US Dynamics Model 475 Series Rate Gyroscope Technical Brief

Scope:

This applications note discusses the US Dynamics Rate Gyroscope typical of the Model 475 design. Included here shall be a brief discussion on rate gyroscope basics, operation, and uses, and a dissection of the model by major component. This applications note is primarily intended to familiarize the reader to the basic rate gyroscope functionality.

Discussion on Rate Gyroscope Operation:

What it does…

The rate gyroscope is a rate-of-turn transducer. The output signal represents the 'angular degrees per second' *(a rate)* of a turning maneuver. The output of a rate gyroscope is calibrated in 'millivolts (mV) per degree per second'. A typical rate gyroscope output, or its scale factor, may be for example '50mV per degree per second' of turning rate provided by the instrument's signal generator, the so called pickoff.

A practical analogy and example of rate of turn is as follows: A car is imagined exiting a freeway via a cloverleaf ramp. As the car is traveling the cloverleaf, its speed may be for example 35mph. This would equate to roughly 51.5 ft/second. Measured in feet per second then, is the car's instantaneous rate of speed or *distance covered* over some time period. If the car travels the full 360° cloverleaf in 15 seconds, then the car's rate of turn will be 360°/15 seconds or 24 degrees/second, or *angle traveled* through over some time period. Therefore, if the car was equipped with a rate of turn indicating meter, the rate gyroscope providing the input to the indicator will have typically as its output, a 'mV per degree per second' signal. Using the '50mV per degree per second' unit described above, the output provided through the turn of the cloverleaf will have been 1.2 Volts (24°/sec times .050V/°/sec).

Although of not much use in one's daily experience in a car, a rate of turn indicator is essential for many applications in navigation. This is especially true where there is no fixed reference, or 'foothold', on which to base the rate of turn measurement's starting point. Therefore, a pilot in either an airplane or ship may need to know his rate of turn in order to make sense of his current or expected heading or attitude, especially if his vision is obscured.

How it does it…

The rate gyroscope is in a family of instruments (or transducers) called inertial instruments. That is, inertia provides the 'foothold' for the measurement. The inertia within the gyroscope is provided by the 'inertia' or 'gyro' wheel. Inertia's influence on an object is such that the object resists a *change* in movement. The gyro wheel is a spinning mass of controlled rotational speed and known moment of inertia *(rotational mass)*. A spinning mass tends to resist any rotational movement, except that of its own spin about its axle. An *allowable* rotational input then, other than in the spin axis, to the gyroscope system yields a predictable rotational response in an *expected* output axis. This process is known as *gyroscopic precession.*

This *expected* response to a rotational input in an axis which is *allowed* to receive that input is a force or torque (torque is rotational force) of a magnitude proportional to the force required to predictably rotate the system against the 'foothold' of the spinning mass. This output torque is *resisted* by means of a spring to provide a gradient for the purpose of measurement. A spring with a known spring rate is used. Typically a spring rate is measured in units of force per inch of spring motion, typically pounds per inch as in a bathroom scale or *inch-pounds per degree-rotation* as in the *rate gyroscope*.

Therefore, the output torque (rotational force) produced by the gyroscope spinning mass system is *countered* by a spring of known characteristics, which allows only so much output rotation for a given force. This output rotation is then measured by the output signal generator, the so called pickoff.

Summarizing, when the rate gyroscope experiences a 'turn', the gyro system will react by outputting a torque which will be opposed in a controlled fashion by a known rate spring. The calibration of the gyro produced output torque versus the known spring rate *scales* the measurement taken by the gyro pickoff. When the turning rate reduces to zero, the output torque of the gyro reduces to zero. The spring opposition force also reduces to zero and the system is said to be at null. At such time there is no rate of turn sensed, and the output from the gyro's pickoff is zero volts.

Where it is used…

The rate gyroscope is used to measure rotation rates when no 'foothold' reference is available. This is common in the air, at sea, and in space. Navigation is the art of knowing how to get where one must go when there are no 'landmarks or signposts' available as guides. Furthermore the absence of a 'foothold' upon which to place a reference for the measurements of distance or rotation *requires* some other method.

Inertial devices such as rate gyroscopes, rate integrating gyroscopes, and accelerometers are common in modern navigation systems. Other uses include active stabilization of cameras, platforms, and other motion sensitive applications. Inertial devices therefore internally contain the required resistance to movement either in the form a spinning mass (a source of *inertia*) such as in gyroscopes, or a suspended mass such as in accelerometers.

