Further Development of an Electromagnetic Position Sensor for a Wind Tunnel MSBS

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ABSTRACT

An Electromagnetic Position Sensor (EPS) was successfully developed in the 1960's for the MIT "6-inch" Magnetic Suspension and Balance System. An updated version remains in use today, based on analog electronics. This paper will review the hardware revisions made to successfully adapt the system for use in sensing 3 degrees-of-freedom motion of small spherical or near-spherical suspended models. Practical challenges related to electrical noise sensitivity and stray coupling paths will be discussed. Preliminary analysis of alternative demodulation approaches, including digital signal processing, will be reviewed.

1. Introduction

The EPS system, originally developed at MIT in the 1960's [1,2], resembles a multi-axis Linear Variable Differential Transformer (LVDT). The full coil array is depicted in Figure 1. A 20kHz excitation field couples to an array of pickup coils, with the coupling a function of position and orientation of the levitated model. The current system is used for 3 degree-of-freedom sensing of spherical or cylindrical soft iron or permanent magnet cores to permit static and dynamic testing of planetary entry capsule shapes. A second MSBS EPS was attempted by the University of Virginia [3], but was unsuccessful owing to technical drawbacks inherent to the specific installation environment.

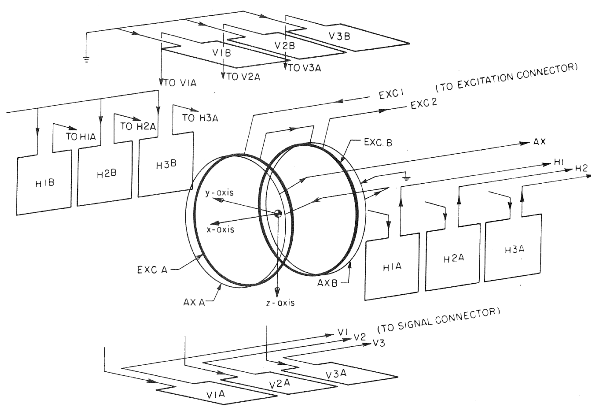

Figure 1 – Schematic of the MIT EPS

2. Theory

A pair of excitation coils, driven from a power amplifier, carry a 20kHz sinusoidal current. Since the coils have significant inductance, a series capacitance is added, creating an RLC configuration, which operates close to resonance. The current produces an oscillating magnetic field along the axis of the test section. For simplicity, the pickup coil geometry was designed such that the received signal tended to be null with no model present, or with the model present but located at the geometric centroid of the EPS "cage". Due to the effect of asymmetries and stray coupling, nulling stages, where the reference signal can be remixed with arbitrary amplitude and phase, are included ahead of the phase-sensitive demodulators.

Coupling variations arise due to model motion, by two distinct mechanisms – fluctuating magnetization of a soft iron core or induced eddy currents in the surface of a conducting core. Using subscripts PA for power amplifier, E for excitation, M for signals related to an iron core and C for signals related to a conducting core, the following relationshipscan be developed, with electromagnetic and geometric constants of proportionality omitted for simplicity:

$$B_M \propto M_E \propto B_E \propto I_E \propto V_{PA} = V_0 Sin(\omega t)$$

$$B_C \propto I_E \propto \frac{dB_E}{dt} \propto \frac{dI_E}{dt} \propto \frac{dV_{PA}}{dt} = V_0 Cos(\omega t)$$

$$V_{out} \propto \frac{dB_M}{dt} \; or \; \frac{dB_C}{dt}$$

In both cases, the pickup coils detect rate of change of radiated fields. It is seen that the pickup signal phase will vary by around 90° depending on model characteristics.

3. Evolution of the MIT EPS

The original electronics performed summing and differencing required to extract the vertical, lateral, pitch and yaw signals prior to demodulation [1,2]. The first generation rebuilt electronics at NASA [4,5] reversed the sequence of these two steps as shown in Figure 2. The electronics have since been rebuilt again, with improved filtering and ease-of-use.

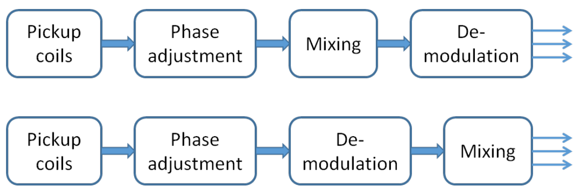

Figure 2 - Simplified EPS block diagram
Prior (upper) and present (lower)

4. System Performance – Existing Analog Electronics

By way of example, some signals have been recorded to illustrate the operation of the system. The model cores were a 1 inch diameter NdFeBo permanent magnet sphere, or a 1 inch diameter iron sphere. It can be seen that the phase shifts between the reference and

