Oscillator/Demodulator to Fit on Flexible PCB
ECE 4901 – Senior Design I

Team 181

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Final Report

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Summary

Linear variable differential transformers (LVDTs) are used in many sensing applications worldwide. Trans-Tek Incorporated is a leading manufacturer of these devices, which require peripheral oscillators and demodulators to function properly. Trans-Tek wants to design a new oscillator/demodulator model to fit inside a 0.7 inch diameter casing along with an LVDT, to reduce size and contain all necessary parts of the oscillator/demodulator/LVDT module within a compact space. Trans-Tek has specified that the demodulation performed by the device should be accomplished using digital signal processing (DSP), while the oscillator portion can be achieved using a hardware circuit. The two circuits will be designed on a proto-board first, debugged, and then placed on a PCB to be implemented with an LVDT inside the 0.7 inch housing.

Background

As technology has improved dramatically over the past few decades, the demand for accurate and reliable measuring devices has also increased. Trans-Tek is a company that focuses on measuring devices, and has a strong reputation for making reliable and accurate linear variable differential transformers (LVDTs). Our project will focus on the combination of these LVDTs, with an oscillator/demodulator circuit. It is paramount to understand these devices and their purpose to fully understand the project at hand.

LVDTs, also known as differential transformers, are electrical transformers that measure linear displacement. This robust device converts a linear displacement signal into an electrical signal. This information contains the direction and amplitude of that signal. It is important to note that the linear displacement signal is referenced off a “null position” or “zeroed” position (mechanical reference). The reason it is said that these devices are so reliable is because there is no electrical contact between the core assembly and the coil. Signals observed from the LVDT depend upon the electromagnetic coupling between the stationary coil and core assembly. This allows the device to survive in extreme heat or cold temperatures.

The oscillator/demodulator device works side by side with the linear variable differential transformers. It is a signal-altering tool that introduces a signal at a certain
frequency to a displacement probe. The output produced by that probe is demodulated, which yields output signals that are relational to the average and dynamic gap distances of that specific probe.

The combination of these devices allows one to obtain a signal and alter it, yielding a set of useful and accurate data.

**Oscillator**

The first part of the device will have 3 sub parts: a voltage regulator, oscillator, and amplifier. The voltage regulator will take the input voltage of 11.5 V to 30 V and keep it a near constant value of 12 V if possible, or a little lower if needed. The output of the voltage regulator will be used to power the amplifiers throughout the circuit as well as an input voltage for the resistor and capacitor components. For the oscillator portion of the device, the output must be a sinusoidal wave form. The total harmonic distortion must be less than 1%. The frequency range needs to be between 1.5 KHz to 12.5 KHz. This will be selectable from a resistor capacitor combination. The oscillator will then drive a primary coil of 50 Ω or greater. The third sub part will be the amplifier. This part of the circuit will take the output of the oscillator and then amplify it to meet the specifications of 1 to 6 VRMS. The amount of amplification will be determined by a variable resistor, the minimum and maximum amounts of which will produce a sinusoidal waveform with the upper and lower voltage limits.

There were three main choices for designing the oscillator: modifying Trans-Tek’s current oscillator model, building a new analog oscillator model from scratch, and using DSP to generate the oscillations. Each choice has advantages and disadvantages. Building a new analog oscillator from scratch would be significantly more difficult and time consuming than modifying the current model, but it would lead to a far deeper understanding of the circuitry involved. There could also be stability issues with designing a new oscillator. Using DSP would reduce the number of component parts needed, but may introduce programming issues into the system, as well as waveform distortion due to sampling. There would also be concerns of the oscillator stability with this design. Modifying Trans-Tek’s current model would be easier to achieve than
building a new oscillator, but tuning it to match the new specifications may prove difficult. The current model is very stable, however.

Because of these reasons, the final design choice that was decided was modification of the current oscillator model. While new resistor and capacitor values will be required to meet the device specifications, this design is still preferable to building a new oscillator from scratch.

**Demodulator**

The function of the demodulator is to receive a signal from the LVDT output and convert it into a useful signal for the corresponding readout device. Due to the design of the LVDTs to be used with this system, this conversion will be from an AC signal to a DC signal. The output from the LVDT will be a sine wave, with an amplitude that varies with respect to the distance from the LVDT core to the null position, and a phase that varies with the direction of the core’s movement from null. The demodulator will receive the LVDT output signal and a reference signal from the oscillator, and compare their amplitudes and phase shift to output a corresponding DC signal.

![Figure 2: The ideal demodulator output voltage, with respect to LVDT core position.](http://www.singer-instruments.com/sites/default/files/images/tutorials/how_lvdt_works_fig3.gif)

Because of the subtractive formation of the LVDTs secondary coils, its output will have a range from $-V_{\text{max}}$ to $+V_{\text{max}}$, where $V_{\text{max}}$ is the maximum amplitude, and 0 will be the default output (when the core is in the null position).

Trans-Tek’s specifications for the demodulator are as follows: input impedance of 1MΩ or greater, selectable output ranges 0-5 VDC, 0-10 VDC, 0.5-4.5 VDC, 0.5-9.5
VDC, ripple voltage of less than 0.2%, non-linearity of less than 0.03%, and temperature coefficient best effort. These device specifications must be met in order to consider this project a success.

