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AIR FORCE SYSTEMS COMMAND

INERTIAL NAVIGATION

by

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INERTIAL NAVIGATION

Yu Hang

Ballistic rockets are comparable to superlong-range "bullets" and inertial guidance systems are comparable to "gun barrels." They can cause rockets to accurately hit their targets. Nowadays, inertial navigation systems are beginning to be installed on new style aircraft.....

The use of gyroscopes as end instruments of sea navigation compasses, direction finders, gyrohorizons, and automatic pilots on aircraft already has a history of several decades. The so-called accelerometer, which utilizes the principle of inertia to measure the acceleration of a moving body, has also been well-known for some time. However, inertial navigation systems (called inertial guidance systems in rocket technology) which are composed of gyroscopes, accelerometers, and electronic computers have only been on the market for a little over twenty years.

In the past twenty years, inertial navigation technology has developed rapidly, and the precision of inertial navigation has increased greatly. In 1944, the "V-2" rocket made the first use of an inertial guidance system. Its range was 320 kilometers and its deviation from impact on target was approximately 1.6 kilometers. But now the range of long-range ballistic rockets has reached 10,000 kilometers, and even though they still use inertial guidance systems, because the precision of inertial elements has been greatly increased the deviation from impact on target is still only about 2 kilometers.

In comparing the two, the precision of target impact of the latter is 25 times greater than the former.

The volume and weight of inertial navigation equipment has been greatly reduced. At the beginning of the 1950's, the weight of the inertial navigation equipment installed on aircraft for testing was over 2100 kilograms and the volume was several cubic meters. But the diameter of one kind of inertial navigation system equipment in the 1960's was only 34 centimeters and the length was only 59 centimeters. Including the electronic equipment and the computer, it weighed 38.5 kilograms altogether.

Now the utilization of inertial navigation systems is expanding every day, not only on middle-range and long-range rockets but also on submarines, spacecraft, and supersonic aircraft.

Characteristics

The main function of navigation is to determine the position of ships or flying vehicles. For several thousand years sailors have been facing the problem of how to determine the positions of ships. Errors in measuring speed and direction and computing position have been caused by ocean currents. When airplanes are in heavy fog or are flying above the clouds, they also face problems on how to determine position. For instance, in regard to airplanes that use magnetic compass navigation equipment changes in the wind velocity and directional errors of the magnetic compass cause serious errors in the computed position data. If astronomical positioning is used it is often limited by weather, and if radio positioning is used it is especially susceptible to enemy interference in time of war. Furthermore, ground equipment for transmitting radio waves is fairly complicated and is also limited by distance.

All of the inertial navigation equipment on ships or flying vehicles is "self-contained." It neither sends nor receives any signals, and thus does not expose itself or receive any man-made or natural interference. No matter how great the distance, whether it is day or night, or how bad the weather conditions, the inertial navigation system always works.

Basically, inertial navigation systems are composed of two major parts. One part measures the acceleration of the moving body and converts it into an electrical signal to be sent out. The other part receives this signal, carries out computations, and finds the position of the moving body at all times and performs navigation. The former part is called an inertial navigation measuring device, while the latter part is called a navigation computer (special articles will be introduced concerning the computer).

Composition

Inertial navigation measurement apparatus is composed of an accelerometer and a gyrostabilized platform. This type of accelerometer-carrying gyrostabilized platform is called an inertial navigation platform. An accelerometer is a measuring device. Figure 1 is a diagram of the principles of a spring-type accelerometer. Inside the casing of the accelerometer, two springs are used to support an inertial mass, and the casing is then firmly affixed to a moving body. Assuming that the directions of the measuring axis of the accelerometer and the moving body are the same, when the moving body is not in a state of acceleration, the mass is held at the null position at the center by the springs with equal tension on the two sides, and there is no electrical signal output showing on the potentiometer. When the moving body is in a state of acceleration, according to Newton's second law an inertial force will be applied to the mass, causing it to deviate from the null position, and an electrical signal output will be shown on the potentiometer. The deviation of the inertial mass is proportional to the inertial force. That is to say, the output is an electrical signal which is proportional to the acceleration of the moving body.

