Basic Output Generator Excitation and Demodulation Requirements for US Dynamics Miniature Gyroscopes

Scope:
This applications note discusses the input signal excitation and output signal conditioning (demodulation) requirements of the transformer type output generator, or pickoff used on the US Dynamics Miniature Rate Integrating Gyroscopes (RIG) and Rate Gyroscopes. In addition, basic transformer type pickoff operation will be presented.

The discussions and circuit examples provided in this note are intended to introduce system designers and engineers to the minimum basic requirements for gyroscope pickoff excitation and demodulation.

Gyroscope Output Generator Basics

The US Dynamics miniature gyroscope output generator, also known as a *pickoff*, generates a user output signal indicating the position of the gyro's gimbal, usually in terms of millivolts per (angular) degree of gimbal *rotation*. All US Dynamics miniature gyroscope pickoff arrangements are implemented in the form a variable *transformer*. There are several variations of this basic variable transformer design used in various gyroscope designs. All transformer based pickoffs however, operate in the same fundamental manner. As in all typical transformers, AC voltage, or *excitation*, is supplied to the pickoff transformer primary winding. From the secondary winding of the pickoff an AC output signal is received.

This type of transformer uses variable coupling from the primary coil to a *differentially wound* transformer secondary coil. That is, there are two coils wound in *opposite* directions, such that as the output of one coil swings positive, the output of the other swings negative. Said another way, one of the secondary coils is wound such that is it in AC phase alignment with the primary coil. The other secondary is wound such that it is out of AC phase alignment (electrically by 180°) with respect to the primary coil. The two secondary coils are then connected electrically in *series*. If the coupling between the primary coil and both secondary coils is even (equal in magnitude), the output of the two differentially wound secondary coils is zero, and the pickoff system is said to be at null. Therefore, the *direction* of gyro gimbal rotation can be resolved by determining if the pickoff output is *in phase* or *out of phase* with the primary excitation signal.

In this regard, the pickoff is similar to a *linear variable differential transformer*, or LVDT. The transformer coupling is affected by a *movable* core of magnetically permeable material. The core may be attached to the gyroscope gimbal (which is free to rotate) and the transformer coils to the gyroscope case structure, or vise-versa. Therefore, since a transformer based pickoff is magnetically coupled, meaning that no contact is necessary between the core and the windings, an essentially *frictionless* method for determining rotational displacement is accomplished.

Summarizing, in order to operate a transformer based gyroscope pickoff, a pickoff primary AC excitation signal is required. To interrogate (read) the pickoff, an output signal interpreter, or demodulator, is necessary to resolve the direction of gyro gimbal rotation, and to scale the magnitude of the signal into useful units.

Gyroscope Pickoff Excitation

The pickoff excitation signal provides the electrical input to the *primary side* of the pickoff. This is a single phase AC signal. As such, some form of oscillator is required to generate the AC signal. The signal is usually sinusoidal in wave shape, and is commonly in the mid audio frequency range. Most US Dynamics miniature gyroscope pickoffs operate by specification at voltages from 5 to 26VAC and at frequencies of from 400 Hz to 12.8 kHz. Since many mechanical systems which would use gyros could have response frequencies up to the 50 Hz range, the (*at least 10 times*) higher frequencies of the pickoffs prevent data aliasing problems. The higher the mechanical system motion speed, the higher the pickoff

frequency should be in order to capture the motion characteristics in a continuous manner, without missing or erroneous data.

The oscillator which produces the AC excitation is a major component in the pickoff system. 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). The pickoff oscillator requirements, however, are not as stringent as those for gyroscope spinmotor excitation.   A simple oscillator, appropriate for gyro pickoff functional testing based on a modified Wien bridge oscillator and an LC resonator operated by a bi-polar (±DC) power supply is shown below in figure 1.
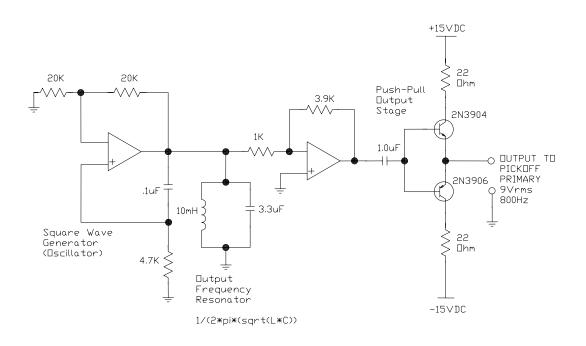
Figure 1 – Simple AC Sinewave Oscillator

This simple oscillator uses a square wave generator (based around the first operational amplifier, or op-amp) which provides a pulse to an LC resonant circuit. This circuit works well when the pulse frequency is approximately .5 to .9 times the desired resonator frequency. Analogous to a mechanical pendulum, a periodic pulse is all that is needed to feed the resonant circuit to keep it in *resonance*. This action is similar to a child on a swing. The resonator frequency is proportional to the inverse of the square root of L (the inductance in Henrys) times C (the capacitance in Farads). The LC resonator provides a sinusoidal waveshape output.

