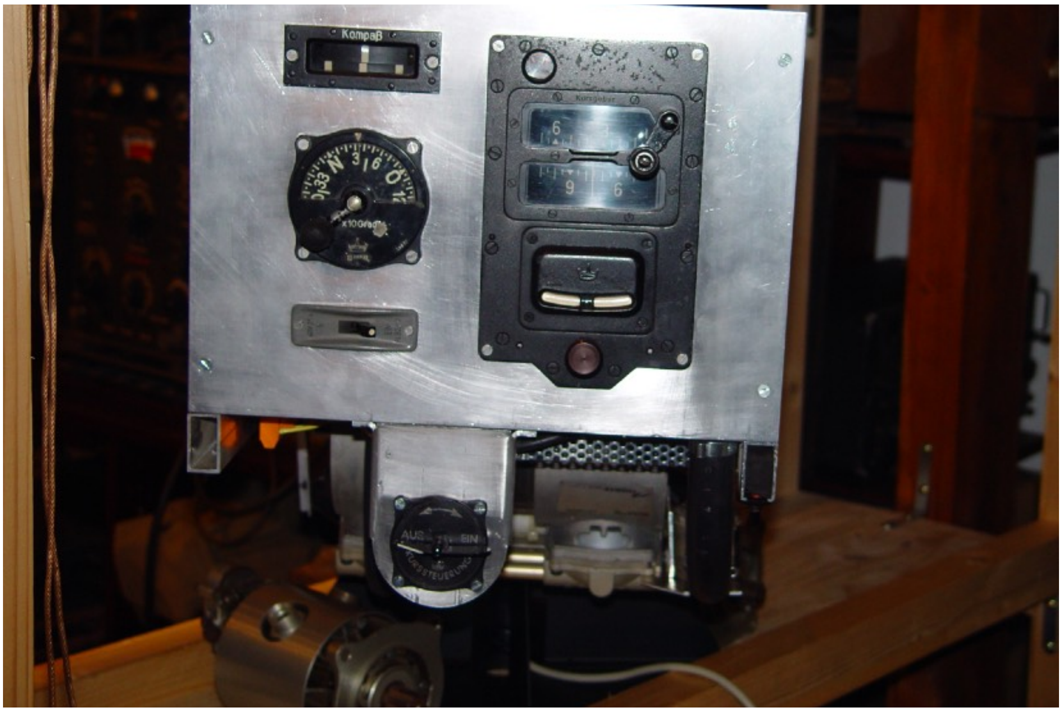
Askania LZ12 autopilot



Askania Lz 12

Introduction

Askania started developing automatic pilots in 1924 after building compasses for the German Navy in the first world war and pneumatic industrial control system in the years between the wars. In 1920's and 1930's the firm obtained several licenses from Sperry to manufacture gyroscopic instruments. In 1927 they combined their experiences in compasses, pneumatic industrial control and gyroscopic instruments to build a course controller for the "Luftschiff Zeppelin" LZ 129. Askania adopted the "Lz" terminology for their course controller and stuck with it during subsequent developments.

In 1927, Askania introduced their Lfk remote compass installation. With aircraft instrument panels containing more and more electrical systems it became more difficult to place the magnetic compass in the cockpit without it being influenced by electric currents. It was therefor desirable to move the compass to a place in the aircraft free of these influences and obtain a remote reading on the instrument panel. The Lfk remote compass consists of a pneumatic master compass, a course setting unit and a pneumatic "left-right" indicator instrument (Kurszeiger). The Lfk system remained in service for many years and was manufactured under license in Spain to well into the 1950's. It also formed the basis of the pneumatic compass used in the V-1 buzz-bomb.

By adding a directional gyroscope to the Lfk compass installation, Askania developed a fully pneumatic "Kurssteuerung", which was tested in the Junkers W33 and Ju 52. In 1931 Askania gained an airworthiness certificate for this system which became known as the Lz 4 "Kurssteuerung".

In 1932 Askania became involved in testing the Sperry A-2 "gyropilot" for the "Deutsche LuftHansa" and obtained licences to build the Sperry artificial horizon.

Whereas the Lz 4 used the less stable course signal directly from the magnetic compass, the Sperry system used a directional gyroscope, which was more stable but was not coupled to a magnetic compass and would deviate over longer time periods. To solve these issues, Askania developed the Lfgk 1 "Fernkurskreisel" gyrocompass. The "Fernkurskreisel" compared a set course with a gyroscopically stabilised flown course and provided a pneumatic output signal if the two were different. The deviation from true magnetic course -provided by a Lfk 9 remote compass- adjusted the gyroscope to keep the system on the true magnetic heading.

Incorporating an improved Lfgk 3 "Fernkurskreisel" into the Lz 4 design coupled to a number of other refinements led to the pneumatic Lz 11a and Lz 12 "Kurssteuerung" systems by the late 1930's. These saw relatively widespread use being adopted by the Luftwaffe, with the Lz 11a seeing use in the He 59 and the Lz 12 in early versions of the He 111 and Do 17 bombers.

The Deutsche Lufthansa also used the Lstz 512 civilian variation in long range aircraft on various European and transatlantic routes.

Due to the use of the automatically compensated gyrocompass and the incorporation of a rate gyro the Lz 12 could be used on aircraft with a limited self-stability and lower inertia, which made it suitable for some of the faster aircraft emerging in the late 1930’s. The Lz 12 proved to be a user friendly and reliable system; the pilot just had to set the desired course and switch the system on, there would be no need for tuning during the flight. The Lz 12 remained in service until the end of WW2, However, the development of the electric/hydraulic systems like the Siemens K4ü rendered the pneumatic systems obsolete, so by the beginning of WW2 the Lz 12 would no longer be applied to newer Luftwaffe aircraft types.

Description of the Lz 12 autopilot

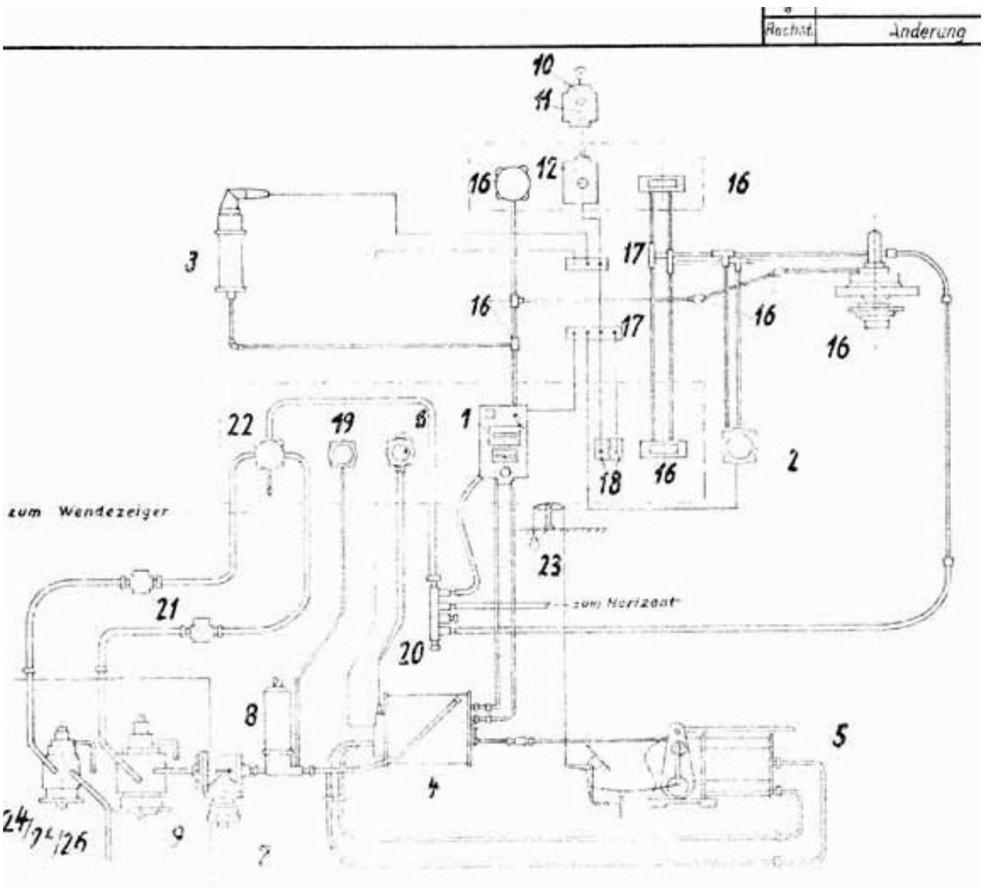


Figure 1: Askania Lz 12 autopilot overview

The Askania Lz 12 consists of -

- a Lfk 9 “Fernkompass” remote compass installation -
    - a Lfk 9 “Mutterkompass” master compass
    - a Lkz 1p or 5p “Kurszieger” indicator,
- a Lrpi 3 “Umwandler” pneumatic to electric transformer

- a Lfgk 3 “Kurskreisel” directional gyroscope,
- a Lz 512 “Kurssteuergerät” control unit,
- a Lc 6 “Arbeitskolben” rudder servo
- a Lsog “Sogpumpe” vacuum pump
- a Lkompr “Luftpresser” air pump
- a Lreg 11a “Zogregler” vacuum regulator
- a Lsz 4r “Hauptschalter” main switch,
- a “Stützschalter” compass coupling switch,

An extra Lkg 3r “Kursgeber” and Lfz 6 “Richtungsgeber” driving a Lfzm 4 “Kursmotor” could be placed on a separate panel, allowing the bomb aimer to take control over the aircraft during the bomb run.

The Lz 12 used vacuum pressure to operate the remote compass systems, to the power gyroscope in the “Fernkurskreisel” and to provide signals between the units. The system uses 1.5 Bar overpressure to drive the gyroscope in the control unit and to provide the power for the servo system.

Some electrical circuits were used in the Lz 12: the course could be set using an electric motor and the “Fernkurskreisel” and the “Umwandler” contained electric circuits for the automatic allignment of the gyroscope with the compass; The Lz 12 system could however operate without any electrical power in which case the pilot would have to manually adjust the gyrocompass from time to time.

The Functioning of the Lz 12 autopilot

The principles of the autopilot

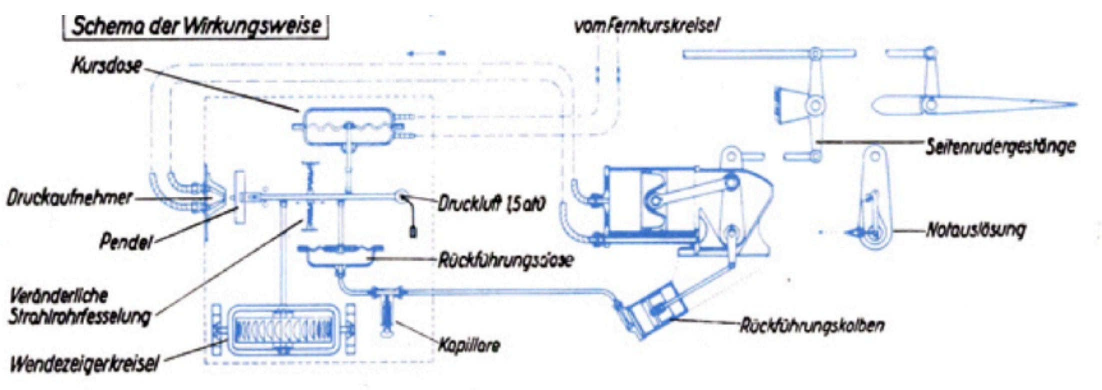


Figure 2: Functional overview of the Lz 12 autopilot

The Lz 11a is in principal a “second order” control system, using a course and rate-of-turn signal to steer the rudder of the aircraft. Movement from the rudder servo is fed back to control the overall gain of the system. The strength of all signals could be tuned to adjust the control system to the inertia and rudder effectiveness of the particular aircraft.

