# Basic Gyroscope Spin Motor Excitation Requirements for US Dynamics Miniature Gyroscopes

**Scope:**
*This applications note discusses basic gyroscope spin motor excitation requirements for many models of US Dynamics miniature Rate Integrating Gyroscopes (RIG) and Rate Gyroscopes. Most US Dynamics miniature gyroscopes utilize 2 phase synchronous (hysteresis) motors to drive the gyroscope inertia wheel.*

*The aim of this note is to introduce system designers and engineers to the basics of 2 phase synchronous induction hysteresis motors used in gyroscopes along with the motor drive excitation requirements. In addition, basic circuitry for the excitation of the 2 phase synchronous spin motors will also be discussed. The reader can then expand on the information presented here as applicable to their specific application.*

---

## 2 Phase Hysteresis Motor Basics

The 2 phase hysteresis motor is in the synchronous AC *induction* motor family. As such, there are no slip rings or brushes to commutate the applied current. Instead, a 2 phase AC power input where the two phases are 90 electrical degrees displaced resulting in a leading phase and a lagging phase is used. The wave shape is typically a sinewave. Refer to figure 1 below.

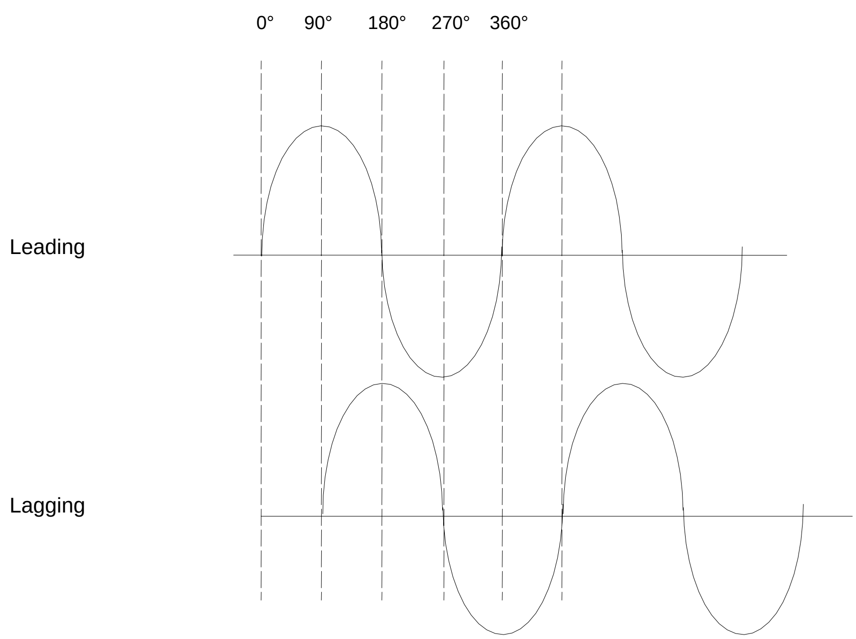


**Figure 1 – Spin motor excitation phase relationship**

The 90° offset *(quadrature)* phase relationship is necessary in a synchronous induction motor to set up a *rotating* magnetic field. The rotation of the field then allows a magnetically *attractive* material, the hysteresis stack in the rotor, to spin with the field. In hysteresis motors, the rotor will eventually (usually within a minute) *lock* into the same rotation rate as the field.


US Dynamics Corporation
425 Bayview Avenue
Amityville, NY 11701
631-842-5600
Revision: 08/2006

The rate of rotation of the magnetic field is governed by the following relationship:

r.p.m. = (120 * f) / p

where: f = excitation frequency
p = number of motor poles
r.p.m. = the rotation rate

The figure (fig. 2) below shows a sectioned view of a typical gyro spin motor, of the 2 phase hysteresis motor design.

