Construction and operation of the remote control system of a German World War II aircraft: three axis autopilot, remote control, automatic landing and description of the automatic bomb release device

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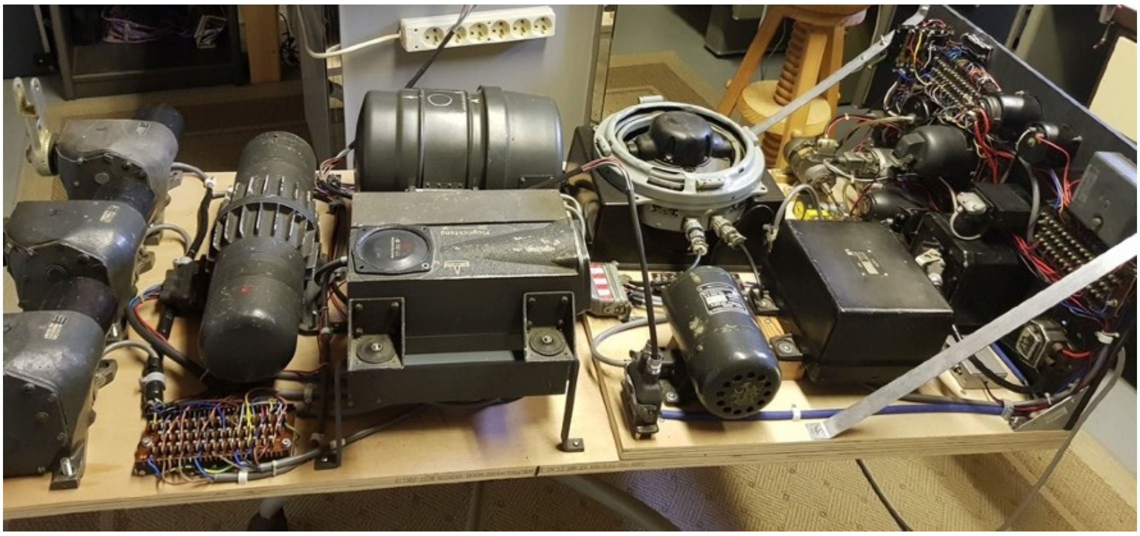


Introduction

The automatic control of aircraft reached a high level during the second world war in Germany, not only did autopilot design achieve a high level of sophistication but autopilots could be coupled to a number of radio navigation systems which ultimately led to automatic targeting systems of high accuracy. This document describes the restoration and re-commissioning of a number of these systems. The first part describes the restoration and commissioning an original automatic 3-axis control used in aircraft like the Do217 and He177. The second part describes the remote guidance and control by means the Y beam system using the FuG 28 beam receiver and the LKZG autopilot interface while the third part describes the operational test of this system by simulating the Y "Wotan" transmission. The fourth part describes how pathfinder aircraft could automatically drop markers on a target by means of remote control. The fifth section describes how partially automated blind landing could be achieved by coupling the Lorenz beam landing signal onto the autopilot. The particular systems described in this document were coupled to trial and demonstrate their concept and functioning. Historically the beam guidance system were more likely used with more commonly applied 1-axis autopilot systems like the K4ü or PKS11 with which they were also fully compatible. An exception was the Arado 234 bomber which had only one man on board, the pilot. The aircraft was equipped with a Patin 3-axis autopilot and a Lotfe bombing calculator. When approaching the bombing target, the pilot switched on the autopilot and turned himself to the optical display of the Lotfe. He steered the aircraft into the target with Lrg5 left-right curve control switch which commanded the course, whilst the autopilot took over the corresponding roll and pitch.

1. The Patin 3-axis autopilot (PDS)

The direction of an aircraft in the air can be defined in three directions: yaw, pitch and roll. Yaw (or course), is controlled by the rudder and determines the compass direction in which the plane flies; Pitch is controlled by the elevators and controls the rate of climb of the aircraft. Finally, roll is controlled by the ailerons dipping the wings left or right during flying of curves. While German autopilots generally only controlled the Yaw (compass course) axis, the Patin PDS autopilot controls all three. The restored PDS consist of a control panel and a two-part base plate which is mounted on the rotating base of an office chair so that the whole system can easily can be rotated by hand. The front panel is equipped as follows:

- Three fuse-switches for: three-phase dynamotor, Leonard generator, automatic pilot
- Three fuse-switches for the derivation motors: course, cross and height
- 24V plug-in
- Siemens course gyro LKu4
- Course indicator
- Controller for the LKu4 illumination
- Main switch
- Switch for fast supporting the horizon mother gyro (quick erection switch)
- Horizon daughter indicator
- Pilot's daughter compass FTK-f3
- Altimeter
- Speedometer and encoder

- Switch: self-automatic-course control vs remote control (with signal lamp)
- List plug for LKZG signal from FuG 28 or test valet
- List plug supplying power for the Bombing Calculator Lotfe
- Plug for directional encoder Lrg2
- Display sign for Lrg5
- Plug for directional encoder Lrg5 and Lotfe
- Potentiometer knob for air/ vacuum pump for speedometer and altimeter

Fig. 1: Front panel of the "aircraft" in operating condition: altitude 500 m, speed 360 km/h, course 31.2° aircraft in horizontal position slightly rising. The red light, top right indicates that the remote control is on.

The base plate (130x60 cm) is divided into two parts. The two parts are connected with a 20-pin List plug (marked red-white-red). On the front part are besides the instrument panel:

- Course motor driving the course gyro, the daughter compass and the LKZG
- Mother compass (functioning German originals are extraordinarily rare. That's why I use a Russian one that has the same dimensions and electrical values and fits exactly into the German support.)
- Two resistance boxes
- Spark extinction box
- Guiding Beam Course setting Intermediate Device LKZG
- Dynamotor (28 V to 35 V 500 Hz, three phases)
- Air pump for speedometer and altimeter
- List plug for connecting front and rear part (red-white-red striped)

- List plug for connecting the blind landing hard ware (to the left of the dynamotor)

At the rear part there are: Horizon mother gyro, Control unit, Leonard-generator 3 rudder motors for course, transverse and height. The complete system is screwed onto the base of a turntable office chair. By turning the chair, course changes can be simulated, as ordered by, the pilot by means of the left-right encoder on the steering column, the auto pilot, ground based remote steering or crosswind.

