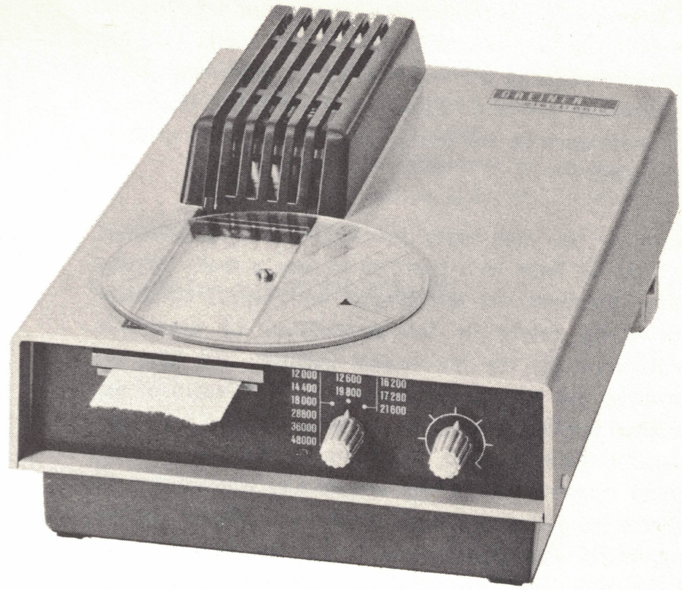
Micromat

Handbook



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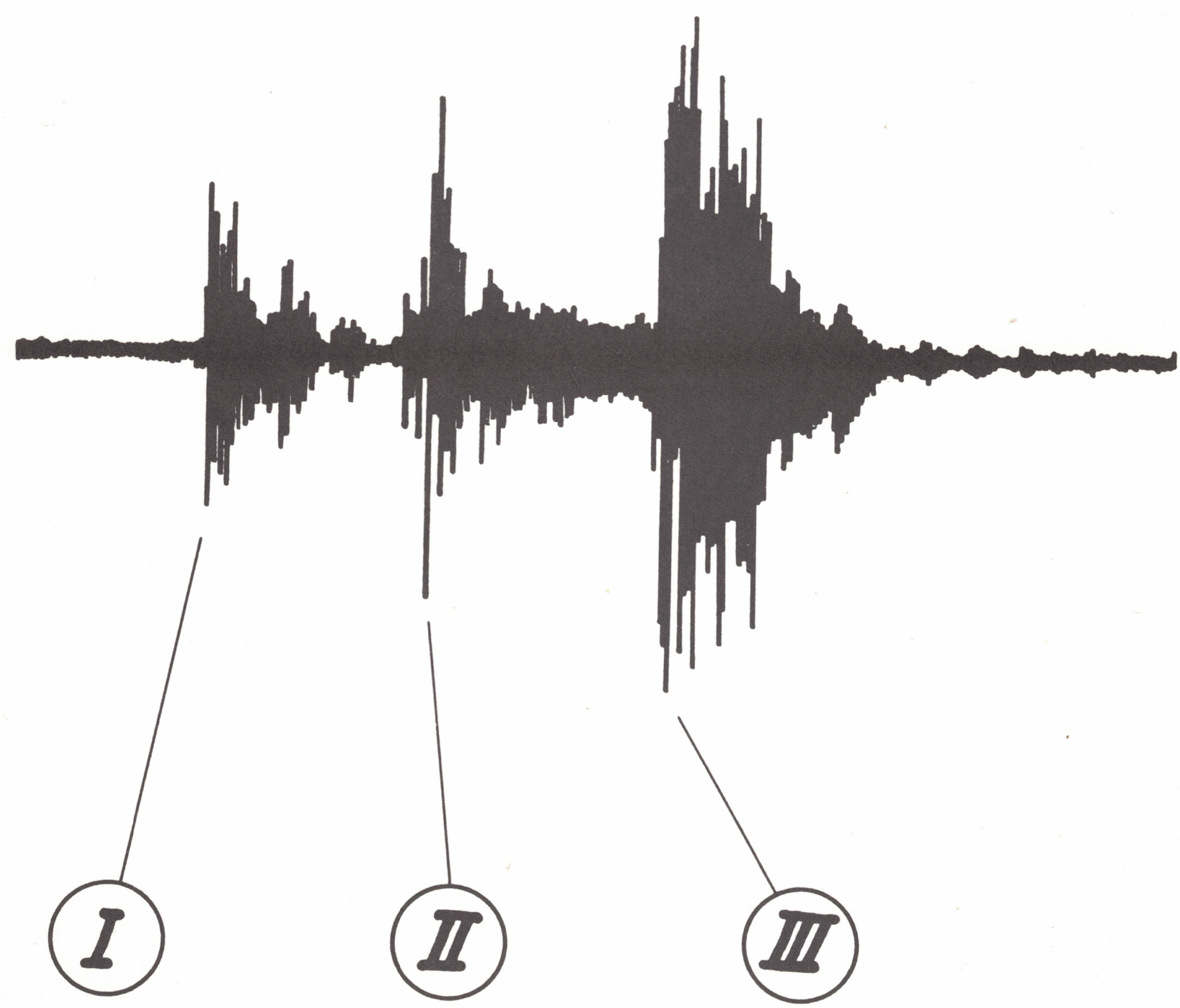
2.1.1. Theory of volume control

Correct use of the volume control is essential when working with the MICROMAT. On the one hand the volume control can be used to compensate for the great differences in beat strength found with various watches, and on the other hand by using different amplification stages specific individual escapement functions can be selected and recorded.

The ticking of a watch, heard by the human ear as a uniform beat, is in fact made up of all the sounds produced by all the moving mechanical parts of the escapement. Every escapement therefore produces a sequence of characteristic individual noises which give a true picture of the dynamic functioning of the escapement. Fig. 2/1 shows the ticking noise of a **lever escapement** as it appears on the screen of a cathode ray oscilloscope to which a watch microphone has been connected. From left to right the horizontal axis corresponds to the time. The vertical axis shows the signal voltage of the microphone proportional to the volume of the noise.

On the oscillogram, 3 distinct parts of the signal can be recognized, each caused by a well-defined phase of escapement action.



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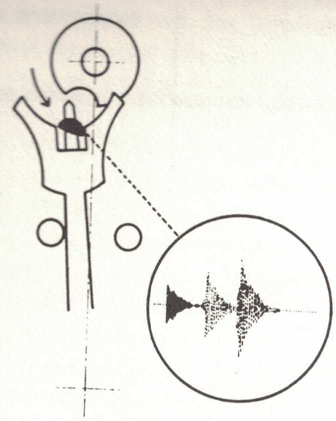

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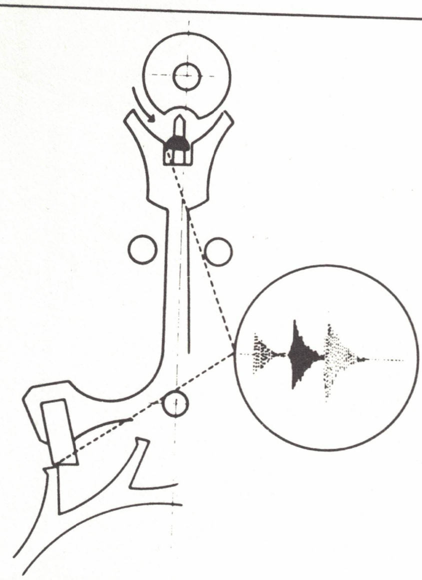

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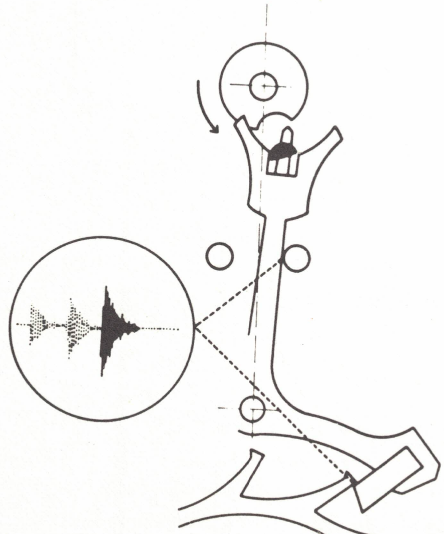

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Fig. 2/2-2/4 show the parts of the escapement and beside these the oscillogram of beat sound. From the point of origin of the mechanical impulse in each case there is a dotted line to the oscillogram where the corresponding part of a signal is marked in black.

Normally the unlocking signal I is the weakest, the impulse signal II is a little stronger, and the drop signal III is the strongest. Even with an impeccable escapement, there are great variations from beat to beat in the volume of the various sounds. The sounds of impulse signal II are often blurred and unstable.

Signal I (Fig. 2/2) is produced at the start of unlocking when the roller pin strikes the fork.

Signal II (Fig. 2/3) is due to the impulse and produced partly by the pallets on hiting the tooth of the escape wheel, but mainly by the movement of the fork to the other side of the roller pin between the end of the unlocking phase and the beginning of impulse action.

Signal III (Fig. 2/4) consists of the drop of the escape wheel against the locking face of the pallet as well as of the impact of the stem of the fork against the banking pins. Both noises occur almost simultaneously, so that they cannot be separated from one another.

In order to understand the effect of the different signals on the MICROMAT, we must explain the function of the lift-magnet at the output end of the amplifier stage.

Normally there is a current flow through this magnet, but as soon as the measuring circuit is excited, the circuit is suddenly opened and this actuates the recording system and a dot is printed on the paper tape.

Before an electrical control signal can excite the circuit, it must exceed a certain minimum voltage which is referred to as the threshold value. Once excited, the control signals immediately following are without effect. Therefore only the first signal to attain the threshold value is recorded. If amplification is slowly increased from zero, the signals will be recorded in a sequence depending on their strength, i.e. in reverse order to their time sequence, since the last signal is the strongest and the first signal the weakest.

