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NON-CONTACT TONOMETER

BACKGROUND OF THE INVENTION

5 Field of the Invention

This invention relates to a non-contact tonometer which blows compressed fluid to an eye to be examined to thereby deform the cornea of the eye and detects a predetermined deformed state thereof and
10 measures the intraocular tension of the eye to be examined.

Related Background Art

Heretofore, in a non-contact tonometer of this kind, compressed air has generally been used as
15 compressed fluid. For example, as disclosed in U.S. Patent No. 3,585,849 and European Patent No. 164,730, the air in a compression chamber is gradually compressed by a piston driven by a solenoid, and the compressed air is injected to the cornea of an eye to be examined
20 through a nozzle and the time until the cornea becomes applanate or the internal pressure of the compression chamber when the cornea has become applanate is measured, whereafter the supply of electric power to the nozzle is cut off. Also, in the non-contact
25 tonometer of this kind, the measurement range is set to the order of 100 mmHg at the greatest so that even high intraocular tension of great strength can be

1 measured.

However, in most of ordinary eyes to be examined, the intraocular tension is up to the order of 30 mmHg at the highest and therefore, an apparatus
5 which injects compressed fluid under more than necessary pressure to the cornea and thereby avoids imparting excessive discomfort to the examinee has also been proposed in Japanese Laid-Open Patent Application No. 63-300740.

10 However, in the above-described example of the prior art, for a certain eye to be examined, change-over is effected to the measurement range for high intraocular tension and measurement is effected, where-
after even if another eye is to be examined, the
15 measurement range for low intraocular tension is not restored as long as a particular range change-over switch is not depressed and thus, measurement is effected in the measurement range for high intraocular tension from first, and if the next eye to be examined
20 is of intraocular tension in a range measurable in the measurement range for low intraocular tension, excess air will be supplied to the eye to be examined to thereby impart discomfort to the examinee.

Also, in the above-described example of the
25 prior art, in the case of an eye to be examined having high intraocular tension exceeding said range, predetermined deformation of the cornea is not obtained

1 as a matter of course when such eye is measured in a
low measurement range and thus, measurement becomes
impossible.

At this time, it is very difficult to
5 distinguish whether the cause of the impossibility of
measurement is range-over or unsatisfactory alignment
caused by movement or blinking of the eye to be examined
during measurement.

10 SUMMARY OF THE INVENTION

It is an object of the present invention to
provide a non-contact tonometer designed not to supply
excess fluid to the cornea of an eye to be examined and
impart discomfort to the examinee.

15 It is another object of the present invention
to provide a non-contact tonometer which is in terms of
standard provided with a measurement range for low
intraocular tension and which, for an eye of high
intraocular tension, is changed over to a measurement
20 range for high intraocular tension.

It is still another object of the present
invention to provide a non-contact tonometer which,
in the case of unsatisfactory alignment, does not
mistake an eye of low intraocular tension for an eye
25 of high intraocular tension and change over the
measurement range to a measurement range for high
intraocular tension.

1 It is yet still another object of the present invention to provide a non-contact tonometer which, for the same object, changes the measurement range during the next measurement in a case where the measured value
5 is high beyond the measurement range when measurement is effected in a measurement range for low intraocular tension or in a case where the measured value is sufficiently low when measurement is effected in a measurement range for high intraocular tension.

10 BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 shows the construction of a first embodiment of the present invention.

Figure 2(A) is a graph of the internal pressure of a compression chamber.

15 Figure 2(B) is a graph of an alignment light output.

Figure 2(C) is a graph of a cornea deformation detection light output.

20 Figures 3A and 3B show a specific example of the range change-over.

Figure 4 shows the construction of a second embodiment of the present invention.

Figure 5 is a flow chart.