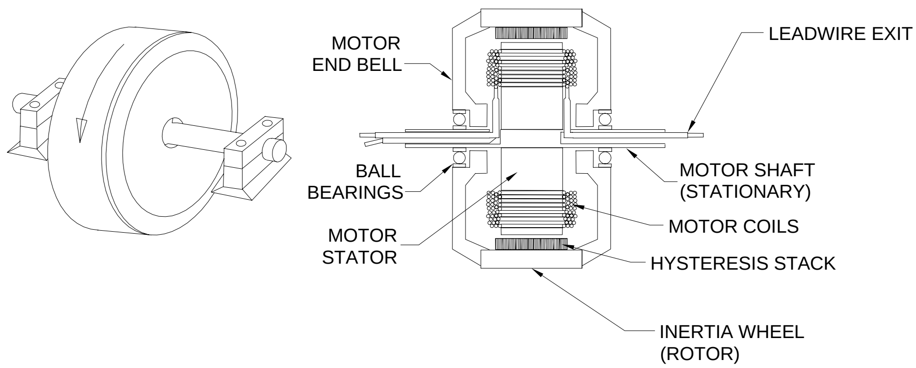


**Figure 2 - Section view of hysteresis spin motor**

In this design, the stator (which also serves as the magnet wire coil form) and the shaft is stationary, and the outer shell comprised of the end bells, inertia wheel and hysteresis stack rotates about the shaft on ball bearings. US Dynamics manufactures gyro spin motors of various pole configurations, voltages, and frequencies to satisfy the requirements of virtually any conventional design.

As with most electric motors, the startup condition of the hysteresis motor will draw a higher current than the running condition. The current draw at startup will be primarily determined by the winding resistance. The current draw when in *synchronous lock* will be determined by a combination of winding resistance and inductance. Upon starting, and when monitored on an oscilloscope, the current waveforms (of each phase) can be seen decreasing in magnitude from the initial application of power, until the rotor is in synchronous lock. At that time, the waveforms can be seen stable at some lower value than that at start-up.

Upon starting, the current level for an instant reaches a maximum, near-locked rotor current. As the rotor begins to turn, a reaction from the inductance of the motor coils contributes a back voltage (back EMF). Simplistically, this back voltage opposes the supply voltage and acts as to reduce the overall input voltage. As a result, the magnitude of the motor *running* current can then be said to be this reduced input voltage divided by the motor winding resistance, per Ohm's Law.

Soon after the application of input voltage to the motor, at some point the rotor will synchronize with the rotation rate of the magnetic field. The hysteresis motor will then track this field rotation rate precisely.

Here, the voltage is not as important as the frequency of the motor supply. *The hysteresis motor will sync-up (synchronize) any rotor load that it can accelerate up to the synchronous speed.* Usually, even moderate voltage dips will not affect the motor. However, frequency jitter and/or poor frequency control of the motor AC supply will affect the rotor speed, and therefore the gyroscope's measurement accuracy.

Another characteristic of the hysteresis motor is that it will not start with a single excitation phase. *Single phasing* will typically cause the active phase winding to heat up, since the current cannot drop due to back EMF. However, a motor which has started and locked-up with two phases may continue to run on a single phase if a phase has dropped out. Here, however, the motor will no longer remain at synchronous speed, and the accuracy of the gyroscope will degrade.

## Gyroscope Spin Motor Excitation

This section discusses the building blocks for the most basic gyroscope spin motor excitation supply. The intent here is to give those not familiar with 2 phase hysteresis induction motors some insight as to what is required to operate the motors. A block diagram of a simple gyro spin motor excitation supply is shown in figure 3 below. A basic circuit such as the one diagrammed in the figure below would suffice for gyroscope spin motor testing for example.