The output of the resonator feeds a second amplifier which boosts the signal to a level acceptable to drive the transistor output amplifier. This is usually required here due to the parasitic resistance of the inductor. The capacitor between the second amplifier and the transistor output stage helps center the sinewave output between the positive and negative power supply inputs, and is commonly referred to as AC coupling.

Usually, the pickoff primary winding is of sufficiently low impedance as to require current levels higher than those available directly from signal level operational amplifiers (op-amps). Current levels exceeding 40mA are not uncommon requirements. As such, an appropriate amplifier is needed to increase the current as well as conveniently provide other signal conditioning opportunities, such as phase correction, if needed. The push-pull output stage (the two small-signal type transistors) in the figure above serves as a low power amplifier to produce a typically 9Vrms signal at about 50mA.

Gyroscope Pickoff Output

As described earlier, the gyroscope pickoff output is also an AC signal. The magnitude of the output signal is dependent upon the amount of coupling between the primary coil and either or both of the secondary coils. The figures 2A through 2C below further clarify this point.

Figure 2A shows a pickoff output *in phase* with the AC excitation voltage fed to the primary. Note the phasing marks (dots) on the PRI and SEC 1 coils in the schematic diagram of figure 2A. The dots are on the same side of the symbol for the coil. This indicates that the output of SEC 1 will be *in-phase* with the primary. Also note the waveforms. The pickoff secondary waveform is shown to be *in phase* with the primary excitation waveform. Finally, the model of the pickoff shows the coupling core "tilted" towards secondary coil #1. The model depicts how secondary coil #1 is coupled to the primary coil via the permeable core. Note the basic flux path. It shall be recognized that there is also some coupling occurring in secondary coil #2 as well. However, the differential signal will be the result of the stronger signal plus the weaker signal (which is necessarily of opposite phase).
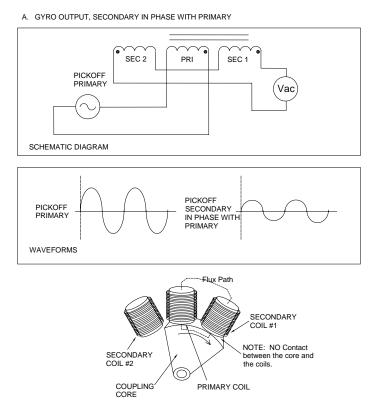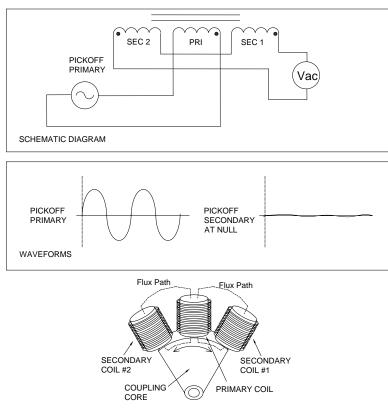

Figure 2A - Pickoff Output - In Phase with Primary

Figure 2B shows a pickoff system at *null*. Here it can be observed that the coupling core is generally midway between both secondary coils, and is centered under the primary coil. The output of both secondary coils is approximately equal. For example, secondary coil #1 may have a .5VAC signal which is in phase with the primary excitation signal. Also, secondary coil #2 may have a .5VAC signal which is out of phase with the primary excitation signal. These two signals of opposite phase when added to each other nearly completely cancel out. The output is essentially 0.0VAC when observed on an AC voltmeter.

In practical pickoffs, there is always some minimal amount of null voltage, usually on the order of a few millivolts AC. The reason for this is that, realistically speaking, no two secondary coils are identical. Therefore, one of the two in the set will be slightly stronger in output than the other. In addition, interwinding effects such as a parasitic capacitance adds to non symmetries (including phase shifting) of the sinewaves contributing to the null voltage.

B. GYRO OUTPUT, SECONDARY AT NULL

Figure 2B – Pickoff Output – At Null

Finally, figure 2C shows a pickoff system with the output out of phase with the primary excitation signal. This figure shows the opposite case of that of figure 2A. The core is now coupling strongly with secondary coil #2. Note the *reversal* of phase in the waveform shown. It is then clear to see that the phase relationship of the secondary waveform with respect to the primary excitation waveform can give information about the direction of *tilt* of the coupling core with respect to the physical orientation of the coils.