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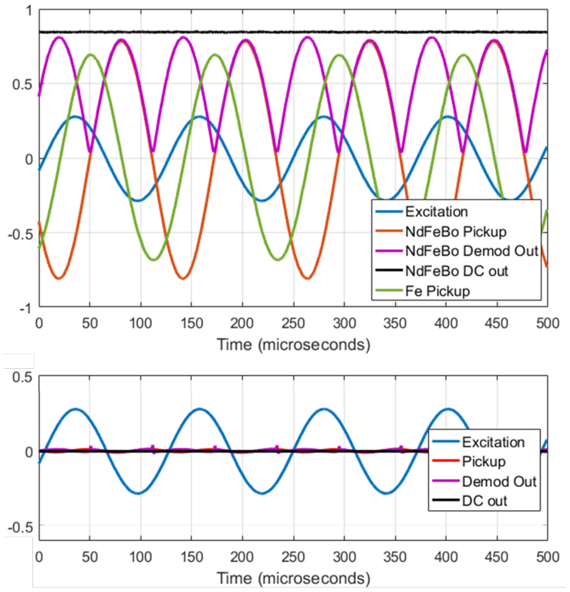

Figure 3 – EPS signals
NdFeBo and Iron cores, x=+1 inch (upper)
NdFeBo core centered (lower)

received signals for the NdFeBo and iron cores differ by roughly 90°

5. Practical Problems

The EPS is an electromagnetic sensor operating inside an electromagnetic levitation system with high amplitude time-varying magnetic fields. A long-standing problem has been rejection of spurious noise. In early implementations, 3-phase thryatron or thyristor power amplifiers switched at 180Hz. Rich harmonics spread across the frequency band, such that relatively complex filters were required in line with each electromagnet. In the new implementation, the power amplifier switching frequency is 51kHz, well above the EPS carrier frequency, such that no filtering of electromagnet currents seems to be required. A strong 51kHz component is present in the EPS outputs (Figure 4), but is reasonably well rejected by the demodulators with residual ripple relatively easily filtered.

Signal transmission paths exist outside the EPS cage,

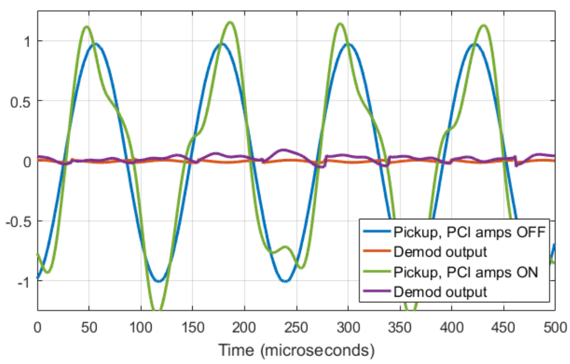

Figure 4 - EPS signals with and without main power amplifiers active (showing 51kHz interference)

which is surrounded by conducting and/or magnetic material, notably aluminum structure, iron electromagnet cores, and copper windings. The signal nulling process compensates for fixed secondary transmission paths, but one particular issue remains. At some point in the past, an electrical short developed in one of the magnetizing coils, perhaps due to temporary obstruction of a cooling passage when operating at high current [6]. The work-around was to short circuit the ends of the affected conductor loops, removing about 30% of the electromagnet capacity. It has been found that the shorted turns contribute to signal coupling in the EPS, with strong temperature dependence as the electromagnets heat up in use.

6. Possibility of Digital Signal Processing

Direct A/D conversion of the excitation and pickup signals, followed by some form of cross-correlation implemented in software, potentially removes the need for most of the hardware adjustments. For example, two 20kHz sine waves, with representative noise and phase shift added to the 2nd, can be processed by an FFT algorithm, with the results for the 20kHz "bins" used to give relative amplitude with insensitivity to phase. Figure 5 indicates that good performance is possible.

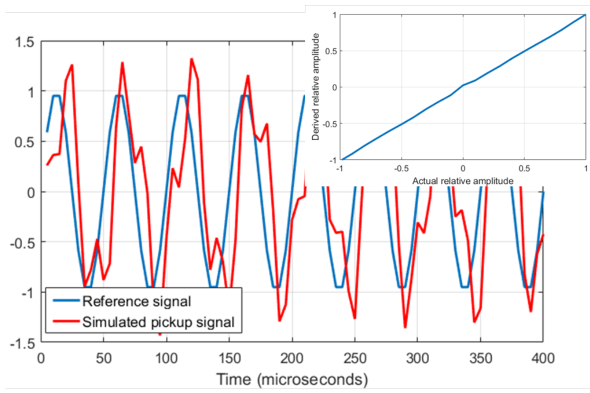

Figure 5 - EPS simulation with direct A/D conversion

7. Concluding Remarks

The EPS continues to be a viable and attractive choice for position sensing in wind tunnel MSBSs. Further performance improvements are anticipated.

Acknowledgements

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References

[1] T. Stephens, MIT-TR-136/NASA CR-66903 (1969)
[2] T. Stephens, in 2nd International Symposium on Electro-Magnetic Suspension, July 1971
[3] W.R. Towler, in 2nd International Symposium on Electro-Magnetic Suspension, July 1971
[4] T.S. Daniels, J.S. Tripp, ISA 88-0708 (1988)
[5] T. Schott, et.al., NASA CP-3152 (1992), 709-740
[6] Anon. Wind tunnel logbook, 1972. Unpublished