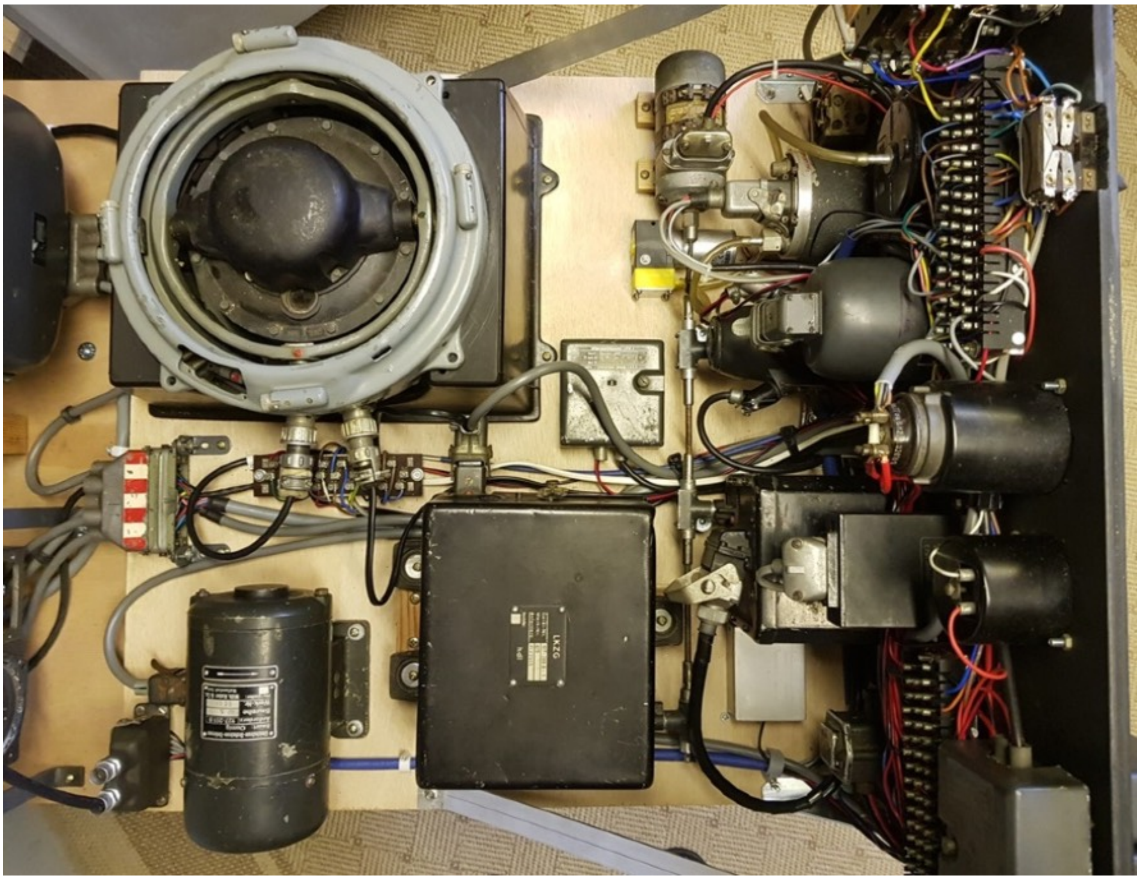


Fig. 2: Front part of the base plate with mother compass, three-phase dynamotor, course motor and LKZG as well as the front panel

Fig. 3: Overall view of the base plate.

The main components will be described in the subsequent sections.

1.1 The Siemens LKu4 Gyrocompass

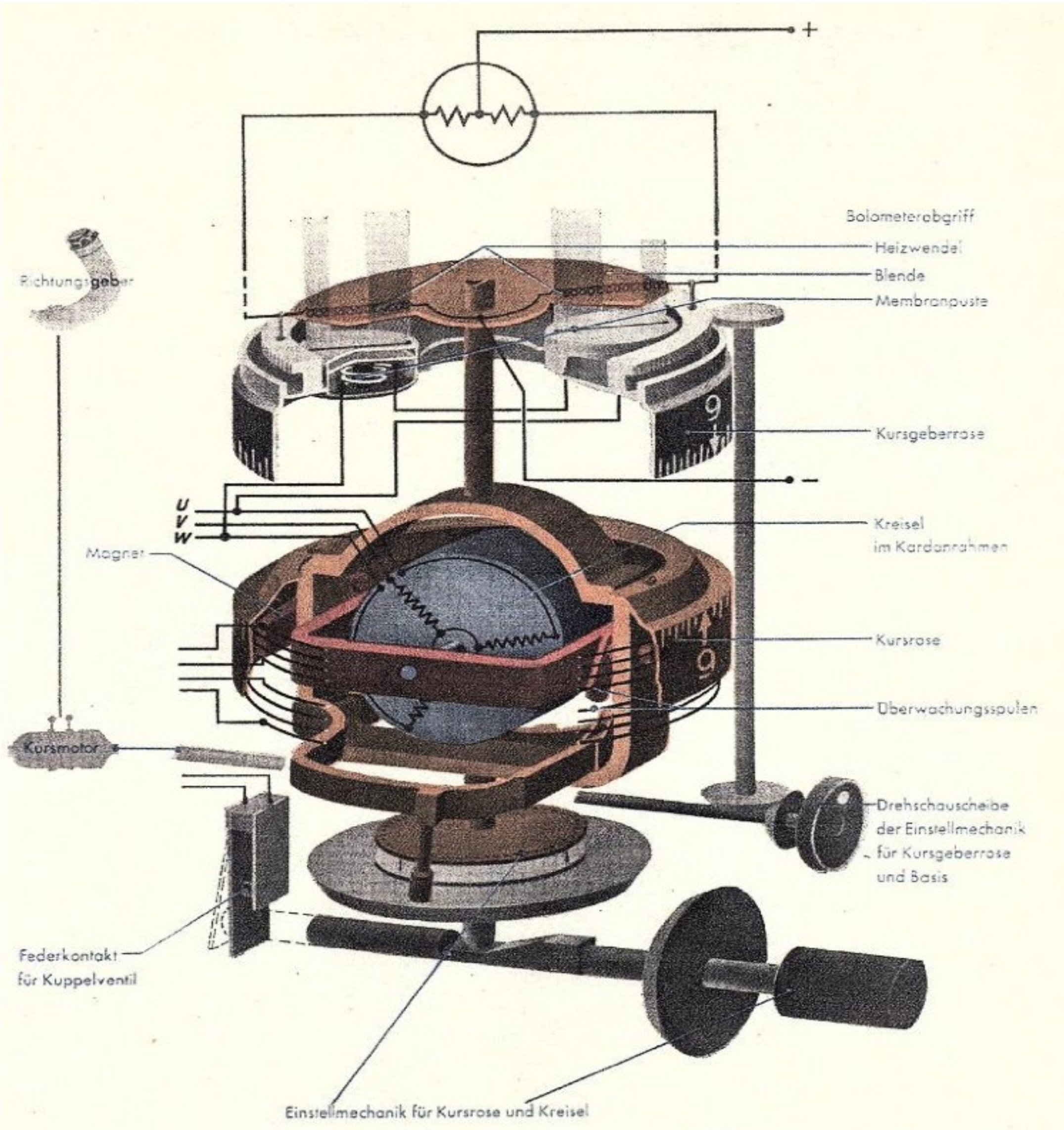


Fig. 4: Explosive view of the Siemens LKu4 gyrocompass

The role of the LKu4 gyrocompass is to detect deviations from the set course and to create course commands that return the aircraft to the set course. The desired course is displayed by the upper course rose. The bottom course rose is connected to the gimbal suspended gyro (powered by three phase 35V, 500Hz) whose axis lies in the horizontal plane of the aircraft. As soon as the aircraft deviates from the course, the housing of the LKu4 moves around the stable gyro which the pilot will observe as a rotation of the bottom course rose.

Two temperature-sensitive 28 V-powered heating coils are cooled from a membrane blower below through two apertures. In the event of a deviation from the course, the position of the apertures change, causing one resistor to receive more, the other to receive less cooling air so that the resistors -placed in a bolometer bridge circuit- become unbalanced. In this way the difference between the upper and lower course rose produces a change of output voltage that is proportional to the degree and direction of deviation. This output voltage drives the course indicator (Kurszeiger) and is fed to the autopilot's control unit which initialises the necessary course correction through the Ward-Leonard generator and the rudder servo.

A gyrocompass will drift over time, due to mechanical friction, banked turns and the rotation of the earth. To keep pointing towards the magnetic north some form of alignment with the magnetic north is required. In the LKu4 this alignment takes place automatically by using an output voltage from the Patin magnetic compass repeater. As soon as the compass repeater deviates from its set course (which is mechanically linked to the set course rose of the LKu4) a small output voltage is generated which is fed to a pair of coils in the LKu4. These coils generate a force causing the gyroscope to precess at a few degrees per minute. This slow precession integrates the magnetic compass' swings over time and allows the LKu4 to provide stable and accurate magnetic course information.