The Lz 12 pneumatic autopilot relied on air pressure to generate the various signals and to power the rudder servo. Within the master compass and the “Fernkurskreisel”, two jets of air blow air onto two apertures with an eccentric disk placed between. In neutral position, the edge of the disk would block each jet/aperture pair for 50%, generating equal pressure in each aperture. As the eccentric disk turns, one jet/aperture pair will increasingly be blocked while the other gets unblocked, generating an increasing pressure differential. This pressure differential can be transported over relatively long impulse lines to other instruments, where the differential pressure is fed to a two-chambered bellow, which translates the differential pressure back into a mechanical movement.

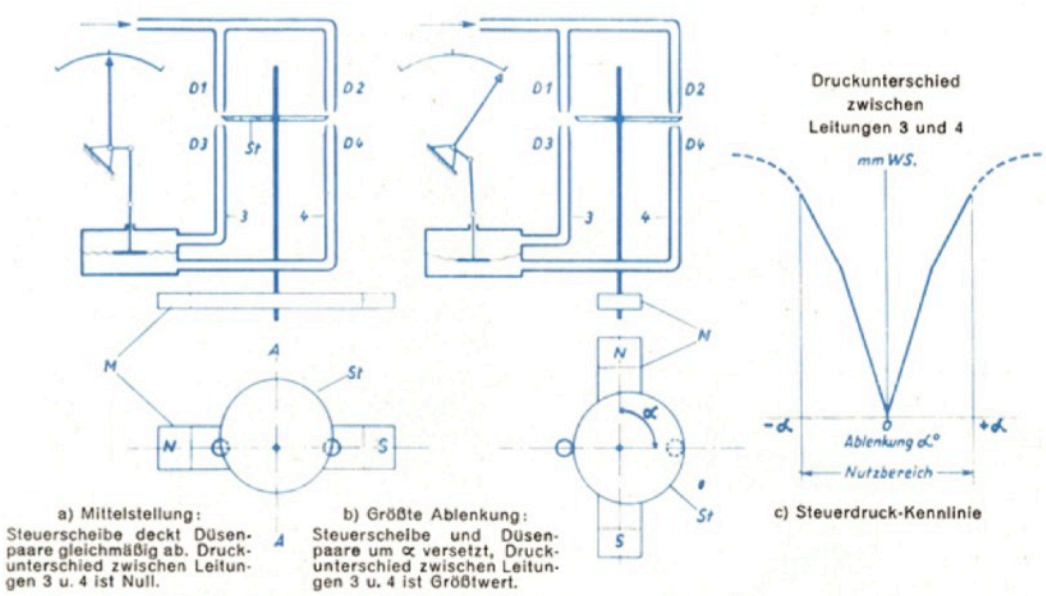


Figure 3: Differential pressure transmitter principle

In the “Kurssteuergerät, the mechanical movement provided in this way is added to the other mechanical movements by means of pivoting arms, whose pivot point can be adjusted so that the addition rates can be varied; this allows the system to be tuned to the characteristics of a particular aircraft.

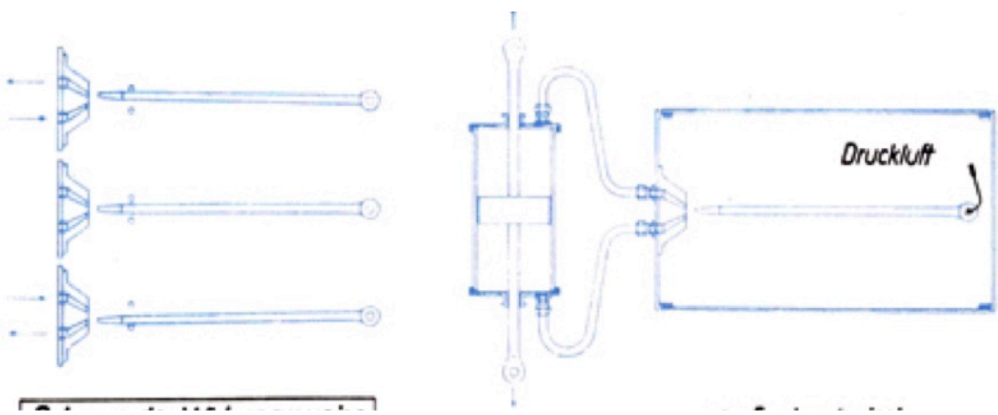


Figure 4: Pneumatic power transmitter principle

The output of the “Kursteueergerät” has to be powerful enough to drive the pneumatic servo. For their industrial control applications, Askania had developed a pneumatic “power” system which allowed for a very precise translation of mechanical movement into a high powered pressure differential. An air jet, fitted to a moveable arm would blow air onto two closely spaced apertures. If the jet was in the central position, the two apertures would generate the same pressure, giving a zero output signal. If the arm moved towards one of the apertures, that aperture would generate a higher pressure than the other one. This differential pressure is fed to both sides of a piston in the rudder servo to generate a strong mechanical movement.

A number of different signals are influencing the movement of the nozzle, in effect the “Kurssteuergerät” is a mechanical computer, adding different pneumatic, electrical and mechanical signals. The output signal is influenced by-

- the course signal from the “Fernkurskreisel”
- the rate of turn signal from the rate gyroscope
- the “Vorgabe” signal from the “Kursmotor”
- the roll signal from a pendulum
- the bias setpoint from a sliding block arrangement

The strengths with which each of this signals influence the output can be varied with the various tuning controls.

The Lfk 9 “Fernkompass” remote compass

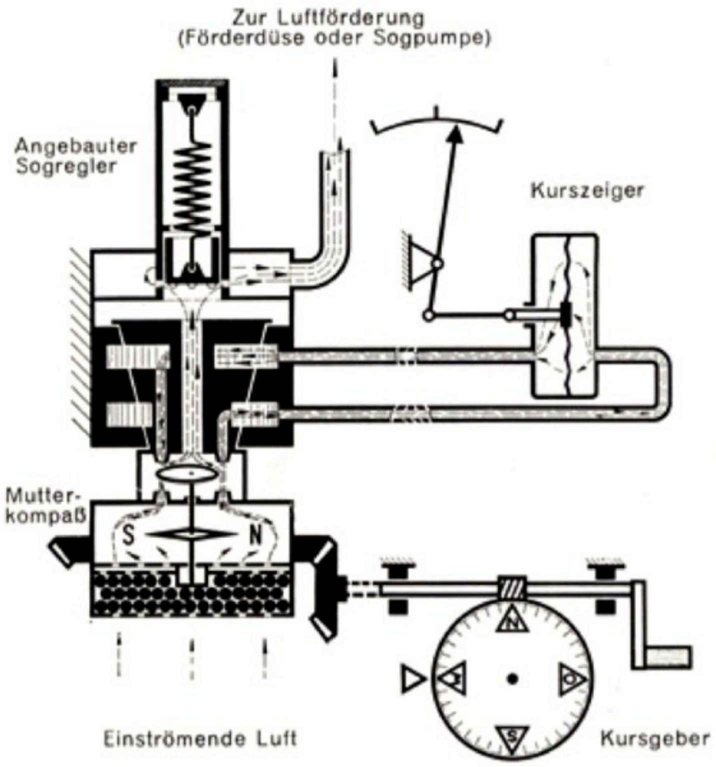


Figure 5: Pneumatic remote compass schematic

The Lfk 9 remote compass installation consisted of the Lfk 9 master compass placed in the rear fuselage of the aircraft. The master compass was connected with a flexible drive cable to the Lkg 3r “Kursgeber”. The Pneumatic output signal of the Master compass was fed through two impulse lines to the “Kurszeiger”.

The Lfk 9 “Mutterkompass” Master compass

The master compass used the rotating disk principle described in the previous section. The disk is connected to the compass needle and will allign to the magnetic North. The compass and disk system is contained in the bottom part of the compass,which is suspended by a cardanic connection so that it remains more or less vertical as the aircraft pitches and rolls. Air is sucked in through a filter mounted on the bottom of the compass. The outer housing can be rotated to adjust the setpoint of the compass. The top part of the compass contains the mechanical drive and pneumatic rotating couplings to allow the housing to rotate. A vacuum regulator is placed on top near the suction inlet; this compensates for the varying air pressure at different heights. The compass is housed in an outer protective cage with a magnetic compensation ring so that the compass can be compensated for any deviations caused by the aircraft structure.

Figure 6: Complete Lfk 9 Master compass fitted with protective housing and compensation ring

The Lkg 3r “Kursgeber”

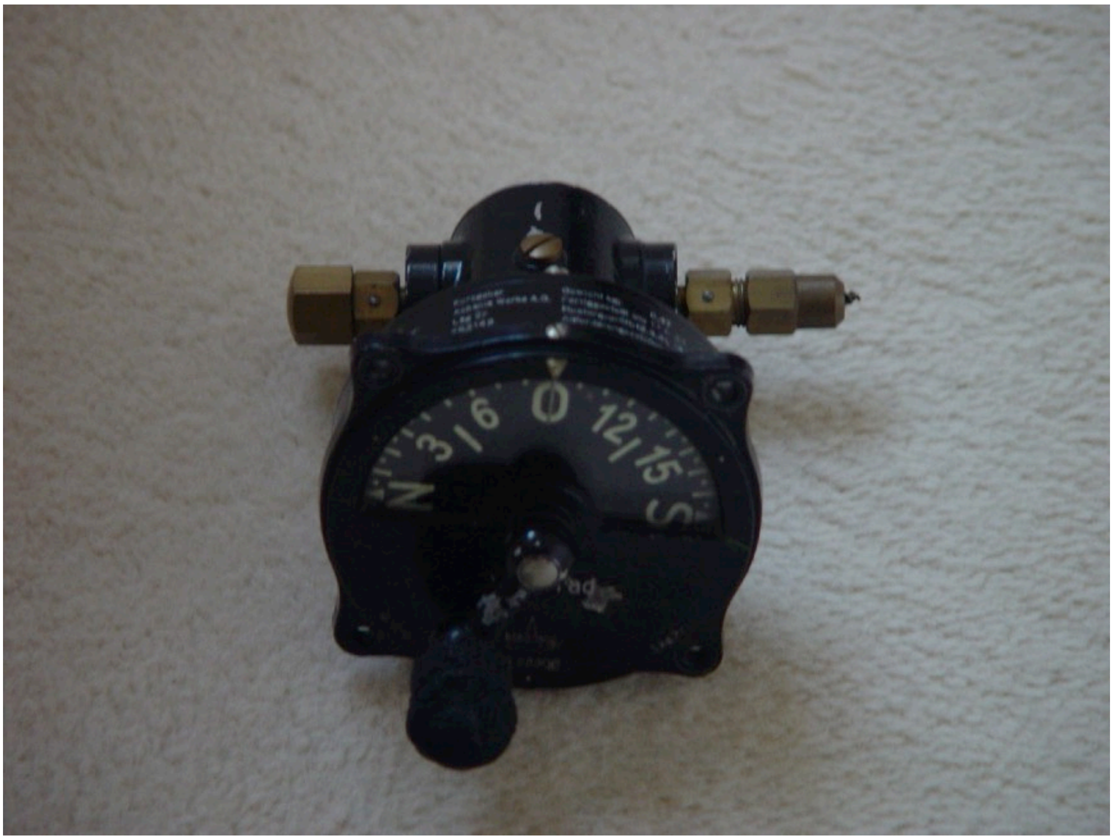


Figure 7: Lkg 3r "Kursgeber"

The “Kursgeber” is a simple mechanical drive coupled to a compass rose indicator. The output shaft on the back of the instrument turns as the crank is turned with the compass indicator on the front rotating at the same time. The output shaft is linked through a flexible drive cable to the master compass to change the setpoint.