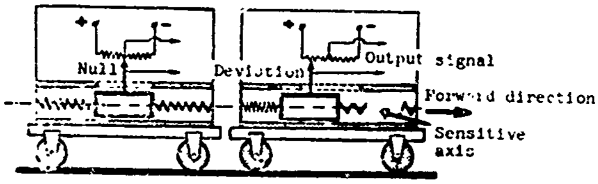

Fig. 1. Diagram of the principles of an accelerometer. Left: when there is no acceleration. Right: when there is acceleration.

Naturally, the accelerometers used in aviation are much more complicated and there are numerous types. Here we will discuss the practical structure of a pendulum-type accelerometer as an example (see Fig. 2). There is a pendulum inside this type of accelerometer, and when there is acceleration the pendulum will deflect as inertial force is applied. An induction-type converter (a so-called micro-synchronizer) is used to convert the deflection. The rotor of the converter is mounted on the same axis as the pendulum; therefore, as the pendulum deflects the rotor rotates together with it. An electrical signal output will be induced on the stator of the converter (the fixed element). After integration (computed according to accumulation of time), data of speed and position variation in a certain direction of the flying vehicle can be obtained.

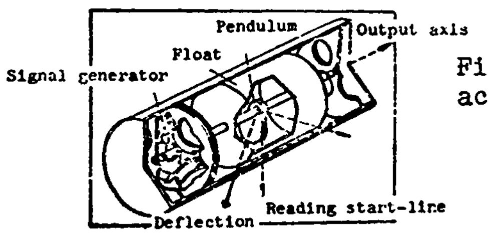

Fig. 2. A pendulum-type accelerometer.

One accelerometer can only measure acceleration in a certain direction. In order to determine the position of an aircraft in the air, we need three accelerometers to separately measure acceleration in the East-West, North-South, and vertical directions. After subsequent computation it will be possible to determine the longitude, latitude, and altitude of the aircraft in the air at all times.

Aside from this, the accelerometer on the aircraft must be placed horizontally; otherwise, a slight tilt (Fig. 3) will induce an erroneous signal due to the effect of the component of gravitational force on the sensitive axis. Even if the angle of inclination is as small as only one minute (1/60th of a degree), the computed position error will reach 18.5 km/hour. In order to eliminate this error and to measure the horizontal component of acceleration of an aircraft along a northerly direction, the acceleration should be place on a gyrostabilized platform (Fig. 4), which is fixed on the local horizon and in the North-South direction.

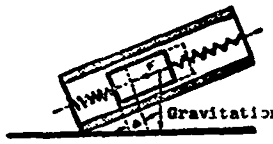

Fig. 3.

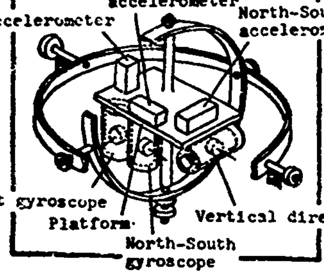

Fig. 4.

Fig. 3. Accelerometer error introduced by the function of the component of gravitational force.
Δ – error; F' – the component of gravitational force on the sensitive axis.

Fig. 4. A gyrostabilized platform.

The term gyrostabilized platform is self-explanatory – it is a platform that is stabilized by a gyroscope. It is true that it is composed of three two-degree-of-freedom integral gyroscopes (two three-degree-of-freedom gyroscopes may also be used) and three sets of servomechanism systems. However, this type of gyroscope-carrying servomechanism system can only maintain the platform in a stable position in space; it cannot constantly maintain the horizon and North-South directions corresponding to the Earth. Therefore, the output signal of the accelerometer should be utilized to send, after computation by computer, the angular velocity signal of the flight direction, North, and East directions to the torque motor of the gyroscope, thus indirectly moving the platform along with the change of flight position and causing it to maintain the local horizon and North-South directions at all times.