In my LKu4 gyrocompass both heating coils were broken. However, they are easily accessible and the heating threads that were broken off at the feeder so could be re-soldered.

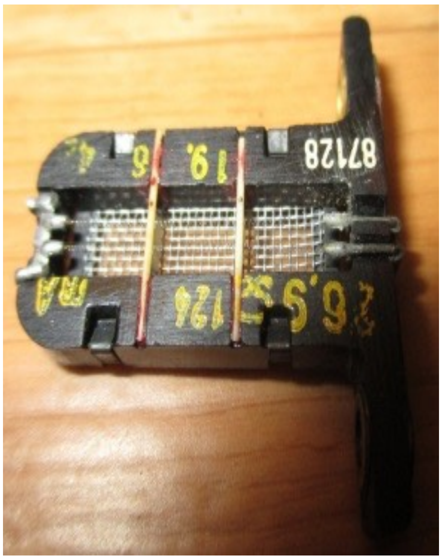


Fig. 5: Heating coil of the course gyro LKu4

1.2 The "Horizontmutter" Horizontal Flight Gyro

The horizontal flight gyro or Horizontmutter type Anschütz device No. 127-255 C (thick, round, longitudinal cylinder in Fig. 3) is structured as follows: It contains a three-phase gyro (36 V 500 Hz) suspended in a gimbal which runs in a sealed tank filled with hydrogen. A pendulum is fitted to the bottom of the gyroscope which gives correction signals to precession coils build into the gimbal system. The 500 Hz correction currents are controlled by a current sensitive relay. While the gyroscope runs up, it draws a high current and the relay ensures that large correction currents are fed to the precession coils, when the gyro achieves full speed, the current reduces causing the relay to turn and reduce the correction signals. The effect is that the gyroscope quickly aligns itself with the gravitational axis (lead line) when running up and only receives small corrections when stable at full speed. The relay thus reduces the power requirements of the correction mechanism and its associated heat losses (the hydrogen filling furthermore serves to improve the heat transfer from the mechanism to the outer body). Should the gyroscope lose its alignment with the vertical axis due to excessive pitch or roll movements by the pilot, it can be quickly re-aligned by switching two of the three phases of the 500 Hz supply, this will inverse the rotating field driving the gyro, first slowing it down to a standstill and re-accelerating it in the opposite direction, all the while with the current relay ensuring maximum correction currents. This procedure puts a significantly increased heat stress into the mechanism and was only allowed to be executed once during a single flight.

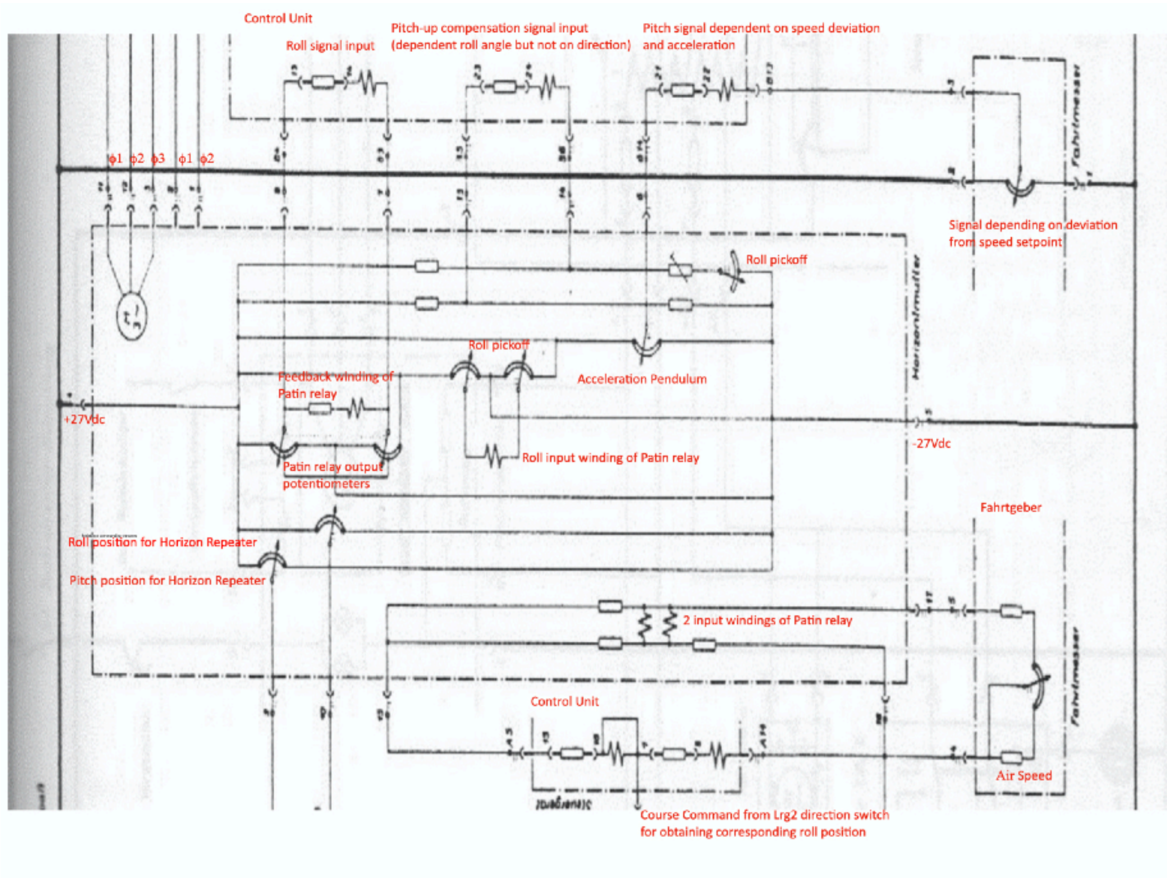


Fig. 6: Circuit diagram of the horizon mother gyro and description of its individual functions

A number of potentiometers are fitted to the gyroscope mechanism to provide output signals from the unit. The following potentiometers are fixed on the roll axis of the gyroscope:

- A roll potentiometer, range +/- 40°, gives a roll position-dependent signal to the Patin Relay fitted to the Horizontmutter as soon as the aircraft leaves the horizontal position. (The Patin relay transfers this roll signal to the control unit)
- A pitch correction potentiometer, range +/-50°, which forms part of a Wheatstone bridge to give pitch-up signal (which only depends on the angle of roll, but not on the direction) to the control unit. This control compensates for any height loss due to the loss of horizontal lift experienced during rolls.
- The “instrument roll” potentiometer, range +/-60°, which operates the roll display in the horizon slave instrument.

The following resistors are mounted on the pitch axis of the gyroscope:

- A "longitudinal acceleration pendulum" potentiometer range +/-11° is connected to one side of the steering coil of the "pitch" Patin relay in the control unit, the other side of the steering coil is connected to the setpoint potentiometer in the speedometer so that the pitch control becomes sensitive to both air speed and longitudinal acceleration.
- The "Instrument Pitch" potentiometer, range +/-30° which operates the pitch display in the horizon slave instrument.

The aforementioned Patin relay fitted in the Horizontmutter has additional input windings which react to curve flying commands given by the Pilot's or Bomb Aimer's "Richtungsgeber". These commands are influenced by a speed sensitive potentiometer in the Air Speed Indicator so that they become proportional to the airspeed of the aircraft. When a curve command is initiated, the setpoint of the Patin relay shifts giving a roll command to the control unit which causes the aircraft to roll until the roll potentiometer in the Horizontmutter equals out the command. As long as the curve command persists, the gyro will now keep the roll angle constant at this new setpoint. As a result, the aircraft will maintain a constant roll angle proportional to the strength of the curve command and the airspeed, keeping the g-forces perpendicular to the floor of the aircraft.

