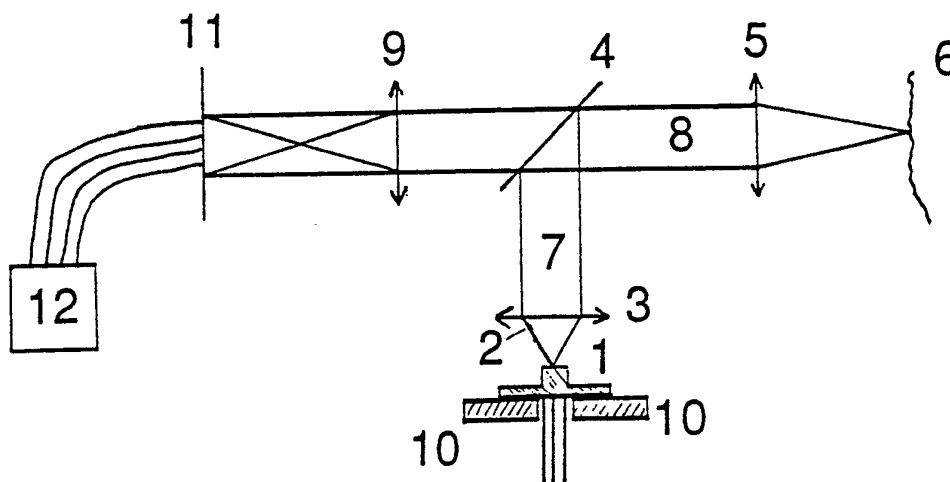




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(54) Title: PROCESS AND APPARATUS FOR MEASURING ABSOLUTE DISTANCE



(57) Abstract

Process and apparatus for measuring absolute distance and distance variations between a reference level and the surface of a body, during which process light emitted from a source of light is reflected from the surface of the body and a part of the reflected light is captured in an optical system, which, with the aid of a light-sensitive device, is converted into an electric signal which is a measure of said distance or distance variation. In order to achieve a symmetrical relationship between the measured distance in respect to a reference distance and the said electric signal, the distance between the focussing device and the transmission device is designed to be equal to the focal length of the focussing device and the distance between the transmission device and the light-sensitive device is designed to be equal to twice the focal length of the transmission device.

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Process and apparatus for measuring absolute distance

The invention relates to a process for measuring absolute distance and distance variations between a reference plane and the surface of a body, in the course of which process light emitted from a source of light is reflected from the surface of the body and a part of the reflected light is captured in an optical system, said light being converted, with the aid of a light-sensitive device, into an electric signal which is a measure of said distance or distance variation.

The invention also relates to an apparatus for carrying out the process.

Examples of such distances and distance variations are dimensions of mechanically machined objects, roughness values of these objects and vibrations in mechanical systems.

Optical measuring methods are frequently contactless so that they do not affect the object to be measured, which is a great advantage in many measuring situations, especially when measuring soft objects and generally wherever high measuring speeds are required.

There exist very many optical measuring methods for measuring distances. A case in point is "Measurement of the RMS Roughness, Autocovariance Function and Other Statistical Properties of Optical Surfaces Using a FECO Scanning Interferometer" by Jean M. Bennett in Applied Optics Vol. 15, pp 2705-2721, 1976, which discusses various methods for optical roughness measurement.

In "Evaluation of a commercial Microtopography sensor" by R. Brodmann and W. Smitga presented at the 4th Int. Symposium on Optical and Opto-electronic Applied Science and Engineering 30/3-3/4 1987 The Hague, Holland, a method is described for measuring structures, thickness and deformations of, inter alia, mechanical objects.

In this paper a measuring method is described, which has been derived from the play-back system in a compact disc player. In this case the distance between the focal plane of a lens and the object is measured, the position of the lens being regulated in such a way that this distance becomes as small as possible. The electrical signal used for this regulation is a measure of the distance from the object.

