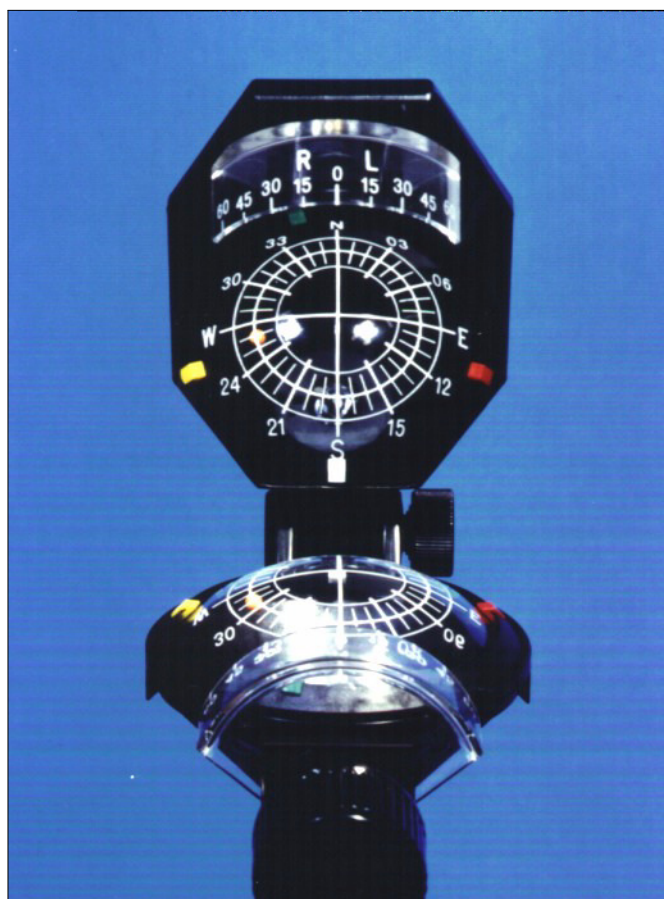




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Magnetsysteme, Dauermagnete, Haftmagnete
Magnetische Messuhrhalter und Spannplatten
Instrumenten- und Bremsmagnete
Kleinst- und Miniaturmagnete
Segelflugzeugkompass und -Variometer

BOHLI COMPASS 46-MFK-1



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Description

Bohli compass for aerial navigation

A device, using the magnetic field of the earth for directional orientation, has been known in China as far back as 2000 B.C. It originally consisted of a magnetic iron splinter, floating on top of a small piece of wood in a water container. Added was a miniature human figure pointing South with an outstretched arm.

Similar designs of water compasses were used right into the Middle Age. They were improved for more accurate reading by painting a compass-rose onto the floating wooden disc and by centering the same with a pin. This type of instrument was known to all seagoing people.

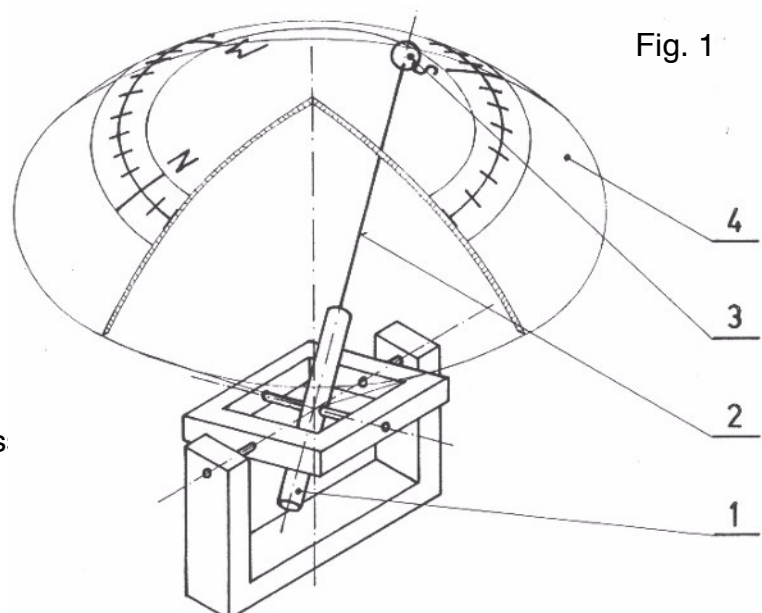
In the 15th to 16th Century a different type of compass became known, which had a "cap" (dab) that supported the magnetic needle on top of a pointed metal pin. The low center of gravity held the needle more or less horizontally; any remaining pitch, due to the magnetic inclination, was counter-balanced with weight. This principle, which uses the horizontal component of the earth's magnetic field, has undergone many refinements. It is widely used in aviation compasses today (Lit. 1, 2).

Unfortunately, this simple instrument fails during turns. Unless the axis of the needle is aligned perfectly vertical to the earth, it will start to swing. In a turn, when heading East or West, the needle does point correctly. But as soon as the aircraft turns towards South or North, the needle will be influenced by the magnetic inclination and will run ahead or behind, depending on the direction of turn. If the angle of bank exceeds 15°, the compass needle goes berserk. Any directional information is lost. The pilot has to fly on a straight heading for some time in order to allow the compass to calm down. Only then can he take a reading and initiate a further correction toward the desired heading, using very little bank (Lit. 3, 4, 5, 6).

The Bohli compass does not know such drawbacks (fig. 1). The magnetic needle of this instrument is hinged in a precision cardan joint and can move freely around two orthogonal axes (a narrow border range excepted). Independent of the aircraft position, the compass needle always points in the direction of the earth's magnetic inclination.

To make it insensitive to acceleration forces, the center of gravity of the magnetic needle with pointer has been positioned at the intersecting point of the two cardan axes.

- 1 magnet
- 2 extension
- 3 marker dot
- 4 spherical dial (calotte) with compass



The inclination varies with geographic latitude. Over the magnetic poles the needle would point down vertically; on the magnetic equator it would lie horizontally. One can notice this effect on long flights going North-South or vice-versa.

The effect shows on the Bohli compass in this manner: the imaginary circle, which the pointer mark describes on the dial during a circle on the plane, becomes wider in lower latitudes and narrower in higher latitudes. At a given inclination (latitude), the diameter of the imaginary circle (described by the red mark) can easily be visualized. Circles for three typical inclinations are painted on the dial. Directional indication is not influenced by a change of latitude. The local variation must, of course be accounted for, as with many other compasses.

Since the magnetic needle maintains its position like a platform, a damping device is superfluous. Directional indication is therefore immediate and without any noticeable oscillation. The chosen magnet exerts a high directional force; at European latitudes it is about 2.5 times stronger than for conventional "declination compasses".

There is very little deviation caused by interfering magnetic fields (inside the cockpit) which are moving around the compass needle during circling. If the source of such interference is more than 20 cm (8 in) away, it may be ignored. The off-center effect caused by such magnetic disturbances is automatically compensated when levelling the compass. The four main magnetic directions can therefore be established on the instrument with precision.