In addition to measuring the instantaneous rate of turn, a rate gyroscope may be used to determine the *amount* of change in direction as follows. The output of the gyro is calibrated in 'millivolts per degree per second'. Therefore, if for 12 seconds, the earlier described 50 'millivolt per degree per second' *scale factor* gyroscope measured an output of 25 millivolts, the device would have 'experienced' a rotation of 6 degrees total. That is, the heading of the vehicle using device to measure its rate of turn will have experienced a turn change of 6 degrees. Obviously, precise timing would be an important part of the measurement equation, and this math process is called *integration*. Knowing how much time an object experiences a rate, gives insight into the total change experienced.

Rate of turn (rate of rotation) information is needed in such applications as;

○ Aircraft Navigation
○ Missile Navigation
○ Submarine and Shipboard Navigation
○ Radar Systems
○ Platform and Camera Stabilization
○ Satellite and Spacecraft Navigation

Dissection of Rate Gyroscope Components:

The US Dynamics Rate Gyroscope is an inertial grade instrument capable of the precise measurement of rates of turn, or rotation rates, of a device or vehicle. Therefore, the individual components used to assemble a rate gyroscope must be of great precision. Following are the basic components which comprise an inertial grade rate gyroscope.

Spin Motor and Inertial Wheel:

The spin motor and inertial wheel of the rate gyro are considered a single component. Typically, a motor is described as a device which converts electrical energy into rotating mechanical energy. This device usually rotates a shaft onto which pulleys or gears are attached to make useful work of the rotational energy. The gyro motor however, is only required to rotate an inertial wheel (the spinning mass) at a constant speed.

In the US Dynamics Rate Gyroscope design the motor's shaft and windings (the stator) is fixed, and the inertia wheel (rotor) rotates around the fixed structure. A class of synchronous motors called 'polyphase hysteresis' is used. Polyphase means that there is more than one alternating electrical current supplies fed to the motor. In this case there are two currents or phases. The alternating electrical currents are usually sinewave shaped. One supply is 90° out of phase with the other (*is said to lead [or lag] in time by 90° out of the 360° cycle*) , which causes the magnetic field in the magnetizable parts of the motor produced by the currents to *rotate*.

The rotor, which is comprised of the inertial wheel and *hysteresis stack*, is pulled along with the rotating magnetic field produced by the two out of phase electrical currents. The hysteresis stack is a thin layered structure of special electrical grade steel that is attracted by the rotating magnetic field. When the alternating currents are supplied to the motor, after a short time the rotor attains the same rotational speed as the rotating magnetic field, thus becoming synchronous with the frequency of the alternating currents supplied to the motor.

Since the spin motor requires alternating current (AC), and further, *two phases* of AC which are related by a 90° phase difference, an appropriate motor power supply is required. The voltage magnitude is not as important however, as the frequency of the alternating current. The frequency determines the speed of the spinning mass. Any variation in the speed of the spinning mass, especially when the gyro is sensing a turn, will cause an error in the output torque response of the gyro system. Therefore, the spin motor power supply is an important consideration in a system using rate gyroscopes.

The spinning mass of the rate gyro inertia wheel, the hysteresis stack, bearings and the rotor end bells (any portion that actually rotates) are precisely designed and manufactured to have the proper rotational or angular momentum when at synchronous speed. The consistency of the speed and moment of inertia (*rotational mass*) of the rotating component is essential. Precision balancing of the rotating mass is performed to remove any rotational bias or excess vibration. It is the angular momentum of the spinning mass which provides the 'foothold' reference for the rate of turn measurement.

The Gimbal:

The gimbal provides the structure in which the motor and inertial wheel is contained. After installation of the spin motor and inertial wheel, the gimbal is completely sealed. The atmosphere inside the gimbal is usually filled with a dry, inert gas such as helium. The helium filled vessel therefore protects the high speed inertial wheel and provides a minimum of *windage* loss ('air' friction).

The gimbal, as a unit, is then floated in a fluid to provide neutral buoyancy. Also known as a *float*, the gimbal is held on one end by a precision, low friction bearing and on the other a torsion spring. The gimbal is also precision- balanced such that (essentially) no rotation is evidenced when floated unrestrained in a fluid.