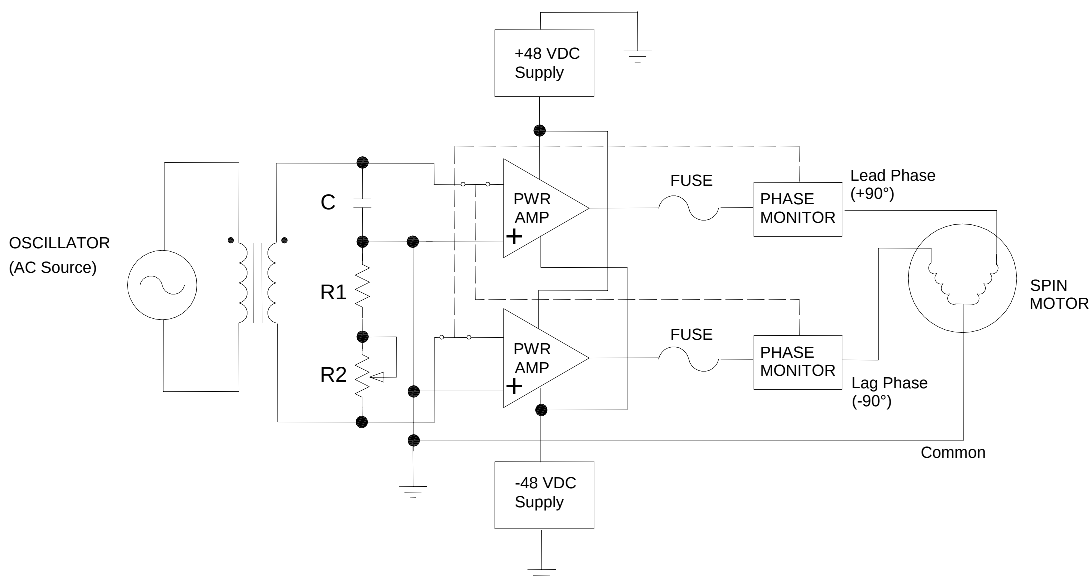


**Figure 3 - Simple spin motor excitation supply block diagram**

The block diagram shows an oscillator, a phase shifter (C, R1 & R2), power amplifiers, phase monitors and the spin motor. Each block component shall be examined further in the following subsections.

Oscillators

In figure 3, an AC source oscillator is shown. This oscillator must be a stable type, ideally with less than 500ppm accuracy. For gyroscopes requiring much greater accuracy, oscillators with accuracies of 1ppm are

not uncommon. Typical oscillator types can include crystal based (the most accurate), or other types such as electronic phase-locked loops (PLL's), R-C and 555 based bi-stable, Wien bridge, or unijunction transistor based relaxation oscillators (typically less accurate). A transformer is shown and is included for isolation. Step-up or step-down types could also be used where appropriate to change voltage levels.

Crystal oscillators are known to be highly stable and offer precise frequency control. This especially true of heated crystal oscillators. However, since crystals resonate at high frequencies, usually starting in the tens of kilohertz, and most gyroscope spin motor applications require frequencies of less than 10 kilohertz, frequency division is required. In addition, the dividers used are often digital and necessarily output typically logic level square wave signals. Therefore, a square wave to sine wave converter, or sine wave synthesis is required. Crystal based oscillators and the associated frequency division schemes are most often used where less than 100ppm frequency drift (stability) is required, for the most accurate gyroscopes.

Another popular type of oscillator is the voltage controlled oscillator, or VCO. The VCO section of a phased locked loop (PPL) device can offer frequency stability typically at about 150ppm. When used as a complete system the PPL monitors the output of the VCO and adjusts the input accordingly to maintain an accurate frequency output. Since the PLL is a closed loop control system where the output of the system (the frequency of the VCO) is monitored via feedback, it can maintain a strict control over the frequency of the oscillator by servo action (fed back into the VCO).

For gyroscope applications where such precision may not be required, options would include R-C based oscillator designs. The R-C type oscillators, including 555 timer based oscillators (comparator switch type), which are simpler in design and more inherently suitable for direct low frequency operation may be more attractive to the designer in applications requiring frequency control of about 300 to 500ppm. Using high grade, stable components, oscillator designs with the required frequency stability are quite possible.

2 Phase (Quadrature) Signal Generation

Since the gyroscope spin motor is a 2 phase hysteresis induction type motor, 2 independent alternating current (AC) sources related in phase by a 90° shift are required (refer again to Figure 1 above). Typically, and most simply, the 90° phase shift between two the AC phases is introduced by means of a phase shifting capacitor.

For a rate gyroscope, a typical voltage requirement may be for example 13.5 VAC to 15.5 VAC, at a frequency of 800 ±10 Hz per phase. The per-phase current requirement is then governed by a combination of the motor stator winding resistance and the motor's self-generated back-EMF when spinning under power. A simple capacitor based, 2-phase spin motor excitation signal, suitable for some types of functional testing, can be generated by a system as depicted below.