The flexible drive cable is also connected to the Lfgk 3 “Kurskreisel” so that it displays the same heading as the “Kursgeber”. A Lfzm 4 “Kursmotor” could also be connected to the cable drive so that the bomb aimer could adjust the setpoint (and with it the heading the aircraft is flying) using a simple electrical switch.

The Lkz 5p “Kurszieger” indicator

Figure 8: Lkz 5p "Kurszeiger"

The Lkz 5p “Kurszeiger” indicator instrument is a simple left-right indicator. The differential pressure coming from the master compass is fed to two sides of a diaphragm which moves the indicator left or right. The “Kurszeiger” is always used in conjunction with a “Kursgeber” or with the “Fernkurskreisel” and shows the deviation from the course set on these instruments. For example, if the “Kursgeber” is set due North, the “Kurszeiger” will be in the central position as the aircraft flies due North. If the aircraft deviates to the West, the “Kurszeiger” indicator will move to the left. The pilot can keep the aircraft on the set heading by compensating the rudder and keeping the indicator in the central position.

The Lkz 1p was a larger version of the same instrument.

The Lrpi 3 “Umwandler” pneumatic to electric transformer

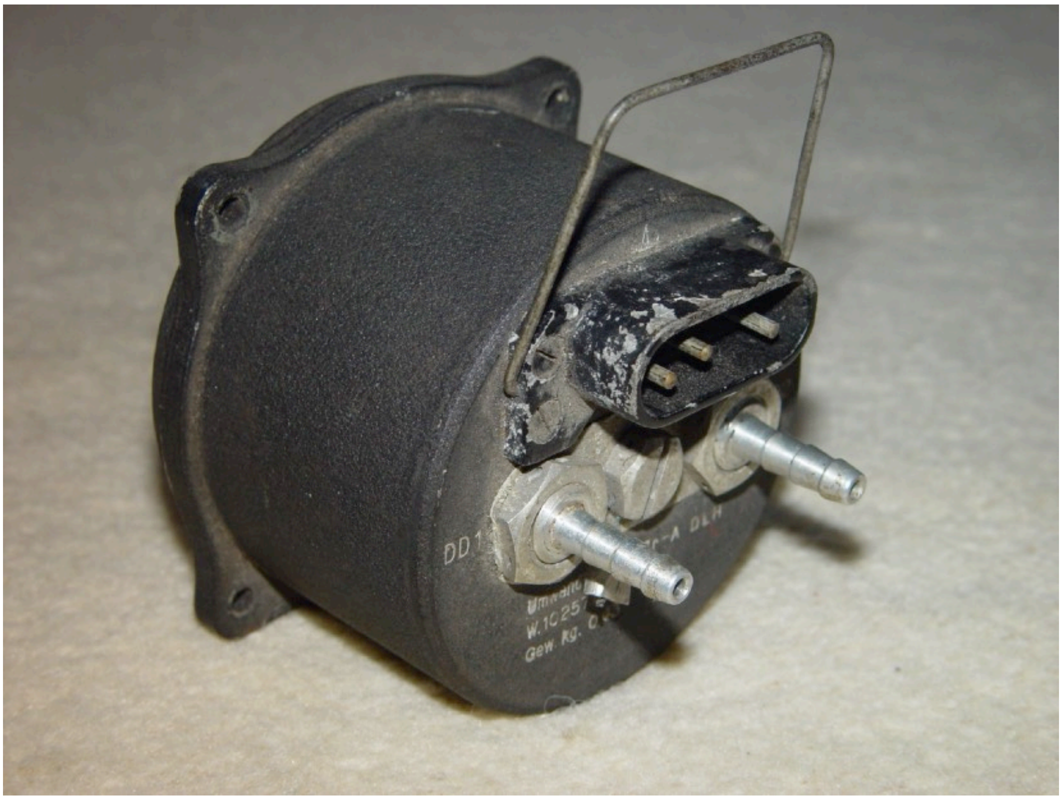


Figure 9: Lrpi 3 "Umwandler"

The Lrpi 3 “Umwandler” is build in a blanked off instrument housing with pneumatic and electric connections at the rear.

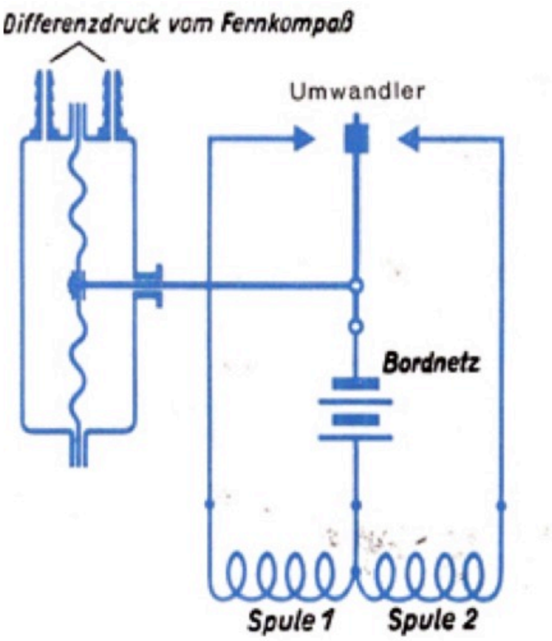


Figure 10: Schematic showing how the “Umwandler” precesses the gyro compass

It contains a switch connected to a diaphragm. As the differential pressure changes across the diaphragm, the switch will close either one of two contacts. If the differential pressure is zero, the switch remains open.

The “Umwandler” transforms a deviation from the set course into an electrical signal, which is used to slowly adjust the gyroscopically stabilised heading in the “Fernkurskreisel”.

The Lfgk 3 “Kurskreisel” directional gyroscope

Figure 11: Fgk 3 "Fernkurskreisel"

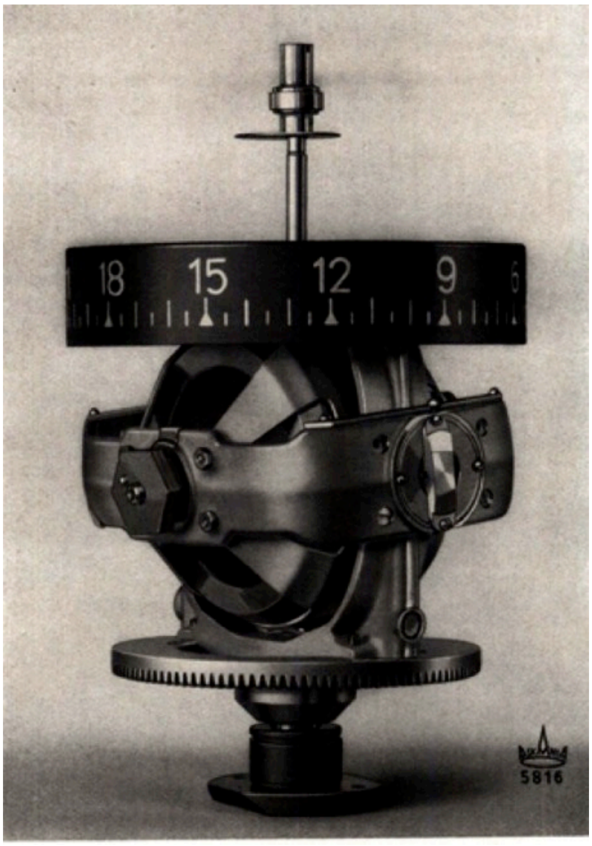


Figure 12: “Fernkurskreisel” gyroscope

The Lfgk 3 “Fernkurskreisel” is based on the Sperry pneumatic gyrocompass built by Askania in licence in the early 1930’s. Whereas the basic Sperry gyrocompass displays a single course indicator ring, the “Fernkurskreisel has two course indicators placed on top of each other so that the set course (top) can be compared to the flown course (bottom). The top course indicator can be adjusted by turning the handle on the instrument (or remotely by the “Kursmotor” placed elsewhere in the aircraft). The top course indicator is coupled by a mechanical drive cable to the Lfk 9 master compass.

The bottom indicator is fixed to the gyroscope, which will try to maintain a fixed attitude in space. As the aircraft turns around the gyroscope, the bottom indicator will keep indicating in the direction of the gyroscope. A knob on the bottom of the instrument can be pushed and turned to align the gyroscope with the magnetic compass. When the knob is pulled out, the gyroscope is free to rotate.

Because of bearing resistance and due to the rotation of the earth, a gyroscope will not automatically stay aligned with the magnetic north. The earth rotation alone will cause the gyroscope to shift by 1 degree every four minutes. For this reason a compensation mechanism was fitted to the “Fernkurskreisel”.

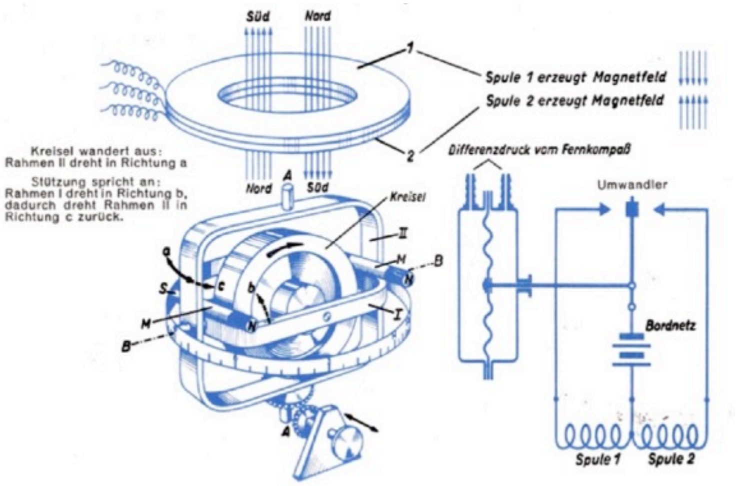


Figure 13: "Fernkurskreisel" compensation mechanism

The electrical signal from the “Umwandler” (discussed above) is fed to two coils which generate a magnetic field pointing upwards or downwards respectively. Fixed magnets attached to the mounting frame of the gyroscope will attempt to tilt it from it’s horizontal axis in this magnetic field, causing the gyroscope to precess around it’s vertical access. The direction of this precession depends on the direction of the magnetic field, causing the gyroscope to slowly follow the magnetic compass. The precession is slow enough not to show any swinging of the magnetic compass but large enough to compensate for deviations of the gyroscope. The Germans called this compensation mechanism “Kreiselstützung” or “Überwachung”. The compensation could be switched on or off using a simple electrical switch.

