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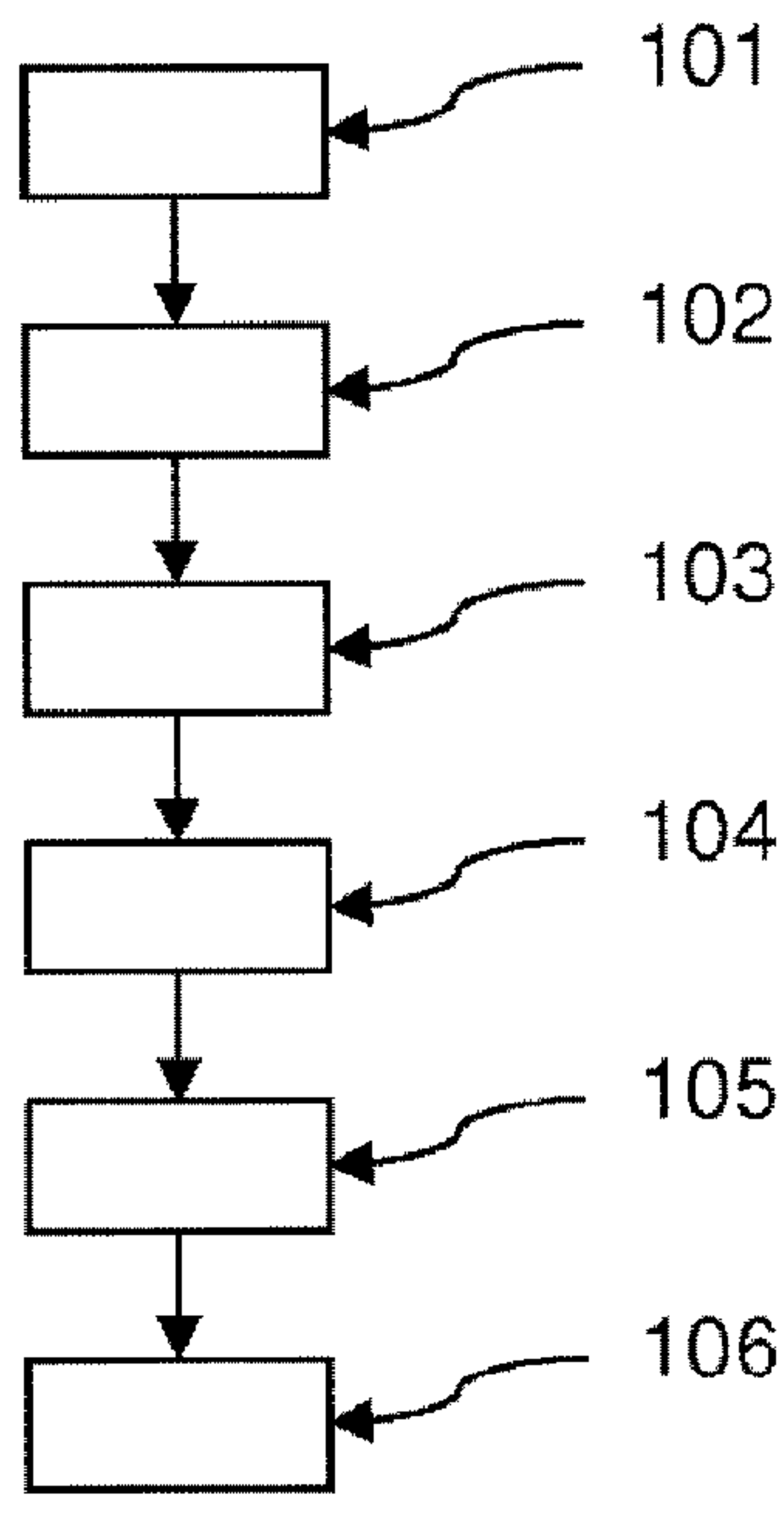

Fig. 1

(57) Abrégé/Abstract:
The invention relates to a method and a device for detecting a fault of a barometric pressure measuring system arranged aboard a flying device. The method has the following steps: ascertaining (101) a current position POSGNss(t) and an altitude zGNss(t) of the

(57) **Abrégé(suite)/Abstract(continued)**:
flying device in a geodetic reference system at a point in time t using a satellite navigation system GNSS arranged aboard the flying device; ascertaining (102) a static pressure pAc(t) and/or a pressure level zAc(t) using the pressure measuring system; ascertaining (103) a geopotential altitude zAN/PROG(t) assigned to the static pressure Pac(t) for the position POSGNSSW in provided weather analysis data ANDAT or in provided weather prognosis data PROGDAT of a numerical weather prognosis model NWP, and/or ascertaining (103) a static pressure pAN/PRoo(t) assigned to the altitude zGNss(t) for the position POSGNss(t) in the provided weather analysis data ANDAT or in the provided weather prognosis data PROGDAT of the numerical weather prognosis model NWP; ascertaining (104) the altitude deviation Az(t) = zGNss(t) - ZAN/PROGW and/or ascertaining (104) the pressure deviation Ap(t) = pAc(t) - pAN/PRoo(t); ascertaining (105) an altitude deviation ??* ascertained over a period of time At from Az(t) = zGNss(t) - ZAN/PROGW and/or ascertaining (105) a pressure deviation Ap* ascertained over the period of time At from Ap(t) = pAc(t) - PAN/PROG(t), wherein a fault of the pressure measuring system is then detected if the ascertained altitude deviation |Az*| is greater than or equal to a specified threshold G1 or if the ascertained pressure deviation |Ap*| is greater than or equal to a specified threshold G2; and generating (106) a warning signal if a fault is detected.

ABSTRACT

The invention relates to a method and device for determining a fault of a barometric pressure measuring system arranged aboard a flying device The method comprises the following steps: Determining (101) a current position $POS_{GNSS}(t)$ and an altitude $z_{GNSS}(t)$ of the flying device in a geodetic reference system at a point in time t using a satellite navigation system GNSS arranged aboard a flying device; determining (102) a static pressure $p_{AC}(t)$ and/or a pressure level $z_{AC}(t)$ for the position $POS_{GNSS}(t)$ in provided weather analysis data AN_{DAT} or in provided weather prognosis data $PROG_{DAT}$ of a numerical weather prediction model (NWP) using the pressure measuring system; determining(103) a geopotential altitude $z_{AN/PROG}(t)$ assigned to the static pressure $p_{AC}(t)$ for the position $POS_{GNSS}(t)$ in provided weather analysis data AN_{DAT} or in provided weather prognosis data $PROG_{DAT}$ of a numerical weather prediction model (NWP), determining (103) a static pressure $p_{AN/PROG}(t)$ assigned to the altitude $z_{GNSS}(t)$; determining (104) the altitude deviation $\Delta z(t) = z_{GNSS}(t) - z_{AN/PROG}(t)$ and/or determining (104) the pressure deviation $\Delta p(t) = p_{AC}(t) - p_{AN/PROG}(t)$; determining (105) an altitude deviation Δz^* averaged over a period of time Δt from $\Delta z(t) = z_{GNSS}(t) - z_{AN/PROG}(t)$ and/or a pressure deviation Δp^* averaged over a period of time Δt from $\Delta p(t) = p_{AC}(t) - p_{AN/PROG}(t)$, wherein a fault of the pressure measuring system is deemed detected if the determined averaged altitude deviation $|\Delta z^*|$ is greater than or equal to a specified threshold G1, or if the averaged pressure deviation $|\Delta p^*|$ is greater than or equal to a specified threshold G2; and generating (106) a warning signal if a fault is detected.