1.3 The Control Unit

The control unit consists of an aluminium cast housing, which accommodates 3 damping gyros and 3 Patin relays for yaw, pitch and roll respectively. The Patin relays can be seen standing in the rectangular compartment. To the left there is the roll damping gyro.

Fig. 7: Control unit. Visible: 3 Patin relays at the top and the roll damping gyro 127-262 10 at the bottom left.

The gyroscopes in the control unit react to the angular rate and acceleration of change to yaw (a), roll (b) and pitch (c) of the aircraft. The gyroscopes are mounted in such a way that the output signal provides a measure of angular velocity and angular acceleration. The ratio of these two factors is fixed in any given gyro unit, the last two digits of the type number (eg. the 10 in 127-262.10) gives an indication of the relative strength of the angular acceleration signal produced by the gyro.

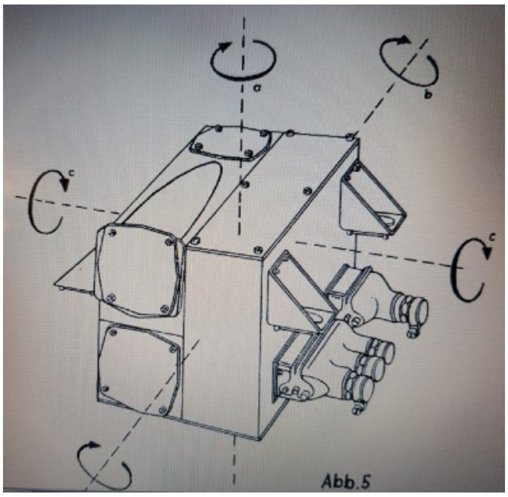


Fig. 8: Sensitivities of the damping gyros.

A Patin relay contains a sensitive galvanometer with four input windings. The turning of the galvanometer drives two potentiometer wipers thus producing an output voltage proportional to a weighed sum of the four input voltages. The delicate galvanometer mechanism is placed in a magnetically shielded housing to avert any influences of the earth's magnetic field. The sensitivity of the relay benefitted greatly from the vibrations caused by the aircraft's engine.

This output voltage of the Patin relay feeds the input of Ward-Leonard dynamotor which powers the rudder servo. One of the input windings is connected via a series resistor directly to the output, thus allowing the amplification factor (gain) of the Patin relay to be controlled. The other three input windings are connected, also via series resistors, to three separate input signals. By changing the resistor value, the strength of this particular input signal can be set allowing the adaptation of the autopilot to specific flight characteristics of an aircraft type.

Fig. 9: Left the yaw and pitch damping gyros and on the right the control resistors to take into account the influence of the specific flight characteristics of an aircraft.

I met the following problem with the three-axis control unit: The (2 μF) capacitors, which bridge the output voltage of the Patin relays had deteriorated and formed a short circuit which burned the output circuit in the Patin relays. In figure 10 you can see a silver wire. This is one of the two thin wires that lead from the potentiometer wipers to the pins 11 and 12. Both were burned out. The connection could be re-established using individual strands from the shielding mesh of a cable as replacements.

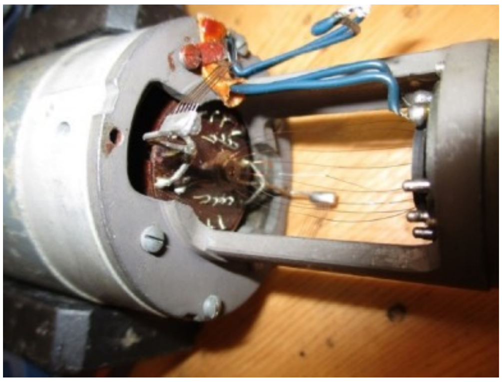


Fig. 10: A opened up Patin relay with burnt-out connecting wire (left) showing the four integrated galvanometer windings (right)

1.4. Operating the 3-axis course setting (excerpt from the operating instructions)

I. Before starting, the fuse-switches belonging to the autopilot and the remote compass system are switched on. The autopilot main switch is set to position “1” allowing the gyroscopes to run up. The autopilot switch (at the steering column) and the three axis control switches are switched off.

II. In flight, the aircraft is trimmed in all three axes. Then, during the horizontal straight flight, the course gyro base is aligned to the course indicated by the Patin slave compass by means of the curve control switch (Lrg2 at the steering column). The course rose at the Siemens course gyro is also aligned with the base and the setting button is pulled out.

III. The autopilot main switch is brought to position "2". When the aircraft is on track, the yaw control switch and then the autopilot switch (usually at the steering column) are switched on. The pilot continues operating the roll and pitch control of the aircraft.

IV. The Patin Horizon slave indicator shows whether the Horizontal flight gyro has run up in the correct attitude, if the display of the two symbols (horizon bar and aircraft figure) corresponds to the actual flight position. Otherwise, the Horizon Quick Erection switch is switched over. The flight position must be displayed correctly after about 3 - 4 minutes by the Horizon slave indicator. (The quick-erection switch must only be operated once during the flight). Only if the Horizon Daughter’s display shows that the horizon mother is working properly, the roll control switch is switched on. The pilot continues operating the pitch control of the aircraft.

V. The desired speed is matched with the Air Speed Indicator display by means of the adjustment button. The pitch control switch can now be switched on.

VI. Changes of direction are brought about by actuating the curve control switch (Lrg2 at the control column). The aircraft will automatically roll into the curve and maintains the g-forces perpendicular to the floor of the aircraft.

VII. If, during horizontal flight, the target speed mark in the Air Speed Indicator is set to a higher speed value without changing the propulsion power, a “Pitch down” command is created. When the target travel mark is set to a lower value, a “Pitch up" command is created. Glide flights can also be brought about if the speed set point is not adjusted, but the engine power is reduced.

VIII. Each axis can be disconnected individually by switching off the relevant control switch, i.e. it can be separated from the automatic pilot. All three rudder servos can be disconnected simultaneously by actuating the autopilot control switch (at the control column). If this has occurred and the aircraft is then to fly again with the three axis autopilot, the three axis control switches are appropriately switched off before the autopilot switched on again. Then, in order, the switches "yaw, roll, pitch" are switched on, taking into account the necessary measures. (Observation whether the gyro rose matches the setpoint, the display of the horizon daughter matches the actual flight position and the speedometer indicates the desired speed).

IX. If unexpected interference occurs in one axis (for example, drift or failure of a command device), the axis control switch in question must be switched off. If it is clearly established that the control is partially or completely dysfunctional, this must be notified to the competent department, which shall notify the technical field service of the Patin Company.

2. **Building up of Y-Beacon remote control**

The German air force developed a number of radio beam navigation systems operating on VHF, one of which was called the Y-system or Wotan II. The Y-system uses two radio signals: a guidance beam and a distance measuring signal, both operating on 42-48 Mhz.
An aircraft equipped with an automatic pilot could be guided remotely from the ground with the help of a Y-Bake. For this purpose, the aircraft was equipped with a FuG 28 for the reception of the guidance beam and an autopilot interface device called the LKZG.