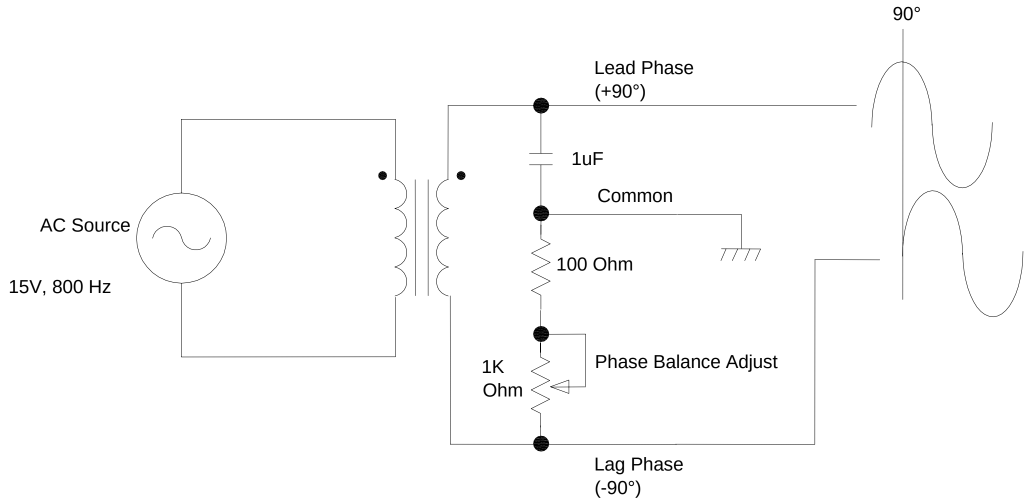


**Figure 4 - Spin motor 2 phase generator**

The 90° phase shift is provided by the 1uF capacitor. An ideal capacitance provides a 90° phase shift, while real capacitive circuits provide a shift *approaching* 90°. In the above circuit, a balance in sinewave amplitude from phase to phase is achieved by adjusting the phase balance adjustment potentiometer. The two sinewaves will be matched when the total resistance of the 100 Ohm resistor and the potentiometer resistance are equal to the capacitive reactance (AC resistance) at the excitation frequency. In the above example, the capacitive reactance, $X_C$, is given by the expression:

$X_C = 1/(2\pi fC)$

where: f = frequency of excitation in Hz
C = capacitance in Farads

Therefore, in the above example, the capacitive reactance, $X_C$ = 199 Ohms. Then, if the potentiometer is set to 99 Ohms and its value is added to the fixed 100 Ohm resistor is 199 Ohms, the peaks of the lead and lag sinewaves will be essentially equal. Using the above circuit, a two phase (90° shifted) spin motor excitation signal is established. For use as a phase shifting element, the capacitor should be a stable, non-polarized film type.

Other phase shifting methods may be used in addition to what is described above. For example, if two independent oscillators which are *synchronized* to be 90° degrees apart in phase are used, the phase shifter circuitry is not needed. As well, other quadrature generation techniques could be used eliminating the need for a phase shifter. These would include digital synthesis, or op-amp based phase shifters.

## Motor Excitation Power Amplifier

In order to actually drive a spin motor, a higher current than would be available from the spin motor excitation signal generator will typically be required. Therefore, the output of the circuit shown in figure 4 will need some amplification to be sure the proper voltage is maintained while delivering the current required by the spin motor. The circuitry shown in figure 5 is typical of what would be required to interface the output of figure 4 to an actual gyro spin motor per phase.

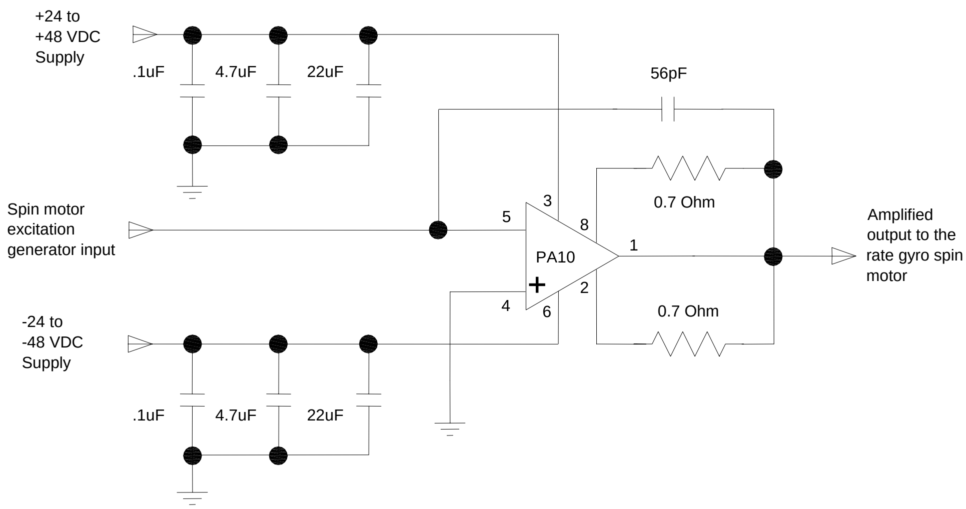


**Figure 5 - Spin motor excitation signal power amplifier**

The power amplifier shown in figure 5 will provide adequate spin motor current and voltage regulation (one amplifier channel per phase) during spin motor start-up and running conditions. *In this regard, a monolithic stereo amplifier may also be used such that more circuitry is housed in a single package for two separate channels of amplification.*