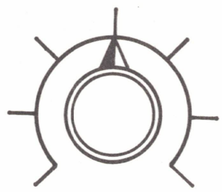
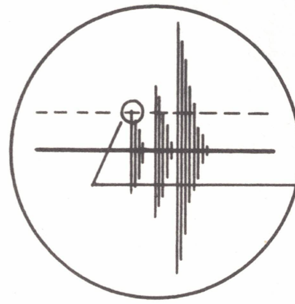
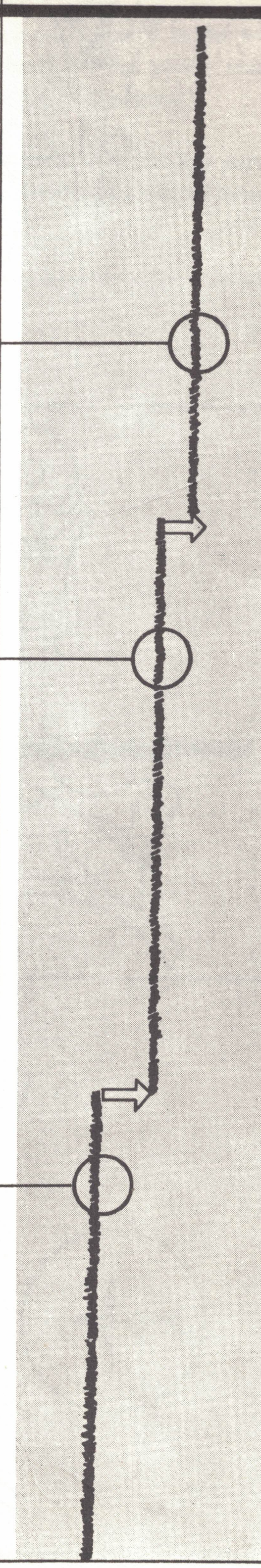
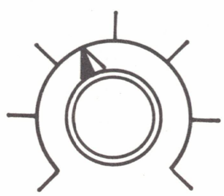
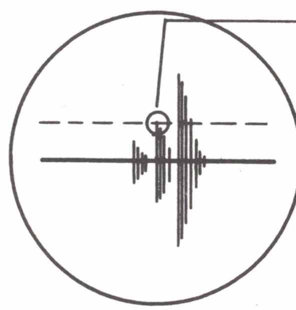
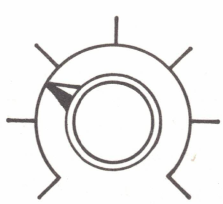
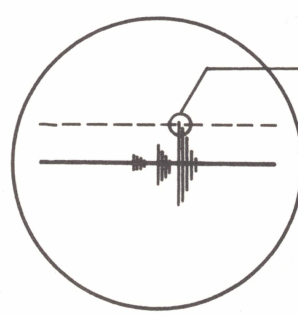
Diagram	Oscillogram	Volume of control position	Phase of escapement action
Unlocking signal I Correct volume control setting for all rate measurements			
Impulse signal II			
Drop signal III Setting for testing escapement and measuring amplitude 2/5			

Fig. 2/5 shown in diagram form how the volume control can be used to select recording of the different functions. The figure shows, side by side, the volume control positions, the oscillograms with the threshold value of the switch marked by dotted line, and an original diagram printed on the instrument. A marking line connects in each case the registered part signal on the oscillogram with the corresponding recording on the tape. In accordance with the chronological formation of the diagram, the different phases must be followed from bottom to top. In the bottom phase, the volume control was slowly turned up from zero just far enough to obtain a continuous recording in the rhythm of the watch beats. As the oscillogram column shows, the drop signal III (Fig. 2/1) is amplified until it just reaches the threshold value. Thus the time sequence of the dropping escape wheel teeth is recorded.

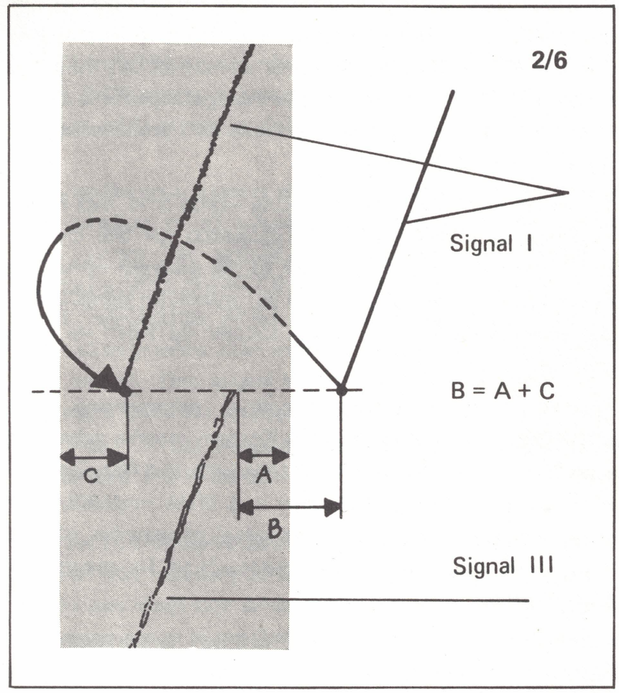
It the volume is now carefully increased a little, the diagram suddenly shifts to the right. The phase shown in the middle is reached when the impulse noise II passes the threshold value of the switch. Since the impulse noise occurs, in time, before the drop noise and since only the first signal emitted at the threshold value volume produces an effect, the impulse is recorded and the subsequent drop noise has no effect. As already stated, even in perfect escapements the noise of the impulse is often unstable so that it is not always possible to obtain a perfect recording of it.

If we now continue to raise the volume, there is a further shift to the right of the diagram, and the top phase is reached in which the unlocking noise I exceeds the threshold value and is recorded alone since both the other noises occur later in time.

The shift to the right of the diagram when the recording passes to an earlier signal is explained by the fact that the recording position moves across the paper tape from right to left (see description of operation 1.6.). If the later signal were already recorded on the right-hand side of the tape, the earlier signal might lie beyond the right-hand edge of the tape. In such a case a dot is already recorded during the preceding rotation of the recording column, this dot appearing at the same distance from the left-hand paper edge as it would lie outside the right-hand edge. Fig. 2/6 shows this apparent displacement to the left. B is the required displacement to the right, this being the sum of distances A + C.

If the repetition of the recording is smaller than the paper width, the difference between paper width and repetition width must be deducted from the value found as described above. The technical data given in the description of the instrument provide further information about this.

For many purposes - e.g. amplitude measurement - the diagram must be evaluated in transverse direction in milliseconds (see technical data 4.).



2.1.2. Practical volume control

A) Free lever escapement

We have seen that of the three signals making up the ticking sound, only the unlocking signal I is directly produced by the oscillating system which at this moment is still within its maximum speed range. Signal I is therefore the most accurate and should be used exclusively for all rate measurements.

To make sure that the unlocking signal is in fact being recorded, the best method is to watch for the characteristic displacement to the right of the diagram occurring when passing from drop signal to unlocking signal when the volume control is slowly turned up from its zero position.

Thanks to the highly sensitive microphone, the MICROMAT has a large amplification reserve adequate even for watches with small escapements and heavy cases. With ordinary timing machines it is often impossible to correctly record the unlocking signal of watches of this type, even when the volume control is set for maximum amplification.

On the other hand the volume must not be unnecessarily high since this may result in secondary noises from the watch or the room causing interference.

To test the escape wheel, and in particular to measure the amplitude, the drop signal must also be used.

Pin pallet escapements give the same signals as the lever escapements described above, but the time interval between the partial signals is greater.

B) Cylinder escapements

The sound of the cylinder escapement consists of a single large signal caused by the drop of the escape-wheel teeth onto the outside or inside cylinder wall, accompanied by strong friction noises for the whole duration of the period.

For this escapement therefore amplification must be just sufficient to allow recording in the rhythm of the beats. Since the beats are not directly produced by the oscillating system, a diagram of a cylinder escapement always shows relatively great scattering of the dots corresponding to the fualts of the cylinder wheel (Fig. 2/7.).

C) Pendulum escapement

The remarks made concerning cylinder escapements apply also to pendulum escapements. It is preferable to attach a clamp microphone to the movement plate. Pendulum clocks with long periods in particular tend to produce considerable scatter. Such diagrams often become more easily legible if the individual dots are numbered chronologically and the even numbers on the one hand and odd numbers on the other hand are joined together by lines (Fig. 2/8.). If we also connect together dots separated from each other by the number of dots equal to the number of teeth of the escape wheel, an accurate rate measurement will be obtained.

D) Chronometer escapements

A perfect diagram of chronometer escapements is obtained if the volume is raised just enough to give a recording in the rhythm of the watch beat. In this case only the noise of the impulse is recorded.

If for a given watch a clear diagram cannot be obtained at any volume control position, the earphone must be used to test whether there is interference from secondary noises.

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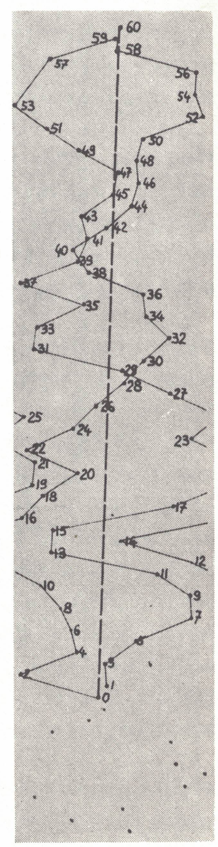


2.1.3. Fundamental principles of rate measurements with timing machines

In order to make intelligent use of the new possibilities provided by the MICROMAT, it is essential to bear in mind certain factors which are important when the rate is measured for a short period only.

Here it is necessary to remember the physical laws governing the rate of the watch and the influences which may cause rate variations:

Mechanical oscillation occurs as a result of an exchange of the kinetic energy of the moving against the potential energy of the directing force. In the pendulum clock, the directing force is represented by the effect of gravity on the raised pendulum bob, and in the balance-wheel watch by the tension of the hair-spring. The directing force attempts to make the oscillating body return to the central position, while the kinetic energy of its mass tends to override the central position. At the points of reversal of motion there exists only potential energy, and on passing through the central position only kinetic energy is active.

An ideal oscillating system in which only mass and linear directing force are in operation has the strictly harmonic motion of a sine function.

The rate of a watch is represented by the frequency of its oscillating system consisting of the balance-wheel and the hair-spring. This frequency is determined by the following element:

1. **The moment of inertia**
   This is dependent on the magnitude and position of the rotating mass.
2. **The directing force**
   This is dependent on the elasticity of the hair-spring, as well as on other forces such as gravity and magnetism.
3. **The anharmonicity**
   This term expresses the deviation from strictly harmonic motion, such motion being impossible to achieve in practice.

Table I summarises the main influences on the right and shows how they can be attributed to each of these three elements. The outstanding importance of the amplitude of the balance-wheel is clearly seen when influences are subdivided into those dependent on amplitude and those independent of amplitude.

Table II shows the main causes of amplitude variations. Almost all the causes of variations in rate and amplitude are present in all watches without exception. The good watch differs from a poor one only to the extent that the effects of these causes remain small or compensate each other.

In the standard method used up to now, the rate of a watch is measured by comparing its state with a standard time piece at intervals of 24 hours. The MICROMAT instrument however records the state of each single beat by comparing it with the built-in electronic time standard. Using the measuring dial, the rate can be established after only a few beats. Although in both cases the result of the measurements is expressed in seconds per 24 hours, there is a fundamental difference.

The measurement result of the first method is the sum of the duration of all single oscillations which the oscillating system has actually performed in the course of 24 hours. With the MICROMAT instrument on the other hand, "seconds per 24 hours" implies a **measuring unit** for the instantaneous rate existing during the brief measuring period. This means that if a watch were to run for 24 hours with no change of rate it would finally reach this rate, i.e. the instantaneous rate would become the actual rate in 24. hours.

In view of the many possible causes of rate variations, it is clear that measurement over 24 hours under unknown conditions does not allow an evaluation of watch performance since it provides no evidence of the incidents occurring during that time.

We can now appreciate the real value of the MICROMAT, not limited to the visual observation of slowly moving watch hands but penetrating directly into the heart of the watch: the oscillating system. Within a short time the MICROMAT measures the rate of a watch under all the various conditions which occur in practice and their specific influences can be separately evaluated. In this way we obtain an accurate picture of the quality of the watch, enabling us to make safe predictions of its future performance. On the other hand, rate measurement over a brief period must not be freely equated with the rate determined over 24 hours, for the reasons set out below.

When a watch is worn - and to some extent also when it is simply left on a shelf etc. - it is exposed to widely varying influences, e.g.:

it may be in any conceivable positions;
there is a certain range of balance-wheel amplitude;
the ambient temperature varies;
there may be external acceleration.

A high quality watch which in spite of these varying conditions shows no alteration in rate is a watch in which the actual rate corresponds with the timing machine measurement, even if it only takes into account one condition. Furthermore it can be predicted that this watch will show good reproducibility (uniform repetition) and rate stability over a long period.