The use of this compass is limited to areas with a magnetic inclination between 40° and 75°. This includes Europe, Iceland, the USA (including part of Alaska), Mexico, southern part of Canada and all of Asia located between 30° and 65° northern latitude. A special model is available for the southern hemisphere, suitable in Australia, New Zealand and South Africa.

The first units of this compass were used during the 1972 World Gliding Championships in Vrsac (Yugoslavia) and have proved successful.

It is not surprising that the glider pilots, in particular, are showing great interest in this instrument. Navigation is more complex in gliding than it is in power flying. Gliding requires frequent transition between straight flight and narrow circling (for gaining altitude). In competitive soaring accuracy is imperative, for instance in maintaining an exactly determined wind correction angle, or when rolling out of a turn onto a precise heading (this problem will be treated in details in a separate article).

For this we need quick and accurate directional information. Furthermore it allows the pilot during circling to determine track radials towards special land marks, clouds or other circling gliders.

In addition, the compass can be utilized for centering thermals. After maximum climb, the pilot makes a 270° turn (3/4 circle), then flies straight for a short moment and continues circling. This will usually be a faster method for getting into the center than by guessing time, using land marks on the ground or other methods.

The instrument can serve the same purpose as a gyrocompass but it needs no energy, is always ready for use and does not drift off. It is equally suitable for visual and instrument flying.

Profound knowledge of the basic principle of this instrument is mandatory in order to fully benefit from its possibilities. For easier understanding, let's have a look at the compass as the pilot sees it.

An image of the dial is visible on the mirror (fig. 2).

Make sure you can see it when the instrument is banked at 60° . The width of the mirror (60 mm) is narrower than the distance between the pilot's eyes, thus the forward view is practically not obstructed.

The compass has been levelled for an average pitch angle of the fuselage (speed 100 - 110 km/h / 62 - 70 mph) and horizontal wings. If the plane makes a full 360° turn without banking, the red pointer mark would describe a circle around the center of the dial. The diameter of this circle depends on the local magnetic inclination (in reality the pointer mark is steady and the dial is rotating. Fig. 3).

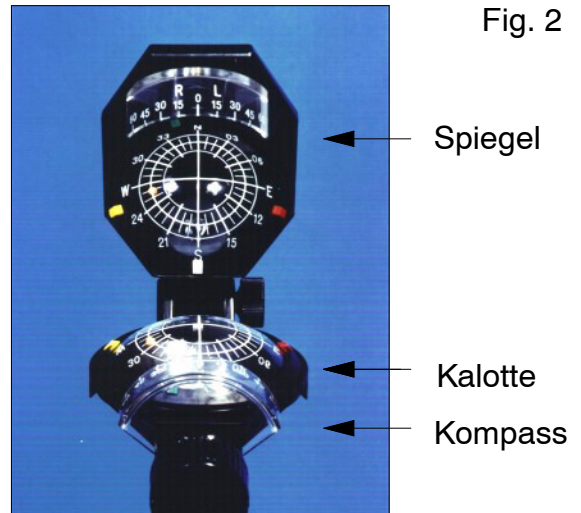
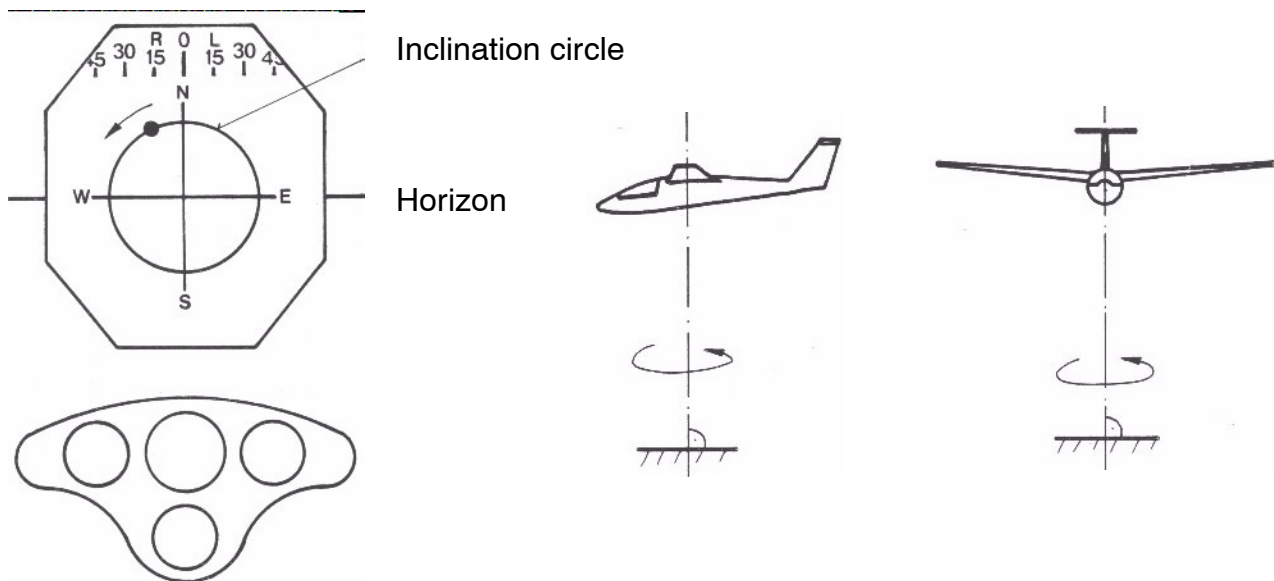