METHOD AND DEVICE FOR DETERMINING A FAULT OF A BAROMETRIC PRESSURE MEASURING SYSTEM ARRANGED ABOARD A FLYING DEVICE

The invention relates to a method and device for determining a fault of a barometric pressure measuring system arranged aboard a flying device.

The barometric pressure measuring system of an flying device is particularly used to determine the barometric altitude $z_{AC}(t)$ (= pressure level) of the flying device, which is determined based on the static pressure $p_{AC}(t)$ at the flight level of the flying device in the undisturbed atmosphere. For this purpose, the static pressure $p_{AC}(t)$ is determined during the flight. Pressure is taken from a suitable point on the surface of the flying device (the "static pressure tapping point"), and the pressure taken from there is measured using respective pressure sensors. This pressure measurement is disturbed by the aerodynamics of the flying device and the current configuration of the flying device, for example as a function of air speed (such as the Mach number).

The altitude of a flying device is typically determined from measuring the static air pressure $p_{AC}(t)$ and converting it to a barometric altitude $z_{AC}(t)$ based on the ICAO standard atmosphere (ICAO: "International Civil Aviation Organization"). Depending on current weather conditions, the status of the local atmosphere can deviate considerably from the ICAO standard atmosphere, and so the barometric altitude $z_{AC}(t)$ of the flying device can deviate from an actual geometric altitude of the flying device. The deviations of the barometric altitude $z_{AC}(t)$ typically are about +/- 5 to 10% of the geometric altitude.

The barometric altitude $z_{AC}(t)$ can thus be determined using the pressure measuring system on the flying device without external aids and is thus traditionally the basis of flight control. Measuring errors due to the disturbances mentioned above and the accuracy of the barometric altitude $z_{AC}(t)$ determined would be unacceptable if it were not for the calibration of the pressure measuring system. For an exact determination of the barometric altitude, the deviation of an actual pressure measurement from the conditions of the surrounding undisturbed atmosphere must be known and corrected accordingly.

When a flying device is licensed, a multitude of calibration measurements are performed on the ground and in flight for calibrating the installed pressure measuring system. The measured values of the sensors of the pressure measuring system on a prototype of the flying device are typically compared to measurements in an undisturbed environment at the same altitude. The pressure tapping fault, which is used for correction in the form of various influencing variables, is determined from the difference. This correction is typically determined uniformly for a specific flying device type and stored in an air data system (ADS). Other relevant data in addition to pressure measurement are provided to the air data system as well.

This correction of pressure measurement is typically determined by comparing measured results of the pressure measuring system and reference measurements, e.g. at a tower or so-called "tower flyby" or measurements of a comparison flying device calibrated accordingly or measurements of the static air pressure in the undisturbed atmosphere far ahead (e.g. using a sensor on a nose boom of the flying device) or behind the flying device (using a trailing probe with trailing cone, so-called trailing cone measurement).

Sufficiently accurate calibration of the pressure measuring system is particularly important if the flying device is to be operated in an air space with reduced vertical separation, such as an air space where "reduced vertical separation minima, RVSM" apply. Flights in such an air space with reduced vertical separation (RVSM air spaces) are only permissible if the flying device has been granted an RVSM operating license from the competent aviation authority. It must be demonstrated for this purpose that the pressure measuring system allows the determination of a barometric altitude $z_{AC}(t)$ with a specified accuracy under specified conditions in the area of use of the flying device.

Determining the required pressure correction in the pressure measuring system today requires complex flight tests of the flying device to be tested, measurements on the ground, accompanying measurements during the flight, or the availability of additional experimental equipment on the flying device.

A known method for determining the barometric altitude $z_{AC}(t)$ in flight is the so-called "Blanchard method". In this method, the pressure difference between various altitudes is determined from the integral of the virtual temperature and corrected using the pressure gradient due to the geostrophic wind (see: *Blanchard, R.L., "An Improvement to an Algorithm for Computing Aircraft Reference Altitude", IEEE Transactions on Aerospace* *and Electronic Systems, Vol. AES-8, No. 5, 1972, pages 685-687;* and *Blanchard, R.L., "A new Algorithm for Computing Inertial Altitude and Vertical Velocity", IEEE Transactions on Aerospace and Electronic Systems, Vol. AES-7, Nov. 1971, pages 1143-1146.*)

Aviation authorities or service providers (approved air navigation service providers, ANSP) also provide so-called "height-monitoring units" (HMUs) for performing the so-called HMU method or so-called "GPS-based monitoring units" (GMUs) for performing the GMU method for checking the accuracy of barometrically determined altitudes $z_{AC}(t)$ in flight operations.

In the so-called "HMU method", the barometric altitude $z_{AC}(t)$ determined by the pressure measuring system of the flying device to be tested is compared to an altitude obtained from comparative measurements. The Blanchard method can be used here as well. The geometrical comparative altitude of the flying device is typically determined within the observation area of an associated ground station (approx. 40 nautical miles around the ground station) by means of a long-term measurement of a transponder signal of the flying device and/or by means of radar. Such comparative measurements are currently limited to a flight level range from FL 290 to FL 410 (FL = flight level). During the comparative measurement, the flying device must fly at a constant altitude for at least 5 minutes. This means that the HMU method requires the use of at least one HMU ground unit, special calibrating flights, partially with additional equipment, and incurs respective additional costs. The services of an approved air navigation service provider are typically needed for this purpose.

The GMU method typically uses a portable GMU (GPS-based monitoring unit) for altitude measurement by means of a Global Navigation Satellite System (GNSS) on board of the flying device for comparative measurements. The comparative altitude is for example determined based on balloon measurements and, optionally, other meteorological measurements (temperature profiler), supported by weather data from numerical models, and adjusted with pressure level measurements of other flying devices in the same air space.

In addition to determining the barometric altitude $z_{AC}(t)$ which is essential for flight control, it is still important to determine the static pressure $p_{AC}(t)$ as accurately as possible to infer the dynamic pressure and thus the air speed (e.g. Mach number) from the measurements of the total air pressure. Faults of static pressure measurement thus immediately affect faults when determining the dynamic pressure. Exact knowledge of the static and dynamic pressure is also required for determining the static temperature from measuring the temperature T_{acc} in the air accumulated in the flying device.

The methods for fault detection in barometric pressure measuring systems known in prior art have the disadvantage that they typically require flight tests and are costly and time consuming. They particularly make minor changes on the flying device, such as temporary add-ons to/removals from the flying device expensive, time consuming and difficult, because these change the aerodynamics of the flying device and therefore require recalibration of the pressure measuring system. It is another disadvantage of prior art that neither the pilots nor air traffic controllers have a simple way of monitoring the functioning and precision of the barometric pressure $p_{AC}(t)$ and barometric altitude $z_{AC}(t)$ determined by the pressure measuring system and to determine respective accuracy trends. Therefore, the functioning and precision of the pressure measuring system has to be checked regularly in a major effort in prior art. Testing the components of the pressure measuring system on the ground cannot sufficiently ensure the precision of the pressure measuring system in flight.