Table I Causes of rate variations

Effect on:	Independent of amplitude	Dependent on amplitude
1. Radius of inertia	Effect of temperature on balance-wheel diameter. Alteration of balance-wheel shape by shocks and stabilisation of internal tensions of material. Dirt deposits.	Development of hair-spring. Deformation of balance-wheel due to centrifugal forces.
2. Directing force	Effect of temperature on: a) hair-spring dimensions b) modulus of elasticity of hair-spring Effect of magnetism and fatigue on hair-spring.	Poising errors of balance-wheels and hair-springs. Non-linear elasticity of hair-spring. Position of points of attachment. Alteration of active length of hair-spring due to play between curb-pins. Alteration of shape of regulator due to stabilisation of internal tensions of material. Magnetic outside the oscillating system.
3. Harmonic motion	Influences from escapement.	All influences mentioned under 1. and 2. in this column. Influences from the escapement. Friction influences.

Table II Causes of amplitude variations

1. Non-uniform force:	Varying main spring tension. Non-constant torque transmission in gear train. Varying power of impulse from escape-wheel teeth.
2. Friction variations:	Different length of lever on which the friction acts at the balance-wheel pivots in horizontal or vertical position. Variation in the quality of the oil with changes in temperature, ageing and evaporation. Diminishing and increasing friction as a result of running and wearing out of all moving parts.
3. Disturbances:	Grazing of parts of the escapement (guard-pin, fork horn, etc.). Faults in escapement functions. Touching of watch hands. External acceleration effects.

In measuring a poor quality watch great differences of rate under different conditions will be found. The actual rate of such a watch is always accidental, depending on the respective duration of the individual conditions. The rate is not easily reproducible and the behaviour of the rate over a longer period of time is unpredictable.

So that conclusions concerning the actual rate in 24 hours for such a watch can be drawn from measurements made on the instrument, the average of several measurements under different conditions is taken. The greater the differences between the rate deviations under the different conditions and the greater the accuracy with which the desired approximation must approach the actual rate, the greater must be the number of measurements made under the different conditions from which the average is calculated.

The average from six positions with large and small amplitude gives a very good approximation to the actual rate of a watch in normal use. As a general rule, one measurement in a horizontal position and one in a vertical position are often sufficient.

Apart from the change of position, amplitude and temperature, there are other influences which can affect the rate of a watch as it runs down. If there are apparently inexplicable differences between the calculated average of the measurements and the actual rate, this may be due to one of the following causes:

A watch which has been stored for some time will not give a reliable measurement immediately after the first winding. Some time is needed for the lubrication to stabilize and a definite amplitude to be reached.

All periodical variations in rate, with a repeat time significantly exceeding the measuring time, are naturally not taken into account. These include: faults in the teeth of gears which rotate slowly, foreign bodies in the gear, touching of watch hands.

Insufficient cannon pinion friction may be a source of error especially in clocks.

If the actual rate gains a great deal, this generally due to intermitent knocking.

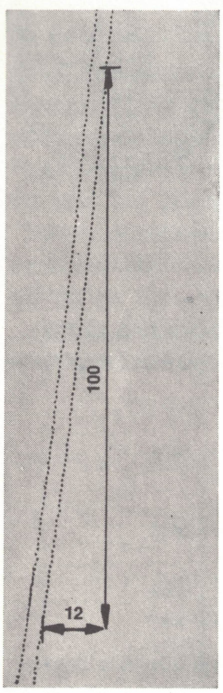
Automatic watches with a slipping ring not operating perfectly may show substantial variations of rate. In vertical positions, the weight of the winding mass forms a driving force additional to the force of the main spring.

2.2.1. Measurement of characteristic watch data

The extraordinary variety of the factors influencing the rate of a watch explains why it is almost impossible for two watches to show identical diagrams and why there is an infinite number of possible variations. It would therefore be pointless to attempt to compile a catalogue of all possible diagrams.

We are therefore limiting ourselves in this section to a discussion of the basic points relating to the formation and interpretation of the diagrams in order to help the expert by guiding him in gathering his own experience.

Any layman can easily recognize a fast or slow rate from the diagram. A more detailed diagnosis however requires a deeper knowledge of watches and a familiarity the way in which diagrams are formed.



= 12 s/24 h

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By "characteristic watch data" we mean the rate and amplitude in the different positions and at varying temperatures, together with the associated isochronism and temperature coefficient.

There are some watches with which price and quality are by no means related. Measurement of characteristic watch data with the MICROMAT is the only way to objectively establish the real quality of watches which are offered for sale.

2.2.2. Rate

Inclination of the diagram **towards the left** signifies a **slow rate.**(See Fig. 2/10)

A diagram **parallel to the edge** of the recording tape signifies an **accurate rate with no deviation.**

Inclination of the diagram **towards the right** signifies a **fast rate.**

The measuring dial is the simplest way of evaluating rate from short diagrams immediately after they have been recorded.

If the paper tape has already been removed from the instrument, the rate can be determined by measuring the diagram inclination. The extent of the inclination corresponds to the daily rate. The technical specification of each instrument determines which recording length corresponds at 1 mm transverse displacement to 1 second per 24 hours rate deviation. Figure 2/9 shows, as an example, a diagram in which one second corresponds to one millimetre transverse displacement over a length of 100 mm.

2.2.3. Amplitude

Most of the factors influencing watch rate are dependent on amplitude. The amplitude of the balance-wheel is therefore, after the rate, the most important of the characteristic features of a watch.

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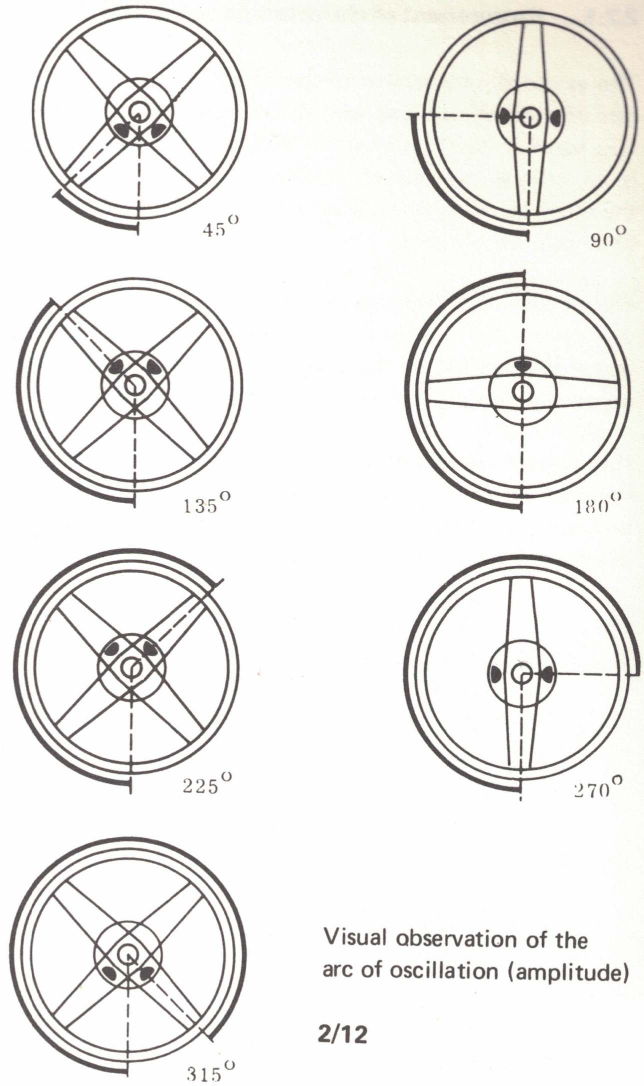
If during rate measurement with the MICROMAT the watch is moved e.g. from the horizontal to the vertical position, no immediate change of rate will be noted. The alteration in rate will take place only when the amplitude has adjusted itself to the new position. On the diagram this process will be expressed by a characteristic transition arc between the two different rates to which the different inclinations of the rows of dots correspond. A transition arc is always proof that a change in amplitude has occurred.

With the movement open, visual determination of the amplitude is easy. Hold the movement in front of you so that the escape-wheel and balance wheel are directly above one another. With the main spring completely released, the balance arms are then generally in the horizontal position, as shown in Fig. 2/11. When the main spring is slowly wound, the arms assume the characteristic position shown in Fig. 2/12 as they pass through the various amplitudes. At an amplitude of 180°, the neutral position is again reached. For amplitudes 45° greater or smaller than 180°, the positions are identical.



Visual observation of the arc of oscillation (amplitude)

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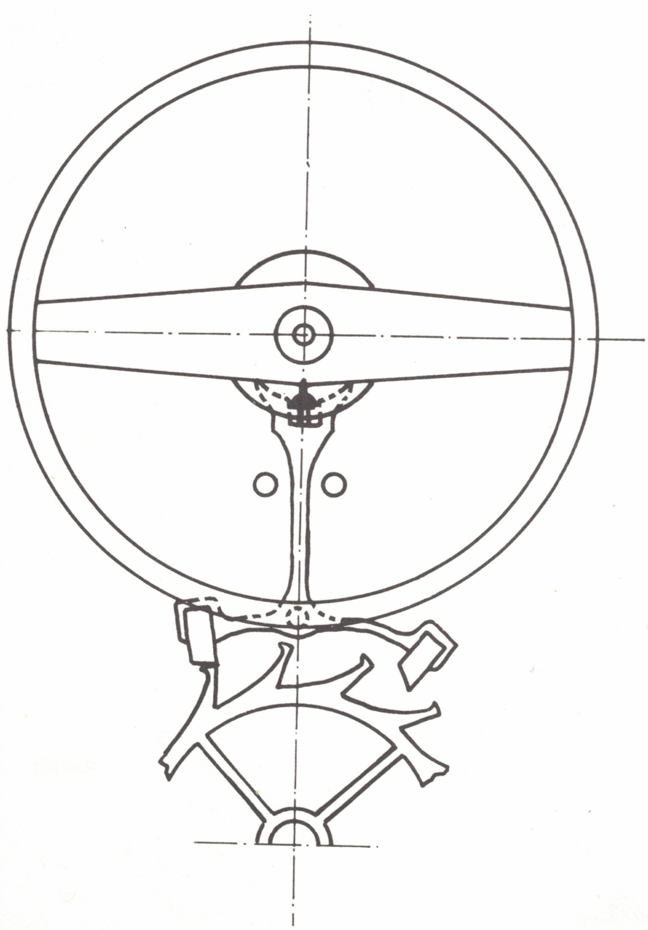
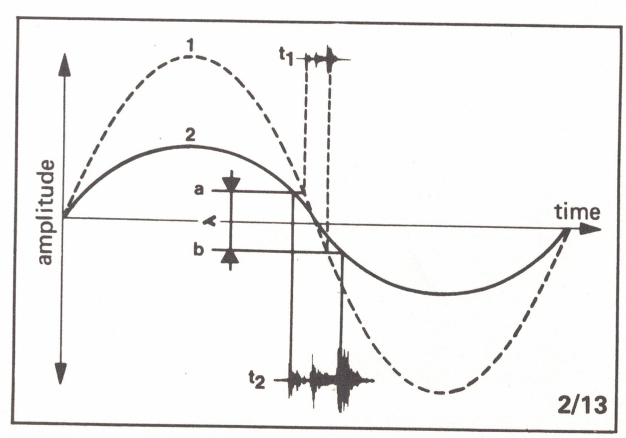


Balance-wheel in neutral position **2/11**

Amplitude 1 passes through the range a-b in a time t_1, which is shorter than the time t_2 for amplitude 2.



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Verification of the different positions of the balance-wheel arms requires some experience which can however be quickly acquired if the balance-wheel is stopped in neutral position and, after release, the transition from one pattern to another is observed. Intermediate positions can be easily estimated.