A source of light illuminates the object through a collimation lens and a focussing lens. These lenses form an image of the reflection point on a 4-segment detector with the aid of a beam splitter and two prisms in such a way that the 4 detector segments are uniformly illuminated only if the reflection point is in the focal plane of the focussing lens. It is possible, therefore, to adjust the position of the focussing lens to a uniform illumination of the 4 segments. The adjustment is effected electrically with the aid of a servo-circuit, a movable coil and a permanent magnet. The electric signal to the coil is a measure of that distance.

A major problem with this method consists in the fact that a possible hysteresis of the coil causes some error in the electric signal. Another problem consists in the inertia of said coil, inasmuch as it imposes an upper limit on the frequency of the distance variations which can be detected. In the given case the latter amounts to 600 Hz. A third problem consists in the fact that the servo-circuit makes it difficult to exchange, if this should be required, the focussing lens for other lenses since the mechanical system is modified thereby.

The object of this present invention consists in bringing about a process enabling absolute determination of distances and distance variations, but which does not necessitate moving components in that part of the optical system which gives rise to the electric signal which is a measure of that distance or distance variation.

This object is achieved, according to the invention, in that the surface of the body is illuminated by a source of light and a part of the reflected light is received, via a focussing device and a transmission device, on a light-sensitive device and in that the distance

between the focussing device and the transmission device is equal to the focal length of the focussing device and in that the distance between the transmission device and the light-sensitive device is designed so as to be equal to twice the focal length of the transmission device.

As a result thereof the relationship formed between the distance from the reflecting surface and the resulting electric signal becomes symmetrical in respect of a reference distance corresponding to the focal length of the focussing device.

10

If required, the source of light can be modulated with a fixed frequency.

The distance of the source of light from (the fixed) collimation device can, if required, be adjusted, subject to control by an electric signal derived from the optical enlargement in that part of the optical system which consists of a collimation lens and a focussing lens, together with the electric signal, which is a measure for the distance between said reference distance and the reflected object.

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The process according to the invention makes it possible to measure very rapid distance variations.

The process according to the invention causes a symmetric connection between the electric measuring signal formed and the measured distance in respect of a reference distance corresponding to the focal length of the focussing lens.

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The process according to the invention also makes it possible to improve the electrical signal-noise ratio during the detection process, by modulating the source of light and an electronic circuit for processing the detected signal adjusted to the modulation selected.

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The process according to the invention also makes it possible to ensure as small a lightspot diameter on the object as possible by adjusting the distance between the source of light and the fixed collimation lens, thus ensuring that any possible hysteresis in the mechanical adjusting system causes uncertainty only as regards the diameter of the spot and not the distance between the object and the reference plane.

The process according to the invention also makes it possible to modify, by simple change of the focussing lens to another focal length, the optical enlargement in that part of the optical system which consists of focussing lens and cylindrical lens, and thus to modify the sensitivity and range of measuring distances and distance variations in relation to a reference distance corresponding to the focal length of the focussing lens.

The invention also relates to an apparatus for measuring absolute distance and distance variations between a reference distance and the surface of a body by carrying out the process according to claim 1.

The apparatus comprises a source of light, the divergent light beam of which is transmitted through a device for collimating the transmitted light; a device for focussing the transmitted beam of light, devices for receiving the light reflected from the surface of the body, devices for branching off a light beam derived from the reflected light beam, devices for transmitting the derived light beam and for transmitting the light beam to a number of light-sensitive devices, each of which is especially equipped to produce a signal depending on the intensity of the light, as well as signal processing devices, comprising devices for continuous recording of the intensity of light of each of the light-sensitive devices and devices for converting this recording to an output signal which is a measure of that absolute distance or distance variation.

The apparatus according to the invention is special in that the device for receiving the light reflected from the surface of the body and the device for transmitting the derived light beam are firmly located at a mutual optical distance corresponding to the focal length of the device for receiving the light reflected from the surface of the body, and in that the source of light is located on a device for varying the optical distance from the device for collimating the transmitted light.