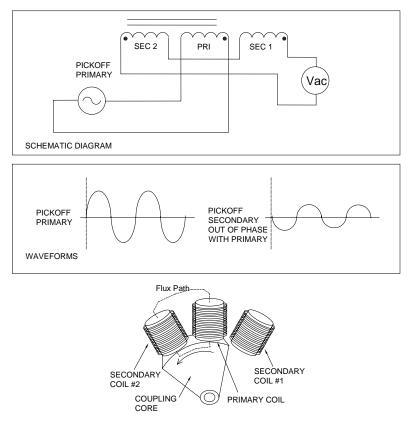C. GYRO OUTPUT, SECONDARY OUT OF PHASE WITH PRIMARY

SEC 2   PRI   SEC 1

PICKOFF
PRIMARY

Vac

SCHEMATIC DIAGRAM

PICKOFF
PRIMARY

PICKOFF
SECONDARY
OUT OF PHASE
WITH PRIMARY

WAVEFORMS

Flux Path

SECONDARY
COIL #2

SECONDARY
COIL #1

COUPLING
CORE

PRIMARY COIL

Figure 2C - Pickoff Output – Out of Phase with Primary

The magnitude of the output waveform indicates the degree of tilt of the coupling core with respect to the physical locations of the coils.

This AC signal can be read on a voltmeter directly if magnitude *only* is of interest. However, as stated earlier, if the direction of tilt, e.g. clockwise versus counterclockwise, is of interest, a pickoff signal demodulator is required. The demodulator is basically a rectifier that converts the AC output into a DC voltage.

The demodulator must be phase sensitive in order to give information about the direction of the motion affecting the coupling core. The demodulator decides if the output signal is in phase or out of phase with a reference signal. The reference signal is usually the primary excitation.

The demodulator also scales the magnitude of the signal into units convenient for the user. For example, if the gyroscope gimbal is free to rotate ±1 degree and the user wants a ±5V full scale output, then the demodulator gain must be such that it can provide a 1V per 0.2 degree of rotation, etc.

Gyroscope Pickoff Demodulator Basics

The gyro pickoff output requires demodulation to convert the AC output voltage to a directional (±) DC voltage. A phase sensitive demodulator is therefore required. A representative sample of a simple phase sensitive, synchronous demodulator is shown in figure 3 below.
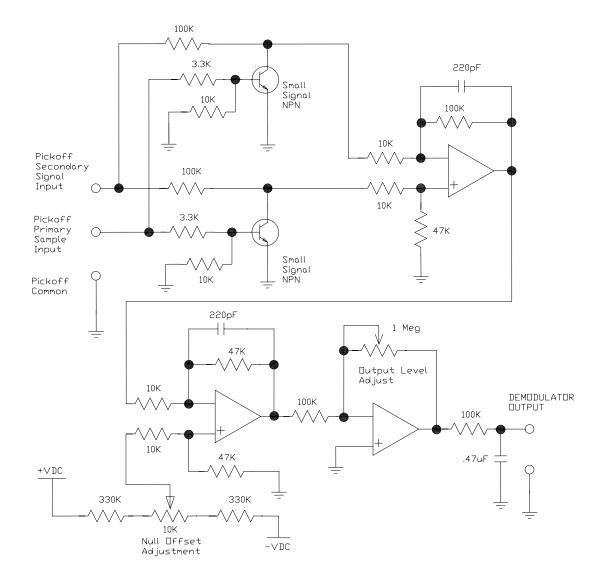
Figure 3 – Phase Sensitive Synchronous Demodulator

As stated earlier, the output of the gyro pickoff (output signal generator) requires demodulation if the output of the gyro is to provide direction of gimbal rotation in addition to absolute magnitude of the rotation. In other words, the output of the pickoff could simply be monitored with a true RMS voltmeter (reading AC) to give the *magnitude* only of the rotation sensed by the gyro, as a voltage. However, most applications do require the sensed rotation direction as well, and would therefore require a phase sensitive demodulator.

Figure 3 shows circuitry generally based on the following three important sections. First, two transistors and the first operational amplifier (op-amp) make up the phase sensitive synchronous rectifier. This rectifier changes the AC signal into either a positive or negative voltage depending on if the phase of the pickoff secondary is in phase or out of phase with the primary excitation voltage. The transistors are operated in phase with the primary excitation signal, hence, *synchronous* with the primary excitation signal. Second, a null offset control is present at the second op-amp. This control allows the output of the

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synchronous rectifier to be shifted slightly about the true AC null seen at the pickoff secondary. Third, the last op-amp amplifies the DC output into a useable voltage which may be scaled to the needs of the user.

