and
- that a first time delay between the consecutive triggering
25 pulses is measured for the measuring (11) and the reference beams (12) and a second time delay for the full half period of one beam, wherein the said phase difference is counted from the said first and second time delays.

30

2. The measuring method according to the claim 1,
characterized in that the coherent and monochromatic light beam is produced by a laserdiode (2), which operates in single mode oscillation (TEM_{00}) and which is temperature stabilized for
35 accurate wavelength stability.

3. The measuring method according to the claim 1,
characterized in that the operational wavelength of the laser-diode is 750 - 850 nm.

4. The measuring method according to the claim 2, characterized in that the light beam from the laserdiode (2) is first collimated and polarized, and then split to make a reference beam (12), which is later turned parallel to the measuring beam (11), which goes through the sample solution, both beams (11,12) being then directed through a common rotating analyzer (6) and then focused on separate but identical detectors (8,7), where the signals suitable for measuring the time delays described above are produced.

10

5. The polarimeter for implementing the method according to the patent claim 1, which polarimeter consists of a laserdiode (2), a fixed polarization element (5), a beam splitter (4) to split the original light beam into a reference beam (11) and the measuring beam (12), a solution sample cell (1) for transmission of the measuring beam (12), an analyzer (6) to each of said split beams (11,12), a motor (24) for rotation of each analyzer (6) and two light detectors (7,8) for measuring alternating signals of the reference (11) and the measuring (12) beams, characterized in that the polarimeter has a mirror (9) for alignment of the reference beam (11) parallel to the measuring beam (12) and that the mirror (9) and the analyzing polarizer have been adjusted in a way that both the measuring beam (12) and the reference (11) beam will go through the common analyzer (6).

6. The polarimeter according to the patent claim 5, characterized in that the polarimeter contains temperature stabilizing elements for the laserdiode.