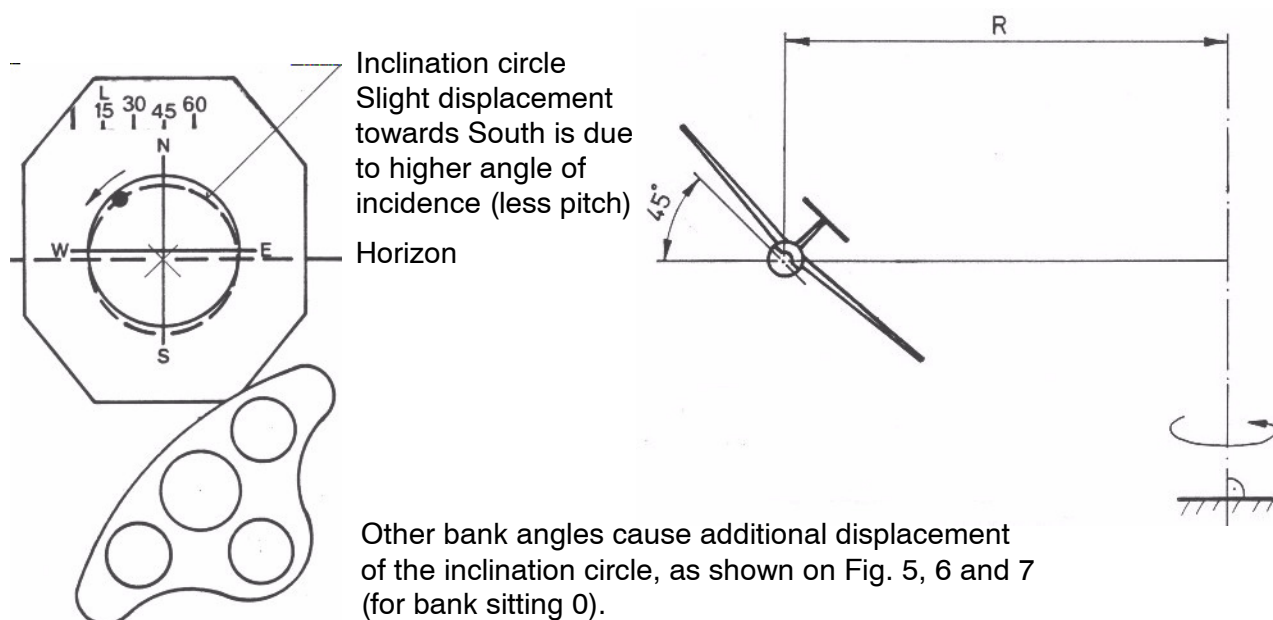
Fig. 2

Fig. 3



The same thing happens in actual circling flight, when the plane is banked but the compass is tilted so that it will remain parallel to the horizon (the bank angle is visible on the special scale which appears on top of the mirror image. Fig. 4).

Fig. 4: circling with 45° bank



If the pilot increases forward pitch, i.e. flies faster, the entire circle described by the red mark will be displaced towards "North" (fig. 5).

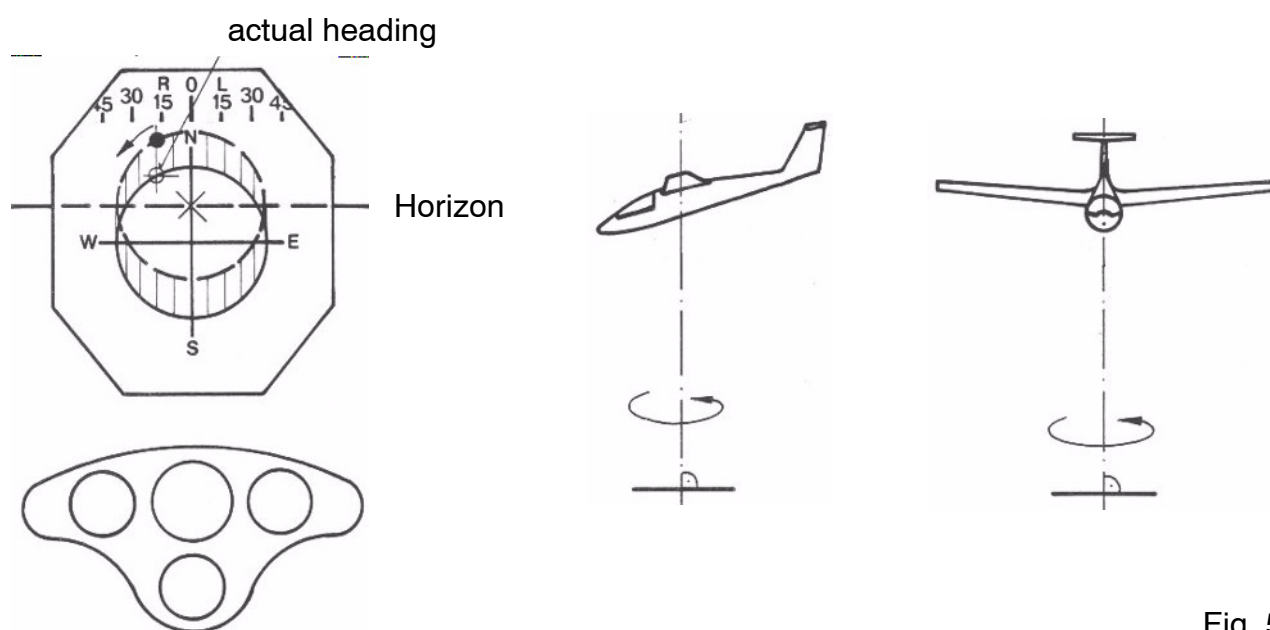


Fig. 5

Increasing the angle of incidence will displace the circle towards "South". Any change in pitch will merely move the red mark parallel to the N-S axis. Equally, banking (the compass) will move the red mark parallel to the E-W axis. Banking to the left will displace the circle towards East and vice versa (fig. 6).

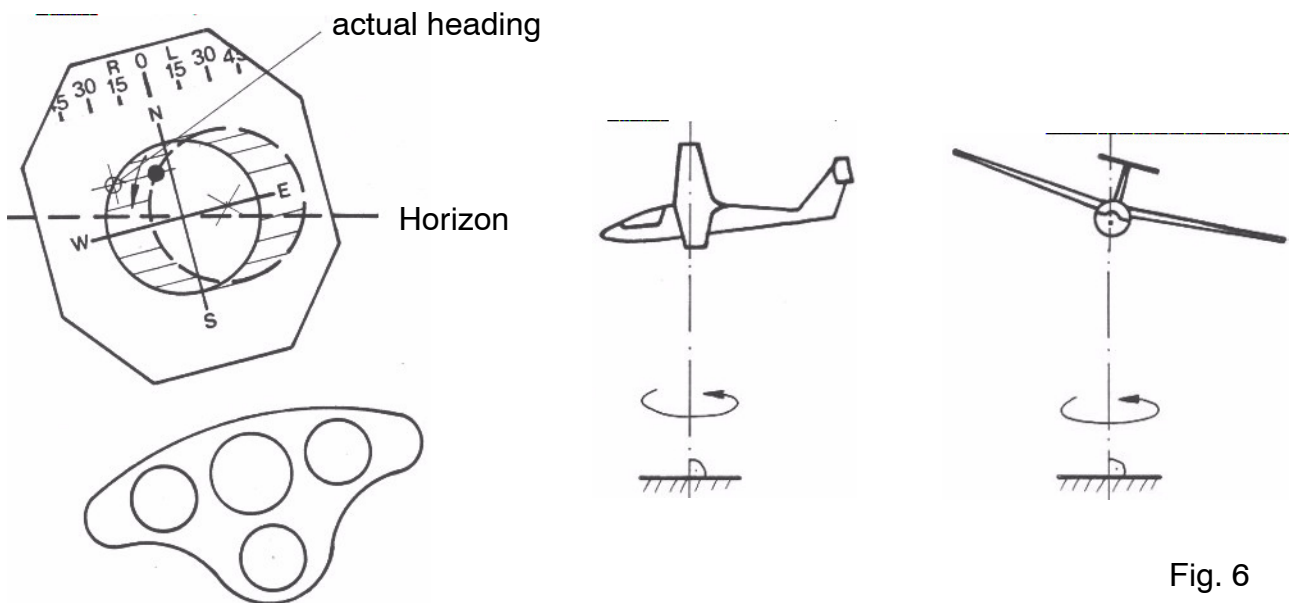


Fig. 6

Simultaneous pitch and bank movement will cause the red mark to move in a direction which is the resultant of both movements (fig. 7). In actual practice the displacement due to banking may be disregarded. During straight flight the compass is horizontal anyway; during circling in the thermals the bank angle applied by a pilot is usually the same or nearly so, thus permitting the use of a single compass bank setting for circling.