The design of the demodulator could be done with two different approaches: using an analog demodulation circuit, or designing for DSP-based demodulation. Using an analog circuit would be simpler for the initial design, because the current demodulator design is composed of analog components. However, it would be challenging to modify and tune, as new circuit components would be required every time changes were made. A DSP-based demodulator would be harder to implement initially, as Trans-Tek currently has no DSP-based systems. However, tuning the demodulator would be far easier with DSP, and the size of the system would be greatly reduced. However, this method would introduce some additional necessary circuitry, such as circuit to apply a DC offset to the reference and LVDT output signals. However, Trans-Tek has specified that a DSP approach would be preferred to an analog approach, and as such, the demodulator design was chosen to be a DSP-based system.

There are two possible approaches to the demodulator design using DSP. Either an embedded microcontroller or a digital signal processor chip can be used. However, due to the size constraints of the design, a microcontroller is a more optimal choice. DSP chips tend to be larger, and while they are designed for use with DSP, they are both larger and more expensive than most microcontrollers. Because only a single signal must be processed in this system, it will be better to use a microcontroller, as it can achieve the same function as a DSP chip while staying within both the size and monetary budgets of the project.

An external and internal flow diagram of the DSP system can be found below.
The demodulator will receive the LVDT output and reference signal from the oscillator, and apply a DC offset, as the microcontroller cannot receive negative voltages for its ADC inputs. It will converts these to digital signals, and perform amplitude and phase comparison. Based on the amplitude ratio and the phase shift, the microcontroller will output the appropriate DC signal after performing the necessary calculations.
**PCB Design**

One of the most critical aspects of our project revolves around the integration of a PCB into the housing of our LVDT. Numerous solutions were devised to resolve this problem. It was proposed by Trans-Tek that we use a flexible PCB for this design. This option focused around the idea that the flexibility of the PCB would offer more space to fit inside the LVDT housing. After looking over this possibility, we determined that the space gained is so small it is almost negligible. Seeing as the flexible PCB can be four times as expensive as a rigid PCB, less reliable, and cause issues down the line with circuit components, we decided to choose a rigid PCB design. It is also important to note that rigid PCBs can be manufactured at different thicknesses. This option may be useful when it comes to fitting the oscillator/demodulator circuit into the LVDT. Considering the bulk of the PCB designing will take place during our second semester, there is still time to change our decision if necessary.

If the space within the LVDT is not enough for the newly designed PCB, Trans-Tek also gave us another option. This would include extending the LVDT housing, but stopping the inner tube and coils. This would allow us to take advantage of the entire .7 inch diameter tubing, rather than squeezing into a space less than half an inch (.491 inches). Though this is not the ideal plan, it can be used as a first generation prototype.

A diagram of the LVDT cross-section, showing the available space for a PCB, can be found below.
Progress

As of December 2013, the oscillator prototype is under construction. After the build is completed, testing and modification of the prototype will be performed. The demodulator microcontroller has been purchased, as well. Preliminary coding will begin, and testing will be undertaken using a function generators for the input signals. PCB design software has been investigated, for the eventual PCB design for the oscillator/demodulator.

Timeline

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So far, we’re slightly ahead of schedule. Some changes have been made to the original timeline. We finished the schematic and ordered the parts ahead of schedule, so changes have been made accordingly. If this timeline is followed closely, we shouldn’t fall behind schedule and finish on time. The timeline used to seem ambitious but we’ve been keeping up with the timeline easily. Prior experience indicates that there will likely be unforeseen problems, especially in the building phase, which is why the debugging
process is expected to take so long. Following this schedule closely should ensure that the project is completed successfully on time.

There are still some questions that remain that we have been working towards an answer for such as: what kind of microprocessor are we going to use for the project? Will it fit onto the flexible PCB? Does it handle the tasks it needs to handle? Does it meet the required specifications? Will the rest of the circuit need to be adjusted in order to compensate for any of the specifications? These are just some of the things that must be accounted for.

The proto-board build is such a crucial aspect of this project because it must be completed before any PCB building can take place. The PCB build is much harder to change, so the circuit must be built and debugged on a proto-board, which is much easier to change. Debugging the proto-board may take a very long time, but it is a vital aspect to the project and must be performed accurately and completely.

**Budget**

Trans-Tek has offered to cover any expenses necessary in the design and implementation of the oscillator/demodulator circuit. The bulk of our costs should be from the component parts for the proto-board and PCB. These include operational amplifiers, capacitors, resistors, and a microprocessor. Other expenses will be from the PCB itself, which may cost significantly more if a flex or rigid-flex PCB is used. Regardless of what materials are used, the overall expenses should be significantly less than the $1000 budget provided by the University of Connecticut’s Department of Electrical and Computer Engineering. So far we’ve bought parts for the prototype build and we’ve only spent $95, which was funded by Trans-Tek. Total project costs, based on this, should not exceed $500. One aspect of the oscillator/demodulator design that will affect costs is the high precision required by many of the circuit components. Because of this, military-grade components were purchased for the oscillator prototype, which cost significantly more than commercial-grade products.