To achieve a given amplitude, the mainspring, completely run down, is wound slowly and carefully tooth by tooth until the desired amplitude is attained.

The MICROMAT also permits measurement of watch amplitudes with cases closed. This is invaluable especially for testing waterproof watches.

The speed of the balance-wheel when passing through the neutral position depends on the amplitude. With high amplitude, the balance-wheel describes a greater arc than with a small amplitude within an identical time and consequently requires less time for a given arc. If the time for a precisely defined arc of the balance-wheel motion is measured, it will therefore be possible to calculate the amplitude (Fig. 2/13).

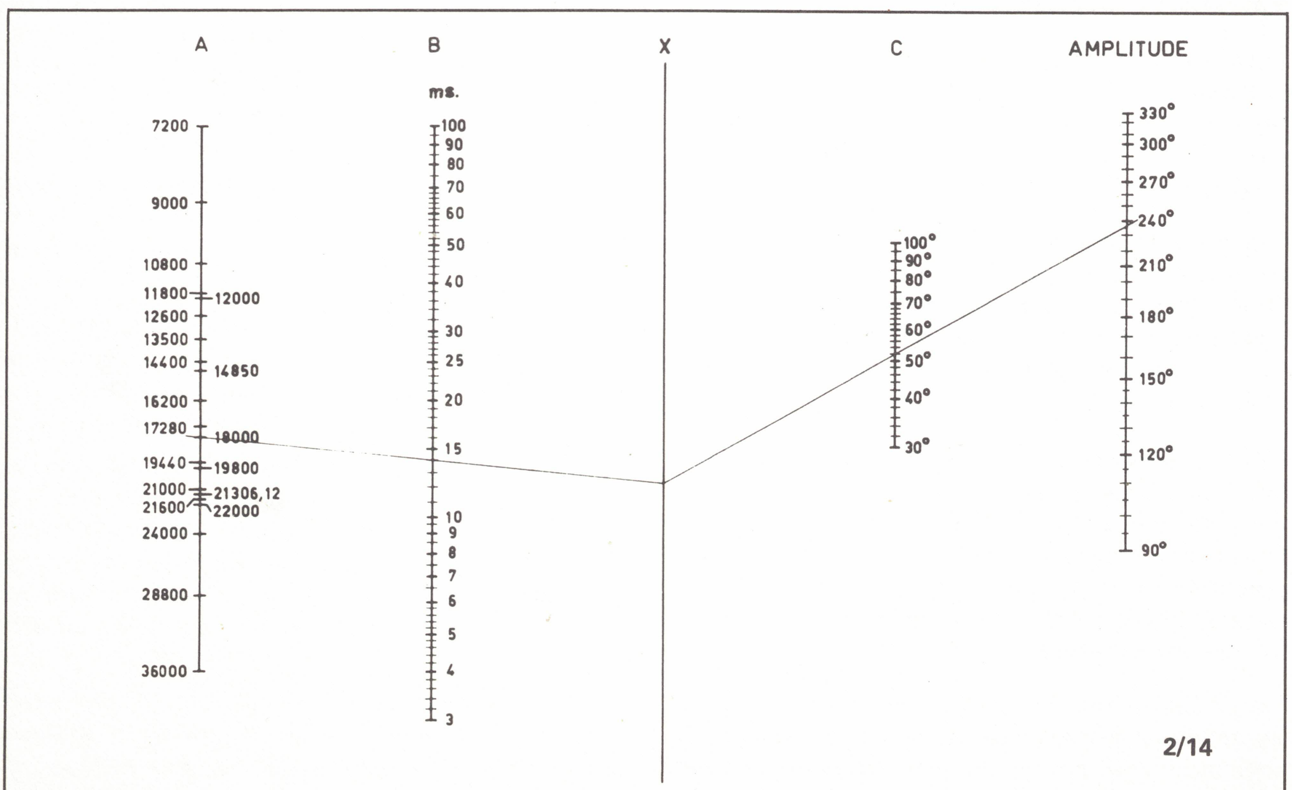
Amplitude measurement is based on this principle. The unlocking signal and the drop signal are used as reference marks for the beginning and end of the arc to be measured. These signals correspond to contact with the roller in the two end positions of the lever (see section 2.1.1. "Theory of volume control"). If we first record the drop signal with minimum amplification and then, by suddenly turning up the volume, switch over to the unlocking signal, the diagram shifts to the right (see Fig. 2/5 and 2/6), the shift being measured in milliseconds. The angular distance between the two measuring marks corresponds to the arc which the balance-wheel describes during the escapement action and is defined as the "lift angle of the balance-wheel", this being determined by the design of the escapement. For most wrist-watches this amounts to 52°, and for pocket-watches 36°.

The nomograph, Fig. 2/14 enables the amplitude of any given watch mechanism to be determined simply from the millisecond value measured between the unlocking and drop.

On scale "A" we find the appropriate value in beats per hour and draw a line from this value to the millisecond value measured on scale "B"; we extend this line until it intersects the line "X". From the point of intersection we draw a straight line through the lift angle of the mechanism shown on scale "C" as far as the amplitude scale, from which the required value can be read off.

Table 3.1. shows the theoretical lift angles for all Swiss calibres.

With the mainspring fully wound, the amplitude in the horizontal position must not be less that 270°. In the case of a good quality watch, the decrease in vertical positions will be only about 45°, and even in a cheap watch the decrease should not be more than 90°.



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2.2.4. Isochronism

"Isochronous" is a Greek word meaning "of equal time". By convention, isochronism is understood to mean the property of an ideal oscillating system to perform all oscillations whether of large or small amplitude in the same time. Isochronism therefore expresses the relationship between rate and amplitude.

No practical oscillating system will show perfect isochronism. The deviation from ideal isochronism is called ANISOCHRONISM or isochronal error. This is the sum of all the rate variations caused by alteration of the amplitude.

The magnitude of the isochronal error varies with the amplitude range and also with the positions of the watch if it is caused by a poising error. Exact information can therefore only be obtained through a set of graphs showing the rate as a function of amplitude for every position. It should be noted that the temperature also has an effect on the isochronal error.

For practical purposes it is sufficient to determine the rate at two different amplitudes. To obtain comparable results we always chose 180° and 270°. This gives two amplitudes which can be determined reliably and easily, and which at the same time cover the range which occurs most commonly in practice. To eliminate the influence of poising error for this informational measurement, we always test in the horizontal position.

If the measured rates at these two amplitudes are e.g. −10 and +20 seconds, the isochronal error is 30 seconds between 180° and 270°. Values quoted for isochronal error without indication of the amplitude range would be useless.

The rate differences between horizontal and vertical positions are in the first place the result of isochronal error. Rate differences between different positions, however, give no indication of the extent of the isochronal error. This error can only be recognized after the amplitude has been determined.

Play at the hair-spring between the curb-pins, and the influence of the escapement, are the main causes of isochronal error in a watch. They both cause the watch to lose at small amplitudes. The manufacturer tries to compensate this by correct choice of the points of attachment and non-linearity of the hair-spring in order to obtain a fast rate at small amplitudes.

Watch quality can be assessed most satisfactorily by determining the magnitude of the isochronal error. A small isochronal error is the best guarantee for good long-term rate stability.

It must however be remembered that any variation of the impulse transmitted by the escapement in itself causes an alteration of the rate, i.e. even before any change of amplitude occurs. If we take as an example two identical watches which show a drop in amplitude to a given value, in one case this decrease may be produced by a mainspring which is almost run down although the movement is otherwise in perfect working order, whilst in the other case, in spite of a fully wound mainspring, the thickness of the oil prevents the amplitude from increasing. The influence of the escapement on the harmonic motion of the oscillating system is small in the first case and much greater in the second example. Although the amplitude is identical in both cases, the rates will be different.

2.15. Temperature coefficient

In normal use watches are exposed to wide variations in temperature.

A watch placed on a bedside table in winter may be exposed to temperatures below freezing point, and even a watch which is worn all the time may undergo temperature variations between 66° F (19° C) and over 100° F (37° C) (P. Berner, SSC Bulletin, 1939).

In general far too little attention is paid to the influence of temperature. In spite of the use of self-compensating hair-springs, the rate is still dependent to a considerable extent on temperature. Furthermore the compensating properties of the hair-springs are not uniform over the entire temperature range that occurs in practice. The temperature coefficient may for instance be 1 second at +50° F (10° C) but 3 seconds at +100° F (67° C). This difference in the temperature coefficients at various temperatures is referred to as the "secondary error". It may assume considerable values.

The following table shows as an example the temperature coefficients (in seconds per 24 hours per degree C) for the different qualities:

	Temperature coefficient	Sec/error
Quality I for movements $10^1/_2$ and larger	0 – ±0,6	0 – ±4,5
Quality I for small movements	0 – ±0,6	0 – ±6
Quality II	±0,6 – ±1,5	0 – ±8
Quality III	±1,5 – ±3,5	±8 and above
Quality V	±6 – ±9	

Watches of standard quality are often fitted with quality V hair-springs. The temperature error of the hair-spring alone may accordingly produce rate variations of several minutes.

It is therefore not surprising that certain watches, when placed on the microphone straight from the bearer's wrist, show an increasing gaining rate as they cool off during the first few minutes.

Apart from its direct influence on the oscillating system, the temperature also exerts an indirect influence on the rate. The viscosity of the oil varies as the temperature changes and thus frictions and amplitude also change. Due to the isochronal error this produces additional rate changes which are however mostly of a compensating nature.

Since a domestic refrigerator is nowadays nearly always available, it is easy to approximately determine the temperature coefficient of a watch, sufficiently for practical purposes.

To obtain better thermal insulation, the watch is placed between two thick metal plates and the whole wrapped in tissue paper. The packet is kept in the refrigerator with a thermometer for at least one hour. When the packet is taken out hold it carefully by the paper wrapping, place it as quickly as possible on the microphone, and measure the rate in horizontal position. Then keep the watch for about one hour at a known ambient temperature, and repeat the measurement. Conversion of the difference in rate at the two temperatures to one degree gives the temperature coefficient.

The microphone can also be placed directly in the refrigerator by passing the microphone cable between the rubber strips of the door.

The following short test gives a general picture of whether a watch shows a substantial temperature error. The watch rate is measured in horizontal position at ambient temperature. The watch is then held firmly between the hands for two minutes and a further measurement is made immediately. Warming a watch placed on a microphone with an electric hair-dryer also rapidly gives a good indication (max. 40° C): see 1.5.1.)

2.3.1. Periodical rate variations

The recording paper tape travels at a constant accurate quartz-controlled speed. The speed corresponding to the different positions of the beat selector is indicated in the technical specifications for the instrument.

By measuring on the diagram in the direction of tape travel, the repeat time and duration of rate variations can therefore be accurately determined.

All power transmission fluctuations in the gear train are of a periodical nature, and the length of the period depends on the particular part which is defective.

Variations in the power acting on the escape-wheel lead to variations in rate which can be traced to two different causes. Firstly, the escapement acts directly on the duration of the oscillation by disturbing the harmonic motion of the balance-wheel. This effect is proportional to the power transmitted to the balance-wheel and occurs instantaneously. Secondly, a power variation is always accompanied by a corresponding variation in balance-wheel amplitude, causing further rate variation due to isochronal error. Alterations in rate caused by amplitude alteration follow the power alterations with a certain time-lag dependent on the damping of the oscillating system.