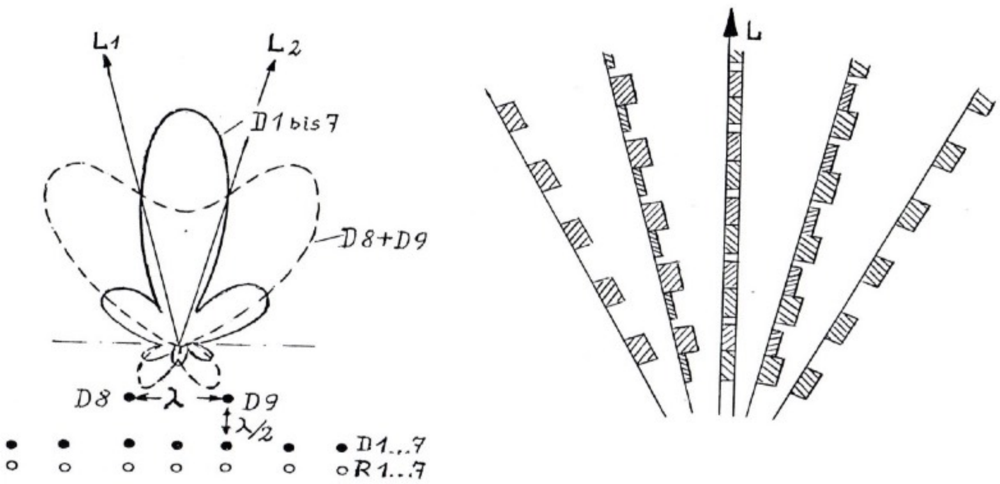


Fig. 11: Characteristics of the radiation of the Y-Bake: L (L1, L2): Guiding beams, An array of dipoles D and reflectors R produces an antenna diagram with a single main lobe if D1 to D7 are activated and a diagram with two side lobes if D1 to D9 are activated, producing two areas (L1, L2) of equal signal strength. By activating D1 to D7; D1 to D9 and pausing in a ratio of 8:8:1 the signal on the right is produced around the "beam". Note that this shows the situation near the left side beam L1, for the right side beam the signals will be mirrored.

The Y beam transmission was a dash-dash signal and a short transmission pause in the ratio 8:8:1 repeated at a frequency is 176/minute. The pulses were modulated at 2000 Hz. This means that the Y-system could be heard, but could not be interpreted by ear and that a special FuG28 receiver was required which produced a positive DC output current for the left side dash-dash signal and a negative DC output current for the right dash-dash signal (the polarity had to be reversed when flying on the right hand beam L2). The output of the FuG28 becomes zero as soon as the aircraft follows the guiding beam L and grows proportionally with the distance from the beam.

In order to remotely steer an aircraft, the following problem must be solved. The aircraft must not cross the guiding beam at a high angle. If it did, a counter-command would immediately return the aircraft to the guiding beam, with the aircraft crossing the beam again, resulting in an increasing oscillation along the beam rendering the remote steering unusable. The aircraft must therefore approach the guiding beam in an S-curve. This means, however, that the course setting must receive an opposite command when approaching the guide beam: Suppose that the aircraft has to turn right, as shown in Fig. 12, the beam receiver (FuG 28) generates a positive direct current (max. 2.5 mA). This decreases when approaching the guiding beam. From a given minimum value, however, the autopilot interface (LKZG) must now produce a negative direct current, which becomes smaller and smaller when approaching the guiding beam putting it asymptotically on the guiding beam. In the LKZG, this problem is solved as follows.

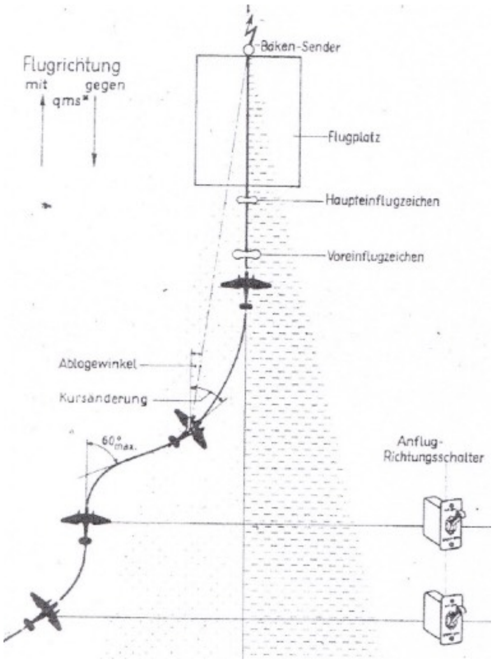


Fig. 12: The aircraft must not cross the guiding beam. This drawing shows the case of using the BL2 blind landing system, but the principle is the same for Y-beacon control.

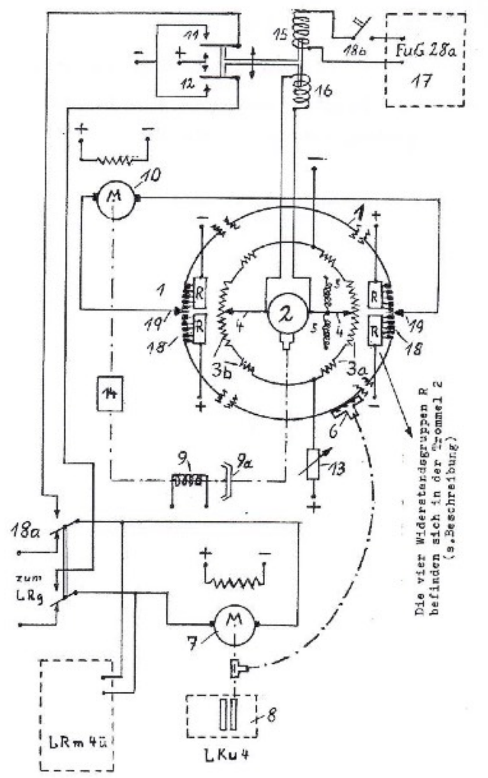


Fig. 13: Principle schematic of the guiding beam course setting intermediate device LKZG

To start with the pilot has to navigate his aircraft to a proximity to the beam so that the FuG28 can pick up the beam signal (this was usually achieved by other navigational means) and put the aircraft on a parallel course to the guiding beam (he will have been given this information during his pre-flight briefing). From the output indicator on the FuG28 he has to determine whether he is flying left or right of the beam. Now the automatic beam approach system can be activated.

Suppose that the aircraft flies to the left parallel to the guiding beam. When the remote control is switched on, the polar relay winding (15) activates the polar relay which powers the course setting motor M via contacts 11 and 12. The course setting motor rotates the course rose of the course gyro KLu4 and at the same time a resistor bridge system (18 and 19) in the LKZG. The course gyro causes a movement of the rudder, which causes a right turn (2°/sec) of the aircraft. Meanwhile in the LKZG, the turning of resistor bridge 18 and 19 causes a “follow-up motor" to start running and speed up while the aircraft turns further towards the beam. The follow-up motor exerts a force on the spring loaded wipers of a second potentiometer system (3a and 3b) so that this bridge generates a voltage proportional to the follow up motor speed. The voltage from potentiometer bridge 3a and 3b is fed to a second winding (16) in the polar relay.
As the aircraft has turned 35° the follow up motor achieves full running speed and polar relay windings (15) and (16) achieve equilibrium causing the course setting motor to stop.
As a result, the aircraft moves in a straight line towards the guide beam and the positive direct current supplied by the FuG 28 is weakening until the polar relay switches in the opposite direction. This causes the course setting motor to reverse direction, which now causes the aircraft to reduce its angle to the beam. This also reduces the voltage across resistor bridge 18 and 19, reducing the speed of the follow up motor and reducing the negative output signal of bridge 3a and 3b until the polar relay is once again in equilibrium. Once on the guiding beam, both the signal coming from the FuG 28 and from bridge 3a and 3b become zero and remain so as long as there are no deviations from the guiding beam due to wind influence. As soon as these occur, the corresponding course correction commands are initiated again by the FuG28.