25 Figure 6 shows a modification in which a display system is added.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to Figure 1 which shows a first embodiment of the present invention, a piston 3 driven by a solenoid 1 through a crank 2 may be advanced into a compression chamber 4 to compress the air in the compression chamber 4 and the compressed air may be blown against the cornea Ec of an eye E to be examined through a nozzle 5. A pressure sensor 6 is provided in the compression chamber 4. A concave mirror 7 is provided forwardly of the nozzle 5, and this concave mirror 7 is a concave dichroic mirror reflecting visible light and transmitting near-infrared light therethrough and is designed to form the image of the front eye part of the eye E to be examined on the fundus of the eye E to be examined. Transmitting windows 8 and 9 made of a transparent material are provided in a portion corresponding to the optical path L rearward of the nozzle 5, which is mounted on the central portion of the transmitting window 8. A dichroic mirror 10 transmitting visible light therethrough and reflecting near-infrared light, lenses 11 and 12 and a photosensor 13 are successively arranged on the optical path L behind the transmitting window 9. A lens 14 and an infrared light source 15 for alignment such as an infrared light emitting diode are disposed on the optic axis of the reflection side of the dichroic mirror 10. A light source 16 and a lens 17 are provided in a direction oblique with respect to the

1 eye E to be examined, and the reflected light of the
light beam from the light source 16 on the front eye
part of the eye E to be examined may be detected by a
lens 18 and a photosensor 19. Further, the output of
5 the photosensor 13 is connected to an A/D converter 21
through an amplifier 20, and the output of the A/D
converter 21 is connected to an interface 22. Also,
the output of the pressure sensor 6 is connected to the
interface 22 through an amplifier 23 and an A/D
10 converter 24, and the output of the photosensor 19 is
connected to the interface 22 through an amplifier 25
and an A/D converter 26. The output of the interface
22 is connected to the solenoid 1 and a display device
27, and a signal may be given and taken between the
15 interface 22 and MPU (microprocessor unit) 28.

The light beam emitted from the infrared light
source 15 is focused near the exit of the nozzle 5
through the lens 14 and the dichroic mirror 10
transmitting visible light therethrough and reflecting
20 near-infrared light. Thereafter the light beam diverges
again and is reflected by the cornea Ec of the eye E
to be examined, whereafter it passes through the concave
dichroic mirror 7 reflecting visible light and trans-
mitting near-infrared light therethrough and the
25 transmitting windows 8 and 9 and is focused on the
photosensor 13 by the lenses 11 and 12. The output of
the photosensor 13 is digitalized through the A/D

1 converter 21. That is, the amount of deviation of the
alignment between the direction of the nozzle 5 and the
optic axis L1 of the eye E to be examined is detected
by the light reception level of the cornea-reflected
5 image of the infrared light source 15.

In the intraocular tension measuring means, the
piston 3 is driven by the rotational solenoid 1 through
the crank 2, whereby the air in the compression chamber
4 is compressed and the internal pressure thereof is
10 detected by the pressure sensor 6. The compressed air
passed through the nozzle 5 deforms the cornea Ec of the
eye E to be examined, and the predetermined deformation,
e.g. applanation, of the cornea Ec is detected when a
maximum quantity of light enters the photosensor 19
15 which receives the light beam from the light source 16.
For example, the light source 16 and the photosensor 19
are provided at the focus positions of the lenses 17
and 18, respectively, and the output of the photosensor
19 is digitalized by the A/D converter 26 through the
20 amplifier 25. The output value of the pressure sensor
6 when the output of the photosensor 19 becomes maximum
is also digitalized by the A/D converter 24 through the
amplifier 23, and by the use of a conversion equation
obtained in advance from the then value, the value of
25 the intraocular tension is calculated in the MPU 28.

The MPU 28 has a program timer and prescribes
the time-up time. That is, when the predetermined

1 cornea deformation signal from the photosensor 19 is
not obtained even if the time-up time passes after the
supply of electric power to the solenoid 1 is started,
measurement is judged to be impossible and an error is
5 displayed on the display device 27.

Here, two cases are conceivable as the cause of
the aforementioned impossibility of measurement. The
first case is a case where the cornea deformation signal
has not been obtained due to alignment deviation or
10 blinking, and in this case, there is a high probability
that measurement becomes possible if measurement is
effected again. The second case is a case where the
compressed air itself could not fundamentally cause
cornea deformation due to the high intraocular tension
15 of the eye E to be examined, and in this case, even if
measurement is effected again, measurement becomes
impossible as long as the eye to be examined is the
same eye. At this time, on the basis of a detection
signal from the photosensor 19 indicative of the
20 impossibility of measurement, the energy imparted to
the solenoid 1 must be made greater, that is, the
pressure range must be changed over, through the
amplifier 25, the A/D converter 26 and the interface 22
from the next measurement, whereby air of higher
25 pressure must be made. That, distinguishing between
these two is indispensable because it is greatly
concerned in the probability of the success of the

1 next measurement.