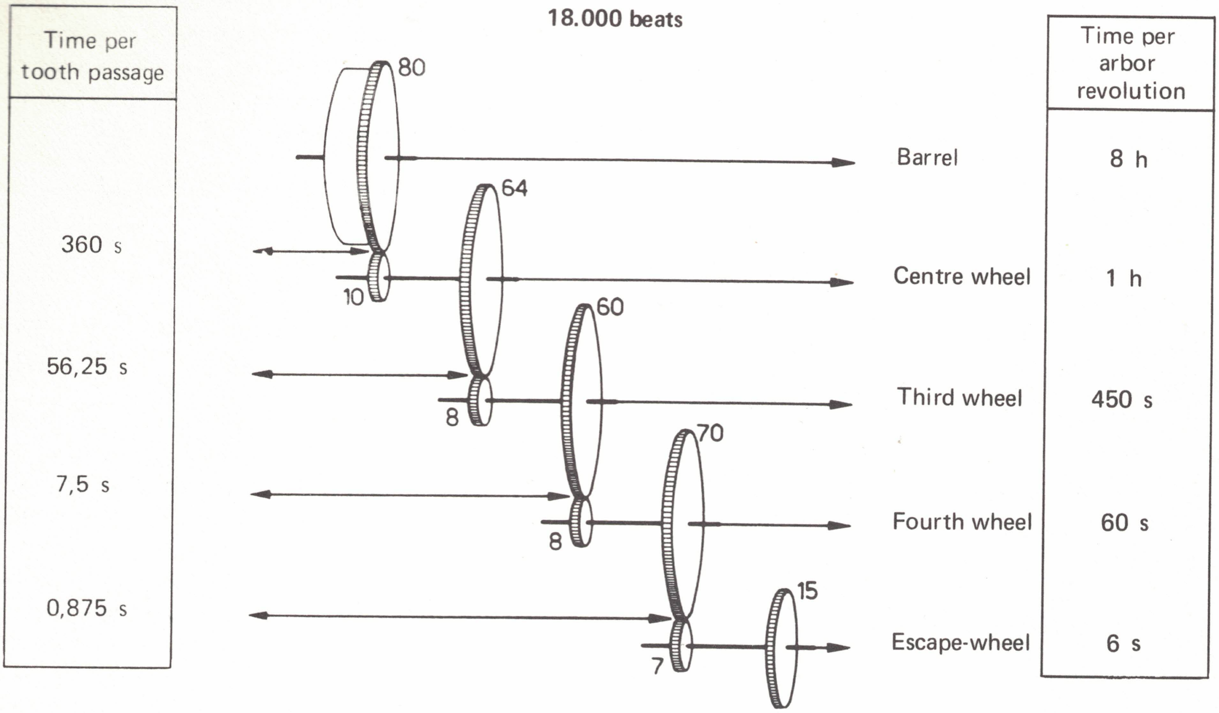
The gear train consisting of wheel and pinion may present the three following basic faults:

Fault	Repeat time	Duration of disturbance
1. All wheel teeth of pinion leaves defective.	Passage of one pair of teeth or leaves	Uniform over whole period
2. Wheel or pinion out of true	1 revolution of defective component	Uniform over whole period
3. Only some wheel teeth or pinion leaves are defective	1 revolution of defective component	Only a part of the period according to ratio of defective to non-defective teeth or leaves

From the repeat time and duration of the disturbance, conclusions can therefore be drawn on the defective component.

If the number of teeth of the wheel or leaves of a pinion is known, their passage time can be calculated easily. By comparison with the rate alteration duration measured on the diagram, the defective component can be determined.

Fig. 2/15 shows in schematic form and as an example the gear train of a 13'' wrist-watch, calibre AS 853. The left-hand column shows the time in seconds for the passage of a pair of teeth in each mesh; the right-hand column shows the rotation times of the individual components.



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This diagram of course only applies with complete accuracy to this particular calibre. Since however all conventional watches have approximately the same number of teeth and leaves, the diagram may be used for all calibres with 18.000 beats. The duration of the periods of the various sources of error differs so widely that the measured value can be easily related by its order of magnitude to the corresponding component. An exception is a revolution of the fourth wheel and a tooth passage between centre wheel/third wheel pinion which give similar times and in the case of a 60-tooth centre wheel are even identical. If there is any doubt, the measurement should extend over several minutes in order to emphasize the difference. The diagram can also be used for calibres with second hands deviating from 18.000 beats. In all other cases the teeth must be counted and a similar diagram drawn up.

In practice, transmission faults which are due to polishing of the pinion leaves are the most frequent defects. A third/fourth wheel pinion tooth passage can be recognized immediately since the duration of its period is about 10 seconds. A centre wheel/third wheel pinion tooth passage lies between 45 and 60 seconds and is the most frequent source of error.

If there are several faulty components, the diagram may become too complex to analyse and it is indispensable to determine the exact numbers of teeth. Since escape-wheels are rarely out of true, when the period corresponds to one revolution of this wheel, escapement faults or magnetism should always be suspected (see 2.3.2. and 2.3.5.).

Two diagrams are shown as examples in Figs. 2/16 and 2/17. The first shows a 7,5 seconds period and comparison with the schematic diagram immediately suggests that the source of error lies in the meshing between the third and the fourth wheel pinion. The second diagram shows a 51 second period corresponding to a mesh error between the centre wheel and the third wheel pinion.

Touching hands and foreign bodies in the gear train may also lead to rate variations which correspond to the rotation time of the particular components.

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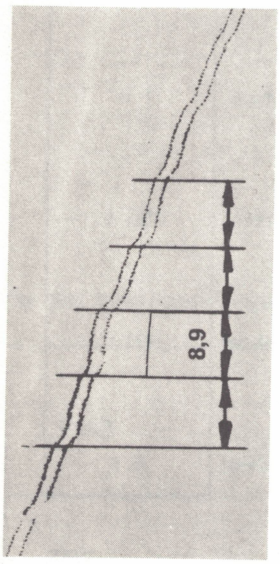

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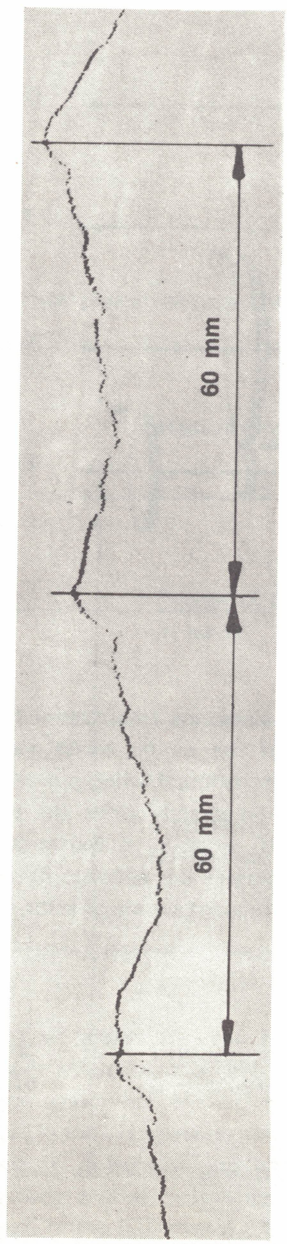


2.3.2. Escapement faults

A) **Faults in escapement function and disturbances**

A diagram in which one or both rows of dots are irregular will be produced if the lever fork is not in exactly the same position at each beat at the moment of contact with the roller jewel.

Fig. 2/18 shows a diagram with an irregular row of dots on the left and, adjacent to the top of the diagram, a schematic illustration of the lever in an undefined position. In the bottom illustration the lever is now on the other side in a definite position so that the regular row of dots on the right is produced.

The irregular recording may be due to very different causes:

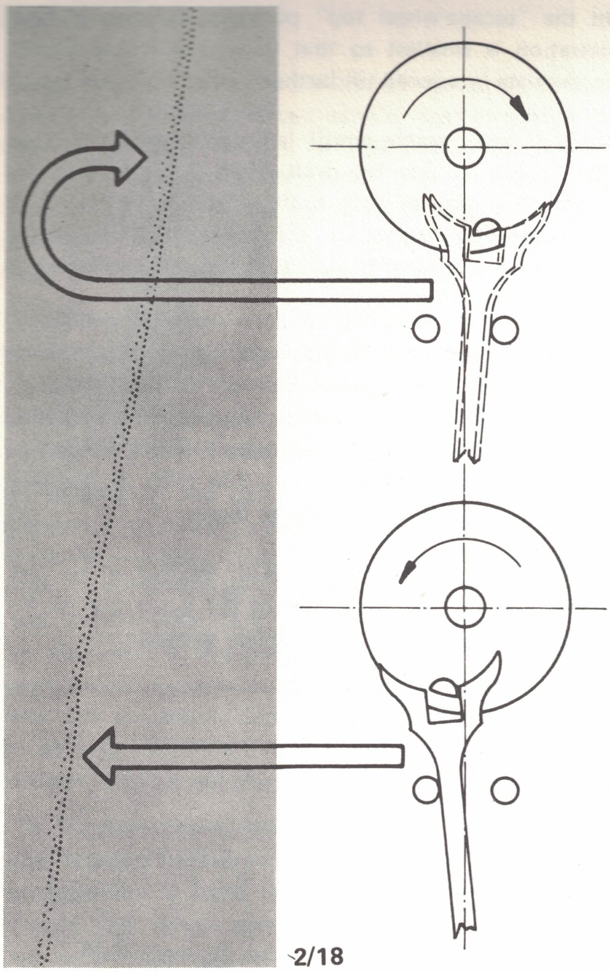
Draft (draw) too weak
Drop lock (locking) too weak
Loose, dirty or defective pallet stones or roller jewel etc.

If an escape-wheel tooth is the cause, the irregularity will repeat itself periodically. If the irregularity occurs on one pallet only it will repeat itself at every fifteenth beat in **one** row of dots. If it occurs on both pallets, it repeats itself in both rows of dots at every fifteenth beat, but displaced by five beats. Fig. 2/19 shows a diagram of such a fault. In general it is not possible to draw direct conclusions concerning a particular fault from the shape of the diagram because identical diagrams can be due to various causes. An indirect method must therefore be applied.

Because of the necessary side and end shake, the mutual position of the balance-wheel and lever in relation to one another and towards the other parts of the movement is not rigidly fixed. They alter their position according to the position of the movement under the influence of gravity. The centre of gravity of the lever does not lie in the axis of rotation, but at some distance away on the fork stem. The escape-wheel on the other hand remains in a fixed position due to the pressure exerted on it by the mainspring.

Deliberate testing of the movement in given positions generally allows determination of a fault which is present, or at least its localisation.

Disturbances in the function and fouling of the safety elements of the escapement are nearly always so critical that the slightest displacement of the elements concerned will be sufficient to make the fault appear or disappear.



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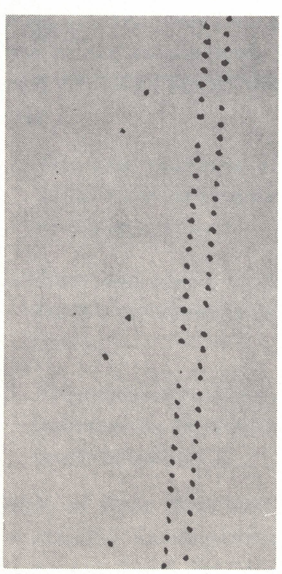

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Fig. 2/20 shows an exaggerated view of the two positions in which the lever may be when the watch is in the du and dd positions. Because of the end-shake of the balance staff and lever staff, the fork horns may foul on the safety roller or the guard pin.