The “Fernkurskreisel” uses the rotating disk principle described in the previous section to generate an output signal based on the difference between the fixed (set-point) and gyroscopic compass scales.

The “Fernkurskreisel” contained a small electrical heating coil, so that the instrument could be used at higher altitudes in sub zero temperatures without the risk of ice forming in the pneumatic system.

The “Fernkurskreisel” had a level indictor fitted to the front panel helping the pilot to maintain the correct roll angle when flying curves.

The Lz 12 “Kurssteuergerät” control unit

The “Kurssteuergerät” is the heart of the autopilot. It receives the pneumatic course input signal from the “Fernkurskreisel” and produces a high-powered pneumatic differential pressure to drive the rudder servo. It is constructed as a “black box” with vibration mountings to the rear and front so that the unit can be mounted in a convenient place in the fuselage of the aircraft.

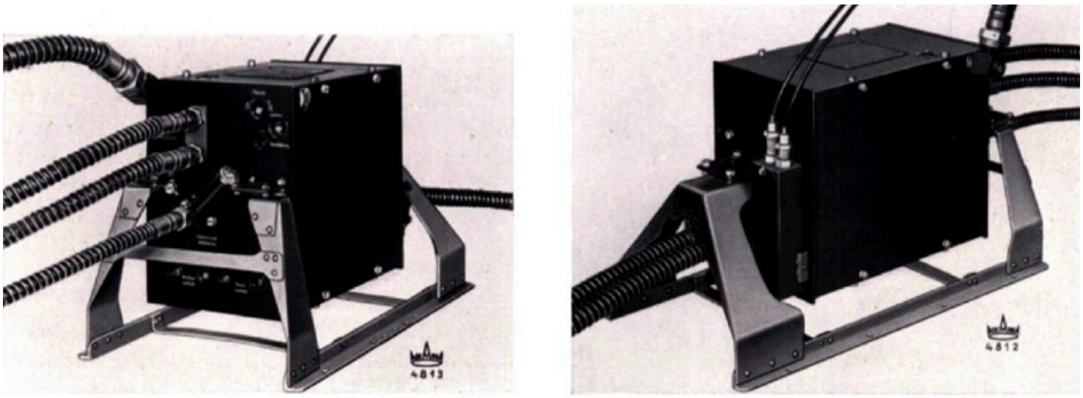


Figure14: "Kurssteuergerät" with mounting bracket and all connections in place

Figure 15: Lz 12 "Kurssteuergerät" – external rear view

On the rear of the “Kurssteuergerät” are the pneumatic input connections from the “Fernkurskreisel”. Also on the rear is the connection for the feedback line from the rudder servo. The latter is placed on an adjustable capilary valve which equalises the pressure in the feedback line. This equalisation is necessary so that height changes of the aircraft do not unduly influence the feedback circuit. A number of tuning controls are visible on the rear panel, these allow the system to be “tuned” to a particular aircraft type. Sticking out from the side near the rear is the main pneumatic supply connection, this would be supplied with 1.5 bar pressure from the compressor. A small window on the top of the unit shows a small spirit level so that the unit can be mounted horizonally in the aircraft. The date plate contains a “Flugrichtung” arrow to remind the installer of the correct direction of travel.

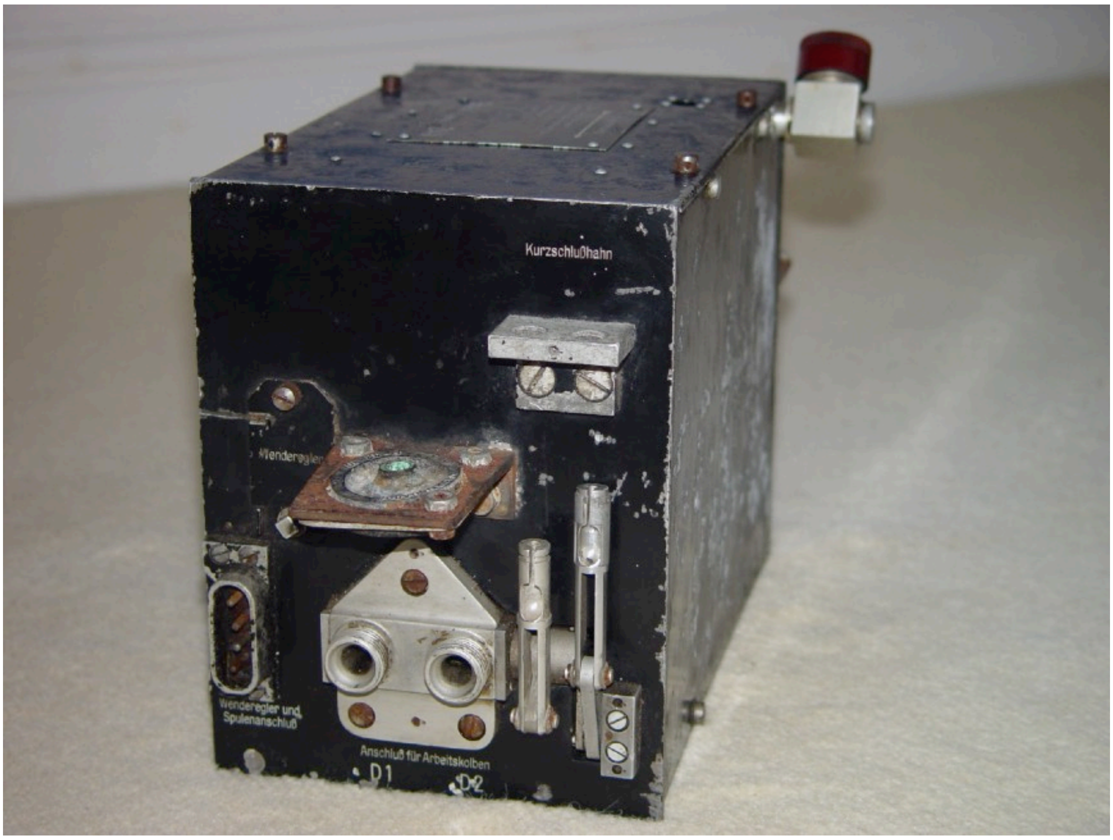


Figure 16: Lz 12 "Kurssteuergerät" - front view

The front of the “Kurssteuegerät” contains the pneumatic output connections to the rudder servo. To the right of the output connections are two arms driving the main output valve. These arms are connected by two bowden cables to the main on-off switch mounted on the instrument panel of the pilot. With the switch in the “off” position, the two output connections are interconnected, meaning that he rudder servo receives no differential pressure and can be moved freely. If the switch is moved in the “on” position, this short circuit is removed and the rudder servo receives the differential pressure from the pneumatic power transmitter discussed above.

To the left of the pneumatic output connections is an electrical socket. This receives a signal when the “Kursmotor” is activated and will introduce an offset (“Vorgabe”) in the output signal of the “Kurssteuergerät”. The “Vorgabe” will ensure that the aircaft will turn promptly and accurately at about 2°/sec when the course setting is changed with the “Kursmoter”. A few more tuning controls complete the front panel.

When the top cover is removed a number of compenents become visible:

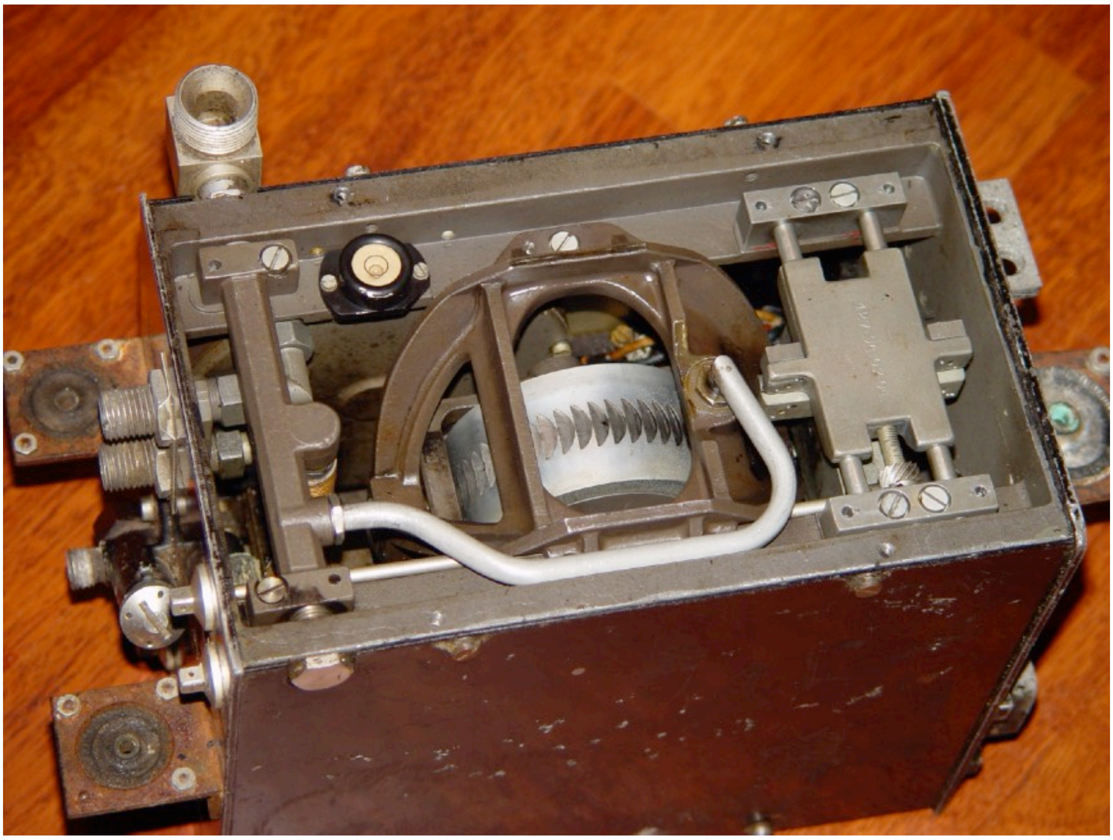


Figure 17: Lz 12 "Kurssteuergerät" internal view

Sitting prominently in the centre of the unit is the rate gyroscope. The airline feeding the gyroscope nozzle is curving towards the main input header. The air is blown onto crescent shaped indentations around the circumference of the gyroscope for maximum “drive”. The air around the gyroscope and the rest of the inside of the box will be kept at ambient air pressure. Also noticable is the shape of the outer mounting frame of the gyroscope. Inside the outer frame, an inner frame allows the gyroscope to turn around the roll axis. This setup ensures that turning of the aircraft will force the gyroscope to precess around the roll axle of the aircraft. The inner mounting frame will transfer this rolling movement into a side to side movement which will be proportional to the rate-of-turn of the aircraft.