It is therefore an object of the invention to provide a method and a device with which a fault of a pressure measuring system arranged aboard a flying device can easily be determined, including during a flight. The invention is to avoid the disadvantages mentioned.

The invention is derived from the features of the independent claims. Advantageous further developments and embodiments are the subject matter of the dependent claims. Other features, applications, and advantages of the invention can be derived from the description below and the explanation of exemplary embodiments of the invention shown in the figures.

A first aspect of the invention relates to a method for determining a fault of a barometric pressure measuring system arranged aboard a flying device, comprising the following steps: In a first step, determining a current position $POS_{GNSS}(t)$ and altitude $z_{GNSS}(t)$ of the flying device in a geodetic reference system at a point in time t using a satellite navigation system GNSS arranged aboard a flying device. In a second step, determining a static pressure $p_{AC}(t)$ and/or a pressure level $z_{AC}(t)$ using the pressure measuring system. In a third step, determining a geopotential altitude $z_{AN/PROG}(t)$ assigned to the static pressure $p_{AC}(t)$ for the position $POS_{GNSS}(t)$ in provided weather analysis data AN_{DAT} or in provided weather prognosis data $PROG_{DAT}$ of a numerical weather prediction model (NWP). Alternatively, or in addition, determining a static pressure $p_{AN/PROG}(t)$ assigned to the altitude $z_{GNSS}(t)$ for the position $POS_{GNSS}(t)$ in provided weather analysis data AN_{DAT} or in provided weather prognosis data $PROG_{DAT}$ of a numerical weather prediction model (NWP). In a fourth step, determining the altitude deviation $\Delta z(t) = z_{GNSS}(t) - z_{AN/PROG}(t)$ and/or determining the pressure deviation $\Delta p(t) = p_{AC}(t) - p_{AN/PROG}(t)$. In a fifth step, determining an altitude deviation Δz^* averaged over a period of time Δt from $\Delta z(t) = z_{GNSS}(t) - z_{AN/PROG}(t)$ and/or determining a pressure deviation Δp^* averaged over a period of time Δt from $\Delta p(t) = p_{AC}(t) - p_{AN/PROG}(t)$, wherein a fault of the pressure measuring system is deemed detected if the determined averaged altitude deviation $|\Delta z^*|$ is greater than or equal to a specified threshold G1, or if the averaged pressure deviation $|\Delta p^*|$ is greater than or equal to a specified threshold G2. In a sixth step, generating a warning signal if a fault is detected.

As used herein, the term “flying device” has a wider meaning. It includes all apparatuses which fly or travel in a planet’s atmosphere (particularly in the Earth’s atmosphere), particularly flying devices which are lighter than the medium of the atmosphere (e.g. air): free balloons, tethered balloons, hot-air balloons, airships, etc. as well as flying devices which are heavier than the medium of the atmosphere: gliders, hang-gliders, paragliders, rotorcraft, drones, military airplanes, cargo airplanes, passenger airplanes, sports airplanes, ultralight airplanes, etc.

The “barometric pressure measuring system” advantageously includes lines to measuring points for tapping the static pressure, for tapping the total pressure, for tapping the differential pressure, furthermore advantageous electric lines to measuring sensors, e.g. for pressures, air temperature and/or humidity, an evaluation device (e.g. an air data computer, ADC) and an electric interface for providing the measured data obtained, particularly the static pressure $p_{AC}(t)$ and pressure level $z_{AC}(t)$. Calibration curves or calibration parameters for determining the static pressure $p_{AC}(t)$ and pressure level $z_{AC}(t)$ or other measured data are taken into account by the evaluation device. The pressure lines must be leak proof. Leakages of the pressure line system will generate measuring errors.

As used herein, the term “fault” has a wider meaning; it generally includes every fault of the pressure measuring system that has an effect on the following measured variables: static air pressure $p_{AC}(t)$ and/or barometric altitude $z_{AC}(t)$ of the pressure measuring system. Such faults can for example be caused by incorrect calibration of the pressure measuring system, a defective sensor within the pressure measuring system, leakages/leaks of the pressure measuring system or faulty electronics of the pressure measuring system.

The "satellite navigation system GNSS" advantageously is a GPS, Galileo, or GLONASS-based navigation system with which the current position $POS_{GNSS}(t)$ (position on the surface of the Earth, e.g. as x,y-coordinates) and altitude $z_{GNSS}(t)$ of the flying device can be determined depending on time in a geodetic reference system. Other satellite navigation systems GNSS are included in the inventive idea.

A differential satellite navigation system (such as a DGPS) is advantageously used as satellite navigation system GNSS aboard the flying device. Such a differential satellite navigation system currently allows altitude measurements for $z_{GNSS}(t)$ at an accuracy of approx. 0.2 m and position measurements for $POS_{GNSS}(t)$ at a resolution of approx. 0.3 m.

As used herein, the term "geodetic reference system" denotes an earth model which advantageously takes into account the most important parameters of the figure of the Earth, the rotation of the Earth, and its gravitational field. Advantageous are the WGS84 geodetic reference system (with the EGM96 or EGM2008 gravitation model) or the ETRS89 reference system. Other geodetic reference systems are included in the inventive idea.

The second step comprises time-dependent determination of the static pressure $p_{AC}(t)$ and/or the pressure level $z_{AC}(t)$ using the pressure measuring system. Current calibration parameters or calibration curves specified for the pressure measuring system are included in the determination of the static pressure $p_{AC}(t)$ and the pressure level $z_{AC}(t)$.

In the third step, weather analysis data AN_{DAT} or weather prognosis data $PROG_{DAT}$ of a numerical weather prediction model (NWP) are provided to determine assigned geopotential altitudes $z_{AN/PROG}(t)$ assigned to the measured static pressures $p_{AC}(t)$ for the positions $POS_{GNSS}(t)$ and/or to determine static pressures $p_{AN/PROG}(t)$ assigned to the determined altitudes $z_{GNSS}(t)$ for positions $POS_{GNSS}(t)$.

A connection between geopotential altitudes $z_{AN/PROG}(t)$ and assigned barometric pressure levels $p_{AN/PROG}(t)$ are taken from the weather analysis data AN_{DAT} and weather prognosis data $PROG_{DAT}$ of a numerical weather prediction model (NWP). The analysis data AN_{DAT} for weather conditions prevailing at point in time t_l and a position $POS_{GNSS}(t_l)$ are only available at a time $t_l + \Delta t_{analysis}$, wherein $\Delta t_{analysis}$ indicates a period of time required for analyzing the weather data detected at time t_l and for providing the respective analysis data AN_{DAT}. Analysis data AN_{DAT} are therefore particularly suitable for later evaluation of measured data which were determined by the pressure measuring system during a flight. Geopotential altitudes $z_{AN}(t)$ and static pressures $p_{AN}(t)$ determined from analysis data AN_{DAT} are typically more accurate than the geopotential altitudes $z_{PROG}(t)$ and static pressures $p_{PROG}(t)$ determined from weather prognosis data $PROG_{DAT}$.