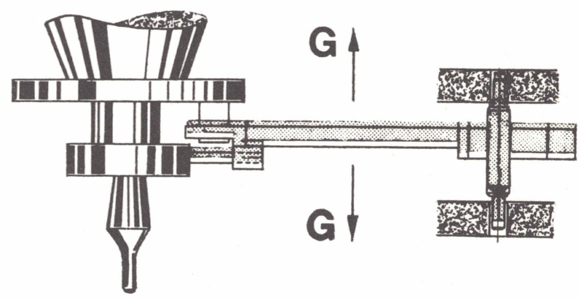

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Fig. 2/21 shows a diagram in which, in dd position only, the guard pin touches the end of the roller jewel. It is typical of a severe disturbance of balance-wheel oscillation.

2/21

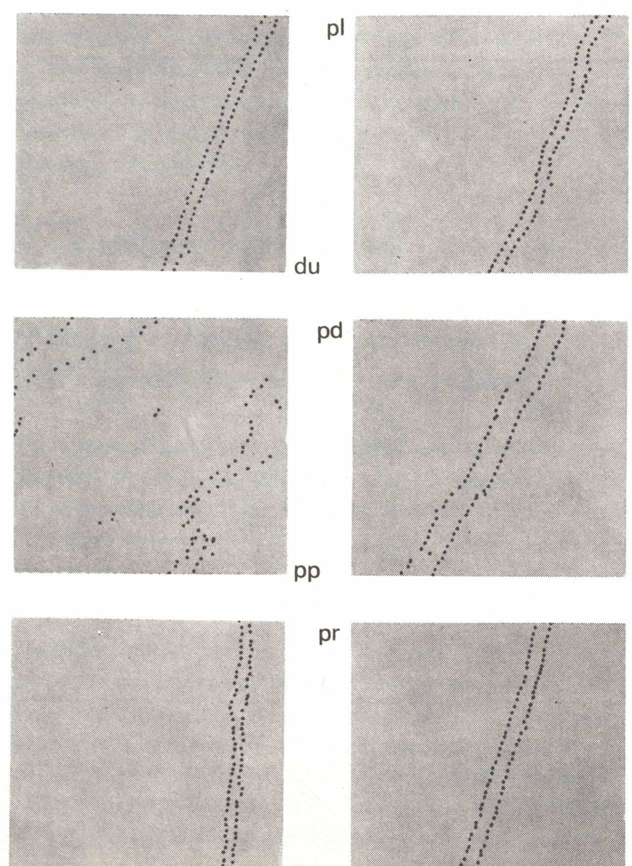
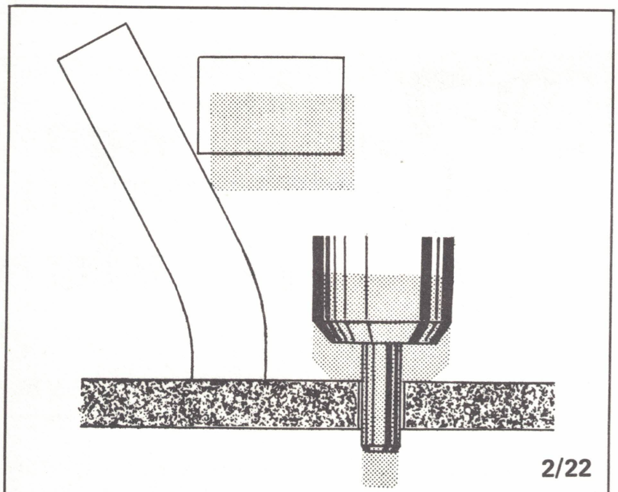


Fig. 2/22 shows how in the case of banking pins deviating from the vertical, the rest position of the lever in positions du and dd may differ so that two values are obtained for drop, locking and impulse.



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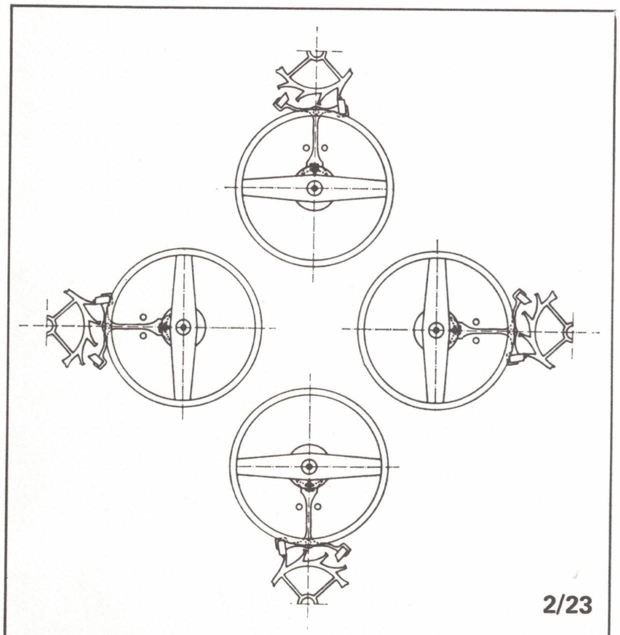
To determine the vertical positions, instead of the winding stem, we use the escape-wheel in relation to the balance axis and thus obtain the four positions: escape-wheel top, bottom, left and right as shown in Fig. 2/23.



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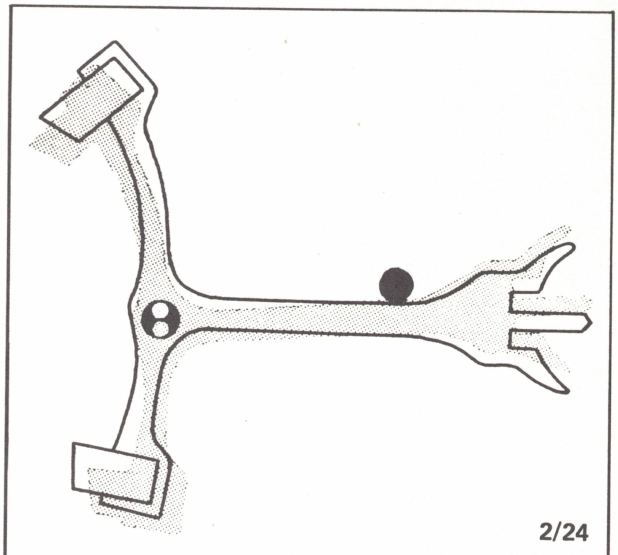
In the "escape-wheel bottom" position, the lever penetrates further, and faults such as insufficient impulse, pitch faults of the escape-wheel, excessive locking, are more pronounced.

In the "escape-wheel top" position, the depth of penetration is smallest so that locking which is already inadequate is reduced till further.

In the two "escape-wheel left and right" positions, gravity acts against the draft when the lever is in the upper position, so that draft which is too weak is weakened still further. In the bottom position of the lever, gravity adds to the draft, so that hard unlocking is hardened further.

In the "escape-wheel left and right" positions, the lever staff drops within the jewel hole as a result of the force of gravity. Since the fork stem lies on the fixed banking pin, the fork consequently tends to lie slightly higher in its two end positions, as shown in Fig. 2/24. At the same time the balance staff lies slightly lower.

In the lower position of the lever, fouling of the fork horns on the roller jewel and of the guard pin on the safety roller is obviously more likely to occur.



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B) Double row of dots

One of the most strinking features of almost all the diagrams is the presence of two parallel rows of dots with a greater or lesser distance between them. This phenomenon is referred to as the "out-of-beat condition" and is caused by non-simultaneous drop of the escape-wheel teeth from the entry and exit pallets of the lever - at least when the distance between the two rows of dots is large.

The balance-wheel turning freely in its bearings is connected with the watch movement only by the outer end of the hair-spring. The only "information" regarding its motion, is transmitted by the signals produced by the impact of the roller jewel on the lever fork.

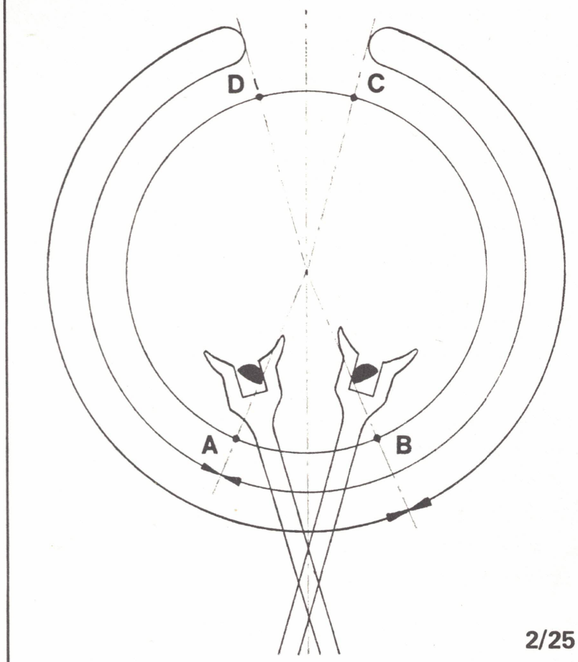
The duration of the oscillation arc shown in Fig. 2/25 determines the exact moment at which the signals occur during the to-and-fro movement sequence of the balance-wheel. A and B indicate the positions at which the roller jewel hits the lever fork; C and D are the positions of the roller jewel at the moment when the motion of the balance-wheel reverses. If the balance-wheel requires the same time to pass through the oscillating arcs A-C-B as for the arcs B-D-A, the rows of dots produced in lever positions A and B will coincide.

If the duration of these two parts of the oscillations is not equal, two parallel rows result, the distance between them corresponding to twice the value of the asymmetry in time. A beat which occurs earlier than at its correct theoretical moment is recorded in the right-hand row of dots, and a later beat in the left-hand row of dots. Depending on whether the asymmetry lies on the left or right-hand side of the centre line, each of the two pallets can produce either the dots on the left or right-hand side of the recording.

If the hair-spring is completely without tension, the roller jewel and the lever fork should be exactly on the centre line of the escapement. If in this case the two rows of dots are to coincide, the following conditions must be met:

1. The two positions of the roller jewel contact (Fig. 2/25) must lie exactly symmetrical to the centre line of the escapement.
2. Time and speed of balance-wheel motion must be exactly symmetrical to the centre line of the escapement.
3. Any asymmetry under condition 1 will have to be compensated by an exactly identical opposite asymmetry under condition 2.

None of these three conditions can be entirely achieved in practice. Consequently two coinciding rows of dots in no way prove accurate adjustment of the escapement.



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Assuming a well-defined position and amplitude, two coinciding rows can always be obtained by turning the collet. This operation however does not usually centre the roller jewel but only compensates already existing asymmetries. With every change of position or alteration of the amplitude two rows will reappear. It is therefore pointless to attach too much importance to the distance between the two rows of dots, especially as the effect on the rate is negligible.

The escapement must be adjusted in such a way that, with very low mainspring tension, the balance-wheel starts perfectly on the receiving and discharging side of the lever irrespective of whether the rows coincide or not.

As a general rule it can be said that a 1° deviation from the centre line at an amplitude of 270° gives a distance of approximately 1 ms between the two rows of dots. In watch factories the watch beat is set to approximately this value.

With the timing machine the "out-of-beat" condition can be not only simply estimated, it can be measured accurately in milliseconds (see technical data). In this way absolute tolerances can be established. Fig. 2/26 shows by way of example a diagram with an "out-of-beat" error of 8,3 milliseconds. All such time measurements must be made at an exact right angle to the paper edge and not vertical to the inclination of the diagram.

With respect to "out-of-beat" error, diagrams of different makes of timing machines are not comparable, even if the inclination of the diagram for a given rate deviation is identical, since the speed of the recording element may vary.