The gimbal is said to be *unrestrained* to gyro system output torques in response to rate of turn inputs. Therefore, the gimbal is free to rotate through a small angle of usually no more than ±3 degrees of rotation.

The fill fluid is also considered fully, as it plays a key role in gimbal movement damping. Damping *kills* unwanted oscillations of the gimbal. Therefore, over-damping could affect the speed of response of the gyro, and under-damping could cause unwanted oscillations which would corrupt the output signal of the gyro.

The Torsion Spring:

The torsion spring provides the rotational resistance gradient against which the output torque produced by the gyroscope is balanced. This spring is a precision machined component of repeatable and predictable spring characteristics. In order to not introduce other force biases, the machining and subsequent handling of the torsion spring is tightly controlled.

The material of the spring, the material temper, and the physical dimensions and contours determine the spring rate achieved. The spring characteristics, along with the gimbal support fluid and gyro system dynamics then determine the natural (resonant) frequency of the gyro system, and ultimately its speed of measurement response.

The Pickoff (Output Signal Generator):

The pickoff or output signal generator provides the user with an AC voltage proportional to the rate of turn resolved by the gyroscope. The pickoff is designed as a non-contact device which can measure the angle of the gyro's gimbal. The gimbal angle is directly proportional to the rate of turn input to the gyro system.

The pickoff is a special variation of an electrical transformer. Electrical transformers work by changing the level of an input AC voltage to an output AC voltage level in some proportion determined by electromagnetic coupling. The proportion of electromagnetic coupling can be varied a number of ways. Most familiar is the ratio of input winding turns (transformer primary) to output turns (transformer secondary) wrapped around a common magnetizable core. Power transformers allow the transformation of AC voltages in this way.

The gyro pickoff however, uses a transformer which can vary the amount of voltage transformation which takes place. The variation is directly and linearly proportional to the gyro's rate of turn input. The ability to vary the voltage output is due to a variable amount of coupling, depending upon the gyro's gimbal rotation angle. Here, a stationary portion of the transformer containing the primary and secondary transformer windings is referenced to the gyro's case, and a moveable portion containing additional magnetizable material is referenced to the gyro's gimbal. Therefore, as the gyro's gimbal rotates in response to the gyro experiencing a rate of turn, a relative rotating motion is sensed by the stationary and moveable portions of the pickoff transformer, which in turn varies the amount of electromagnetic coupling.

The non-contacting stationary and moveable portions of the pickoff transformer allow for a frictionless and continuous process of providing a gyro output signal. Since the pickoff is a transformer device, it does require AC voltage to operate. Likewise, the output is an AC voltage. At the gyro's null, or rest position, a trivial voltage, or null voltage is present. As the gyro experiences a rate of turn input, the output AC voltage will increase in magnitude.

This magnitude of voltage increase however, does not overtly indicate the direction of the rate rotation, for example clockwise or counterclockwise rotation. If the pickoff output voltage was measured by an AC voltmeter, there would be *NO* indication of the direction of rotation. The gyro's pickoff transformer is wired however, such that the output AC is referenced to the input excitation AC. Thereby a reversal of phase orientation is evident on the output signal when the gyro senses a change from clockwise, through the null position, to counter-clockwise rotations and *vice versa*.

The directionality of the output signal is then said to be *phase sensitive*. This feature requires a phase sensitive demodulator to interpret the gyro's output signal. This means that the output AC signal is compared to a *sample* of the input AC signal to indicate to the signal conditioning unit, the direction of rotation sensed in addition to the magnitude of the signal, which represents the rate of turn.

US Dynamics Corp.'s Engineered Approach to Rate Gyroscopes:

US Dynamics Corp. Model 475 Series Rate Gyroscopes are custom engineered to meet a variety of applications. Model 475 Series rate gyroscopes can be designed to measure input rates up to 1200° per second. The output scale factors are designed to give excellent resolution and linearity.

Custom designed multiple pole motors are tailored to give optimal performance in demanding applications. Exacting combinations of gyro wheel momentum and torsion springs are factored into each design to provide the most accurate, stable, and fast measurement of rates of turn. The spinning mass rate gyroscope is unmatched in its inertial grade characteristics and flexibility of design.

The complete control over rate gyroscope design is further enhanced by many years of practical in-house gyroscope design experience, sophisticated rate gyroscope design tools, and complete prototyping, testing, and product qualification capability. This extensive capability allows new designs to be quickly developed and proven and also allows design enhancements of those instruments used in legacy systems.