30

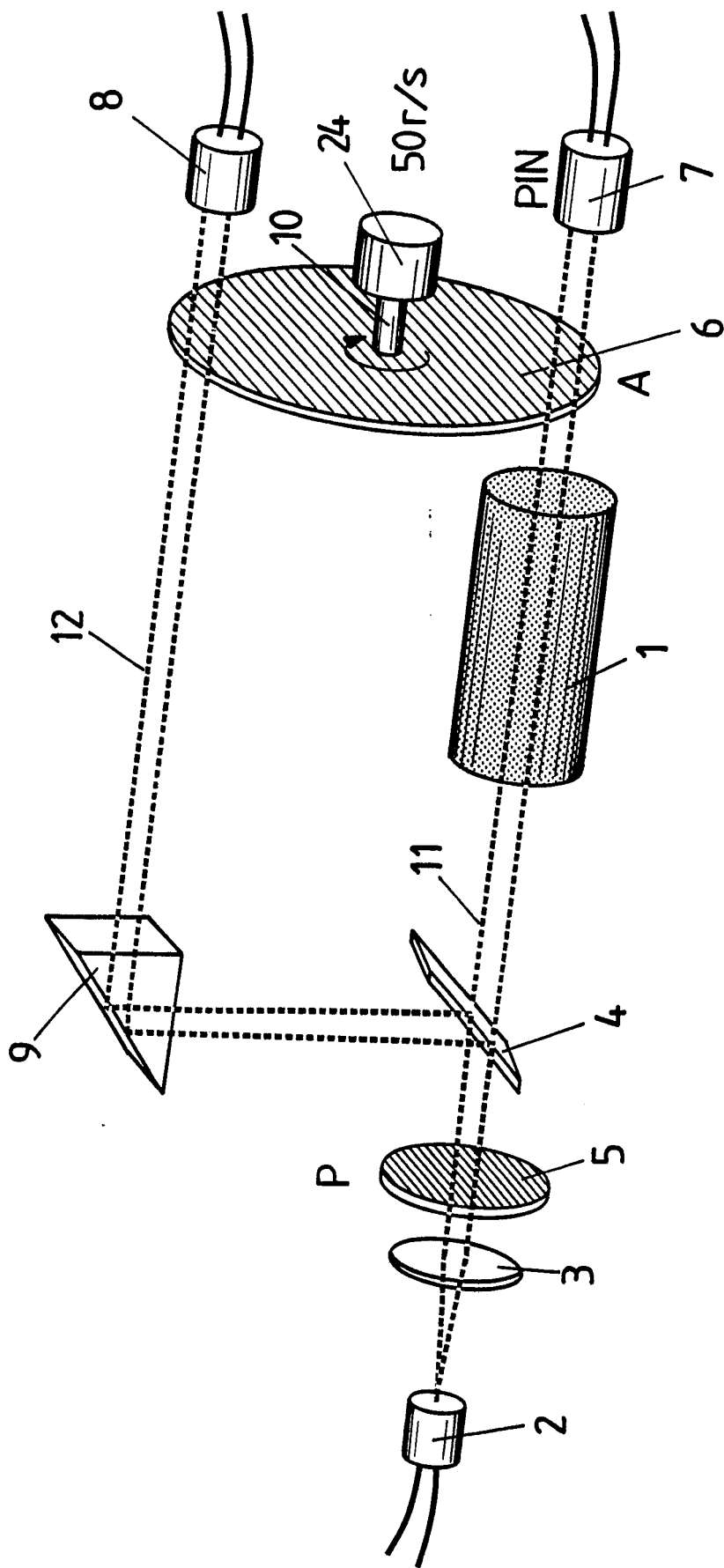


FIG. 1

2/3

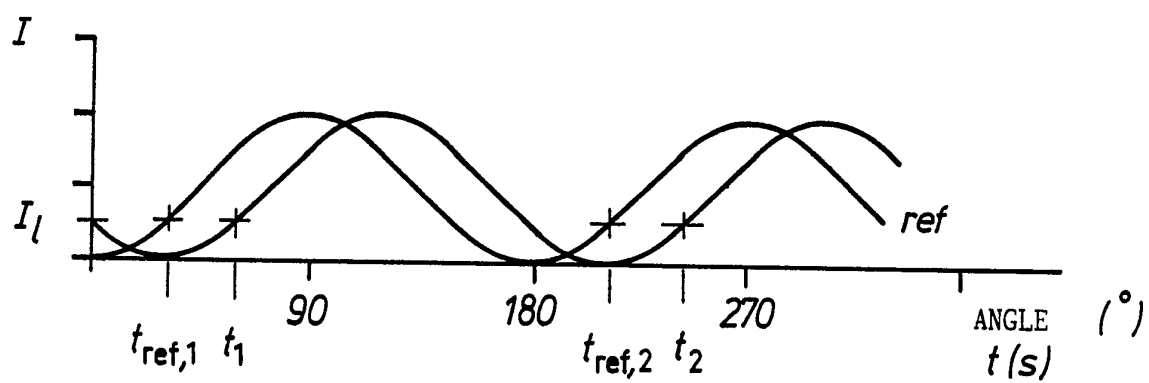


FIG. 2

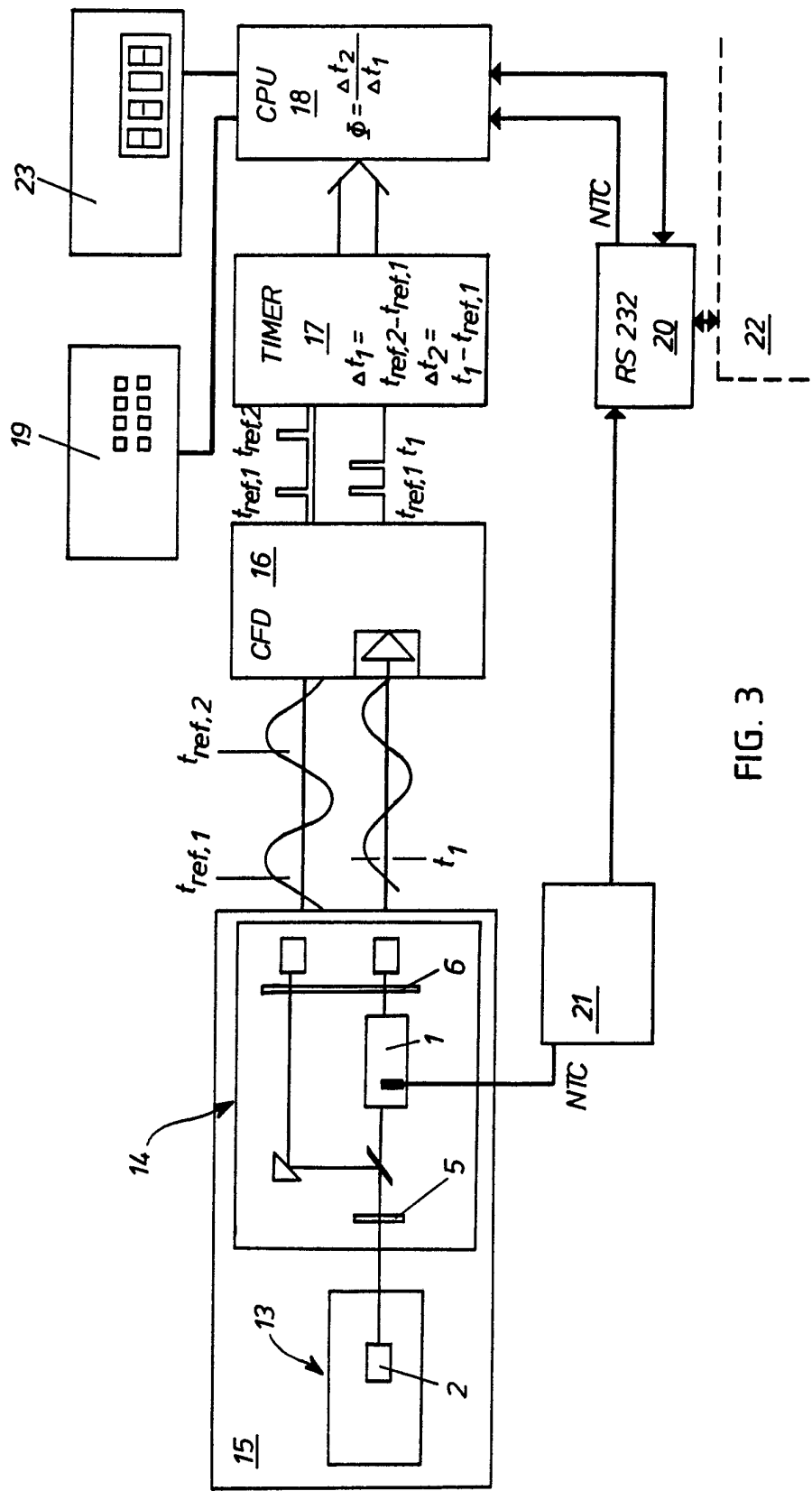


FIG. 3

INTERNATIONAL SEARCH REPORT

International Application No PCT/FI 92/00017

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) ⁶ According to International Patent Classification (IPC) or to both National Classification and IPC IPC5: G 01 N 21/21; G 01 J 4/00																	
II. FIELDS SEARCHED Minimum Documentation Searched⁷ <table style="width: 100%; border: none;"> <tr> <td style="width: 25%; border: none; vertical-align: top;"> Classification System </td> <td style="width: 75%; border: none; vertical-align: top;"> Classification Symbols </td> </tr> <tr> <td style="border: none; vertical-align: top;">IPC5</td> <td style="border: none; vertical-align: top;">G 01 J, G 01 N</td> </tr> </table> Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in Fields Searched⁸ SE,DK,FI,NO classes as above			Classification System	Classification Symbols	IPC5	G 01 J, G 01 N											
Classification System	Classification Symbols																
IPC5	G 01 J, G 01 N																
III. DOCUMENTS CONSIDERED TO BE RELEVANT⁹ <table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th style="width: 10%;">Category *</th> <th style="width: 60%;">Citation of Document,¹¹ with indication, where appropriate, of the relevant passages¹²</th> <th style="width: 30%;">Relevant to Claim No.¹³</th> </tr> </thead> <tbody> <tr> <td style="text-align: center; vertical-align: top;">A</td> <td>GB, A, 1603256 (FRANZ SCHMIDT & HAENSCH) 25 November 1981, see column 2, line 60 - column 3, line 104; figure 1 -- </td> <td style="text-align: center; vertical-align: top;">1-6</td> </tr> <tr> <td style="text-align: center; vertical-align: top;">A</td> <td>US, A, 4850710 (YOSHIHIRO MOCHIDA ET AL) 25 July 1989, see abstract; figure 1 -- </td> <td style="text-align: center; vertical-align: top;">1-6</td> </tr> <tr> <td style="text-align: center; vertical-align: top;">A</td> <td>US, A, 4309110 (LEO TUMERMAN) 5 January 1982, see abstract; figure 1 -- </td> <td style="text-align: center; vertical-align: top;">1-6</td> </tr> <tr> <td style="text-align: center; vertical-align: top;">A</td> <td>DE, A1, 3830310 (BODENSEEWERK PERKIN-ELMER & CO) 15 March 1990, see abstract; figure 1 -- </td> <td style="text-align: center; vertical-align: top;">1-6</td> </tr> </tbody> </table>			Category *	Citation of Document, ¹¹ with indication, where appropriate, of the relevant passages ¹²	Relevant to Claim No. ¹³	A	GB, A, 1603256 (FRANZ SCHMIDT & HAENSCH) 25 November 1981, see column 2, line 60 - column 3, line 104; figure 1 --	1-6	A	US, A, 4850710 (YOSHIHIRO MOCHIDA ET AL) 25 July 1989, see abstract; figure 1 --	1-6	A	US, A, 4309110 (LEO TUMERMAN) 5 January 1982, see abstract; figure 1 --	1-6	A	DE, A1, 3830310 (BODENSEEWERK PERKIN-ELMER & CO) 15 March 1990, see abstract; figure 1 --	1-6
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A	DE, A1, 3830310 (BODENSEEWERK PERKIN-ELMER & CO) 15 March 1990, see abstract; figure 1 --	1-6															
* Special categories of cited documents:¹⁰ "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier document but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance, the claimed invention cannot be considered novel or cannot be considered to involve an inventive step "Y" document of particular relevance, the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art. "&" document member of the same patent family																	
IV. CERTIFICATION <table style="width: 100%; border: none;"> <tr> <td style="width: 50%; border: none; vertical-align: top;"> Date of the Actual Completion of the International Search </td> <td style="width: 50%; border: none; vertical-align: top;"> Date of Mailing of this International Search Report </td> </tr> <tr> <td