Advantageously, the weather prediction model (NWP) considers an acceleration due to gravity g = g(POS, h) depending on the position POS (on the surface of the Earth) and altitude h, as well as a geoid undulation for generating the weather prognosis data $PROG_{DAT}$. "Geoid undulation" denotes a distance of the geoid from a reference ellipsoid in the ellipsoid point reviewed, measured along the ellipsoid normal. Geoid undulations can be up to 100 m with respect to a medium reference ellipsoid for the Earth.

Furthermore advantageously, the numerical weather prognosis system NWP comprises model pressure surfaces p_k, for which prognostic equations for temperature, humidity, etc. are solved, such that prognosis data $PROG_{RAWDAT}(t)$ are initially available for the model pressure surfaces p_k. For determining the weather prognosis data $PROG_{DAT}(t)$, the prognosis data $PROG_{RAWDAT}(t)$ are advantageously linearly interpolated over time t and linearly interpolated over geographic coordinates and logarithmically interpolated over the pressure field with respect to the position $POS_{GNSS}(t)$ of the flying device between model half-level pressure surfaces $p_{k+1/2} = a_{k+1/2} + b_{k+1/2} * p_{sfc}$, wherein:

$k = 0, \ldots, K$;
$p_{k+1/2} = 0$ for $k = 0$;
p_{sfc}: static pressure on the ground for $k=K$; and
$a_{k+1/2}$, $b_{k+1/2}$ are constant coefficients.

For more information about model pressure surfaces in a numerical weather prediction model (NWP), see the article by *Simmons, A. and Burridge, D.M., "An Energy and*

Angular-Momentum Conserving Vertical Finite-Difference Scheme and Hybrid Vertical Coordinate" Mon. Wea. Rev., Vol. 109, No. April 1981, pages: 758 to 766. Other numerical methods use unstructured networks, finite elements, or other discrete approximations of the calculated field variables. These require adjusted optimized interpolation methods.

The above-mentioned advantageous features of the weather prediction model (NWP) result in an increase in the level of accuracy with which the variables $z_{AN/PROG}(t)$ and $p_{AN/PROG}(t)$ can be determined. Because short-term prognoses are more accurate, it is advantageous to use weather prognosis data $PROG_{DAT}(t)$ for a forecast period of less than two days.

Advantageously, the "Integrated Forecast System" (IFS) of ECMWF ("European Centre for Medium-Range Weather Forecasts") is used as NWP weather prediction model. Other weather prediction models are of course covered by the inventive idea.

The fourth step comprises determining the altitude deviation $\Delta z(t) = z_{GNSS}(t) - z_{AN/PROG}(t)$ and/or determining the pressure deviation $\Delta p(t) = p_{AC}(t) - p_{AN/PROG}(t)$.

The fifth step comprises determining an altitude deviation Δz^* averaged over a period of time Δt from $\Delta z(t) = z_{GNSS}(t) - z_{AN/PROG}(t)$ and/or determining a pressure deviation Δp^* averaged over a period of time Δt from $\Delta p(t) = p_{AC}(t) - p_{AN/PROG}(t)$, wherein a fault of the pressure measuring system is deemed detected if the determined averaged altitude deviation $|\Delta z^*|$ is greater than or equal to a specified threshold G1, or if the averaged pressure deviation $|\Delta p^*|$ is greater than or equal to a specified threshold G2.

The altitude deviation Δz^* advantageously results, for example, in an average value $\langle \Delta z(t) \rangle$ or in a difference of mean values $\langle z_{GNSS}(t) \rangle - \langle z_{AN/PROG}(t) \rangle$ for the period Δt. Likewise, the pressure deviation Δp^* results, for example, in an average value $\langle \Delta p(t) \rangle$ or in a difference of mean values $\langle p_{AC}(t) \rangle - \langle p_{AN/PROG}(t) \rangle$. Advantageously, average values are only generated for flight stages with a constant altitude and air speed. Furthermore advantageously, no flight maneuvers such as turns are performed in these flight stages. The period Δt is advantageously selected from the range [1 min, 10 h], it advantageously is 10 min, 20 min, 30 min, 1 h, 2 h, 3 h, 4 h, or 5 h. Advantageously, sliding average values are determined for the period Δt. The average value can be determined in the most varied ways. For example, an average value can be a median, an arithmetic mean, a geometric mean, a harmonic mean, a quadratic mean, or a cubic mean, etc. Furthermore, the average value can be weighted.

It is already possible today, when using the proposed method, to verify the pressure and altitude measurements on a flying device in the range of globally available weather data with an accuracy of better than +/-10 m or +/-30 feet at a 95% confidence interval based on weather analysis data AN_{DAT} or weather prognosis data $PROG_{DAT}$ of a numerical weather prediction model (NWP).

The proposed method allows monitoring the functioning and accuracy of the pressure measuring system in flight. The results of this monitoring can be output in the flying device and/or transmitted to a ground station and output there.

An advantageous further development of the proposed method is characterized in that the altitude deviation $|\Delta z(t)|$ or $|\Delta z^*|$ is greater than or equal to a specified threshold G1, or that a warning signal is generated if the pressure deviation $|\Delta p(t)|$ or $|\Delta p^*|$ is greater than or equal to a specified threshold G2. This warning signal is advantageously an electric warning signal, which particularly can trigger the output of an optically, haptically, and/or acoustically perceivable warning.

In an advantageous further development of the method, the warning signal is output aboard the flying device as an optical, haptic, and/or acoustic warning signal, and/or it is transmitted to a ground station to be further processed there and/or to be output there as an optical, haptic, and/or acoustic warning signal.

An advantageous further development of the method is characterized in that a calibration of the pressure measuring system, advantageously an automatic self-calibration of the pressure measuring system is performed based on the altitude deviation $\Delta z(t)$ or Δz^* and/or the pressure deviation $\Delta p(t)$ or Δp^*. Calibration of the pressure measuring system is for example performed after a flight for which the respective data was determined. It is advantageous to perform automatic self-calibration of the pressure measuring system in flight. Automatic self-calibration is advantageously triggered if the averaged altitude deviation $|\Delta z^*|$ is greater than or equal to a specified threshold G3, or if the averaged pressure deviation $|\Delta p^*|$ is greater than or equal to a specified threshold G4. Self-calibration ensures more robust accuracy of the variables determined by the pressure measuring system in flight.

An advantageous further development of the method is characterized in that, based on an electric status $STAT_{elec}(t)$ of the pressure measuring system and based on one or several of the variables: $\Delta z(t)$, $z_{AC}(t)$, $z_{GNSS}(t)$, $z_{AN/PROG}(t)$, $\Delta p(t)$, $p_{AC}(t)$, $p_{AN/PROG}(t)$, total pressure $p_{stau}(t)$, stagnation temperature $T_{stag}(t)$, and optionally other variables, an automatic evaluation is performed with respect to a sensor fault, an electrical fault, or a line breakage/leakage of a pressure line of the pressure measuring system. If the evaluation results in detection of one of the faults described above, such fault will advantageously be specified in an optical and/or acoustic output, i.e. a sensor fault or electrical fault or line breakage/leakage in the pressure measuring system is advantageously displayed in the flying device and/or a ground unit in communication with the flying device, depending on the type of fault.