To the right of the gyroscope frame a sliding block is visible. This supports a pendulum that is connected to the output nozzle. By turning one of the tuning controls on the rear panel, the block can be moved from side to side; in this manner the bias setpoint of the output nozzle can be adjusted. The pendulum adjusts the bias of the output nozzle if the aircraft is rolling. In the 1930’s, pilots (sitting on the left) would often roll the aircraft slightly to the left to get a better view of the ground. If not compensated, this roll angle will cause the aircraft to veer off course. The pendulum in the “Kurssteuergerät” will automatically adjust the rudder to compensate for this roll angle. This also explains why the unit needs a spirit level as it is important that it is mounted horizontally in order not to impede the functioning of the pendulum system.

To the left of the nozzle you can just see an airline going downwards from the middle of the input header. This is the input line –and pivot point- of the nozzle of the pneumatic power transmitter discussed above.

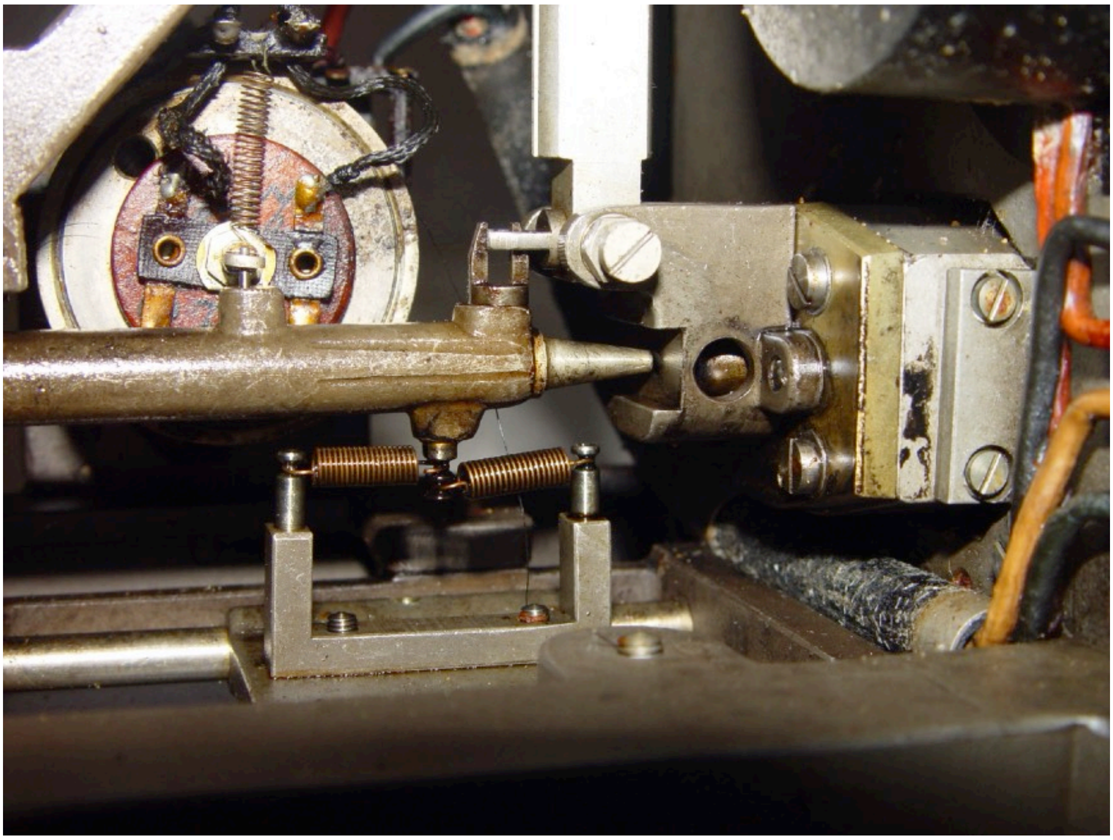


Figure 18: Nozzle of the pneumatic power transmitter

The above figure shows the output nozzle which blows a jet of compressed air onto the apertures of the output connections on the right side of the box. In the background is the electrical “Tauchspule” coil that moves when the “Kursmotor” is activated. The arm coming from the top of the picture is connected to the pendulum that inputs the roll angle of the aircraft. The nozzle is coupled via two springs to a sliding block underneath the nozzle. This sliding block can be moved forward or backward by one of the tuning controls and influences how hard the nozzle is pulled back to the central position by the springs.

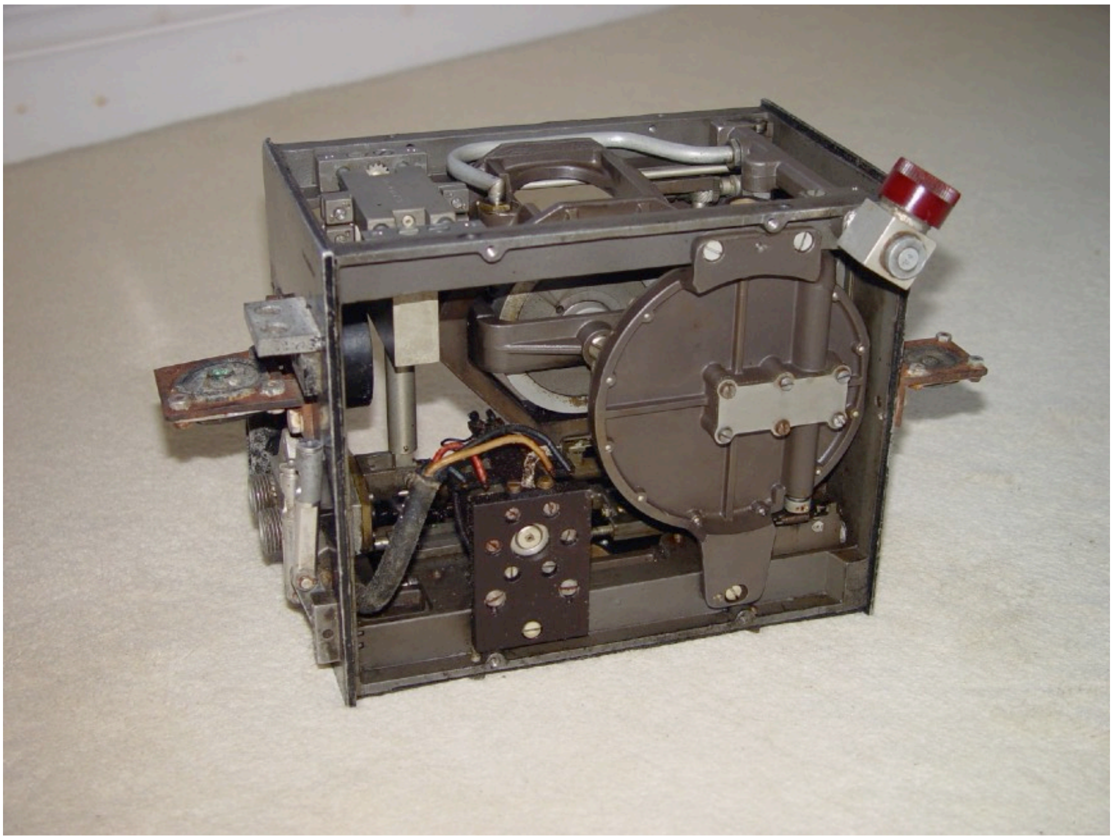


Figure 19: Left side view of the "Kurssteuergerät"

The left side view prominently shows the round “Kursdose” bellow, which adds the pneumatic signal from the “Fernkurskreisel” into the mix. The the two pneumatic input connections are connected to air chambers inside the “Kursdose” which will cause a side to side movement with the differential pressure. Left of the gyroscope the pendulum to compensate for the roll angle can be seen. Bottom left of the “Kursdose” is the the electrical “Tauchspule” coil with it’s electrical connections.

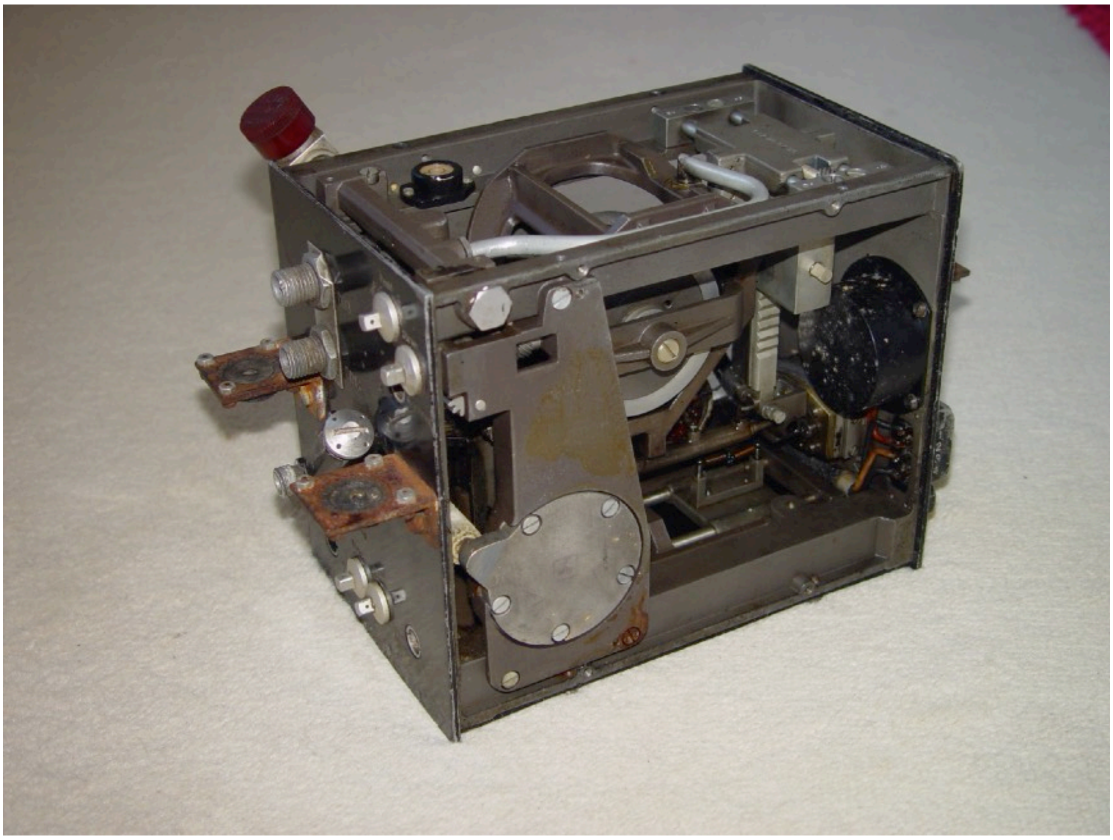


Figure 20: Right side view of the "Kurssteuergerät"

The right side view shows another smaller circular rudder servo feedback bellow.