Fig. 14: "Remote control" with the help of the LKZG test unit

At the beginning, the system was “remote controlled” with the help of the LKZG test unit which allows a manual input of the “FuG28” current. However, I needed a co-pilot who slowly reduced the control signal whilst I was turning the aircraft, i.e. the office chair, according to the course command. And behold, the "aircraft" flies first to the right and bends to the left towards the guiding beam when the input signal decreases.

3. Remote control with the help of the FuG 28

It turned out to be impossible to find the service manual and thus the circuit of the FuG 28 neither in Europe nor in the USA or Russia. So I had to partially disassemble my device to record the circuit and understand how it works. Thus, it was also possible to fix various failures. Next, I was able to build a test board.

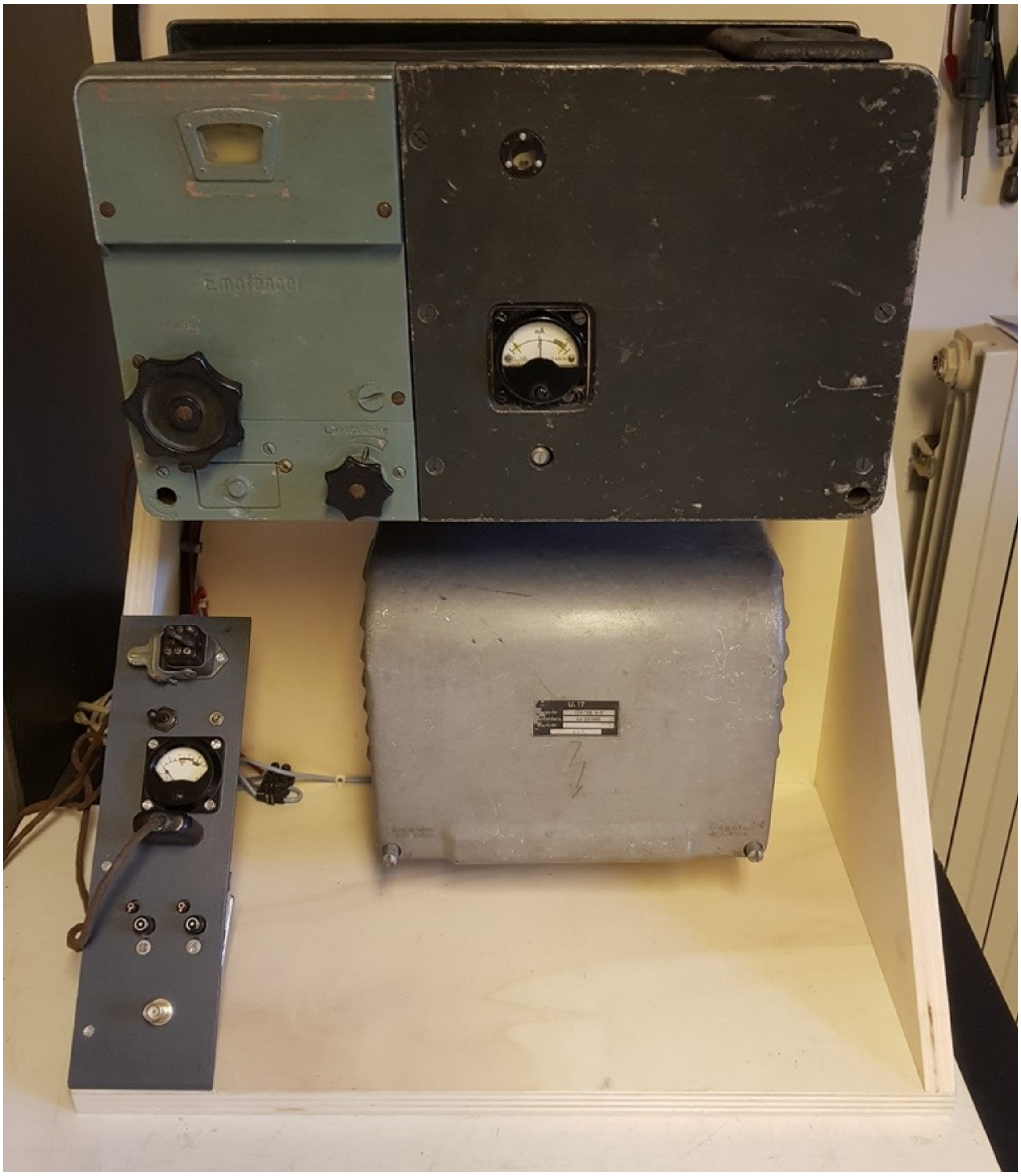


Fig. 15: Test board for FuG 28. The original receiver 17E is replaced by the equivalent receiver of the naval equipment Lo 10 UK 39 (painted in green)

Fig. 16: HP pulse generator

The guiding beam signal is produced with the help of the HP pulse generator and a Tektronix frequency generator. This is triggered by the HP pulse generator and produces pulsed 2 kHz. This signal is connected to the external amplitude modulator of an R&S HF generator so that a 44 MHz Y-beacon signal can be simulated. The ratio of pulse length to pause can be adjusted with the potentiometer "Pulse Width" of the HP generator.

However, as Fig. 11 shows, the beacon signal consists of a double pulse which, except on the central beam L, has two different amplitudes. I have no possibility to produce such double pulses, but the evaluation device of the FuG 28 reacts to a shorter second pulse as if it were smaller. So I can at least simulate the control on the left side.

With a beacon signal that is slightly more than half-long, the FuG 28 and thus the course setting react with a course command that initiates a 35° right curve.

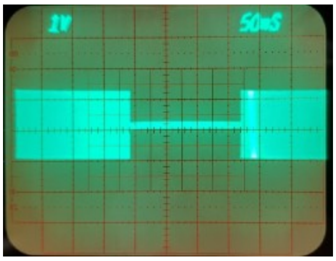


Fig. 18: Beacon signal received and demodulated by the FuG 17 receiver of the FuG 28

Fig. 19: The dashboard is now extended by a FuG 28 instrument (top right) and next to it an AFN2, for the blind landing described in the last chapter.

The "aircraft" flies at an altitude of 600 m at 435 km/h and the FuG 28 instrument indicates that we are to the left of the guiding beam.

Fig. 20: The beacon signal is now about ¾ of its length.

The aircraft is closer to the guiding beam L and the LKZG provides a command for a left turn to the course setting, despite the instrument displaying that we are to the left of the guiding beam.

When approaching the guiding beam, the signal received slowly gets to its full length and the FuG 28 output tends to zero. Once this is reached, the rudder stays in the middle and the aircraft flies straight until a different command is transmitted by the Y-Bake. On crosswind gusts, FuG 28 and LKZG react with corresponding course correction commands. For these pictures of figure 19 and 20, the autopilot is only in one-dimensional mode. Therefore, the artificial horizon gives false information.

4. A He111 as a precursor to a modern drone

Fritz Trenkle describes in his book "Die deutschen Funk-Navigations- und Funkführungsverfahren bis 1945" how a He111, for example, could be equipped like a modern drone. With the Y- beacon, as described above, the aircraft's course could be controlled from the ground. This was however only one part of the Y-system. The second part concerns a setup with which distance to a base station could be measured. For this purpose, the aircraft had a FuG17E transceiver beside its FuG28. It received a wave sent from the ground station, which could be modulated with 300 Hz for coarse measurement or with 3 kHz for fine measurement. The FuG 17 sent this wave back on a different transmission frequency. The time for the radio wave to travel to the aircraft, pass through the FuG17E and return to the ground station could be measures with the help of the phase difference of the sent and received waves; the ground station was thus able to determine the exact distance of the aircraft.