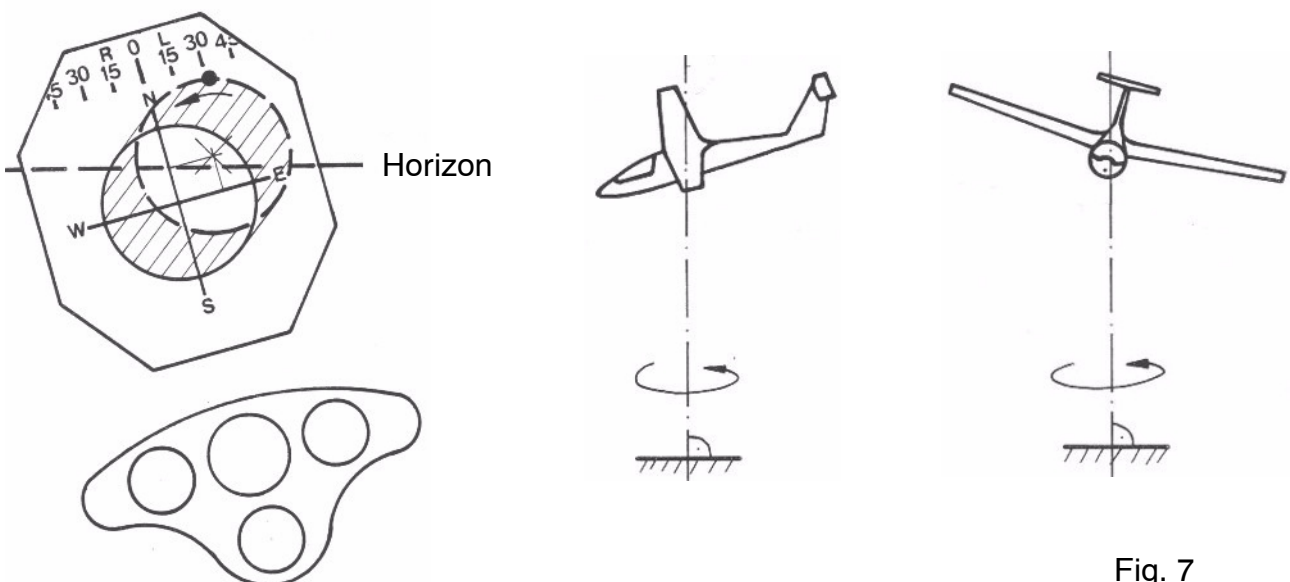


Fig. 7

Consequently, the pilot has to bother only with those displacements of the mark which are due to pulling and pushing the stick (dolphin flying) and he must learn to interpret them. The effect is minimized in gliders with flaps since the pitch angle of the fuselage changes little with different speeds.

Of course, it would have been possible to design a compass with adjustable forward pitch, or one which is hinged freely for fore and after movements. But the ensuing complications would offset the advantages. It is much easier to accept the effects of small pitch changes and to account for them by mentally understanding their geometrical effects. If you are flying at a different pitch angle from the one at which the compass was levelled, then think of a vertical line through the red mark dot (parallel to the N-S axis). At the point where this imaginary line intercepts the circle on the dial (with diameter according to the local inclination), this is the point where the red dot would be with correct pitch; consequently the heading is to be read at this point. On easterly and westerly headings the imaginary vertical lines will be tangent to the circle on the dial; reading will be inaccurate (compare fig. 5). Accurate headings in easterly and westerly directions can therefore only be obtained if the flying speed is maintained such as the compass has been levelled. Or, alternatively, corrections for different speeds should be established and memorized. For this purpose, the division on the compass-rose may be often varied (dolphin), so there are ample opportunities for reading off the correct heading (always then when the fuselage pitch is the same as when the compass was levelled).

What are the procedures for determining the magnetic radial (track) from one's own position towards another point? For the change of headings during straight flight? For leaving thermals on a precise heading? Or the 270° thermal centering method? All these procedures are fairly simple. They will briefly be described in that order.

If, during circling, the magnetic radial (track) towards another point is to be established, then it is merely necessary to adjust the compass to be parallel to the horizon. At the precise moment when the nose of the glider is pointing towards the relevant target, the heading (track) can be read on the compass. With a known wind correction angle (add or deduct), the target will be reached in the shortest possible time. The same method may be used for accurate turn point photographs which must be taken in a specific compass direction.

A precise change of direction in straight flight is done as follows. The turn is initiated with normal bank. The compass is set parallel to the horizon and observed. The roll-out manoeuvre must be initiated before the desired heading is fully reached. With a rolling time of 4 sec and bank angles of 45°, 30° or 15°, roll-out must be initiated in advance by 25°, 10° or 3° respectively. For small heading changes it is not necessary to tilt the compass. Several small corrections might be necessary; the accurate heading can immediately be read after every leveling-out. It is also possible to simply watch the red mark describe part of a circle, which now appears displaced to the E or W. This movement is mentally projected onto the equivalent circle on the dial and the turn is stopped when the desired angle is reached (deduct angle for roll-out). The latter method is possible with banks up to max. 15° only, as otherwise the pointer would hit against the stop, especially in low latitudes.

A special case is turning onto an E or W heading with little bank. Level flight is initiated in this case as soon as the edge of the red dot is touching the W-E axis.

The manoeuvre of leaving a thermal on a precise heading is done in the same manner as described for a change of direction. The preceding angle for roll-out must, of course, also be taken into account.

Some special reflections are necessary in order to correctly determine the angular advance to compensate time lags (fig. 8). Since different flying manoeuvres are applied for shifting towards the center, depending on personal preference and type of glider (levelling-out or sliding with opposite rudder, etc.), the amount of angular lag compensation is to be determined individually by each pilot. Point \star is the location of strongest lift during the circle. With feeling alone it is hardly possible to determine this point exactly; the lift usually increases gradually and we cannot "feel" the peak. Due to its lag, the variometer will indicate maximum climb at point \bullet . The amount of turn that was flown during the variometer lag is shown by the angle α ; it represents the angle α by which the heading has changed from \star to \bullet in direction of circling. When using a fast variometer, one must reckon with a time lag of approximately 3 sec. With a full-circle time of 16 sec (40 - 45° bank) this causes an angular lag of $\alpha = 67.5^\circ$ ($360^\circ : 16 \times 3 = 67.5^\circ$).