The synchronous demodulator works as follows (refer to figure 4). When the secondary voltage is in phase with the primary excitation (which used as a reference voltage for the demodulator), the positive portions of the sinewaves are grounded by both transistors. This occurs because the positive portion of the sinewave is fed into the base terminals of the transistors. This turns the transistors on, thereby grounding the positive portion of the signal and preventing it from reaching the amplifier. Therefore only the negative portion is amplified, and a negative output alone is present. In this way the circuit acts as a phase sensitive synchronous rectifier.
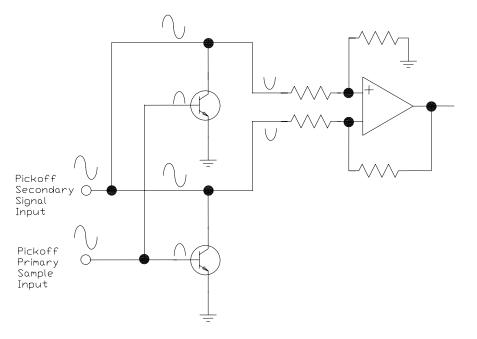

Figure 4 – Phase Sensitive, Synchronous Rectifier

Likewise, when the pickoff secondary output is out of phase with the primary excitation, the negative portions of the sinewaves are grounded by both transistors. Therefore only the positive portion is amplified, and a positive output alone is present. Note that the NPN transistors switch-on (to ground out a signal) only on a positive going cycle of the primary excitation reference voltage input.

Additional filtering and amplification of the signal is usually required. Figure 3 above shows two additional amplifiers after the synchronous rectifier stage explained in Figure 4. The second amplifier serves as an offset control to allow the output of the circuit to be matched to the actual pickoff characteristic when at null. When the AC rms output of the pickoff secondary is at its lowest level, the pickoff is said to be at null. An adjustment such as the one on the second amplifier can offset the DC voltage produced in the synchronous rectifier stage. The Third amplifier is simply a DC gain stage which allows the DC output to be scaled to the preference of the user.

After the third stage an RC (capacitive) filter is applied. In addition, phase corrections may be implemented if the need arises at the third amplifier.

Putting the System Together

A typical transformer based gyroscope pickoff system of excitation, output characteristics, and signal conditioning has been presented in the discussions above.
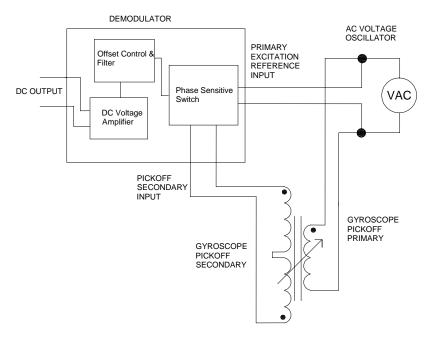

Figure 5 – Pickoff System Block Diagram

Figure 5 presents a simplified block diagram view of a typical transformer based gyroscope pickoff system described in this note.

As stated earlier, the transformer coils may remain fixed with respect to the coupling core, which may be affixed to the gyroscope gimbal which is free to rotate albeit limited to usually ±3° or less. The system can also be operated with the coupling core fixed with respect to transformer coils which would then be free to rotate. These design details are usually determined the gyroscope designer.

The coupling allows the variable transfer of energy from the primary windings of the transformer to the differentially wound secondary coils via magnetic lines of flux. In this way, a non-contact, frictionless instrument is realized for determining the amount of gimbal rotation in the gyroscope. In some *real* systems, a slight reaction torque (force) generated by the pickoff may be present but is usually insignificant and can be ignored.

Since the pickoff is an AC transformer, an AC signal must be fed to the pickoff primary, and the interpretation of an AC signal from the pickoff secondary must be made. The AC input is typically provided by a sinewave oscillator. The interpretation of the pickoff output signal is made with the use of a phase sensitive synchronous demodulator. The demodulator rectifies and scales the pickoff output signal to allow a determination of direction and magnitude of gyroscope gimbal rotation.

The discussions and sample circuitry presented above should allow system designers and test engineers to gain a basic insight as to the requirements for operating a transformer based gyroscope pickoff, for either end use system design, or gyroscope test system design. The ideas presented herein can be extended by the user to meet any gyroscope pickoff transformer requirement.