Trenkle now describes a set of devices in which a target distance for a bomb drop could be compared with the actual distance of the aircraft. If matched, the bomb drop was automatically triggered from the ground site via a Morse signal. Horst Beck thankfully left to me the trigger mechanism of the command device for the automatic drop-triggering.

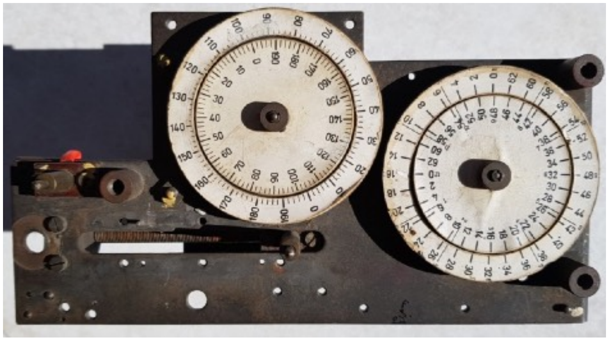


Fig. 21: Display of the aircraft distance and the distance of the drop target.

The left circle is concerned with fine measurement with 3 kHz and the right circle with 300 Hz for rough measurement. The fine measuring disc covers 0 to 200 hm while the coarse measurement ranges from 0 to 620 km, wherein the distance between two scale strokes is 20 km. The outer scales are connected to each other by a gearbox and can be adjusted to the desired target distance with a resolution of better than 100 m by means of an electric motor (that no longer exists). The two inner discs are each coupled to two synchro transmitters, which transmit the measured fine and coarse distance measurements.

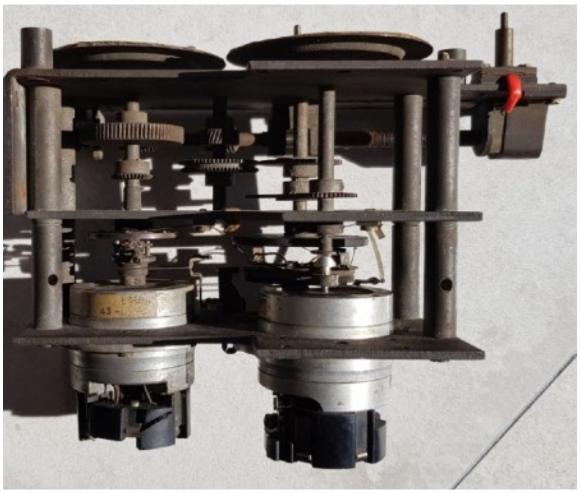
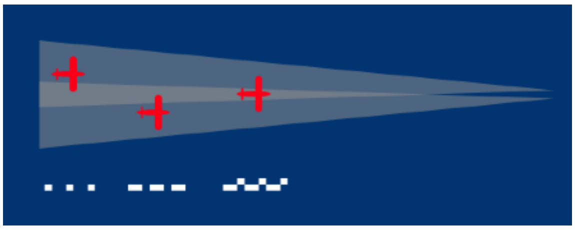


Fig. 22: View of the mechanics of the trigger device with gearbox, rotary field encoders and contact discs

The rotary field encoders move each a contact disc on which sliding contacts are mounted, which are connected to the gearbox of the circular display for the desired distance. This allows a contact to be established when the desired and actual distance are identical. Then a Morse signal is sent to drop the bomb or mine with the help of an unknown electronics.

5. Structure of the control for automatic landing with the blind landing system Bl2

Another commonly used beam system was the “Lorenz” blind landing system operating on 30-33.3 Mhz. The Lorenz system uses only three dipoles, the outer two of which are alternatively energised with a 1150 Hz AM signal for 1/8 and 7/8 of a second respectively, creating two slightly shifted lobes, one transmitting dots, the other dashes. In the centre line the two signals are of equal strength and a continuous a 1150 Hz continuous tone is received, deviate left and the dots get stronger while the dashes weaken, deviate right and the opposite happens. The problem of automatized blind landing is the same as described in chapter 2 about the LKZG; the automated blind landing system was however called the “Kursfunkanlage) and is shown in Fig. 23.



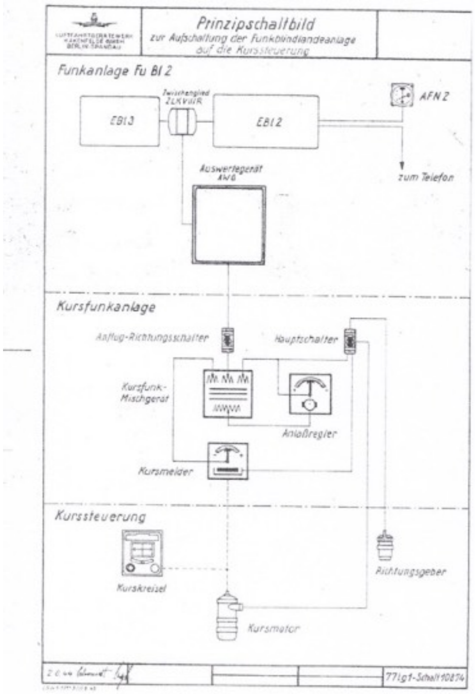


Fig. 23: Radio signal and principle diagram of the radio system FuBl 2

The FuBl2 receiving system for the blind landing consists of the two receivers the EBl3 and the EBl2. Between the receivers and the “Kursfunkanlage” is an “Auswertegerät” AWG1, or AWG2 or AWG3. The function of the AWG is to convert the output pulses generated by the FuBl2 into a DC voltage like that of the FuG28. However, no surviving examples or circuit diagrams are known to exist from these devices (only some exterior photographs). The AWG must therefore be replaced by modern electronics to replicate its function.

Fig. 24: Test board for the blind landing system with Bl2, Bl3f, converters and auxiliary equipment

The “Kursfunkanlage”, which processes the direct currents supplied by the AWG in such a way that the aircraft flies the desired S-curve, is shown in Fig. 23.