Fig. 8

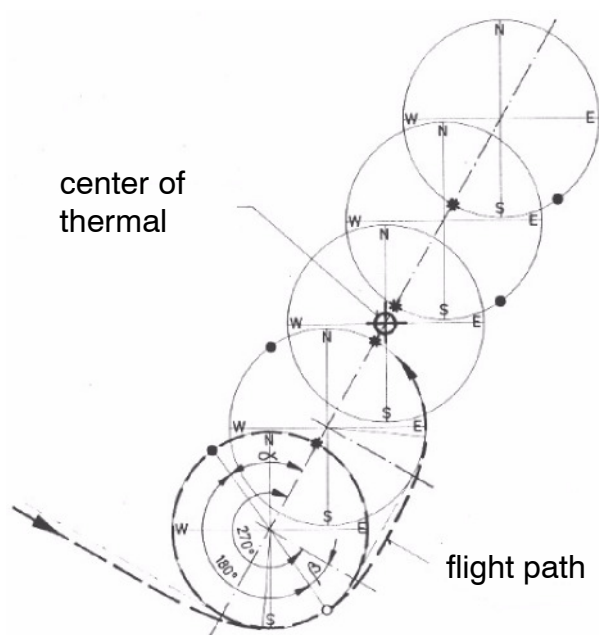
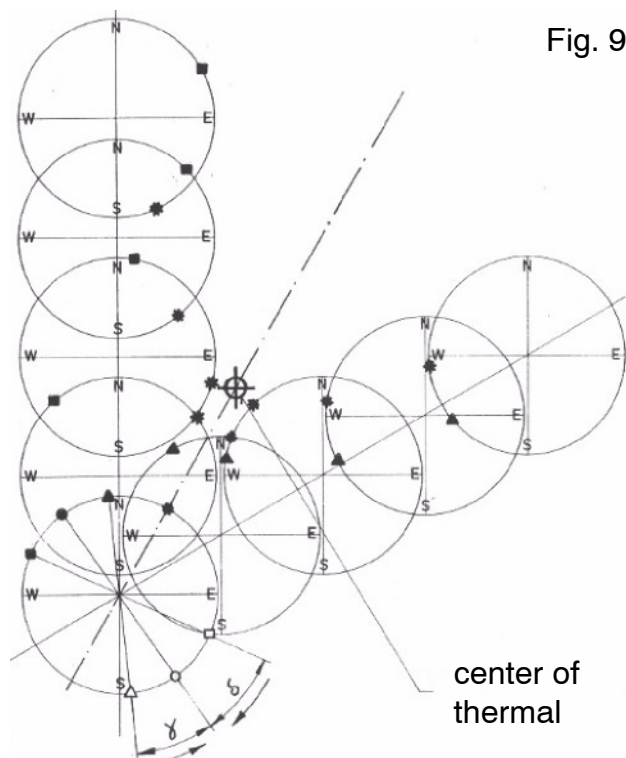


Fig. 9



If we add the angle β which is to counter-act the roll-out lag and if $\beta = 25^\circ$, we obtain 92.5° or approx. 90° total angular lag. In consequence, roll-out for shifting towards the center must be initiated $270^\circ - 90^\circ = 180^\circ$ after the moment of maximum climb indication. If we work with the compass it is not necessary to take readings of headings and make calculations; there is an easier way. At the moment of best climb indication, we mentally retain the position of the red mark and project it across the center of the dial into the opposite quadrant. Thus, the heading for initiating straight flight (roll-out) becomes evident at a glance.

If a 90° total angular lag was a correct assumption for a specific flying style, glider and variometer, then we are gradually shifting closer towards the center of the thermal. The reading of the heading at best climb \bullet should remain the same after every manoeuvre. If we have reached the center, there will be an almost identical climb indication on the variometer around the full circle. If we have overshoot the center of the thermal, then the heading at the moment of best climb will suddenly be 180° opposite from before.

If the indication of best climb occurs later after a shifting step, this is an indication that roll-out has been initiated too early as shown by ▲ in figure 9. On the other hand, if the relevant heading for best climb is encountered earlier after every step, then roll-out was initiated too late ■. Based on these observations an additional correction angle γ or δ may be introduced, where γ is added to 180° and δ is subtracted. The rough amount of these angles is easily determined by each pilot for his personal style, plane and instruments.

If, after the short straight flight, we want to quickly come back to the same bank as before (and thus the same radius of turn), we merely have to watch the mirror image of the E-W axis and get it aligned with the horizon. In clouds, the same bank is confirmed when the red mark travels on a concentric circle around the center of dial.

The aim of the Bohli inclination compass is purposely not an extremely high accuracy for reading headings. The instrument has been conceived, in the first place, to furnish information fast; information which is not blurred or distorted by movements or accelerations. It also does away with the complicated rules (lacking precise information) governing the interpretation of declination compasses.

This instrument certainly also offers advantages in power and helicopter aviation, provided the operating area is within the defined latitudes.

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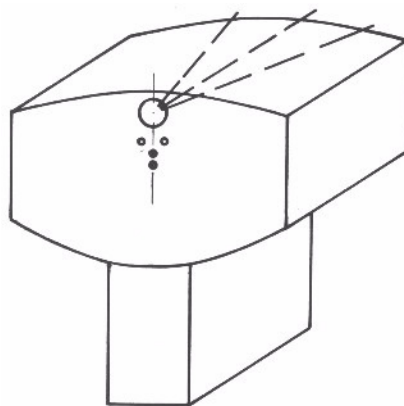
Installation

The specially developed compass 46-MFK-1 offers a number of important advantages over conventional types. In order to benefit fully from its unique information and presentation possibilities the following instructions must carefully be followed.

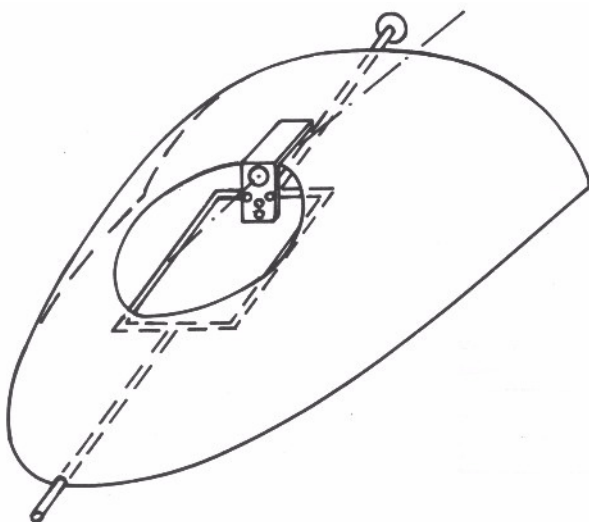
Mounting

The compass must be mounted at least 15 cm (6 in) away from any ferrous parts. If possible it should be even further away from moving coil instruments, loudspeakers or dynamic microphones. This is mandatory in order to reduce deviation. The best location is centrally on top of the instrument cover board (fig. 10). The compass may be sunk into the cover board so that merely the mirror remains in sight (also when banked in 60°). The width of the mirror is slightly less than the average distance between the two eyes of the pilot, thus giving an unobstructed forward view from a few yards in front of the fuselage onwards.