Advantageously, when calibrating the pressure measuring system, particularly during automatic self-calibration of the pressure measuring system, a status STAT(t) of the flying device is taken into account. The status STAT(t) of the flying device is for this purpose detected and provided by respective sensors. As used herein, the term "status of the flying device" has a wider meaning. It particularly includes the aerodynamic status and the mechanical configuration status of the flying device.

Advantageously, the status STAT(t) of the flying device is determined by one or several of the following variables: Mach number, angle of attack, yaw angle, roll angle, weight of the flying device, configuration of the flying device with respect to its outer shape (such as temporary external add-ons to the flying device, such as antennas, aerodynamic covers for measuring systems (radar, LIDAR, etc.)), flap position, and/or landing gear position. The configuration of the flying device with respect to its outer shape can for example be taken into account in the form of specified or stored key figures.

The proposed method has the following advantages. The proposed method allows making a statement whether the calibration of the pressure measuring system is within specified thresholds or whether is must be corrected. The proposed method further allows calibration of the pressure measuring system as a function of the parameters specified above both in flight and after or before other flight operations. The method makes it particularly possible to permanently monitor quality of the pressure measuring system in flight operations. For example, the method can be used to check the function of the barometric altimeter across all altitude levels during the entire flight. The check can simultaneously be performed on the ground, or the monitoring result can be transmitted to a respective ground facility. For example, air traffic control can be informed that the altitude readings of the flying device are unreliable, such that respective action can be taken. The numerical data needed for the method (analysis data AN_{DAT} / weather prognosis data $PROG_{DAT}(t)$) are currently available every 12 hours, due to weather forecasts even for days ahead, including the period of time of a pending flight and in time before takeoff.

These weather prognosis data $PROG_{DAT}(t)$ can be loaded before takeoff from the ground from a data network onto a computer aboard the flying device and/or onto a computer of an air traffic controller on the ground. Advantageously, the measured data of the pressure measuring system: $z_{AC}(t)$ and/or $p_{AC}(t)$ and the satellite navigation system: $POS_{GNSS}(t)$, $z_{GNSS}(t)$ are communicated online to a ground facility and are available there for a respective evaluation, as described above. In this way, the deviation $\Delta z(t)$ between the altitude measured by the satellite navigation system $z_{GNSS}(t)$ and the altitude $z_{AN,PROG,}(t)$ predicted based on weather prognosis data $PROG_{DAT}(t)$ and/or determined based on weather analysis data AN_{DAT} can be determined both in the flying device and at a suitable ground facility, such that respective conclusions can be drawn, and action be taken where required.

The method described avoids the disadvantages mentioned in the introduction to this description of prior art methods for fault detection in a barometric pressure measuring system of a flying device. Particularly, no additional flights, no special installations of measuring equipment, and no services by a navigation service provider are required.

There is a demand for the proposed method for calibrations of pressure measuring systems among manufacturers of flying devices of all kinds. When developing new flying device types, numerous test flights are performed for manifold purposes as part of flight testing. The presented method can be used here for quality monitoring and independent testing of the pressure measuring system of the flying device. The method described herein can be applied particularly cost-effectively, easily, and operationally when modifying flying devices, repairing damaged flying devices, for first licensing of a flying device with add-ons, or for any other changes of the aerodynamic properties of a flying device. This is particularly true of flying devices having extreme fields of application (altitudes and speeds), in which respective test flights are difficult due to lack of an observer on board or other ways of comparison.

Another aspect of the present invention relates to a device for determining a fault of a barometric pressure measuring system arranged aboard a flying device, which is configured and designed for determining a static pressure $p_{AC}(t)$ and/or a pressure level $z_{AC}(t)$.

The device includes a satellite navigation system GNSS arranged aboard the flying device for determining an actual position $POS_{GNSS}(t)$ and an altitude $z_{GNSS}(t)$ of the flying device in a geodetic reference system at the time t; an interface for providing weather analysis data AN_{DAT} or weather prognosis data $PROG_{DAT}$ of a numerical weather prediction model (NWP) for the position $POS_{GNSS}(t)$ and altitude $z_{GNSS}(t)$; and an evaluation unit for determining a geopotential altitude $z_{AN/PROG}(t)$ assigned to the static pressure $p_{AC}(t)$ in the weather analysis data AN_{DAT} or weather prognosis data $PROG_{DAT}$, and/or for determining a static pressure $p_{AN/PROG}(t)$ assigned to the altitude $z_{GNSS}(t)$ in the weather analysis data AN_{DAT} or weather prognosis data $PROG_{DAT}$; wherein the evaluation unit is furthermore configured and designed for determining the altitude deviation $\Delta z(t) = z_{GNSS}(t) - z_{AN/PROG}(t)$ and/or the pressure deviation $\Delta p(t) = p_{AC}(t) - p_{AN/PROG}(t)$ as well as for determining an altitude deviation Δz^* averaged over a period Δt from $\Delta z(t) = z_{GNSS}(t) - z_{AN/PROG}(t)$ and/or for determining a pressure deviation Δp^* averaged over the period Δt from $\Delta p(t) = p_{AC}(t) - p_{AN/PROG}(t)$. Finally, the device comprises a comparator unit which determines a fault of the pressure measuring system as detected if the averaged altitude deviation $|\Delta z^*|$ is greater than or equal to a specified threshold G1, or if the averaged pressure deviation $|\Delta p^*|$ is greater than or equal to a specified threshold G2, and which unit generates a warning signal if a fault is detected.

The device is particularly designed and configured for performing a method as described above.

An advantageous further development of the device is characterized in that the pressure measuring system is designed and configured for automatic self-calibration of the pressure measuring system based on the determined altitude deviations $\Delta z(t)$ or Δz^* and/or the determined pressure deviations $\Delta p(t)$ or Δp^*, wherein this self-calibration is performed if the comparator unit has detected a fault and/or the warning signal was received.

In one embodiment of the proposed device, the interface, the evaluation unit and the comparator unit are arranged aboard the flying device. The interface is advantageously connected to a receiver, which is designed and configured for wireless receipt of the weather analysis data AN_{DAT} or weather prognosis data $PROG_{DAT}$. The interface is advantageously connected to a storage unit, on which the weather analysis data AN_{DAT} or weather prognosis data $PROG_{DAT}$ can be stored. Furthermore advantageously, a communication unit is provided, which communicates the warning signal generated and/or the variables: $z_{GNSS}(t)$ and/or $p_{AC}(t)$ and/or $\Delta z(t)$ and/or $\Delta p(t)$ to a ground facility. Advantageously, the ground facility outputs an optically, acoustically, and/or haptically perceivable warning after receiving the warning signal.

Advantageously, the device further comprises a status detection unit, which determines a status STAT(t) of the flying device, wherein the pressure measuring system performs the automatic self-calibration depending on the status STAT(t) of the flying device. The status detection unit has respective sensors for this purpose. These sensors are designed such that one or several of the following variables can be determined: Mach number, angle of attack, yaw angle, roll angle, weight of the flying device, center of gravity, flap position, and/or landing gear position. Furthermore, the status detection unit is connected to a storage unit on which the outer aerodynamically effective (outer) shape of the flying object can optionally be stored in the form of features or a respective coding. The outer shape covers, for example, aerodynamically effective add-ons, tank vessels, radomes, antenna assemblies, etc. and thus taken into account during the calibration of the pressure measuring system.