Figures 2(A), (B) and (C) are graphs regarding two examples in which measurement error has been judged as previously described and one example of usual measurement. Figure 2(A) is a graph of the output of the pressure sensor 6 and time t , Figure 2(B) is a graph of the output of the photosensor 13 for alignment and time t , and Figure 2(C) is a graph of the output of the photosensor 19 for cornea deformation detection and time t .

In these graphs, t_s indicates the measurement starting point of time, and t_u indicates the time-up point of time, and here, as shown in Figure 2(A), it is to be understood that the air in the compression chamber 4 has been compressed. Oa shows the case of an error which has caused alignment deviation during measurement, Ob shows the case of a range-over error, and Oc shows the case of usual measurement. At the measurement starting point of time t_s , the output of the alignment light and the output of the deformation detection light and both Oa, Ob and Oc and there is no appreciable difference therebetween. However, when as shown by Oa, alignment deviation has been caused during measurement and the output of the alignment light has dropped rapidly, the deformation light output also remains small until the time-up point of time t_u . When as shown by Ob, the measurement range

1 is originally unsuitable for the eye E to be examined,
even if the air in the compression chamber 4 is
gradually compressed as shown in Figure 2(A), the
output of the cornea deformation detection light is not
5 obtained from the photosensor 19. However, the
difference of this case from Oa is that the output of
the alignment light remains holding a predetermined
level. If the pressure is gradually increased for Oc
in the case of normal measurement, the cornea Ec becomes
10 applanate and the output of the cornea deformation
detection light gets to have a certain peak as shown in
Figure 2(C) when a pressure corresponding to the
intraocular tension is reached. With this, the output
of the alignment conversely drops suddenly, but when
15 the cornea restores its original convex state, the
alignment light again restores its original output
level.

As described above, whether measurement has
been effected properly can be judged by detecting the
20 output level of the output of the cornea deformation
detection light by the MPU 28, and if the output level
still keeps a small level even at the time-up point
of the time t_u , the level of the alignment light at
that point of time, and if the level is smaller than
25 a predetermined level T_h , it is judged to be a
measurement error caused by alignment deviation, and
if the level is greater than the predetermined level

1 Th, it is judged to be a measurement error caused by
range-over, and thus, distinction becomes possible.

Figures 3A and 3B show a second embodiment
of the present invention, and the difference of this
5 embodiment from the embodiment of Figure 1 is that an
energy converter circuit 29 is interposed between the
interface 22 and the solenoid 1. A specific form of
this energy converter circuit 29 is described in
detail in Japanese Laid-Open Patent Application No.
10 63-300740. That is, Figure 3B shows an example
of the control circuit for controlling the torque of
the solenoid 2, and a charging resistor 121 and an
electrolytic condenser 122 are provided to supply a OC
power source for the solenoid 2, and the two source
15 resistors 124a and 124b of an MOS type field effect
transistor 123 may be changed over to thereby increase
or decrease the electric current I supplied to the
solenoid 2. In Figure 3B, the reference numeral 125
designates a switch for changing over the source
20 resistors 124a and 124b, the reference numeral 126
denotes the gate resistor of the transistor 123, the
reference numeral 127 designates a surge absorbing diode,
and the reference numeral 128 denotes a constant
voltage circuit for providing a gate voltage in the
25 form of pulse.

In the case of Figure 3B, it is possible
to charge the electrolytic condenser 122 from an applied

1 voltage V_i through the charging resistor 121, and
control the electric current flowing to the solenoid
2, correspondingly to the source resistor 124a or 124b
selected by the switch 125.

5 Here, when the cause of the impossibility of
measurement is the range-over caused due to too high
intraocular tension of the eye E to be examined and
deformation of the cornea fails to be caused, the
energy converter circuit 29 may be controlled by the
10 output of the interface 22 so that greater energy may
be imparted to the solenoid 1, whereby measurement of
the even higher intraocular tension becomes possible
during the next measurement.