In the "escapement function faults" section, it was pointed out that in the two "escapement left" and "escapement right" positions, gravity causes the balance staff to be displaced downwards and the lever forks upwards (Fig. 2/24). This displacement has an effect on the distance between the rows of dots. In practice the distance between the rows of dots will be considerably smaller in one of these positions than in the other. In the alternation which moves the lever from top to bottom, these displacements produce partial compensation of the asymmetry - directed upwards - which diminishes the distance between the rows. The following valuable rule can be deduced from this fact and used for the correction of small errors:

If the distance between the rows of dots is smaller in the "escapement left" position, the collet must be turned clockwise - or the adjustable stud anti-clockwise.

If the distance between the rows of dots is smaller in the "escapement right" position, the collet must be turned anti-clockwise - or the adjustable stud clockwise.

The same considerations also allow the left or right-hand row of dots to be attributed to the entry or exit pallet, which may be valuable in the case of unilateral diagram anomalies:

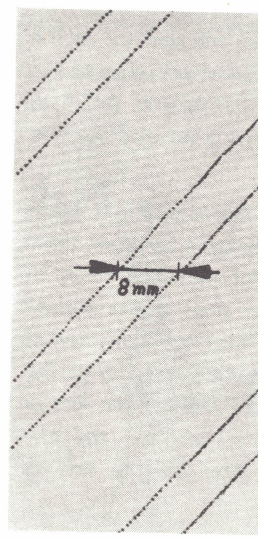
If the distance between the rows of dots is smaller in the "escapement left" position, the entry pallet is associated with the signal of the left-hand row.

If the distance between the rows of dots is smaller in the "escapement right" position, the exit pallet is associated with left-hand row signal.

C) Knocking

When the balance-wheel amplitude is too great, the roller jewel may hit the back of the fork (Fig. 2/27). This disturbs the oscillation to such an extent that the recording is scattered across the entire tape width. In an otherwise correct watch, knocking will occur only in horizontal position, with mainspring fully wound, because the maximum amplitude will be present under these conditions.

Excessive amplitude leading to knocking often occurs only at the peaks of power fluctuations, so that knocking is intermittent. Fig. 2/28 shows such a diagram: small stretches of normal rate alternate with large displacements towards the right, i.e. periods of excessively fast rate. A reduction in oil-viscosity when temperature rises may also cause knocking.



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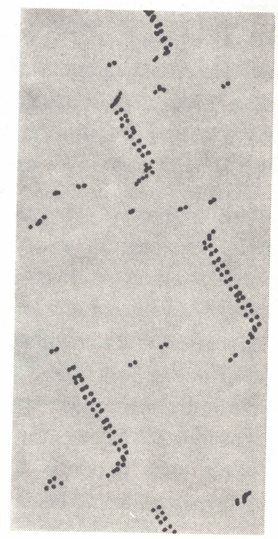
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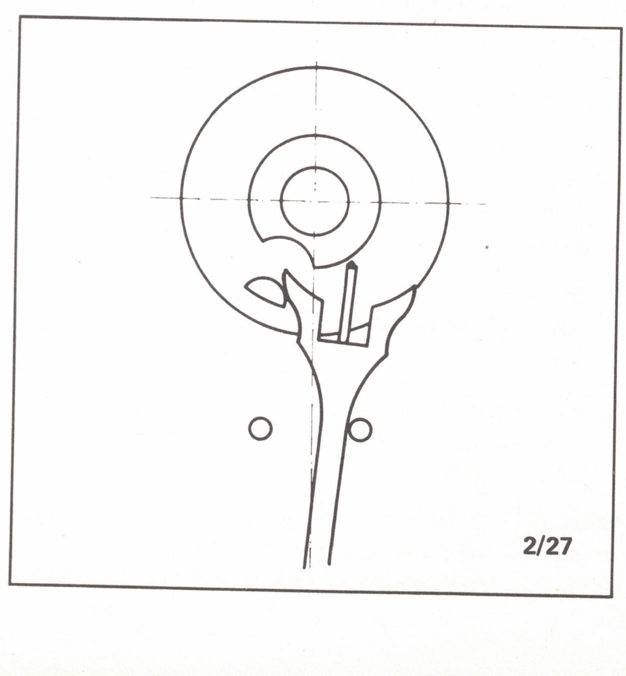
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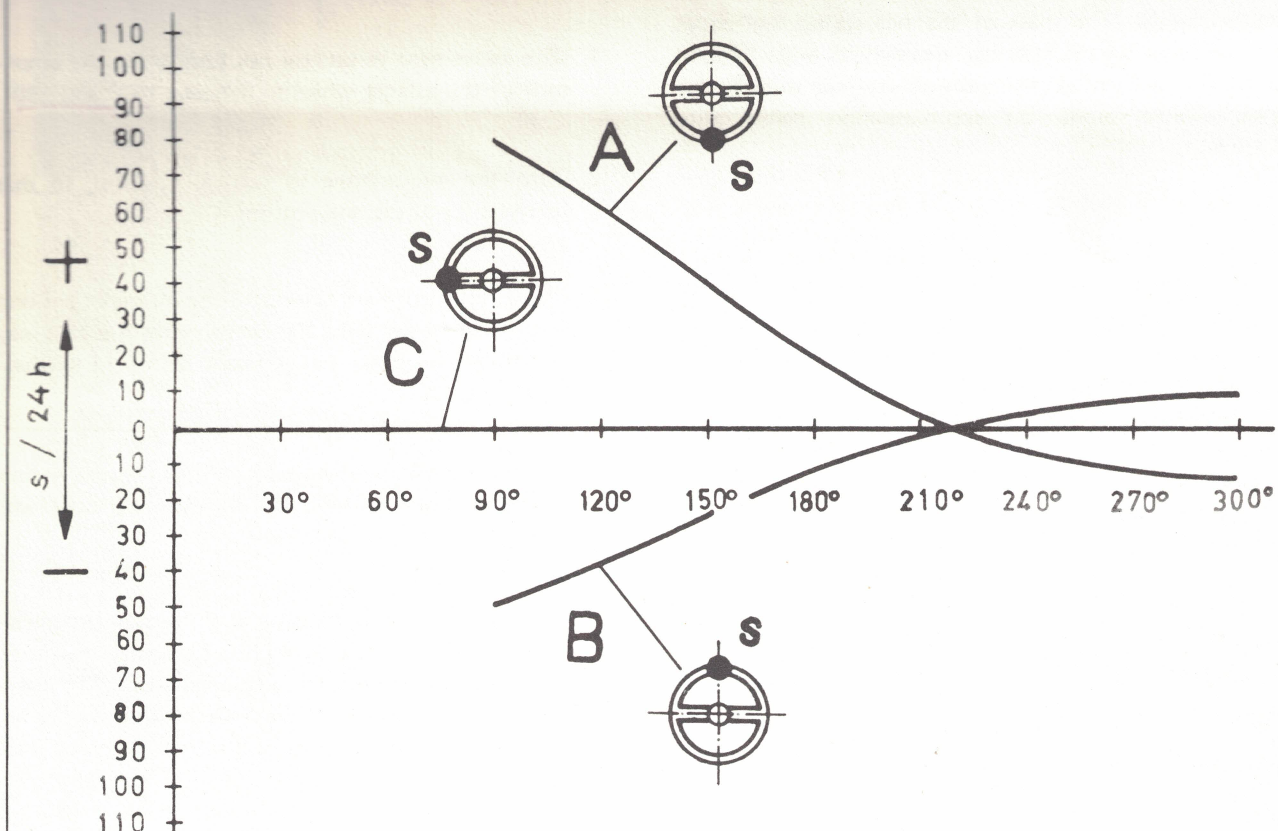

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2.3.3. Poising errors of the oscillating system

If the centre of gravity of the oscillating system is not precisely in the axis of rotation, gravity exerts an influence on the rate in all positions deviating from the horizontal. The directing force no longer consists only of the hair-spring elasticity, since the unbalanced mass acts as an additional gravity pendulum.

The influence of imbalance on the rate depends on its magnitude, its angular relationship to the vertical in the axis of rotation, and on the amplitude. These conditions are shown in Fig. 2/29. On the vertical scale, the effect on rate can be seen in seconds per 24 hours, the amplitude being plotted horizontally in degrees. Curve A is characteristic of an imbalance which lies below the axis of rotation when the balance-wheel is in its neutral position. The influence which causes a fast rate is considerable at small amplitudes. It diminishes progressively and crosses the zero line at 220°. With larger amplitudes, the influence is reversed and causes a slow rate. The curve shown in the figure gives only one example of rate values. These values depend on the extent of the imbalance and the angular deviation from the vertical. If the imbalance is precisely above or below the axis of rotation, its effect on rate will be greatest. If on the other hand it is precisely horizontal to the left or right, its influence on rate is zero. An infinite number of curves are possible on the diagram, all having the same shape but differing from each other in their gradient.

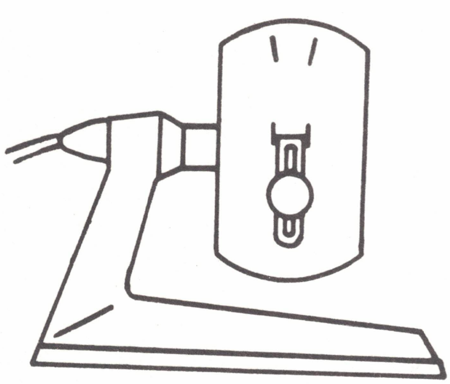
If the imbalance is located above the axis of rotation with the balance-wheel in its neutral position, curve B is produced. It is the mirror image of curve A. The rate deviation values have the opposite sign. Curve B shows an example of smaller rate deviation values than curve A.

In the whole field of watch timing there can scarcely be any other subject about which so much has been written and with such confusion as about poising errors, the determination of the imbalance position, and its correction. Usually very accurate poising of the balance-wheel is insisted upon. Some extraordinarily involved calculations have been suggested for locating the imbalance, which surprisingly enough still exists after poising on a poising tool. Here GREINER timing machines have opened up completely new possibilities.

The effective mass of the oscillating system is - contrary to common belief - not completely restricted to the balance-wheel. The mass of the hair-spring, the collet and to some extent also the escapement must be considered. It is pointless therefore to attempt to poise the balance-wheel alone, an approximation being quite sufficient.

It has been shown that the influence on rate is greatest when the imbalance lies exactly vertically below above the axis of rotation. We need therefore only find the position in which the influence of the imbalance on the rate becomes greatest in order to determine the location of the imbalance, without any calculation. Moreover, we now deal not only with the static imbalance of the balance-wheel alone, but with the actual sum of all effective imbalances in the entire oscillating system. For this reason the method is called "dynamic poising".

The procedure described below is astonishingly simple and has been worked out by GREINER ELECTRONIC especially for users of their watch timer.



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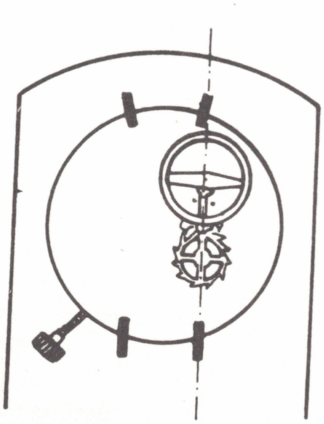

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2.3.4. Dynamic poising of the oscillating system

1. With movement in vertical position, bring the amplitude of the balance-wheel to between 150° and 180°.

2. Turn the microphone to vertical position, so that brackets are at top and bottom (Fig. 2/30).

3. Clamp the movement directly or by means of a round movement-holder onto the microphone in such a way that the escape-wheel lies vertically under the balance-wheel (Fig. 2/31).