Advantages and advantageous further developments of the proposed device can be derived by applying the explanations made in conjunction with the method described analogously and accordingly. Reference is made for this purpose to the preceding parts of this description.

The invention further relates to a flying device having a proposed device.

The object of the invention is further achieved by a computer system with a data processing device, wherein the data processing device is designed such that a method as described above is executed by the data processing device.

The object of the invention is further achieved by a digital storage medium with electronically readable control signals, wherein the control signals can interact with a programmable computer system, such that a method as described above is executed.

Furthermore, the object of the invention is achieved by a computer program product with a program code stored on a machine readable carrier and intended for executing the method as described above when the program code is executed on a data processing device.

Finally the invention relates to a computer program with program codes for executing the method as described above if the program runs on a data processing device. The data processing device can be designed for this purpose as any computer system known from prior art.

Other advantages, features and details can be derived from the description below, in which at least one exemplary embodiment is described in detail and with reference to the drawing, where appropriate. Identical, similar and/or functionally identical parts were assigned the same reference symbols.

In the drawings:

Fig. 1 shows a schematic flowchart of a variant of the proposed method,
Fig. 2 shows a schematic flowchart of a variant of the proposed method.

Fig. 1 shows a schematic flowchart of a variant of the proposed method for determining a fault of a barometric pressure measuring system arranged aboard a flying device. The method comprises the following steps.

In a first step **101**, a current position $POS_{GNSS}(t)$ and altitude $z_{GNSS}(t)$ of the flying device in a geodetic reference system at a point in time t is determined using a satellite navigation system GNSS arranged aboard a flying device.

In a second step **102**, a static pressure $p_{AC}(t)$ and/or a pressure level $z_{AC}(t)$ is determined using the pressure measuring system.

In a third step **103**, a geopotential altitude $z_{AN/PROG}(t)$ assigned to the static pressure $p_{AC}(t)$ is determined for the position $POS_{GNSS}(t)$ in provided weather analysis data AN_{DAT} or in provided weather prognosis data $PROG_{DAT}$ of a numerical weather prediction model (NWP), or a static pressure $p_{AN/PROG}(t)$ assigned to the altitude $z_{GNSS}(t)$ is determined for the position $POS_{GNSS}(t)$ in provided weather analysis data AN_{DAT} or in provided weather prognosis data $PROG_{DAT}$ of a numerical weather prediction model (NWP).

In a fourth step **104**, the altitude deviation $\Delta z(t) = z_{GNSS}(t) - z_{AN/PROG}(t)$ and/or the pressure deviation $\Delta p(t) = p_{AC}(t) - p_{AN/PROG}(t)$ are determined.

In a fifth step **105**, an altitude deviation Δz^* averaged over a period of time Δt from $\Delta z(t) = z_{GNSS}(t) - z_{AN/PROG}(t)$ and/or a pressure deviation Δp^* averaged over a period of time Δt from $\Delta p(t) = p_{AC}(t) - p_{AN/PROG}(t)$ are determined, wherein a fault of the pressure measuring system is deemed detected if the determined averaged altitude deviation $|\Delta z^*|$ is greater than or equal to a specified threshold G1, or if the averaged pressure deviation $|\Delta p^*|$ is greater than or equal to a specified threshold G2.

In a sixth step **106**, a warning signal is generated if a fault is detected.

Fig. 2 shows a schematic flowchart of a variant of the proposed method for determining a fault of a barometric pressure measuring system arranged aboard a flying device, which determines a static pressure $p_{AC}(t)$ and/or a pressure level $z_{AC}(t)$. The device includes a satellite navigation system **201** GNSS for determining an actual position $POS_{GNSS}(t)$ and an altitude $z_{GNSS}(t)$ of the flying device in a geodetic reference system at the time t; an interface **202** for providing weather analysis data AN_{DAT} or weather prognosis data $PROG_{DAT}$ of a numerical weather prediction model (NWP) for the position $POS_{GNSS}(t)$ and altitude $z_{GNSS}(t)$; an evaluation unit **203** for determining a geopotential altitude $z_{AN/PROG}(t)$ assigned to the static pressure $p_{AC}(t)$ in the weather analysis data AN_{DAT} or weather prognosis data $PROG_{DAT}$, and/or for determining a static pressure $p_{AN/PROG}(t)$ assigned to the altitude $z_{GNSS}(t)$ in the weather analysis data AN_{DAT} or weather prognosis data $PROG_{DAT}$; wherein the evaluation unit is furthermore configured and designed for determining the altitude deviation $\Delta z(t) = z_{GNSS}(t) - z_{AN/PROG}(t)$ and/or the pressure deviation $\Delta p(t) = p_{AC}(t) - p_{AN/PROG}(t)$ as well as for determining an altitude deviation Δz^* averaged over a period Δt from $\Delta z(t) = z_{GNSS}(t) - z_{AN/PROG}(t)$ and/or for determining a pressure deviation Δp^* averaged over the period Δt from $\Delta p(t) = p_{AC}(t) - p_{AN/PROG}(t)$, and a comparator unit **204**, which determines a fault of the pressure measuring system as detected if the averaged altitude deviation $|\Delta z^*|$ is greater than or equal to a specified threshold G1, or if the averaged pressure deviation $|\Delta p^*|$ is greater than or equal to a specified threshold G2, and which unit generates a warning signal if a fault is detected.

Although the invention was described in detail by means of preferred exemplary embodiments, the invention is not limited by the disclosed examples, and a person skilled in the art can derive other variations from it without leaving the scope of protection of the invention. It will therefore be appreciated that a plurality of variation options exists. It will also be appreciated that embodiments mentioned as examples are indeed just examples, which should not be interpreted as limiting, for example, the scope of protection, potential applications, or the configuration of the invention. Instead, the above description and description of figures enable a person skilled in the art to implement the exemplary embodiments in detail, wherein the person skilled in the art, knowing the disclosed rationale of the invention, can make manifold changes, for example with respect to the function or arrangement of individual elements mentioned in an exemplary embodiment, without leaving the scope of protection which is defined by the claims and their legal equivalents, such as the further explanation in the description.