Referring to Figure 4 which shows a second
15 embodiment of the present invention, a piston 32
driven by a solenoid 31 may be advanced into a
compression chamber 33 to compress the air in the
compression chamber 33, and the compressed air may be
blown against the cornea E_c of an eye E to be examined
20 through a nozzle 34. A pressure sensor 35 is provided
to measure the internal pressure of the compression
chamber 33. Transparent windows 36 and 37 made of a
transparent material are provided in the portion of
the compression chamber 33 which corresponds to the
25 optical path L, and the nozzle 34 is mounted on the
central portion of the transparent window 36.

Adjacent to objective lens 38, half-mirrors 39

1 and 40 are obliquely disposed on the optical path L
behind the transparent window 37, and further, an
imaging lens 41 and a television camera 42 are
successively arranged, and the output of the television
5 camera 42 is connected to a television monitor 43. A
lens 44 and an infrared light source 45 for alignment
such as an infrared light emitting diode are disposed
on the optic axis of the reflection side of the half-
mirror 39, and a lens 46 and a light receiving sensor
10 47 are disposed on the optic axis of the reflection
side of the half-mirror 40. The light receiving sensor
47 is disposed so that the quantity of incident light
becomes greatest when the cornea Ec becomes applanate.
A plurality of light emitting elements 48 for
15 illuminating the external eye are provided around the
transparent window 36. The output of the pressure
sensor 35 is connected to MPU (microprocessor unit)
51 through an amplifier 49 and an A/D converter 50.
The output of a reset switch 52 is connected to the MPU
20 51, the output of which is connected to an analog
switch 53. The analog switch 53 operates so as to
alternatively connect a source resistor RL or RH to a
solenoid control circuit 54 for driving the solenoid
31. Also, the output of the light receiving sensor
25 47 is connected to the MPU 51 so that as shown in
Figure 1, the impossibility of measurement is detected

1 and the driving of the solenoid can be controlled.

At first, the examiner carries out alignment by observing the image Ea of the eye to be examined formed on the television camera 42 through the
5 objective lens 38 and the imaging lens 41 and the light source image 45a emitted from the infrared light source 45 and reflected by the cornea Ec on the television monitor 43, and when this alignment is completed, the solenoid 31 is automatically or manually
10 energized. So, as previously described, the piston 32 is driven by the solenoid 31 and the air in the compression chamber 33 is compressed and is injected from the nozzle 34 to the cornea Ec, which thus begins to be deformed. When the cornea Ec becomes
15 applanate, the quantity of light entering the light receiving sensor 47 becomes greatest and therefore, the pressure in the compression chamber 33 when the output of the light receiving sensor 47 has reached its peak is directly detected by the pressure sensor 35, and by
20 the use of the value of this internal pressure, the intraocular tension is measured from a conversion equation prepared in advance. Also, the change-over of the measurement range becomes possible by changing over the source resistors RL and RH of the field
25 effect type transistor included in the solenoid control circuit 54 for controlling the electric current supplied to the solenoid 31, by the analog switch 53.

1 Here, let it be assumed that the relation
between the two source resistors RL and RH is $RH > RL$
and the intraocular tension has been measured with the
source resistance tentatively set to RH. If in this
5 case, the intraocular tension converted on the basis
of the result of A/D-converting the output from the
pressure sensor 35 by the A/D converter 50 is over the
measurement range, the MPU 51 controls the analog
switch 53 from the next measurement so that the source
10 resistor RH is automatically changed over to RL and
more electric current flows to the solenoid 31.

Conversely, if the measured value obtained
when the source resistance is set to RL is within a
range which can be measured even by the source
15 resistor RH, the source resistance is likewise
automatically set to RH by the command of the MPU 51
so that no excess shock may be imparted to the eye E
to be examined from the next time.

Here, in the present embodiment, when the
20 examinee is replaced by another examinee, the examiner
closes the reset switch 52 to thereby automatically
return the measurement range to the initial setting
before the measurement of the next examinee. The reset
switch 52 may serve also as a printing switch for a
25 printer or other functional switch such as a switch for
clearing the intraocular tension data in the past,
whereby the cumbersomeness of the switch operation can

1 be mitigated at any rate. This is a very important
function when it is considered that in the case of the
measurement of intraocular tension, almost all eyes to
be examined are of normal intraocular tension and with
5 regard to an eye of high intraocular tension, an
attempt is made to reduce the intraocular tension of
such eye on the spot by the use of a medicine and
therefore the probability with which measurement can be
accomplished in a low range is considerably high. That
10 is, it is more popular to select a low range as the
initial setting.