The PA10 type high voltage and current power amplifier can provide up to 60 watts of power availability in a TO-3 type package. As shown above, adequate power supply bypassing is essential in order to provide continuous current to the spin motor under severe power supply transient conditions. The 4.7uF and 22uF capacitors can be either wet or dry tantalum type. Typically, the use of 10uF per Ampere of peak output current is a good rule-of-thumb to follow when bypassing the power supplies of a high power amplifier such as the PA10.

In addition, a frequency compensation capacitor is shown from the output terminal (pin 1) to the inverting input terminal (pin 5) of the PA10. The *low value* capacitor provides a reduction of amplifier gain in the event of a high frequency noise input. This tends to keep the amplified output frequency very close to the input frequency, by not allowing the amplification of high frequency (nuisance) noise. The 0.7 Ohm resistors provide current limiting within the amplifier to protect it from short circuits, should one occur due to mis-wiring or other output related failures. Again, since there are two phases required to power the spin motor, two power amplifiers as depicted in figure 5 above will be required, one for each motor phase.

## Gyroscope and System Protection Circuitry

In most real applications, including gyro testing, motor excitation phase monitoring will be included in the design. The most basic monitor will include a current feedback element for each motor phase. This feedback element will measure the phase current and input information into a circuit that as a minimum will turn off all excitation to the motor in the event of a current fault.

For example, if one phase monitor indicates that no current is being drawn, the motor cannot start because there is no rotating magnetic field being generated. In this case, the phase that is energized is drawing the full start-up current on that phase for an indefinite period of time. If excessive heating occurs due to the extended period of high current draw, it will eventually degrade the magnet wire insulation on that phase winding in the motor. Thus, if a monitor detected this condition and switched off the current to the "live" phase and alerted a system supervisory function of a fault, potential damage to the gyro would be mitigated.

If on the other hand, the motor started without issues, and a phase cut out during gyro operation, the gyro motor would slow down and change the characteristic of the gyro output. This changed characteristic may give the system false or misleading information. Such a scenario puts the entire system in question. Here, a phase monitor would detect the problem and either shut the gyro down and/or alert a system supervisory function of the problem.

The phase monitor could be implemented simply as a voltage level comparator. A current sensing resistor will have an rms voltage presented across its terminals when current is flowing through the circuit. This voltage would then be compared to some reference signal at the input to a comparator. If a fault condition occurs, the comparator output trips a relay or signals other circuitry to place the system in a safe mode by taking some appropriate action.

## Advanced Gyroscope Spin Motor Starting Concepts

Some systems require their gyros to start-up quickly. In these cases, a spin motor excitation system may be designed with a feature called a "hot start". A hot start issues a short period of higher than running (normal) ***voltage*** to the spin motor during a predetermined period of time. The higher voltage allows a greater current to be drawn (per phase) to give the motor a *kick*. Since this higher starting voltage may be detrimental to the motor windings if held in place for an extended period, phase current monitoring here is essential.

## Summary

The above discussions present an overview of basic US Dynamics miniature gyroscope spin motor design and the minimum requirements to excite and operate it. This note is intended for system designers or engineers who wish to become familiar with the art.

Spinning mass gyroscopes depend on the constant momentum of the gyro wheel to provide its gimbal inertia, or the gimbals' resistance to rotational movement. The constant momentum is directly related to the speed of rotation of the gyro wheel. That speed is dependent on the gyro spin motor excitation frequency.

When designing a gyroscope spin motor excitation supply, much consideration must be given to the type of oscillator used. The stability of the gyroscope system depends greatly on the stability of the oscillator used. In addition, the other components of the spin motor excitation system, including the necessary phase shift circuitry, the amplifiers used to provide adequate drive current, and any monitoring of the individual motor phase current conditions are equally important to consider early on in any system development effort.

Such external factors as gyroscope operating environment, performance specifications, noise and interference compatibility and gyroscope design particulars must also be considered by the spin motor excitation system designer in determining the best combination of components to use.