style="border: none; vertical-align: top;">10th April 1992</td> <td style="border: none; vertical-align: top;">1992 -04- 22</td> </tr> <tr> <td style="border: none; vertical-align: top;"> International Searching Authority </td> <td style="border: none; vertical-align: top;"> Signature of Authorized Officer </td> </tr> <tr> <td style="border: none; vertical-align: bottom; text-align: center;"> SWEDISH PATENT OFFICE </td> <td style="border: none; vertical-align: bottom;"> KARIN SAFSTEN </td> </tr> </table>			Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report	10th April 1992	1992 -04- 22	International Searching Authority	Signature of Authorized Officer	SWEDISH PATENT OFFICE	 KARIN SAFSTEN							
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International Searching Authority	Signature of Authorized Officer																
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III. DOCUMENTS CONSIDERED TO BE RELEVANT (CONTINUED FROM THE SECOND SHEET)		
Category *	Citation of Document, with indication, where appropriate, of the relevant passages	Relevant to Claim No
A	SE, B, 442919 (ARNO MÜLLER) 3 February 1986, see page 4, line 6 - line 27; figure 2 --	1-6
A	GB, A, 2197467 (DAVID MURRAY GOODALL ET AL) 18 May 1988, see abstract; figure 2 -- -----	1-6

**ANNEX TO THE INTERNATIONAL SEARCH REPORT
ON INTERNATIONAL PATENT APPLICATION NO.PCT/FI 92/00017**

This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report. The members are as contained in the Swedish Patent Office EDP file on 28/02/92
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Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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US-A- 4850710	89-07-25	JP-A- 63082345	88-04-13
US-A- 4309110	82-01-05	NONE	
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		FR-A-B- 2393296	78-12-29
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		WO-A- 88/03266	88-05-05