Also, even in the same examinee, the value of
intraocular tension may vary depending on the eye to
be examined and therefore, it is desirable to return
15 the measurement range to the initial setting each time
the switching of the eye to be measured is detected by
a microswitch 52' for detecting the movement of a stage
which means the switching of the left and right eyes.

These actions are executed by the MPU 51
20 operating in accordance with the flow chart of
intraocular tension measurement shown in Figure 5.
That is, with the start of measurement, at step 101, the
source resistance is changed over to RH by the analog
switch 53 and setting is made to a low pressure range.
25 Subsequently, at step 102, measurement is effected,
and at step 103, whether it is range-over is checked
from the result of the measurement. If it is not

1 range-over, advance is made to step 105, and if it is
range-over, at step 104, the source resistance is
changed over to RL by the analog switch 53 to set it
to a high pressure range. If at step 105, the reset
5 switch 52 is ON, the eye to be examined is judged to
have been replaced by another eye, and return is made
to step 101. Also, if the reset switch 52 is OFF and
measurement is not to be terminated at step 106, return
is made to step 102, where measurement is effected in
10 the high pressure range. If measurement is to be
terminated at step 106, the measurement is terminated.

Figure 6 shows a modification of the Figure 4
embodiment in which the display of the selection of the
measurement range and the display to the effect that
15 the measurement range is range-over is effected by a
display element 55. When the source resistance is set
to RH, a green light emitting diode is turned on, and
when the source resistance is changed over to RL, a
red light emitting diode is turned on. Where
20 measurement cannot be effected in the state in which
the source resistance is set to RH, that is, where the
measurement range is range-over or alignment is
unsatisfactory, the green light emitting diode is
turned on and off with the frequency changed, and
25 where measurement cannot be effected (alignment is
unsatisfactory) in the state in which the source
resistance is set to RL, the red light emitting diode

1 is turned on and off.

When the measurement range is range-over, it may be displayed by characters (e.g. "over"). By the above-described display, it can be confirmed with the aid of turn-on of the green light emitting diode during the change of the eye to be examined that the measurement range is a low pressure range, and the wrong operation of forgetting to depress the reset switch during the change of the eye to be examined and effecting the next measurement without a high pressure range being changed can be prevented. Also, where measurement cannot be effected in spite of alignment being good with measurement being effected in the low pressure range in which the green light emitting diode is turned on, that is, where the measurement range is range-over, there takes place the above-mentioned display "over" and immediately after that, the measurement range changes over to the high pressure range and the red light emitting diode is turned on.

Also, where the measured value is high when measurement is effected in a measurement range for low intraocular tension and the change-over of the range is effected through the MPU 51 so that at the next time, the measurement range is a measurement range for high intraocular tension for the same eye to be examined, change-over takes from the turn-on of the green light emitting diode to the turn-on of the red light emitting

1 diode. Also, where the measured value is low when
measurement is effected in a measurement range for
high intraocular tension and the change-over of the
range is effected through the MPU 51 so that at the
5 next time, the measurement range is a measurement
range for low intraocular tension for the same eye to
be examined, change-over takes from the turn-on of the
red light emitting diode to the turn-on of the green
light emitting diode. The display element 25 may
10 effectively be a liquid crystal element, an electro-
luminescence element, an electrochromic element,
a photochromic element or the like, and any of these
may be a single element, an array element or a matrix
element.

15 As regards the display, use may be made of a
change in the luminance of emitted light, besides a
change in hues such as green and red. Although the
visual display has been described above, at least
part of the display may be done by sound. For example,
20 where the measurement range is range-over, it may be
displayed by sound and the selection of the measurement
range for low intraocular tension and the selection of
the measurement range for high intraocular tension may
be displayed by the turn-on of a green light emitting
25 diode and a red light emitting diode, respectively.