- 10 The apparatus does not require any movable components within the signal-generating part of the optical system and is therefore capable of carrying out measurements at considerable speed and can, in simple manner, be caused to cover a wide measuring range by exchanging the device equipped for receiving the light reflected from the surface of the body. By varying the position of the source of light it is possible to ensure, with e.g. especially exacting measurements, the least possible spot of light on the surface of the body, and, owing to the optical enlargement, it is nevertheless possible to achieve considerable measuring speeds. In addition, it is directly possible to modulate the source of light so as to be able to improve the resulting electric signal-noise ratio, it being further possible to combine the collimation device, focussing device, receiving device, branching-off device and transmission device to a composite device possessing the same characteristics as the separate devices but from a mechanical point of view considerably more stable than the latter.

With a preferred embodiment of the apparatus the source of light is located on the surface of a piezo-electric crystal for varying its position in relation to a collimation lens. The transmission device is designed as a cylindrical lens, which forms an image of the light reflected from the surface of the body on a light detector consisting of four individual detector elements. The electric signal from these detector elements contains information about the required measuring distance.

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The invention is described below in greater detail with reference to the drawing in which

Figure 1 shows a diagram of an optical system suitable for use in the apparatus according to the invention.

5 Figure 2 shows the curve illustrating the relationship between the distance from the surface of the body to a reference distance and the electric signal emanating from the light-sensitive devices in an apparatus according to the invention.

10 Figure 3 shows a diagram of a preferred embodiment of the light-sensitive devices according to the invention.

Figure 4 shows a diagram of an embodiment of signal processing devices in an apparatus according to the invention.

15 The process according to the invention is based on the use of an optical system, in which a divergent light beam emanating from a source of light passes through a collimation lens, a beam splitter and a focussing lens, said light beam being transformed thereby to a
20 thin light beam reflected from the surface of the body. The reflected light is caused to be transmitted through the focussing lens, the beam splitter and through the cylindrical lens located at a distance from the focussing lens corresponding to the focal length of the focussing lens to the detector element, which is located at a distance from the
25 cylindrical lens corresponding to twice the focal length of the cylindrical lens. The distance signal is derived from the signal emanating from the various detector elements.

A practical embodiment of such an optical system can be as shown in
30 Fig. 1. The optical system comprises a light source 1, emitting a divergent light beam 2 which is transmitted through a collimation lens 3 and further on through a partly reflecting mirror 4. A part of light beam 7 is branched off and transmitted through a focussing
lens 5, which focusses the branched-off light beam 8 on surface 6 of
35 the body. A part of the light beam is reflected back through focussing lens 5 and the partly reflecting mirror 4.

A part of the reflected light beam is transmitted without refraction through the partly reflecting mirror and further through a cylindrical lens 9 and is then directed towards a light-sensitive device 11. The optical distance between cylindrical lens 9 and the light-sensitive device 11 is exactly equal to twice the focal length of the cylindrical lens. The optical distance between focussing lens 5 and cylindrical lens 9 is exactly equal to the focal length of the focussing lens.

The optical distance between source of light 1 and collimation lens 3 can be varied by means of a piezo-electric crystal 10, on which the source of light is mounted. The signal for changing the dimension of the piezo-electric crystal and, as a result, the distance between the source of light 1 and collimation lens 3 can, if required, be derived from the electric signal processing devices 12. The light-sensitive device 11 consists of not fewer than four light-sensitive partial devices 11a, 11b, 11c, 11d, which are separate from one another. The electric signal from each of these light-sensitive partial devices is passed on to the electric signal processing devices 12, from which a signal is derived, which contains information about the absolute distance between reflecting body surface 6 and the focal plane of focussing lens 5.

With the process according to the invention it is possible to achieve a signal i , which may be written

$$i = \pi - 4 \tan^{-1} \frac{[d^{-1} x + y]}{[d^{-1} x - y]}$$

30

where d is the distance between the reflecting body surface and the focal plane of the focussing lens, and x and y are constants. This can be achieved in signal processing devices corresponding to that shown in Fig. 4. The signal processing devices shown are largely based on conventional signal processing technology, and the diagram is intended solely by way of a specimen embodiment showing how the electric signals from the light-sensitive partial devices can be caused to indicate the distance between the reflecting body surface and the

focal plane of the focussing lens. The signals from the four light-sensitive partial devices are passed on to four current supply devices 13a, 13b, 13c and 13d. The output signal from 13a and 13c is conducted to a summation device 14a and the output signal from 13b and 13d is similarly conducted to an identical summation device 14b. The output signals from these summation devices are passed on to a differentiation device 15 so that the entire signal processing operation, analogue or digital, can be written

$$(I_a + I_c) - (I_b + I_d)$$

where I_a , I_b , I_c , I_d are the signals from the four partial devices 11a, 11b, 11c and 11d.