The three two-degree-of-freedom integral gyroscopes are mounted on the platform along the East-West, North-South, and vertical directions respectively. Their basic functional principles are the same; therefore, we will only need to discuss one of them. The gyro wheel of the gyroscope is mounted on a gimbal. Not only does it rotate on its own axis, but it also rotates on the axis of the gimbal, providing two degrees of freedom in rotation; therefore it is called a two-degree-of-freedom gyroscope. Because the input of this type of gyroscope is angular velocity and the output is an angle, it is equivalent to the performance of an integral computation and so is also called an integral gyroscope. An induction-type signal generator is mounted on one end of the gyroscope. Its rotor and the gimbal are mounted on the same axis, so when the gyro wheel of the gyroscope rotates along the gimbal axis the rotor of the generator also rotates and an output signal is induced on the stator. Assume that the direction of the axis of the gyroscope rotor is the same as the x-axis of the aircraft; suddenly a gust of wind blows on the aircraft, causing a rotation along the z-axis of the aircraft. This angular velocity rotating along the input axis of the gyroscope will cause the gimbal axis of the gyroscope, which is the output axis, to rotate. Thus, a signal is sent out by the generator. The signal is amplified by the amplifier in the servomechanism system and is then able to start the stabilizing motor to stabilize the position of the platform.

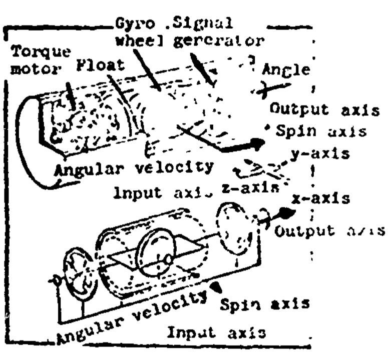

Fig. 5. Diagram of a two-degree-of-freedom integral gyroscope and its principles.

With an accelerometer mounted on a gyrostabilized platform of this type, regardless of the destination of the aircraft or changes in course, the acceleration in each direction can be accurately measured and sent to a computer; after computation the position of the aircraft can be accurately determined at any time.

Improvements

The key to increasing the accuracy of inertial navigation is to improve the inertial elements — the accuracy of the accelerometer and the gyroscope. We can see from Figs. 2 and 4 that the pendulum and gyro wheel of the gyroscope are sealed within a float. A liquid is placed between the float and the casing in such a manner that the bouyancy of the liquid exactly equals the total weight of all of the components of the flcat. In this way, we can reduce the frictional torque on the axis to a minimal degree. This is one method of increasing measurement precision. Presently every nation in the world with advanced aviation technology is pouring a loc of men and materials into research for much higher precision in accelerometers and gyroscopes in order to increase the precision of inertial navigation.

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The use of gyroscopes as end instruments of sea navigation compasses, direction finders, gyrohorizons, and automatic pilots on aircraft already has a history of several decades. The so-called accelerometer, which utilizes the principle of inertia to measure the acceleration of a moving body, has also been well-known for some time. However, inertial navigation systems (called inertial guidance systems in rocket technology) which are composed of gyroscopes, accelerometers, and electronic computers have only been on the market for a little over twenty years. In the past twenty years, inertial navigation technology has developed rapidly, and the precision of inertial navigation has increased greatly. In 1944, the "V-2" rocket made the first use of an inertial guidance system. Its range was 320 kilometers and its deviation from impact on target was approximately 1.6 kilometers. But now the range of long-range ballistic rockets has reached 10,000 kilometers, and even though they still use inertial guidance systems, because the precision of inertial elements has been greatly increased the deviation from impact on target is still only about 2 kilometers.

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