Note that all the moving components are suspended in a very thick and stable chassis. The chassis has to ensure that aircraft vibrations and forces can not unduly influence the working of the autopilot.

Also note some oil staining on some of the chassis parts, when first inspected quite a lot of old thickened oil was found in the unit, a sign that this particular “Kurssteuergerät” had actually been flown and that the oil filter downstream of the compressor had not been entirely effective. Perhaps the groundcrew had neglected to drain the filter sufficiently before flights or perhaps it is the result of an accumulated build-up over a long time. It illustrates one of the disadvantages of pneumatic systems: they are sensitive to dirt and oil which will eventually lead to a blockage of the pneumatic servo system and failure of the autopilot.

The Lc 6 “Arbeitskolben” rudder servo

The “Arbeitskolben” rudder servo translates the differential pressure generated by the “Kurssteuergerät” into a force to operate the aircraft’s rudder. The output pressures are fed to both ends of a piston, which will move if there is a differential. The piston is connected with a connecting rod to the output shaft of the servo on which the servo lever is mounted. Also connected to the output shaft is a small feedback piston. With a 1.5 bar supply pressure, the “Kursteuergerät” produces a differential pressure of about 1.35 bar maximum which generates a force of about 120 Kg at the end of the rudder servo lever. This force is large enough to operate the rudder of even the larger aircraft in service at the time yet small enough so that the pilot can just about overpower it with his legs on the rudder pedals.

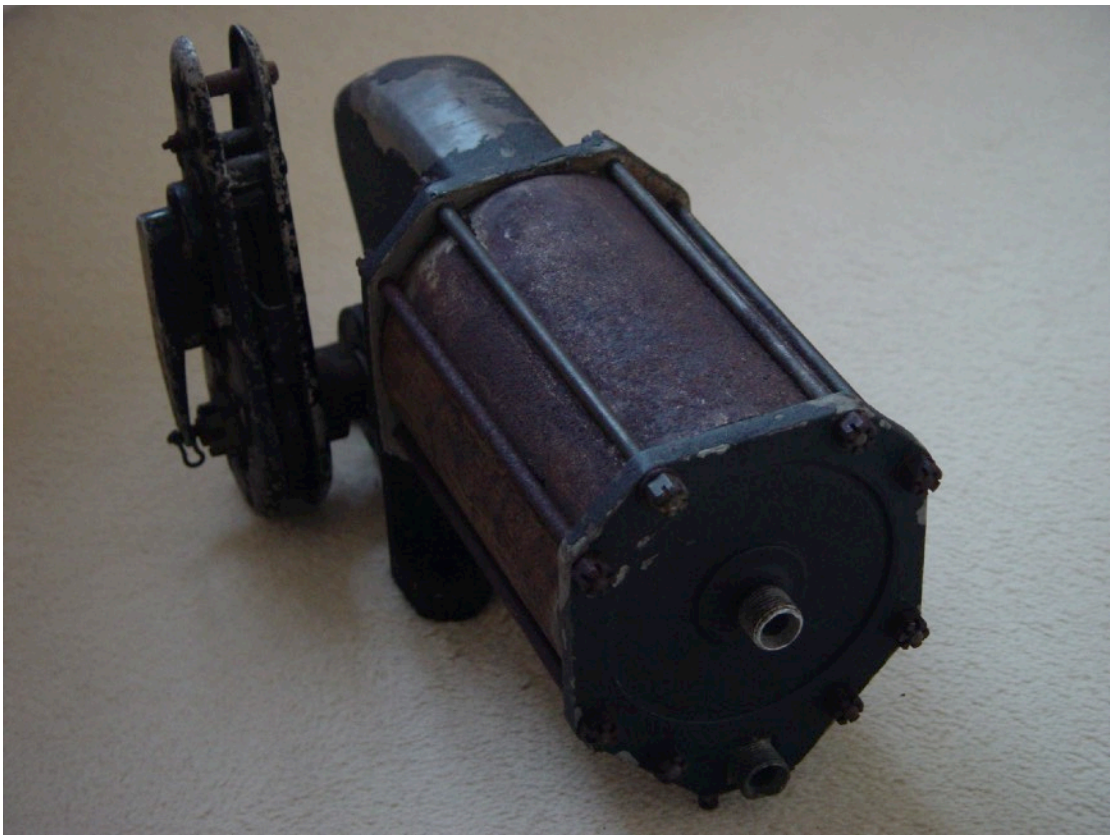


Figure 21: Lc 6 "Arbeitskolben" rudder servo

Figure 15 shows the two pneumatic connections on the end of the cylinder. The rudder servo lever is visible on the left with the emergency release lever on the far left.

Figure 22: Close up of the output lever with the emergency release lever

The rudder servo lever is fitted with an emergency release mechanism operated by a bowden cable from the cockpit. If the emergency release cable is pulled, a lever releases a latch in the output lever, allowing the lever to move freely around the output shaft. This will disable the autopilot for the rest of the flight and can only be reset on the ground after the cause of the fault has been established.

The Lsog “Sogpumpe” vacuum pump and the Lkompr “Luftpresser” compressor

The Lz 12 system is fed by two pumps driven by the engines of the aircraft. In order to provide some redundancy the vacuum pump would be driven by one engine while the compresser, which would also generate a vacuum pressure on the inlet, was driven by the other engine. (The similar LZ 11a system used a ventury to generate the vacuum and a propellor driven pump to compress the air).

Figure 23: Lsog vacuum pump

The Lsog pump provided vacuum to drive the “Fernkompass” and the “Fernkurskreisel” of the autopilot system (and any other pneumatic instruments like artificial horizon, turn indicator etc.).

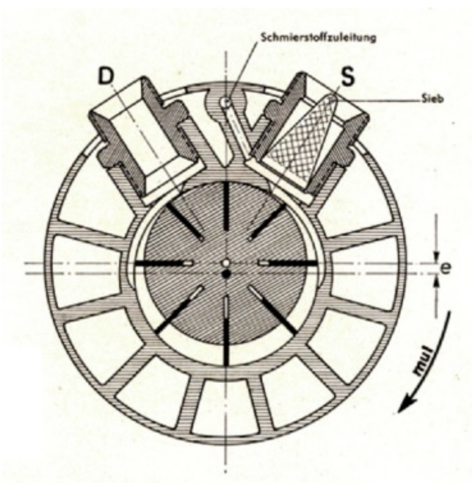


Figure 22: Rotary vane compressor cross section

It is a rotary vane pump with eight vanes mounted in an eccentrically placed rotor. As the rotor turns, the volume between two vanes will first increase, sucking in air through the inlet nozzle. When the vane moves past the inlet opening, the air becomes trapped in an ever decreasing volume between the vanes until it reaches the output opening where the pressure is released into the atmosphere. The vaccum pump can be operated both clock- and anticlockwise.

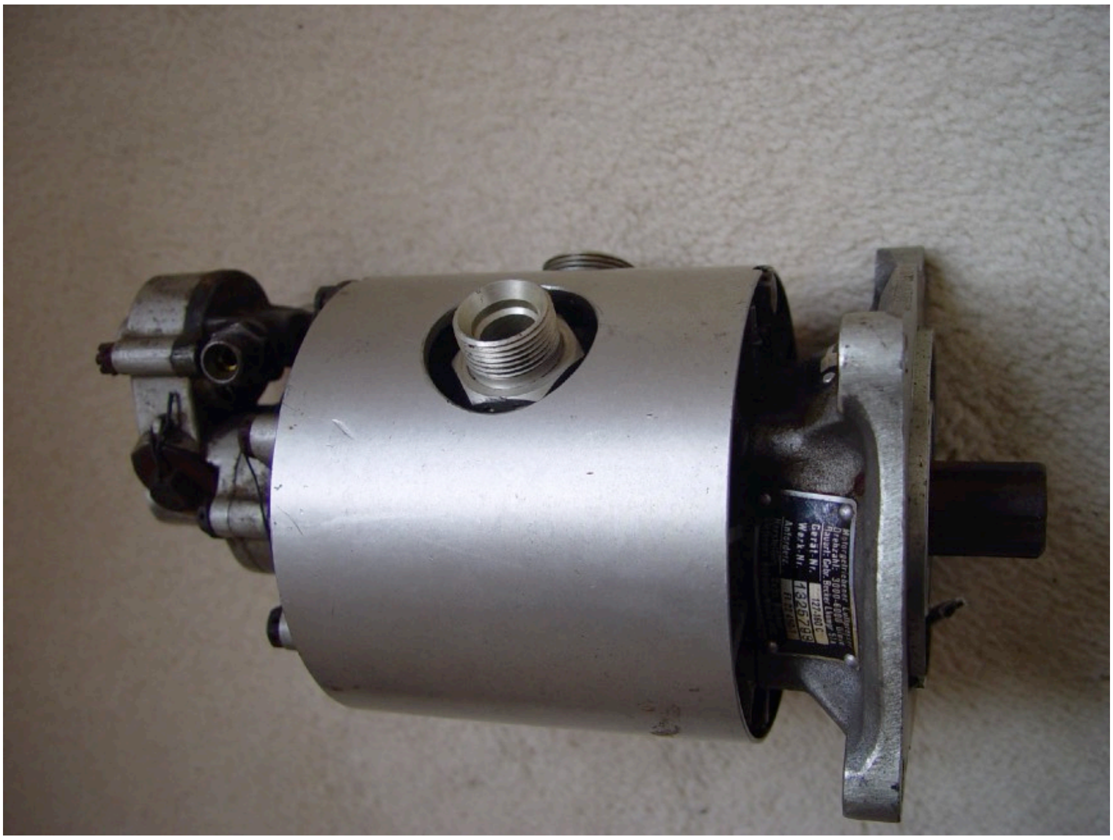


Figure 24: Lkompr air compressor

The Lkompr air compressor works on the same principle. The main difference is the larger housing. As compressing air can generate a lot of heat, a compressor requires significantly more cooling than the vacuum pump. Exterior air can be fed through passages between the inner and outer housing (visible in the cross section) to provide a forced cooling. The Lkompr provides the air supply to the “Kurssteuergerät” to drive the rate gyroscope and to power the “Arbeitskolben” rudder servo.

Both pumps are fitted with a small oil pump to lubricate the bearings and vanes. This means that the compressed air circuit needs and oil filter before being connected to the autopilot to remove any oil carried with the compressed air.

A pressure instrument would be mounted on the pilot’s instrument panel to indicate the compressed air pressure provided by the compressor.

The Lsz 4r “Hauptschalter” main switch and Lv 194 “Umschalthahn” pneumatic control switch

A number of switches allowed the pilot to control the functions of the autopilot.

The Lv 194 “Umschalthahn” pneumatic control switch allowed the pilot to select the vacuum supply from either one of the two pumps. The vacuum pressure supplied to the pneumatic instruments could be regulated from 0 to 10 by turning the inner control knob

Figure 25: Lv 194 "Umschalthahn" pneumatic controller

The “Hauptschalter” is the main on-off switch for the autopilot system. Via two Bowden cables it operates the short-circuit valve in the output of the “Kurssteuergerät”. In the “Aus” position, the output of the “Kurssteuergerät” is short circuited, leaving the “Arbeitskolben” rudder servo to move freely. Wen the “Hauptschalter” is turned to the “Ein” position, the short circuit valve is closed, applying the full differential output pressure of up to 1.35 bar to the rudder servo.