List of reference symbols

101 – 106	Method steps
201	Satellite navigation system GNSS
202	Interface
203	Evaluation unit
204	Comparator unit

CLAIMS

1. A method for determining a fault of a barometric pressure measuring system arranged aboard a flying device, comprising the following steps:
   - Determining (101) a current position $POS_{GNSS}(t)$ and altitude $z_{GNSS}(t)$ of the flying device in a geodetic reference system at a point in time t using a satellite navigation system GNSS arranged aboard a flying device;
   - Determining (102) a static pressure $p_{AC}(t)$ and/or a pressure level $z_{AC}(t)$ using the pressure measuring system,
   - Determining (103) a geopotential altitude $z_{AN/PROG}(t)$ assigned to the static pressure $p_{AC}(t)$ for the position $POS_{GNSS}(t)$ in provided weather analysis data AN_{DAT} or in provided weather prognosis data $PROG_{DAT}$ of a numerical weather prediction model (NWP), and/or
   - Determining (103) a static pressure $p_{AC}(t)$ assigned to the geopotential altitude $z_{AN/PROG}(t)$ for the position $POS_{GNSS}(t)$ in provided weather analysis data AN_{DAT} or in provided weather prognosis data $PROG_{DAT}$ of a numerical weather prediction model (NWP);
   - Determining (104) the altitude deviation $\Delta z(t) = z_{GNSS}(t) - z_{AN/PROG}(t)$ and/or determining (104) the pressure deviation $\Delta p(t) = p_{AC}(t) - p_{AN/PROG}(t)$;
   - Determining (105) an altitude deviation Δz^* averaged over a period of time Δt from $\Delta z(t) = z_{GNSS}(t) - z_{AN/PROG}(t)$ and/or determining (105) a pressure deviation Δp^* averaged over a period of time Δt from $\Delta p(t) = p_{AC}(t) - p_{AN/PROG}(t)$, wherein a fault of the pressure measuring system is deemed detected if the determined averaged altitude deviation $|\Delta z^*|$ is greater than or equal to a specified threshold G1, or if the averaged pressure deviation $|\Delta p^*|$ is greater than or equal to a specified threshold G2; and
   - Generating (106) a warning signal if a fault is detected.

2. The method according to claim 1,
   in which the warning signal generated on board of the flying device triggers an optically, acoustically, and/or haptically perceivable output of the warning signal, and/or the warning signal is transmitted to a ground facility to be processed further

and/or to trigger an optically, acoustically, and/or haptically perceivable output of the warning signal there.

3. The method according to claim 1 or 2, in which the geodetic reference system is the WGS84 geodetic reference system with the WGS84 or EGM2008 gravitation model or the ETRS89 reference system.

4. The method according to any one of claims 1 to 3, in which the satellite navigation system GNSS is a differential satellite navigation system.

5. The method according to any one of claims 1 to 4, in which the pressure measuring system performs an automatic self-calibration of the pressure measuring system if a fault is detected.

6. The method according to claim 5, in which a determined status STAT(t) of the flying device is taken into account during the automatic self-calibration of the pressure measuring system, wherein the status STAT(t) of the flying device is determined by one or several of the following variables:
   - Mach number,
   - Angle of attack,
   - Yaw angle,
   - Roll angle,
   - Weight of the flying device,
   - Center of gravitation,
   - Configuration of a flying device,
   - Flap position,
   - Landing gear position.

7. The method according to any one of claims 1 to 6, in which the numerical weather prediction model (NWP)
   - comprises model pressure surfaces p_k, for which initially there are prognosis data

$PROG_{RAWDAT}(t)$, and wherein for determining the weather prognosis data $PROG_{DAT}(t)$, the prognosis data $PROG_{RAWDAT}(t)$ are advantageously linearly interpolated over time t and linearly interpolated over geographic coordinates and logarithmically interpolated over the pressure field with respect to the position $POS_{GNSS}(t)$ of the flying device between model half-level pressure surfaces $p_{k+1/2} = a_{k+1/2} + b_{k+1/2} * p_{sfc}$, wherein k=0,..., K; $p_{k+1/2} = 0$ for k = 0; p_{sfc}: static pressure on the ground for k=K; and $a_{k+1/2}$, $b_{k+1/2}$ are constant coefficients;

- takes into account an acceleration due to gravity g depending on the position POS and altitude h; and
- takes into account a geoid undulation.

8. A device for determining a fault of a barometric pressure measuring system arranged aboard a flying device, which determines a static pressure $p_{AC}(t)$ and/or a pressure level $z_{AC}(t)$, comprising:

- a satellite navigation system (201) GNSS or determining an actual position $POS_{GNSS}(t)$ and an altitude $z_{GNSS}(t)$ of the flying device in a geodetic reference system at the time t,
- an interface (202), by means of which analysis data AN_{DAT} or weather prognosis data $PROG_{DAT}$ of a numerical weather prediction model (NWP) are provided for the position $POS_{GNSS}(t)$ and altitude $z_{GNSS}(t)$,
- an evaluation unit (203) for determining a geopotential altitude $z_{AN/PROG}(t)$ assigned to the static pressure $p_{AC}(t)$ in the weather analysis data AN_{DAT} or in the weather prognosis data $PROG_{DAT}$, and/or determining a static pressure $p_{AN/PROG}(t)$ assigned to the altitude $z_{GNSS}(t)$ in the weather analysis data AN_{DAT} or in the weather prognosis data $PROG_{DAT}$; wherein the evaluation unit is furthermore configured and designed for determining the altitude deviation $\Delta z(t) = z_{GNSS}(t) - z_{AN/PROG}(t)$ and/or pressure deviation $\Delta p(t) = p_{AC}(t) - p_{AN/PROG}(t)$ as well as for determining an altitude deviation Δz^* averaged over a period Δt from $\Delta z(t) = z_{GNSS}(t) - z_{AN/PROG}(t)$ and/or configured and designed for determining a pressure deviation Δp^* over a period Δt from $\Delta p(t) = p_{AC}(t) - p_{AN/PROG}(t)$; and
- a comparator unit (204), which determines a fault of the pressure measuring system as detected if the averaged altitude deviation $|\Delta z^*|$ is greater than or equal to a specified threshold G1, or if the averaged pressure deviation $|\Delta p^*|$ is greater

than or equal to a specified threshold G2, and which unit generates a warning signal if a fault is detected.

9. The device according to claim 8,
in which the pressure measuring system is designed and configured such that it performs an automatic self-calibration of the pressure measuring system if a fault is detected based on the averaged altitude deviation Δz^* and/or the averaged pressure deviation Δp^*.