Fig. 10
Instrument cover boards



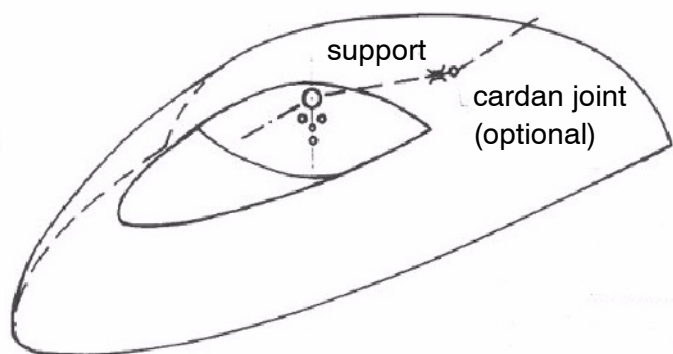
Instrument console
e.g. Kestrel 401, 604
Bank adjusting shaft
straight or at angle,
depending on
instrument arrangement



Central rod to canopy lock

e.g. ASW 17

Reshaping rod around compass,
cut-out hole in instrument cover
closed with textile bag, \varnothing 110 mm.
Use angular aluminium piece as support.



Bypassing instruments with shaft
e.g. LS 1

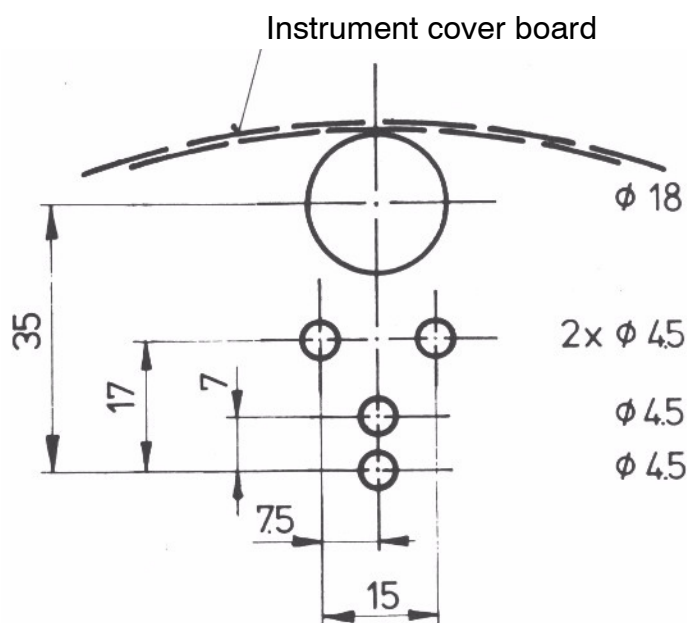
Cut out part instrument cover board turn
cut-out piece upside down and glue onto
vertical end plate. If necessary reinforce
lower drilling holes with aluminium sheet
(2 mm).

The compass may also be mounted off center, but in this case the pilot may have to slightly move his head to the side in order to see the entire dial when circling. In cockpits with central forward canopy locks, it pays to modify the knobs of levers, by-passing the compass. Use antimagnetic materials (aluminium, brass, etc.). The compass base plate is bolted against a surface which should be as vertical as possible in flight.

The drilling plan gives details on the three mounting holes and the holes for the shaft and central screw. The upper edge of the top hole for the shaft shall, if possible, be located just slightly below the instrument cover board. Examples of suggested installation possibilities are shown on enclosed sketches. The shaft with the bank adjusting knob may be brought through the instrument panel at the most suitable location. Drill a $\varnothing 5.2$ mm hole, or a slot of 5.2 mm width near the edge of the instrument cover board (thus the entire assembly may be taken off with the cover board). Should another deep instrument already occupy the top central space on the panel, then it may be necessary to install an additional (optional) universal joint and an additional support in order to by-pass said instrument with the bank adjusting shaft.

Fig. 11

Drilling plan 1:1



Levelling of compass

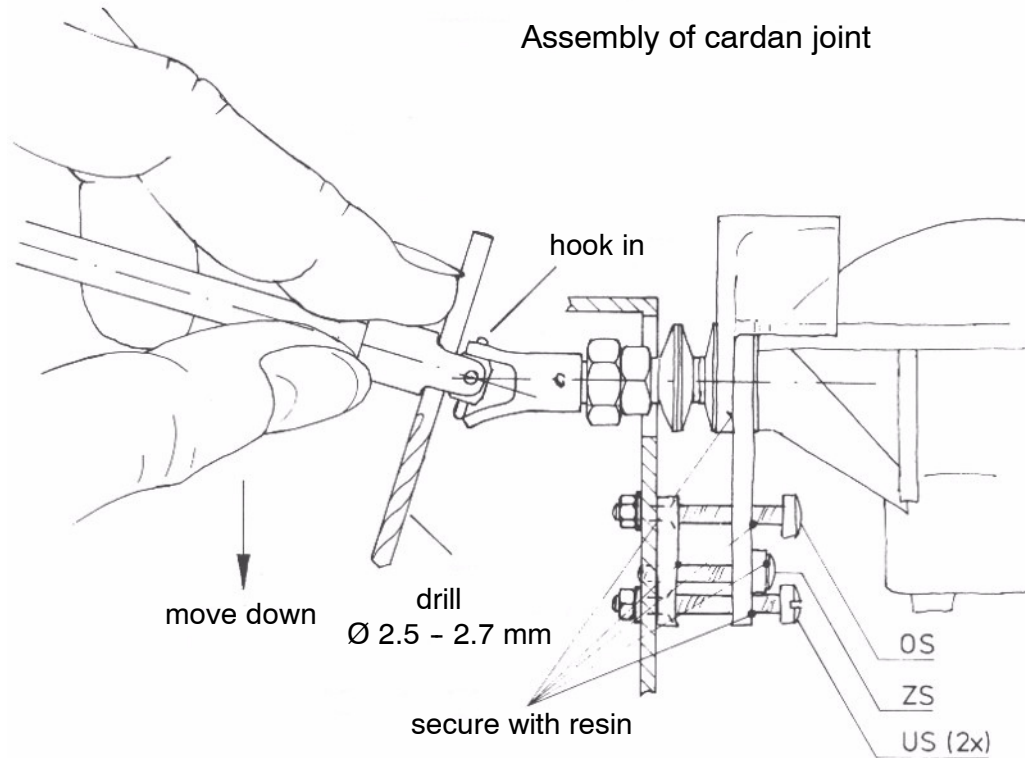
For levelling the compass it is important to know the fuselage pitch angle which corresponds to a flying speed of 100 to 110 km/h (62 to 70 mph). For gliders without flaps this will give the lowest average indication errors (over the entire speed range) on headings East and West.