Figure 26: Lzr 4r "Hauptschalter" main operating switch

In the “Aus” position, all other elements of the Lz 12 remain in standby operation with the gyroscopes running. With the “Hauptschalter” the autopilot can instantly be switched on or off.

An electrical toggle switch would also be placed on the pilot’s instrument panel to engage the automatic course compensation mechanism for the “Fernkurskreisel”.

Operating the Lz 12 autopilot


Figure 27: Cockpit overview with controls for the Lz 12 autopilot

Before flight

Before starting, check that the “Hauptschalter” is switched to the “Aus” position. Check that the bottom knob of the “Fernkurskreisel” is pushed in.

The Lz 12 autopilot is supplied with vacuum and air pressure by engine-mounted pumps, so the motor to which the air compressor is mounted must be started. Rev the engine until the air pressure instrument reads 1.5 bar and leave the engine running at this speed.

Move the “Umschalthahn” to the appropriate position so that vacuum is applied to the compass system and the “Fernkurskreisel”. Allow a few minutes for the gyroscopes to run up.

Turn the crank of the “Fernkurskreisel” until the indicated heading on the top scale of the “Fernkurskreisel” is showing the desired heading. The “Kurszeiger” should indicate if this heading is to the left or right of the direction in which the aircraft is parked.

Align the bottom scale of the “Fernkurskreisel” with the set heading by pressing and turning the bottom knob.

Adjust the aircraft's rudder to the approximate central position. The rudder control should run free.

Switch the "Hauptschalter" to the "Ein" position. The rudder should remain in the central position, but it should no longer run free; applying pressure on the rudder controls should not move the rudder.

Turn the crank of the "Fernkurskreisel" a few turns to the left; the left rudder pedal should start moving forward. Turn the crank of the "Fernkurskreisel" to the right; the right rudder pedal should now start moving forward. If the rudder pedal is not moving check if the emergency release of the rudder servo is pulled. If so reset the emergency release (but not after establishing the cause of the fault that led to the emergency release being pulled). Repeat the test. After the test return the top scale of the "Fernkurskreisel" to current compass heading and ensure the bottom scale is aligned to.

Turn the "Hauptschalter" to the "Aus" position. The rudder should again run freely and unobstructed from end to end.

Throttle back the engine to idle and pull out the bottom knob on the "Fernkurskreisel". The autopilot is now primed and ready to use.

Before take off

Switch the "Umschalthahn" to position "1" if not already there. If required, switch on the heating of the "Fernkurskreisel". Check that the "Hauptschalter" is in the "Aus" position. The autopilot should not be engaged during take off.

During flight

Switch on the "Überwachungsschalter" to engage the automatic compensation of the "Fernkurskreisel". Select the required heading by turning the crank on the "Fernkurskreisel".

Turn the aircraft manually onto the required heading. The "Kurszeiger" should be in the central position when this is achieved. Bring the aircraft in level flight. If required, push and turn the bottom button on the "Fernkurskreisel" to re-align the bottom scale. Ensure that the button is pulled out.

Switch on the autopilot by switching the "Hauptschalter" to the "Ein" position. The aircraft will now automatically hold its course. The pilot is still required to control the roll and pitch of the aircraft manually.

Flying a straight course

The autopilot will hold the aircraft on a fixed heading. The “Kurszeiger” of the remote compass should stay roughly in the middle. There may be a slight and slow oscillation of the aircraft around the set course, this are caused by the sensitivity of the compass system and should not be considered a fault.

Flying a curve

To fly a left curve using the autopilot, the crank on the “Fernkurskreisel” is turned to the left. The aircraft will immediately start to turn with a constant rate of 2°/s. This rate of turn is independent of how quick or far the crank is turned, so the pilot can select the new set course as quickly as he desires. With the turning of the crank, the magnetic “Fernkompass” is set to the new course and the top scale of the “Fernkurskreisel” can be observed turning towards the desired course, under no circumstances should the bottom scale be adjusted. During the curve, the pilot should adjust the roll angle of the aircraft so that the roll indicator on the “Fernkurskreisel” remains central during the turn. About 3° before reaching the set course, the pilot should bring the aircraft back to level flight as to ensure a smooth transition. Some practice may be required to get a feel for the correct roll adjustment.

Flying a bomb run

During a bomb run, the bomb aimer can take control over the autopilot. The pilot will first switch off the “Überwachungsschalter”, to avoid any unexpected movements caused by the automatic correction of the “Fernkurskreisel”. The bomb aimer can now steer the aircraft very precisely left or right using the “Richtungsgeber” switch on his panel (or by activating a special “Richtungsgeber” attached his the bombsight). The “Kursmotor” is geared to run much slower than the normal manual adjustment rate, so very find adjustments can be made.

The pilot in the mean time ensures that the aircraft remains level flight during the bomb run. After completing the bomb run the pilot will take over control and will switch the “Überwachungsschalter” back to the on position and quickly turn the aircraft around to a homewards heading.

In case of failure

Should the autopilot malfunction in any way the pilot should move the “Hauptschalter” to the “Aus” position. If this does not allow free movement of the rudder, the pilot shall pull the emergency release button. The autopilot will now remain disabled for the rest of the flight.

The pneumatic compass and the “Fernkurskreisel remain in operation independent of the operation of the autopilot.

The unlatched lever of the rudder servo should only be reset on the ground after the flight and after investigation and remediation of the cause of the failure.

When sudden undesired rudder movements occur, the autopilot can be overpowered by forceful operation of the rudder pedals as an immediate reaction. Should the undesired movement persist, the autopilot should be switched off or disengaged as described above.

If the vacuum supply fails, all the pneumatic instruments (artificial horizon, turn indicator, remote compass and “Fernkurskreisel”) will start to fail and the “Umschalthahn” should be moved to the “2” position. Bear in mind that the gyroscopic indicators will keep running for another 5-15 minutes, a loss of vacuum pressure will however have an immediate effect on the indication of the “Fernkompass” and functioning of the autopilot.

If the electrical supply falls, the “Kursmotor” can no longer be used. Also the “Überwachung” automatic compensation and heating of the “Fernkurskreisel will fail. The failure of the “Überwachung” will slowly become apparent when the “Kurszeiger” of the magnatic compass system wanders away from the central position. When this occurs, the pilot will need to manually adjust the bottom scale of the “Fernkurskreisel” which should not be done with the autopilot engaged. Switch the “Hauptschalter” to the “Aus” position and turn the aircraft manually to the set course. When the set course is achieved, the bottom button of the “Fernkurskreisel” can be pushed in and the bottom scale adjusted to align with the top scale. Pull out the bottom button and re-engage the autopilot by switching the “Hauptschalter” back to the “Ein” position. This procedure will have to be repeated every 5-10 minutes. The heating in the “Fernkurskreisel” will also fail so if possible reduce height to avoid the risk of icing.

Landing

Do not land the aircraft with the autopilot engaged. Switch the “Hauptschalter” to the “Aus” position during level and straight flight. The pilot should prepare by placing his feet in the rudder pedals so that he can immediately take over control and make a smooth transition into manual flight. With the “Hauptschalter” in the “Aus” position, the rudder should move freely.

After landing

After parking the aircraft check that the “Hauptschalter” is in the “Aus” position. Move the “Umschalthahn” to the “1” position. Switch the “Überwachungsschalter” and the heating switch of the “Fernkurskreisel to the “Aus” position. Depress the bottom button on the “Fernkurskreisel”. Check that the rudder moves freely and leave it roughly in the central position. Switch off the engines. If any failures have occurred during flight, report these to the relevant ground personnel, especially in case that the emergency release has been pulled.

Restoring a functioning LZ12 autopilot

With all the individual components restored to working order, they were fitted to a turn table. The Turn table was fitted with a drive system creating a closed loop system where the autopilot controls the movement of the turn table. It was challenging to find an air pump small and light enough to fit to the turn table; the air pump has the provide both vacuum and compressed air. It turned out that a “silent” piston compressor of about 500 W would just about do the job, the compressor was fitted out of sight under the turntable with the auxiliary electronics for the turn table drive system

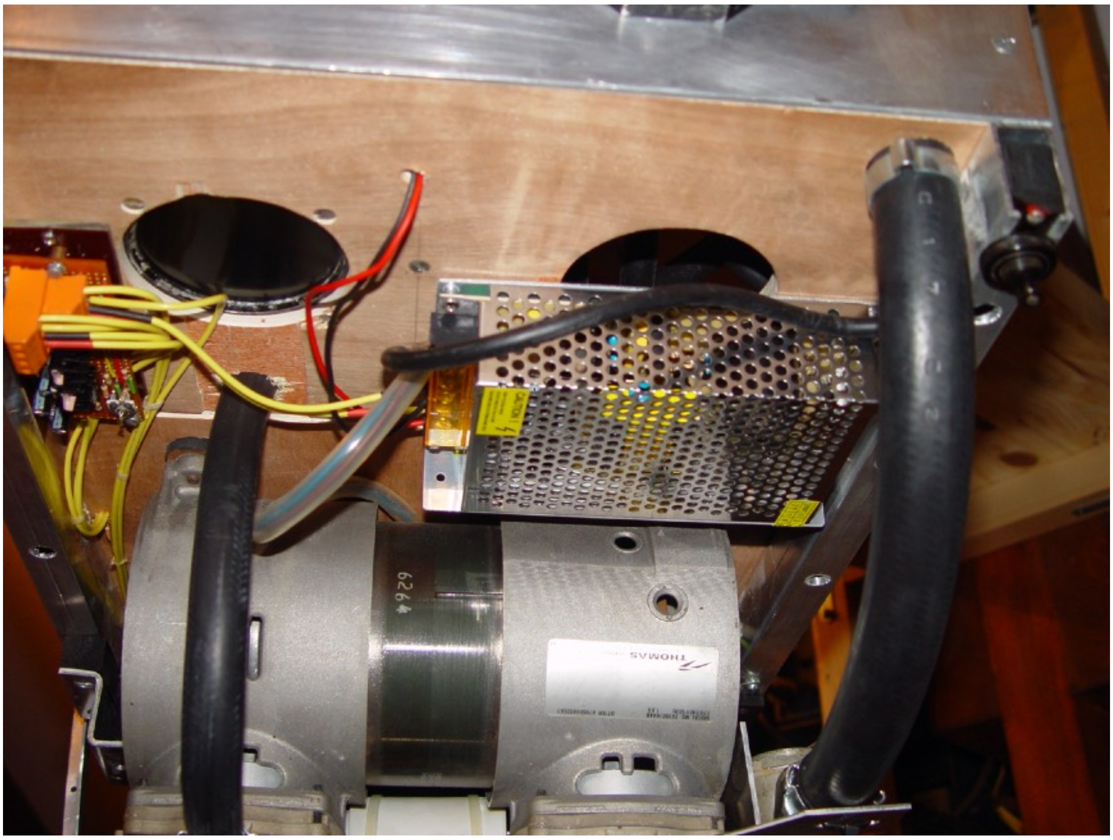


Figure 28: A suitable air pump that could provide both vacuum and compressed air was found and mounted under the turn table with the auxiliary electronics

The compressor and electrical systems produce stray magnetic fields, for this reason the master compass was fitted as far away from these units, at the rear of the turn table.