The above signal processing can, if required, be developed by standardisation in respect of the total sum of the signals I_a , I_b , I_c and I_d .

Claims

1. Process for measuring an absolute distance and distance variations between a reference plane and the surface of a body, during which process light emitted from a source of light is reflected from the surface of the body and a part of the reflected light is captured in an optical system, which with the aid of a light-sensitive device is transformed into an electric signal forming a measure of said distance or distance variation, characterised in that the surface of the body is illuminated by a source of light and a part of the reflected light is received through a focussing device and a transmission device on a light-sensitive device and in that the distance between the focussing device and the transmission device is equal to the focal length of the focussing device and in that the distance between the transmission device and the light-sensitive device is designed to be equal to twice the focal length of the transmission device.
2. Process according to claim 1, characterised in that devices for modifying the length of the light path are located between the source of the light and the surface of the body.
3. Apparatus for measuring absolute distance and distance variations between a reference distance and the surface of a body while carrying out the process according to claim 1, whereby said apparatus comprises a source of light, the divergent light beam of which is transmitted through a device for collimating the transmitted light; a device for focussing of the transmitted beam of light, devices for receiving the light reflected from the surface of the body, devices for branching off a beam of light derived from the reflected beam of light, devices for the transmission of the beam of light derived and for transmitting the beam of light to a number of light-sensitive devices, each of which is specially equipped to emit a signal depending on the intensity of the light and on the signal processing devices which comprise devices for continuous recording of the intensity of light at each of the light-sensitive devices and devices for

transforming said recording into an output signal which is a measure of said absolute distance or distance variation, characterised in that the device for receiving the light reflected from the surface of the body and the device for transmitting the derived beam of light are located firmly at a mutual optical distance corresponding to the focal length of the device for receiving the light reflected from the surface of the body, and in that the source of light is located on a device for varying the optical distance between the device for collimating the transmitted light.

4. Apparatus according to claim 3, characterised in that the source of light is located on the surface of a piezo-electric crystal on which acts a signal derived from the signal processing devices with a view to determining the distance between the surface of the body and a reference distance.

AMENDED CLAIMS

[received by the International Bureau on 10 April 1989 (10.04.89)
original claim 3 subdivided into amended claims 3 and 4; claim 4
renumbered as claim 5; other claims unchanged (1 page)]

- 5 transforming said recording into an output signal which is a
measure of said absolute distance or distance variation,
characterised in that the device for receiving the light
reflected from the surface of the body and the device for trans-
mitting the derived beam of light are located firmly at a mutual
optical distance corresponding to the focal length of the device
for receiving the light reflected from the surface of the body.
- 10 4. Apparatus according to claim 3, characterised in that the source
of light is located on a device for varying the optical distance
between the device for collimating the transmitted light.
- 15 5. Apparatus according to claim 3, characterised in that the source
of light is located on the surface of a piezo-electrical crystal
on which acts a signal derived from the signal processing devices
with a view to determining the distance between the surface of
the body and a reference distance.