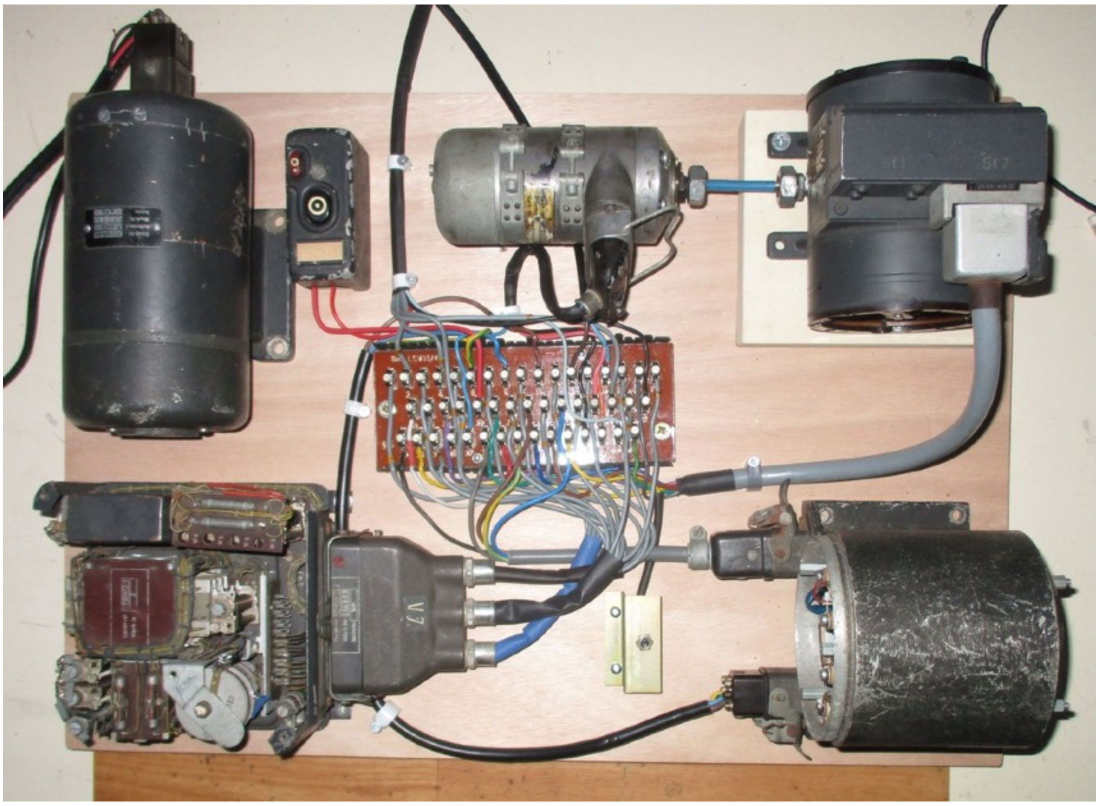


Fig. 25: "Kursfunkanlage" for automatic landing with the Lorenz beams

The following components are necessary for this: a three-phase converter (top left of the picture) that delivers 35 V at 500 Hz for the magnetic amplifier. In the middle at the top of the picture the course setting motor, which moves the course gyro base in the three-axis control and is here mechanically connected to the course transmitter. At the bottom left of the picture is the magnetic mixing amplifier and to the right of it is the motor start controller. The switch between these two devices can be used to actuate the course transmitter's clutch for test purposes.

This autonomous set up was necessary in order to be able to tune the mixing amplifier and to carry out any repairs on individual devices. As soon as it was fully functional, it was connected to the 3-axis control via a cable and a connector. This also supplied the 35 V 500 Hz current from the autopilot, so that the converter could be eliminated. The course motor of the 3-axis control was then switched parallel to the one of this autonomous structure.

The functioning of the system can be explained in a simplified way with the help of the schematic of figure 26.

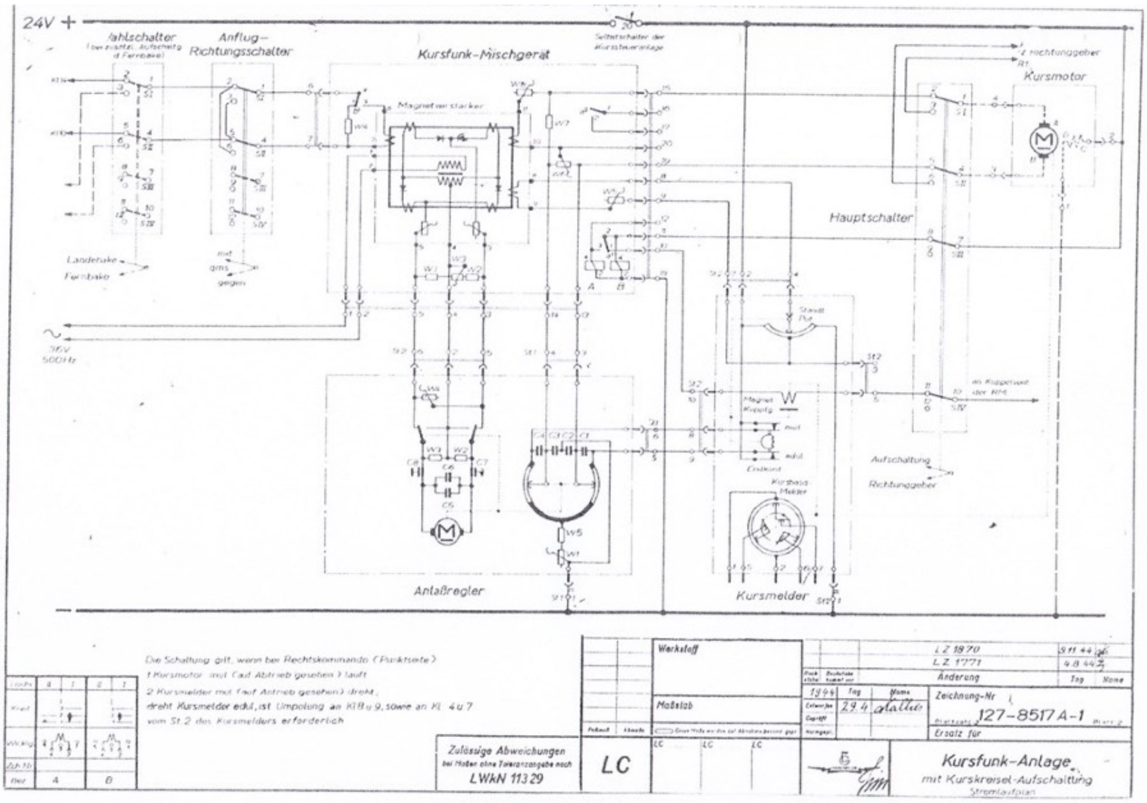


Fig. 26: Circuit diagram of the course radio system

It is assumed that the aircraft flies parallel to the Lorenz beams before the automatic landing is initiated as in figure 12 (the pilot would know the exact heading of the runway and therefor the direction of the landing beam). The pilot switches on the controller with the clutch switch, which connects the AWG output to the mixing amplifier via a relay and closes the clutch of the course transmitter so that it is mechanically connected to the course setting motor. The beam signal (converted into a DC signal by the AWG) is amplified in the mixing amplifier and is fed to a motor in the power controller. The power controller motor turns a potentiometer bridge which provides a high power DC voltage to the course setting motor. This voltage is also fed back to a second input winding of the mixing amplifier (via a tuning resistor), the power controller motor only runs until these two signals are equalised, thus ensuring that the output of the power controller (and with it the turning speed of the course setting motor) becomes proportional with the strength of the beam signal. The course setting motor now receives a voltage proportional to the beam signal and as a result, the aircraft begins to curve towards the beam. The tuning resistor allows the overall gain of the system to be adjusted so that the maximum turn speed of the course setting motor does not exceed 2°/sec

As the course motor forces the autopilot to changes course, it also moves the potentiometer of the course transmitter from the central position. This provides an opposing voltage to a third input winding of the mixing amplifier. The mixing amplifier compares this opposing course signal with the beam signal and reduces its output accordingly, which starts to reduce the speed at which the course setting motor turns and consequently reduces the rate of turn of the aircraft. The course setting motor therefore runs until the beam and the course transmitter signals are equalised at which point the aircraft reaches its maximum angle to the beam.

As the aircraft approaches the guiding beam at its maximum angle, the beam signal starts to reduce while the course transmitter voltage stays at its maximum. The output voltage of the amplifier therefore changes polarity and the course motor starts to move in the opposite direction. The aircraft thus starts to reduce its angle to the beam. As the aircraft nears the beam, the beam signal continues to weaken, causing the aircraft to turn back to a course parallel to the beam until all voltages become zero.

Once the aircraft has arrived on the guide beam it will fly directly towards the runway. If the aircraft deviates from the centre of the guide beam by crosswinds, the blind landing receiver receives Morse dots or dashes, which are converted into direct current by the AWG, which move the course motor and thus the rudder to return the aircraft to the centre of the beam.

The pilot would still have manually manage the height of the aircraft and the monitor the signal strength of the beam signal (inversely proportional to distance) and listen out for the landing warning beacons at 3 km and 300 m before the runway to execute the landing. It is likely that the “Kursfunkanlage” was primarily aimed for use with the long distance “Knickebein” beam system, which used the same frequencies and signals as the Lorenz blind landing beacons.