In the case of gliders with flaps these errors are negligible since the pitch angle of the fuselage remains constant over a wide speed range. If the pitch angle of the fuselage at the above indicated speed is not known, it may be determined during a flight with the adjustable water-level supplied with the compass. This must be fixed somewhere in the cockpit (canopy frame, etc.) for this purpose. If desired, the water-level may remain mounted in the plane and can later serve to verify the pitch angle of the fuselage at which the compass always indicates correctly.

By turning the two lower adjustment screws (US), the N-S axis of the compass is now turned to be exactly in line with the center line of the fuselage. For turning the scale to the right screw (US) must be loosened and the left screw (US) tightened and vice-versa. After the sailplane has been prepared in this manner, it is moved to a compass compensation spot which is aligned to the magnetic pole. Levelling of the compass and, at the same time, compensation (swinging) are then a simple matter.

Fig. 12

Assembly of cardan joint



First, with the wings held horizontally, the sailplane is aligned to face exactly towards magnetic North. The fuselage pitch angle is not important here, as it only causes the indicator to move along the N-S axis. Using the turning knob, the compass is now adjusted so that the N-axis will cut centrally through the red marker dot. Slight tapping on the knob will eliminate friction on the compass needle. This tapping must be done during the entire compensation procedure (in flight, friction is automatically eliminated by the ever-present vertical and horizontal accelerations). Now the bank indication scale is adjusted so that its 0-mark is exactly aligned with the N-S axis.

The center point of this circle lies now exactly on the N-S axis of the scale. Now, the center point must also be brought onto the E-W axis.

The plane is turned to face exactly towards magnetic West. In this position the pitch angle of the fuselage is important. By unscrewing the upper screw (OS) and tightening the center screw (ZS), or vice-versa, the W-axis is moved exactly above the red mark. In order to have easier access to the screws, the compass may be banked to position 45° "R". The red mark is then somewhere near the E-axis and the centering adjustment may be completed by using this axis. Make sure to remove the screw-driver from the compass for every reading in order to eliminate interference. When bringing the compass back to level, the red mark must now be located exactly on the W-axis.

By this comparatively simple levelling procedure (which must be done accurately, however) the compass has been adjusted for zero bank and for a pitch angle of the fuselage corresponding to a flying speed of 100 to 110 km/h (62 to 70 mph). By the same procedure all stray magnetic fields within the glider have been compensated. A check may be done by taking other compass readings on different headings, e.g. from 30° to 30°. In most cases there will be no noticeable deviation. A special deviation or correction table is consequently superfluous. In an exceptional case only, when strong and uneven magnetic fields are influencing the compass, such a table may become necessary.

Due to the compensated stray magnetic fields the compass is not necessarily aligned with the vertical or cross axis of the plane. The mirror must now be adjusted, so that the N-S axis of the scale appears vertical on the image, and the E-W axis horizontal. Thus, when circling, the image of the E-W axis may always be set parallel to the horizon. The bank angle scale shall be visible along the top edge of the mirror, but it need not regularly be observed in flight. If the compensation area is aligned with the geographic (true) North, the local variation must be added or subtracted (if the red mark would be adjusted to the true North, the error when facing South would be twice the local variation).

If no calibration area is available, the compass may be levelled and compensated by lifting the tail to the proper height and, with the wings held level, rotating the whole plane around 360° several times in a row. By adjusting the upper center screw (ZS) and turning the knob, the compass is adjusted until the red mark describes a circle around the center point of the dial (and concentric to the circles marked thereon). Obviously, this must be done way out on a field, away from constructions, steel, cars, etc. The compass can then be checked in flight by flying parallel to known tracks, such as roads, railway lines, etc. The local variation and possible deviations must accurately be accounted for when using this last method of compensation.

Maintenance and care

The compass requires little maintenance. The maximum permissible shock acceleration is approx. 25 g. Care must be taken to avoid hitting the instrument against hard objects or letting it drop. A dusty or dirty mirror shall be cleaned by breathing against and using cotton-wool. The same applies for the two dials. Make sure never to come close to the compass with a strong magnet. When adjusting the screws with the screw-driver, turn gently and avoid swinging the needle against the stop with a jerk. If treated with care, the compass will function properly for years.

Technical data

Operating area:	Northern hemisphere in areas with approx. 75° - 45° inclination; this corresponds to latitudes between approx. 65° - 30° North.
Inclination on scale:	inner circle = 72,5°, center circle = 65°, outer circle = 57,5°
Scale division:	10°
Temperature range:	Minus 20°C to plus 60°C
Max. permissible acceleration:	25 g
Hysteresis:	on ground $\pm 3^\circ$, in flight practically nil

General hints

Experience has shown that after final adjustment the adjusting screws “US” and “OS” and the center screw “ZS” must be secured with lacquer or resin. This is to prevent them from becoming loose during trailer transports (which would require a new adjustment).

If there is any chance that the bank indication scale may be de-regulated (by inattention when cleaning the canopy or if access to the compass is possible to spectators) this scale should also be secured. This is done by glueing one of the edges against the aluminium support. Only resin may be used, since dissolvents such as acetone, nitro, petrol or benzine etc. will cause small cracks in perspex. The same applies to the spherical cap with the dial which must never come into contact with such a dissolvent.

If the water-level, which is supplied with the compass, shall remain installed, it is recommended to secure it with lacquer.

Before take-off, the compass, like other instruments, should be protected from direct sunlight in order to avoid excessive heating.

Information on the use of compass 46-MFK-1 model “South” for southern hemisphere

Generally, the mode “South” is suitable for use in Australia, New Zealand and South Africa.

Externally, the models “North” and “South” differ only by the design of the compass rose. On model “South” the “S” appears in the mirror on top, “W” on the right, and “E” on the left. With model “North” it is vice-versa: “N” in the mirror on top, “W” to the left and “E” to the right.

Installation is done exactly the same as for model “North”.

If a compass “North” is to be replaced by a model “South”, the center screw “ZS” must be unscrewed, whereupon the compass can be taken off and the other one inserted. Attention: Don't lose the concave washer!

Levelling of the model “South” is possible only in the Southern hemisphere. It is done in the same manner as for model “North”. A compensating spot with magnetic North indication is useful; otherwise the N-S and E-W axes may be established by other means (using an other, calibrated compass and marking the main directions with stretched strings).