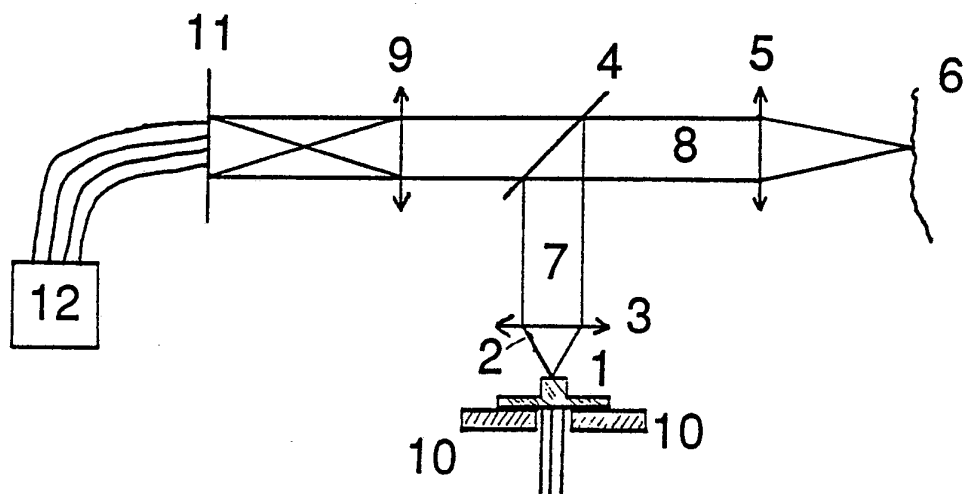


Figure 1

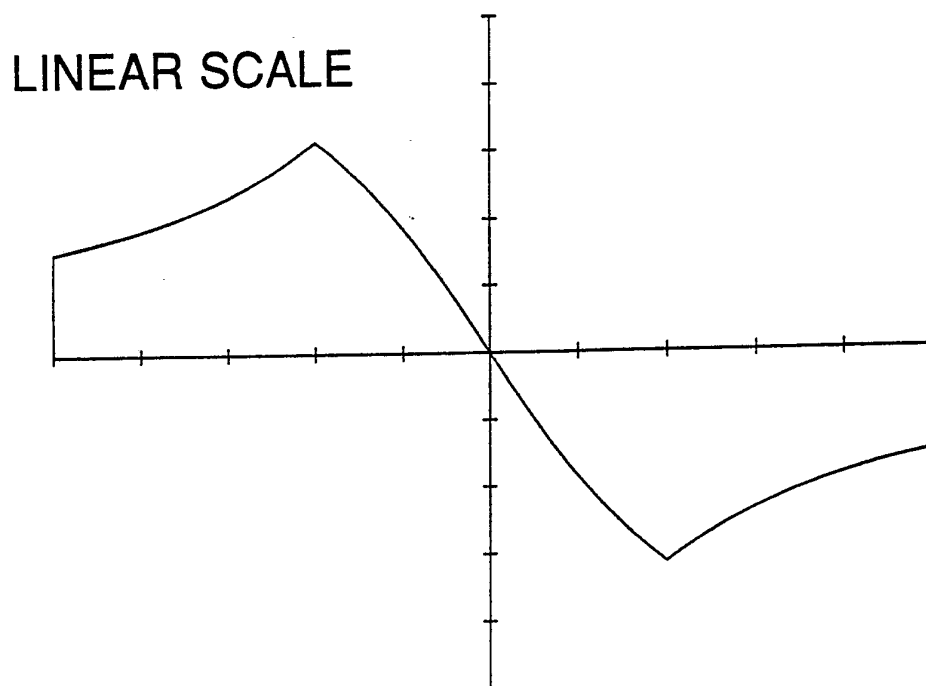


Figure 2

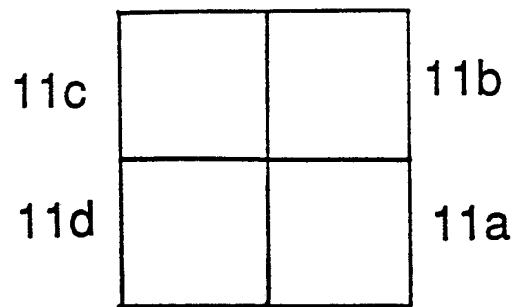


Figure 3

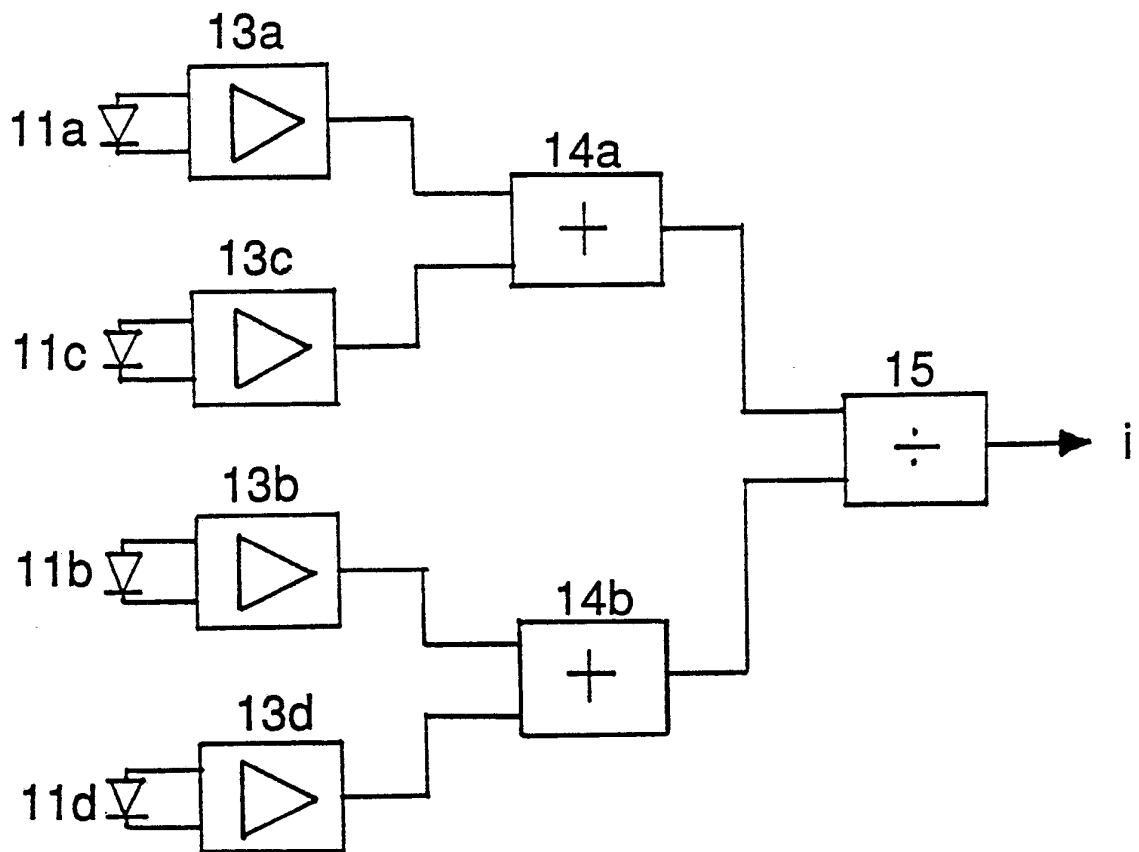


Figure 4

INTERNATIONAL SEARCH REPORT

International Application No PCT/DK88/00179

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) *		
According to International Patent Classification (IPC) or to both National Classification and IPC 4		
G 01 B 11/00		
II. FIELDS SEARCHED		
Minimum Documentation Searched 7		
Classification System	Classification Symbols	
IPC 4 US C1	G 01 B 11/00-/06,/14,/24,/30; G 01 C 3/00,/06,/08; G 01 H 9/00 73:653,655,657; 250:559-561,571,572; 356:3, 4, 120,156,237, 371, 372, 375, 376	
Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched 8		
SE, NO, DK, FI classes as above		
III. DOCUMENTS CONSIDERED TO BE RELEVANT 9		
Category *	Citation of Document, 11 with indication, where appropriate, of the relevant passages 12	Relevant to Claim No. 13
A	WO, A1, 86/07444 (BENGTSSON ANDERS) 18 December 1986 & SE, 447848	
A	GB, A, 2 158 228 (SPECTRON DEVELOPMENT LABORA- TORIES INC) 6 November 1985	
* 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		
Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report	
1989-02-08	1989-02-14	
International Searching Authority	Signature of Authorized Officer:	
Swedish Patent Office	Ingemar Josefsson	