10. A flying device with a device according to claim 8 or 9.

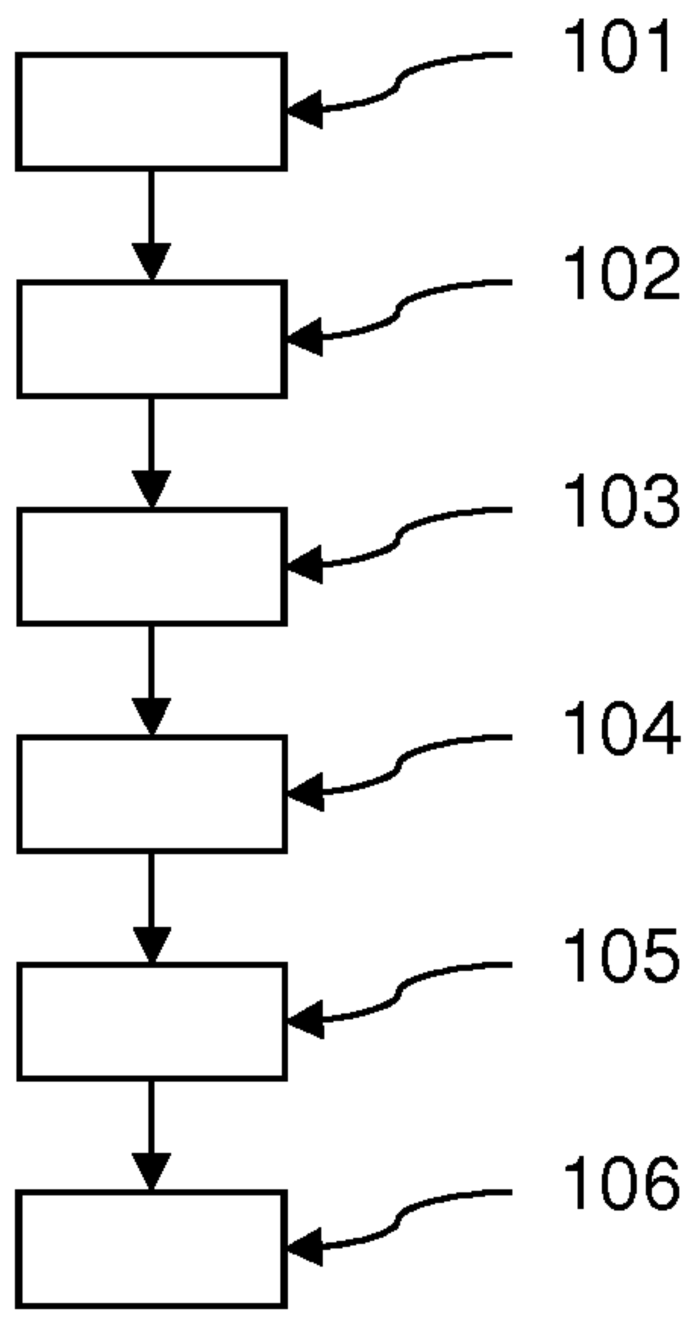

Fig. 1

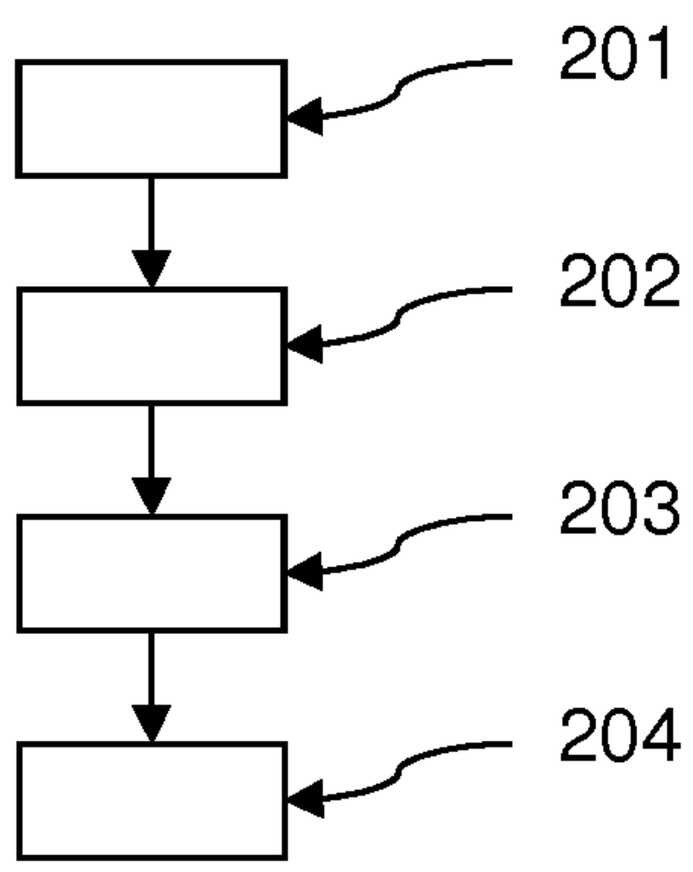

Fig. 2

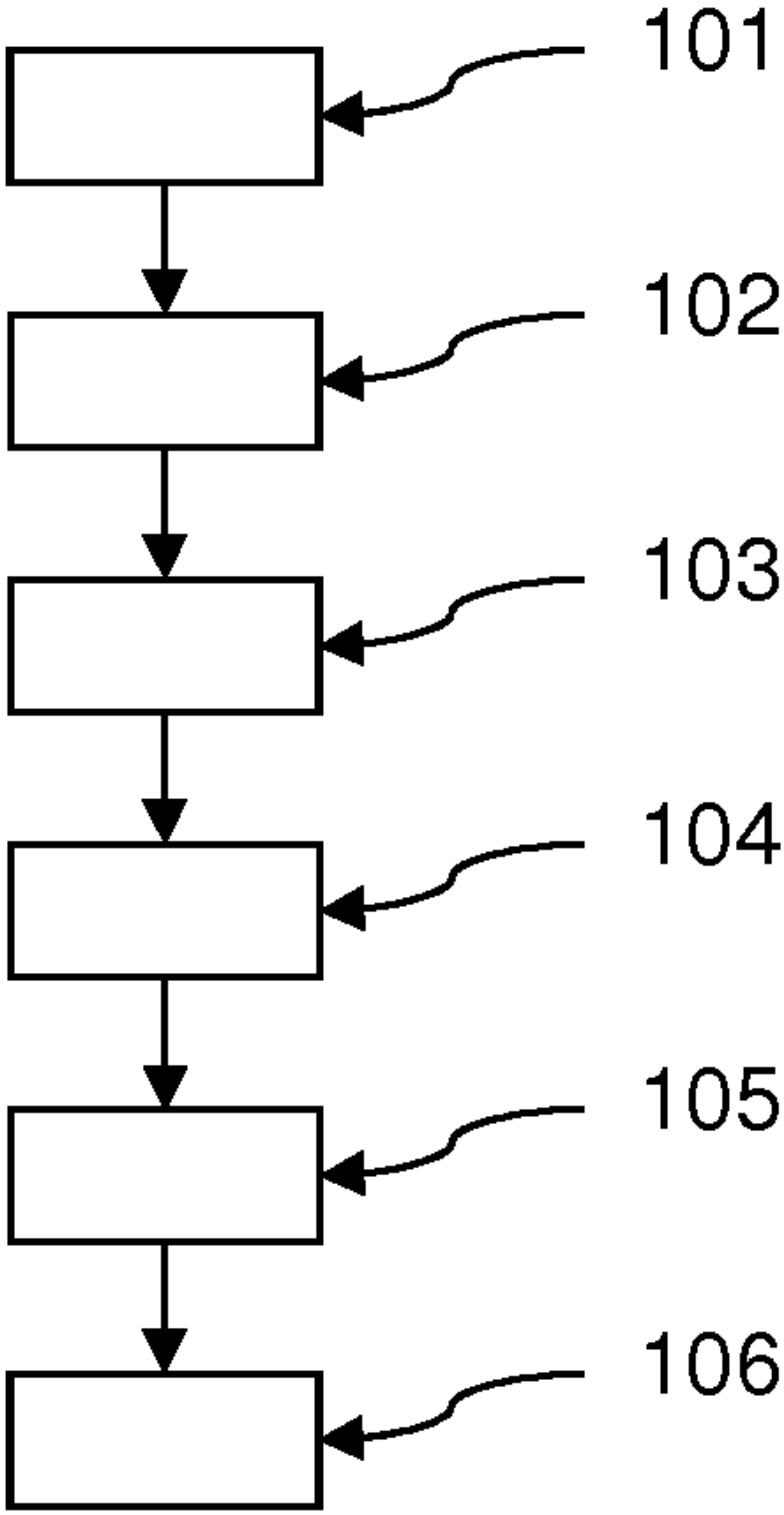

Fig. 1