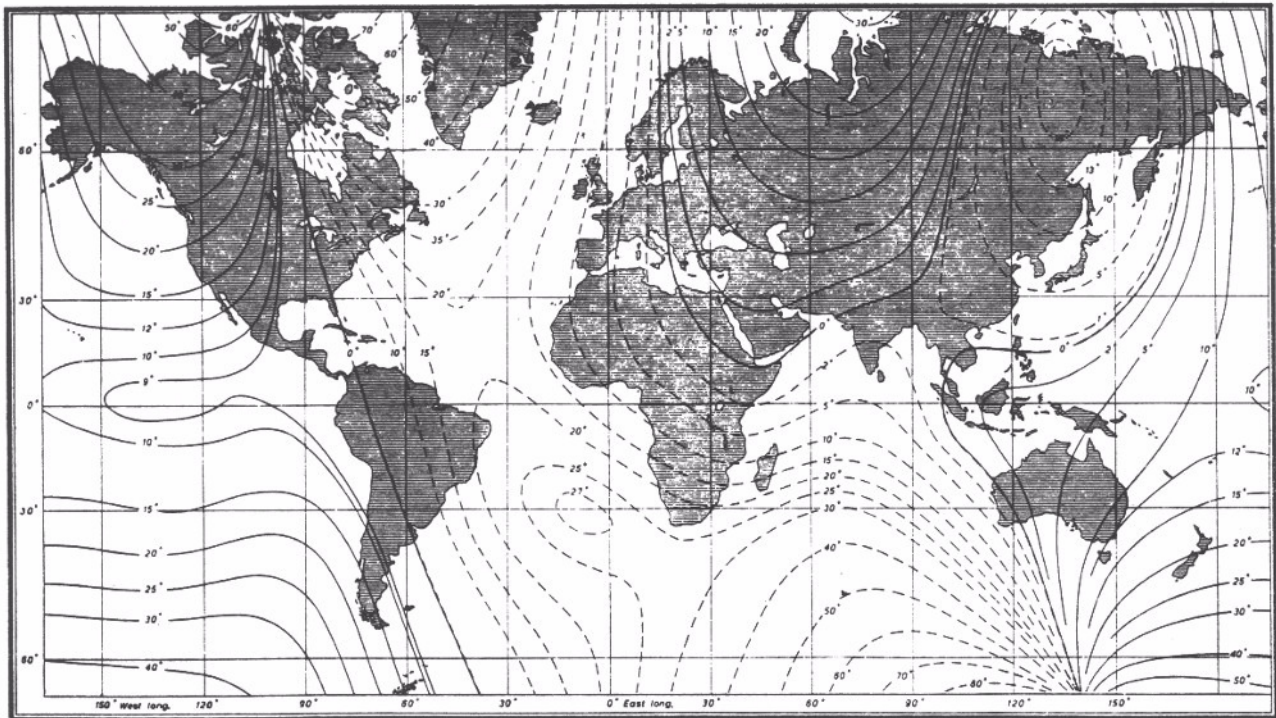


FIG. 2.6. Isogonic chart for 1965
The isogonic lines join places of equal magnetic variation.

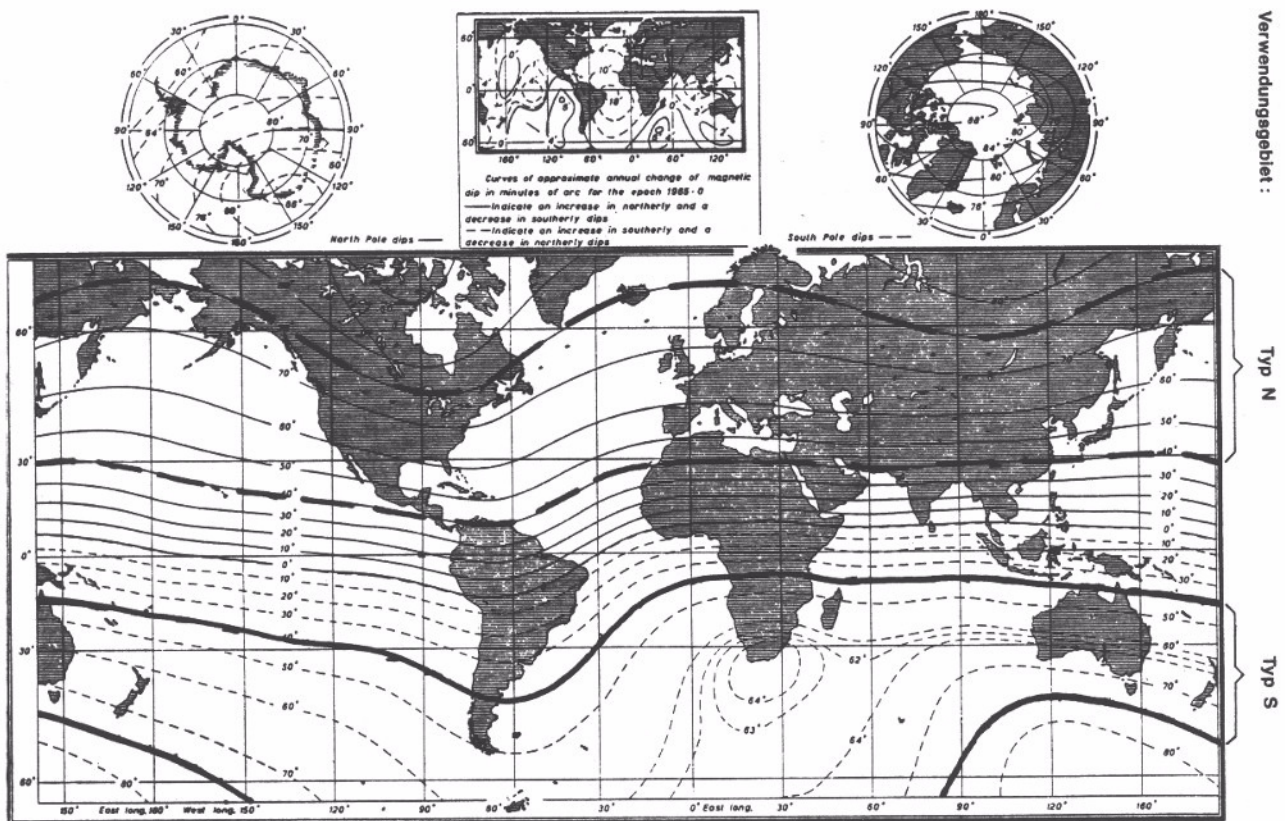


FIG. 2.8. Lines of equal dip for 1965

BOHLI manufacturing programme:



Standard program:

Magnetic holding devices

Dial test indicator holder

Selecting magnet

Demagnetizer for steel

Holding and sticking magnets

Rubber magnets

Sailplane instruments

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