CLAIMS

1. A non-contact tonometer having:

fluid projecting means for compressing fluid in a
compression chamber and projecting the fluid to the
5 cornea of an eye to be examined located at a
predetermined distance therefrom, said fluid
projection means being capable of selecting a first
range as a pressurizing range for measurement of
intraocular tension and a second range including a
10 value higher than in the degree of pressurization
relative to said first range;

measuring means for detecting a predetermined
deformation of the cornea of the eye to be examined
caused by the projection of the compressed fluid and
15 measuring the value of the intraocular tension of the
eye to be examined;

change-over means for changing the pressurizing
range for measurement of intraocular tension between
said first range and said second range;

20 state detecting means for effecting at least one
of detection of the fact that measurement is
impossible by said measuring means and detection of
the replacement of the eye to be examined by another
eye; and

25 control means for operating said change-over means



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on the basis of at least one of the output of said state detecting means and the measured value measured by said measuring means.

5 2. A non-contact tonometer according to Claim 1,
wherein said state detecting means comprises alignment
detecting means, and further comprises means for
discriminating whether measurement is impossible
within a prescribed time due to unsatisfactory
10 alignment or whether measurement is impossible because
the cornea of the eye to be examined does not exhibit
the predetermined deformation in spite of satisfactory
alignment, and wherein said change-over means changes
the pressurizing range in reponse to said
15 discriminating means discriminating that measurement
is impossible because the cornea of the eye to be
examined does not exhibit the predetermined
deformation in spite of satisfactory alignment in the
latter case.

20

3. A non-contact tonometer according to Claim 2,
wherein said change-over means produces an output
which is transmitted to said control means to change
the pressurizing range for measurement of intraocular
25 tension from said first range to said second range.



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4. A non-contact tonometer according to Claim 2,
wherein if said state detecting means detects the
replacement of the eye to be examined by another eye,
and said control means controls said change-over means
5 to return said fluid injecting means to said first
range in accordance with the detection of the
replacement of the eye by said state detecting
means.

10 5. A non-contact tonometer according to Claim 1,
wherein said control means controls said change-over
means to change the pressurizing range in accordance
with the magnitude of the measured value measured by
said measuring means.

15 6. A non-contact tonometer according to Claim 1,
wherein said state detecting means comprises
determining means for determining the replacement of
the eye to be examined by another eye means, and
20 wherein said state detecting means from an output of
said determining means that the eye to be examined has
been replaced by another eye.



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7. A non-contact tonometer according to Claim 1,
wherein said state detecting means comprises a reset
switch for resetting said tonometer wherein said state
detecting means detects by the output of said reset
5 switch that the eye to be examined has been replaced
by another eye.

8. A non-contact tonometer according to Claim 7,
wherein said reset switch serves also as an operation
10 starting switch of a printer for recording the result
of the measurement of intraocular tension.

9. A non-contact tonometer according to Claim 7,
wherein said reset switch serves also as a clear
15 switch for clearing previous measurement data of
intraocular tension.

10. A non-contact tonometer according to Claim 1,
wherein said change-over means comprises a solenoid
20 for driving a piston in the compression chamber and
means to change the circuit resistance of said
solenoid.



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11. A non-contact tonometer according to Claim 1,
further comprising display means for effecting at
least one of the selective display of said first range
and said second range and the display of the fact that
5 measurement is impossible by said measuring means
because the pressurizing range during measurement is
inappropriate.

12. A non-contact tonometer according to Claim 11,
10 wherein said display means includes visual display
means.

13. A non-contact tonometer according to Claim 11,
wherein said display means includes aural display
15 means.

14. A non-contact tonometer comprising:
fluid projecting means for compressing fluid in a
compression chamber and projecting the fluid to the
20 cornea of an eye to be examined located at a
predetermined distance therefrom, said fluid
projecting means being capable of selecting a first
range as a pressurizing range for measurement of
intraocular tension and a second range including a
25 value higher in the degree of pressurization relative



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to said first range;

measuring means for detecting a predetermined deformation of the cornea of the eye to be examined caused by said compressed fluid and measuring the value of the intraocular tension of the eye to be examined;

change-over means for changing the pressurizing range for measurement of intraocular tension between said first range and said second range;

state detecting means for effecting the detection of the fact that measurement is impossible by said measuring means and the detection of the replacement of the eye to be examined by another eye;

control means for operating said change-over means on the basis of at least one of the output of said state detecting means and the measured value measured by said measuring means; and

display means for effecting at least one of the selective display of said first range and said second range and the display of the fact that measurement is impossible by said measuring means because the pressurizing range during measurement is inappropriate.