4. Record about 4 cm of diagram and then carefully turn the microphone through 45° clockwise on its vertical axis and record a further 4 cm.

   Now continue to record diagrams of this type progressively turning in steps of 45° in clockwise direction until the starting position is reached again. The eight diagrams are marked off from each other during recording by horizontal lines and numbered from 0 to 7, as shown in Figs. 2/32 and 2/33.

5. Now locate the position at which there is the greatest tendency to gain (i.e. maximum gain), or if all positions show a loss, the minimum loss position. After some practice it will become easy to detect the tendency to gain already during recordings in the various 45° positions. A soon as a position is reached in which there is a tendency to lose in comparison with the preceding position, the maximum tendency to gain has been passed, and the remaining positions for completion of microphone revolution can be dispensed with (see arrow between positions 4 and 5, Figs. 2/32 + 2/33).

6. As shown in Fig. 2/34, a drawing is made with 8 radii numbered from 0 to 7. The zero line should preferably be drawn in red.

   The removed balance cock with balance-wheel is inverted and placed on the drawing with the balance staff and the centre and the roller jewel on the red zero line. The imbalance is now on the line which has the same reference number as the portion of the diagram with the maximum tendency to gain. For most purposes, determination of imbalance to within an accuracy of 45° is sufficient. To improve accuracy, intermediate positions can easily be found in the same way once the imbalance has been roughly located.

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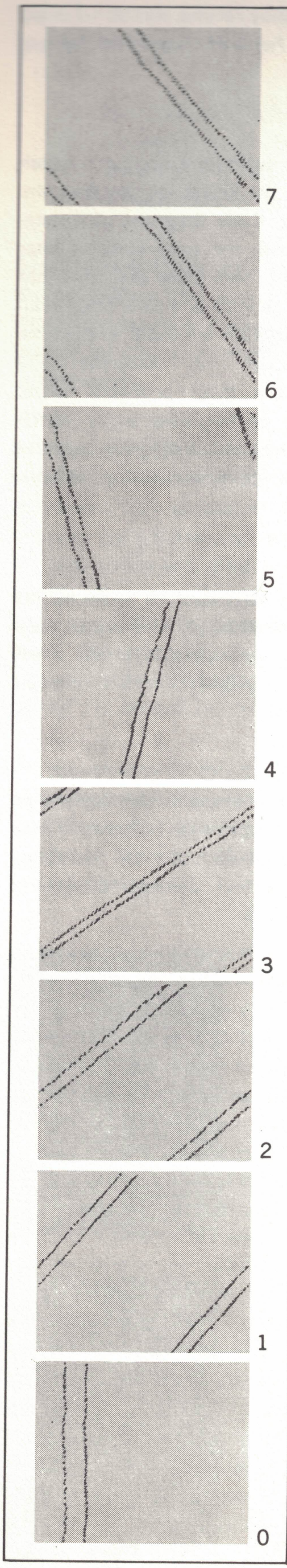

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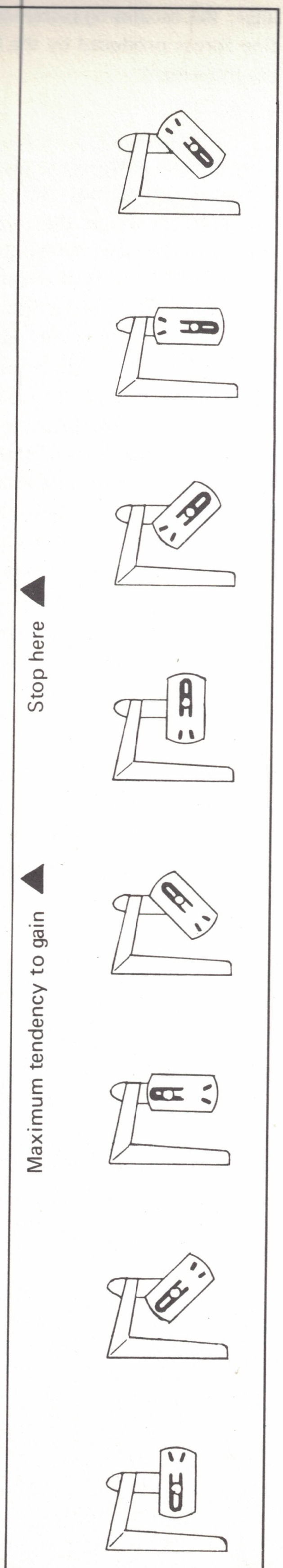


1. Balance-wheel with screws

a) If on average the watch shows a **slow** rate in the vertical positions:
lighten the screw at the location of the imbalance.

b) If on average the watch shows a **fast** rate in the vertical positions:
place a washer under the screw diametrically opposite to the imbalance.

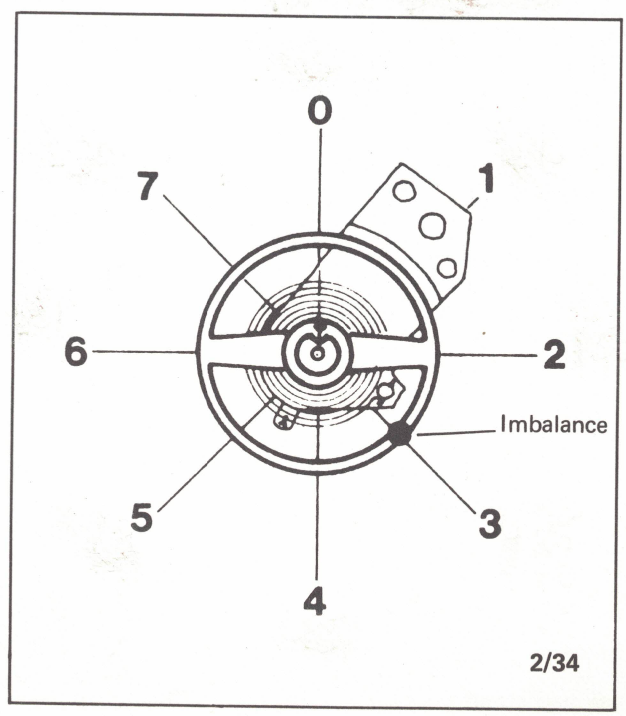
c) If on average the rate is **zero**:
Correct in two halves by making the screw lighter at the point at which the imbalance is located, and place some weight diametrically opposite.

2. Balance-wheel without screws

It is impossible to add weight to these balance-wheels, so that irrespective of average rate material must always be removed at the point at which imbalance is located.

After correcting the imbalance, the rate must be brought to the required value by adjusting the regulator.

It is usually necessary to repeat the operations described above once or twice, in order to obtain the best results. It is advisable to check the rate in the horizontal position between operations in order to avoid axcessive deviations from the zero rate.



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It is particularly important to note that the balance-wheel of an oscillating system poised by this method will show an imbalance when tested on a poising tool alone. This imbalance compensates the imbalance of the other part of the oscillating system.

Lubrication

If the balance-wheel of an oiled watch has to be removed for correction of imbalance, the jewels and pivots must be completely cleaned and re-oiled when the work is finished. To avoid this inconvenience it is better, after cleaning and reassembly, to oil the entire watch except the balance jewels. If the lever pallets have been oiled, the balance-wheel will show an amplitude of almost exactly 180° without oil on the balance jewels.

2.3.5. Magnetism

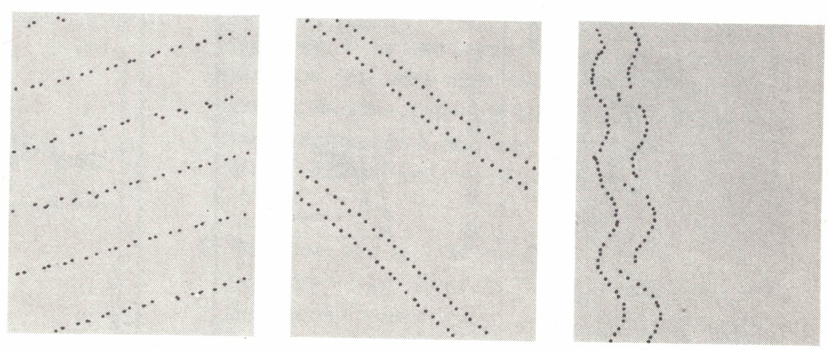
The widespread use of technical products containing strong stray magnetic fields has resulted in magnetism becoming a real problem in watches. No watch is truly "anti-magnetic". The effect of magnetic fields on the rate may be reduced in anti-magnetic watches, but when the fields exceed a certain magnitude, permanent changes of rate will remain. The effects of magnetism on rate are complex. The elastic characteristics of the hair-spring alter; the oscillating system may receive additional directing forces produced by the fields of magnetised parts of the movement.

It is impossible to accurately determine whether a watch is magnetised or not from the shape of the diagram. Fig. 2/35 shows, at the top, three diagrams of magnetised watches, and below these the same watches after de-magnetisation. It is evident from these diagrams that magnetism may cause a fast as well as a slow rate. In all case when periods of rate variation are equal to the time taken by the escape-wheel to complete one revolution, magnetism is the most probable cause. It is therefore advisable to de-magnetise every watch requiring repair. A short check-diagram should be recorded before and after de-magnetisation, in horizontal position.

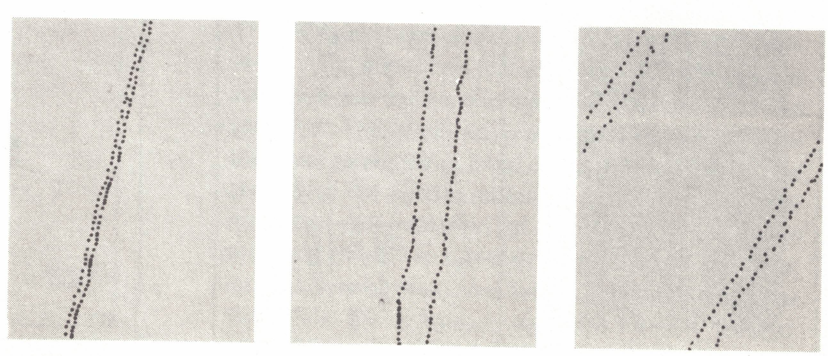
The de-magnetising coils in widespread use today do not usually allow complete neutralisation, and unless they are applied with great skill the opposite effect often results, i.e. a previously non-magnetic watch becomes magnetised.

GREINER ELECTRONIC manufacture de-magnetising instruments designed in conformity with completely new scientific techniques and which do not entail the above disadvantages. Absolutely perfect de-magnetisation is guaranteed within a few seconds.

magnetic



de-magnetised



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2.6.1. Tolerances for various movement qualities

Type movement	Number of test position	Position error s/24 h	Temperature error +5°/ +25°	Isochronal error over 24 hours
1. Pocket watches				
Precision movement	6	5 sec.	5–10 sec.	5–10 sec.
Average quality (bon courant)	4	30 sec.	30–60 sec.	30–60 sec.
Simple pallet, Good pin pallet	2	1 min.	1– 2 min.	2– 3 min.
Cheap pin pallet, Cylinder	1	2– 3 min.	2– 5 min.	3– 5 min.
2. Wrist-watches				
Precision movement	6	10 sec.	10 sec.	10–20 sec.
Average quality (bon courant)	4	30–60 sec.	30–60 sec.	40–80 sec.
Simple pallet, Good pin pallet	2	1– 2 min.	1– 2 min.	2– 3 min.
Cheap pin pallet, Cylinder	1	3– 5 min.	3– 5 min.	5–10 min.