The various components of the LZ12 were interconnected with rubber hoses of various diameters.

A “Rudder” was mounted on top of the turn table driven by the rudder servo. The rudder is coupled to the input potentiometer of the turn table drive system so that any rudder movements result in a turning force being applied to the turn table

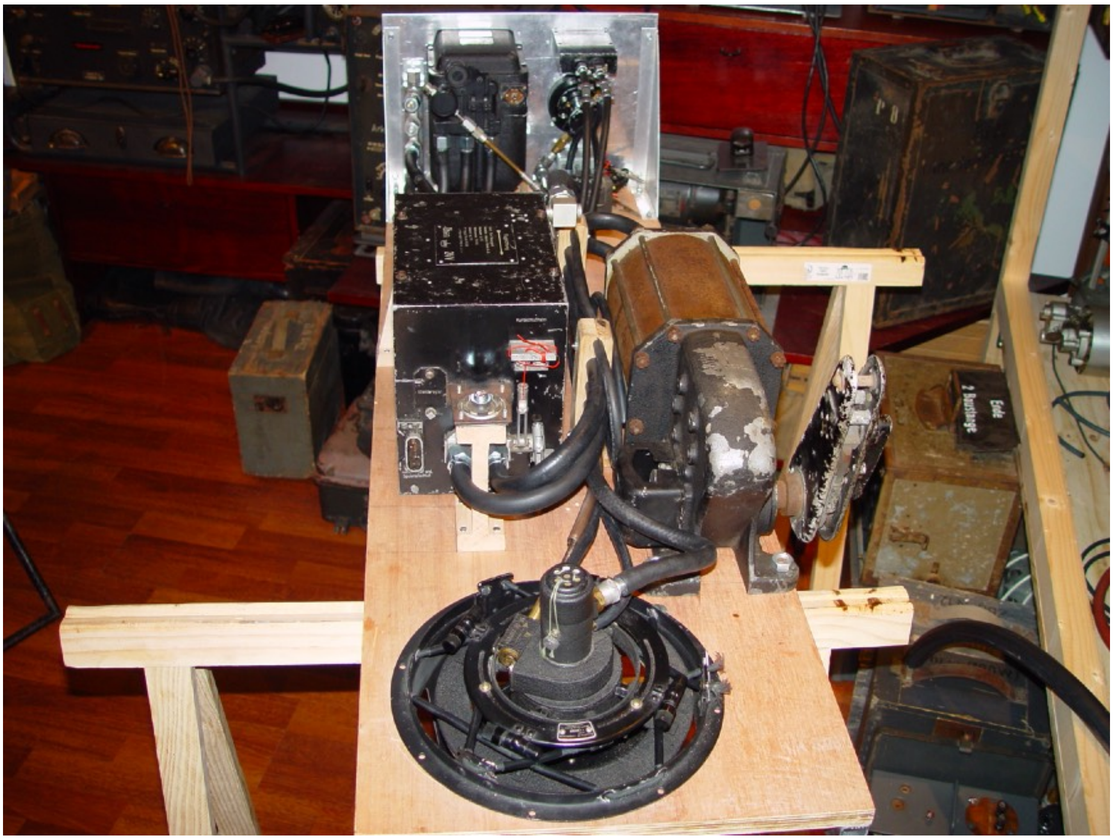


Figure 29: the master compass was mounted as far away from the electrical components to avoid magnetic interference

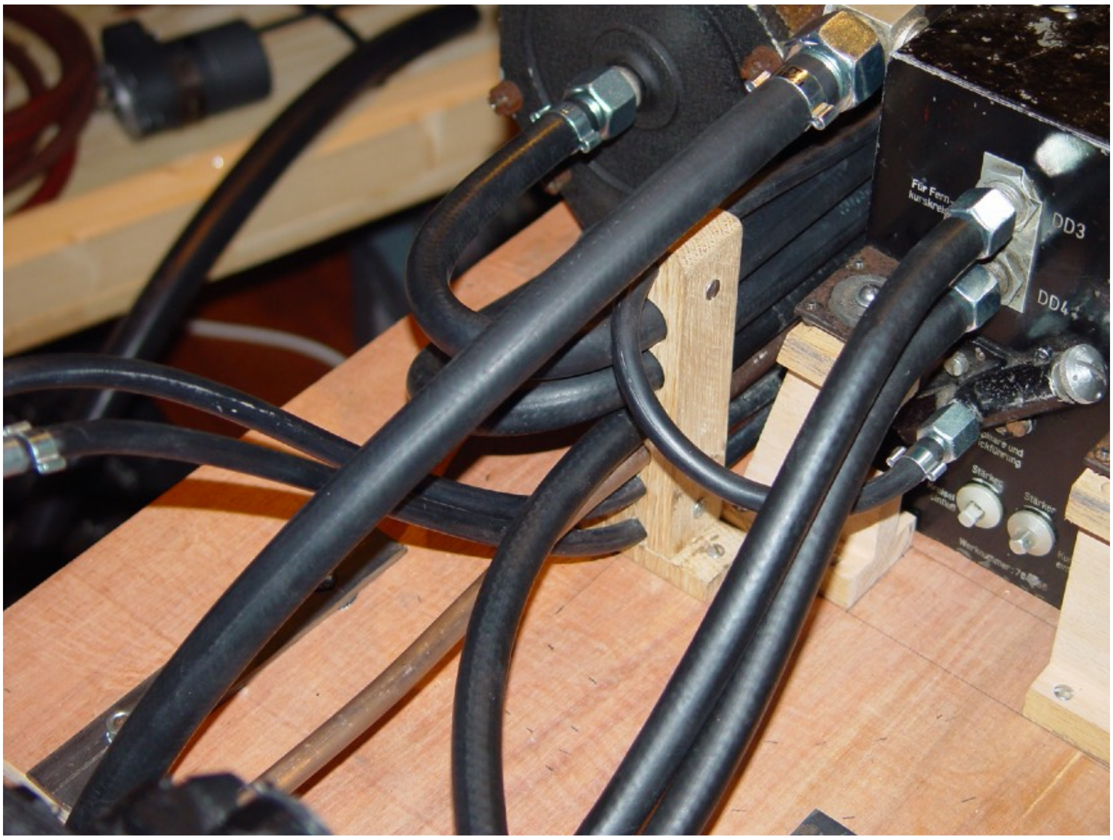


Figure 30: the components are connected with rubber hoses

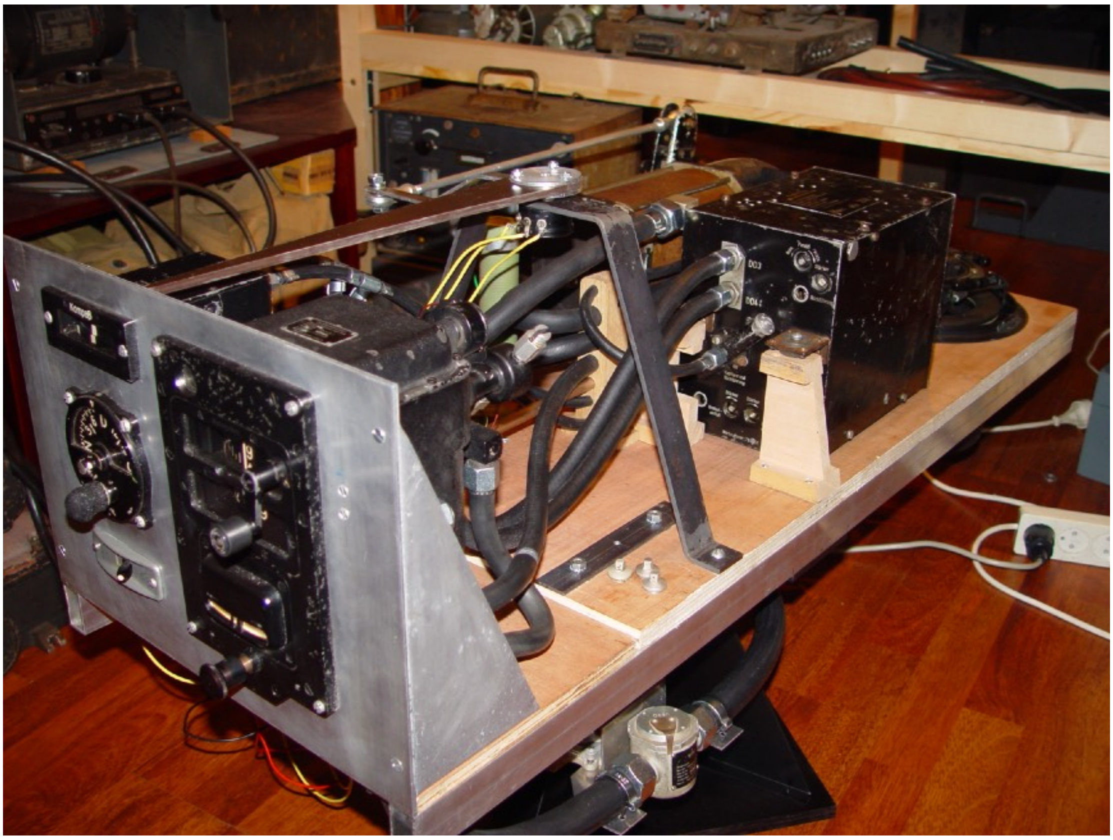


Figure 31: The complete system mounted on the turn table. The "rudder" on top is coupled to the drive system of the the turn table so that the LZ12 controls the movement of the turn table.

Figure 32: Instrument panel of the LZ12 autopilot model

A mains on/off switch was hidden in the support frame of the turn table, when this is switched on, the compressor starts running and a small 24V DC supply provides power to the gyro precession system. The compossor sucks in air via the vacuum header from the magnetic compass system and the gyro compass. After passing through the compressor, the compressed air is fed to the control unit. The air flow causes the gyroscopes in the gyrocompass and the control unit the run up (taking several minutes to get up to full speed). If the master switch (fitted under the centre of the panel) is switched to the on position, the control unit feeds compressed air to the rudder servo which moves the rudder. The turntable will now start to oscillate left and right until the damping gyroscope in the control unit has reached full speed.

If the electrical switch on the panel is switch to the on position, a blinker in the gyrocompass indicates that the precession system is switched on. Whenever the compass indicator deviates from the control position, a small force is applied to the gyro compass, causing it to slowly precess at a few degrees per minute. After a while the gyrocompass and magnetic indicator are aligned and are kept in alignment as long as the precession system is kept switched on.

Due to the limited capacity of the compressor, the damping gyro probably runs slightly slower than intended but it is just possible to achieve sufficient damping for stable operation of the model with the damping signal set to maximum and the directional signal from the gyrocompass set to minimum. The model reacts smoothly to disturbances to the set course; it will arrest the disturbing motion and will slowly bring the model back to its original position.