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UNIPROBE: Universal Inductive Proximity Probe Design and Testing

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1. Introduction

Currently, there are thousands of proximity probe series, part numbers, types, and lengths available for many industrial applications. The variety of options makes ordering a challenge for users to choose the correct type. This paper presents a senior design project that aims to create a universal inductive proximity probe that can be mounted into any machine casing, that is backwards compatible with many standard proximity probe drivers, that uses a newer, low-cost body, cable, and connector that will make the ordering process for users much simpler. The universal proximity probe aims to be API standard 670 compliant and suitable for machinery protection systems across the world. The universal proximity probe will be suitable for a wide range of vibration measurement applications such as radial shaft vibration, shaft axial position, piston rod drop and much more. The proposed UniProbe will drop the need for users to choose the correct series type, since the probe will be backwards compatible with current systems, there is only one system to choose from. The cable and connector will also be designed to be backward compatible with current hardware. The probe body will be designed in a way to fit into most machine casings. Users will simply choose between metric or standard threading, which makes the ordering process much simpler.

2. Background and Principles

Figure 1 shows a cut-away view of a machine bearing casing with two proximity probes mounted 90º apart, highlighted in pink, the eddy current field visualized in blue, and the output displayed on a computer monitor.

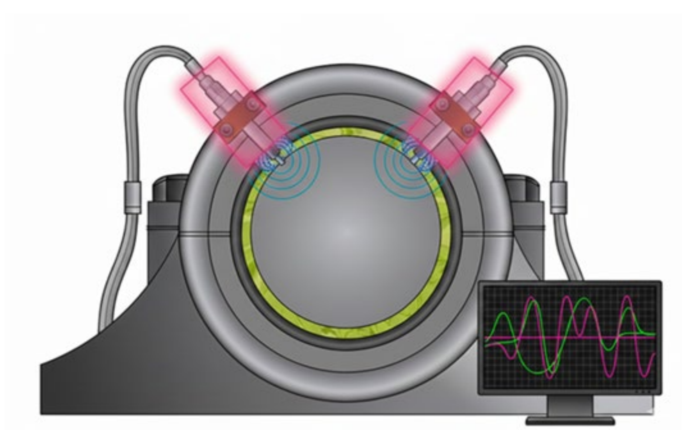

Figure 1. A cut-away view of a machine bearing casing with two proximity probes

2.1. Inductive Proximity Sensor Principles

Inductive proximity sensors, also known as eddy current sensors, are non-contact devices used to measure the position or vibration of a metallic target. Proximity probe systems operate on the principle of electromagnetic induction and have the following specifications.

1. Magnetic Field Generation: The Probe Driver (oscillator) sends a high-frequency AC signal through the probe's inductive coil, creating an alternating magnetic field at the tip. Figure 1 illustrates the probe's electromagnetic field with the use of the blue waves emanating from the probe tip.
2. Eddy Current Formation: When a conductive metallic target (such as a 4140 stainless steel shaft) enters the field, the magnetic field induces small circulating electrical currents, called eddy currents, on the target's surface.
3. Energy Loss: These eddy currents create their own opposing magnetic field, which reduces the strength of the probe's original field. This results in an energy loss in the sensing circuit.
4. Signal Conversion: The driver detects this change in impedance and converts it to a DC voltage. As the distance (commonly referred to as the "gap") between the probe tip and the target increases, the voltage output increases linearly, typically at a rate of 200 mV/mil.

2.2. API Standard 670

The American Petroleum Institute (API) Standard 670 is the industry-recognized benchmark for Machinery Protection Systems (MPS). It establishes the minimum requirements for sensors used to monitor critical machinery, such as turbines and compressors, where failure could result in catastrophic damage or personnel injury. API 670 requires specific materials and electrical protection because sensors are often mounted in hazardous areas where flammable gases may be present. To ensure interchangeability, the standard specifies probe tip sizes (e.g., 5mm or 8mm) and electrical sensitivity (7.87 mV/µm).

In addition to radial shaft vibration, the standard covers measurements of the machine's external housing or casing. It outlines requirements for sensors that monitor how fast a shaft is spinning and provides logic for "over-speed" protection to prevent mechanical failure. API 670 sets minimum requirements for measuring "critical machinery temperatures," such as bearing metal temperatures using thermocouples or RTDs.The standard covers "phase reference" (often called a Keyphasor), which is essential for determining the timing of vibration relative to shaft rotation. Beyond rotating machinery, it includes monitoring for piston rod drop (which the UniProbe is designed to support) and surge detection for compressors.

While the UniProbe focuses on displacement and radial vibration , API 670 is a multidisciplinary standard that also governs the requirements for casing vibration, rotational speed, over-speed protection, and critical machinery temperatures. This ensures that all vital health parameters of a machine—not just shaft position—are monitored under a unified safety framework.

2.2 Problem Definition and Objectives

Currently, the market is saturated with thousands of proprietary part numbers and cable lengths from different manufacturers, creating a significant "lock-in" effect. The UniProbe project addresses this by designing a single sub-assembly that meets the stringent industry standards while remaining compatible with existing hardware from multiple vendors.

An important condition will be meeting the requirements set forth by the American Petroleum Institute (API) Standard 670. The requirements outlined in the API 670 are stringent for a reason that the equipment compatible with API 670 is very likely to be mounted within hazardous areas. These areas require special protection for electrical circuits to ensure personnel are not harmed due to the unwanted ignition of hazardous gas caused by an electrical spark. The API 670 also sets forth requirements on suitable materials allowed for use within hazardous areas. Choosing a proper material for our sensor body will require some research to decide the best option.

The challenges that we will have to overcome in this project and testing procedures include:

- Designing a probe body that will mount into any rotating machine casing and allow the shaft travel distance to be monitored.
- Designing an inductive coil to mount at the tip of the probe that will create the eddy current and detect the target material.
- Integrating a new low-cost three-wire cable possibility while making it work seamlessly with the standard coaxial cable connector.
- Sourcing an electrical connector capable of withstanding industrial corrosive environments and extreme temperatures.

2.3 Technical Barriers

The absence of a universal inductive proximity probe in the industrial market is not due to a lack of demand, but rather a combination of commercial and technical factors that have favored proprietary ecosystems for decades. Traditionally, manufacturers have designed proximity probe systems as "matched" sets where the probe, extension cable, and driver are specifically calibrated to work only with one another. This proprietary approach ensures accuracy but forces users to navigate thousands of specific part numbers and series types to maintain their systems. To meet API 670 standards, the total system must maintain a strict linearity of 200 mV/mil. Achieving this with a "one-size-fits-all" probe is difficult because different drivers expect specific inductance (L) and capacitance (C) values from the probe and cable assembly. The industry has long relied on expensive coaxial or triaxial cables as mandated by the minimum requirements in API 670 documentation. Because these cables are standardized, there was little incentive for manufacturers to deviate toward lower-cost alternatives that might require complex re-linearization. Rotating machinery across the world features a vast array of casing thicknesses and mounting requirements. Historically, it was more straightforward for a manufacturer to sell dozens of different probe body lengths than to design a modular sub-assembly that could adapt to any machine. The UniProbe project challenges these traditional barriers by utilizing a novel sub-assembly and a trial-and-error engineering methodology to prove that a single, low-cost design can achieve backwards compatibility with industry-leading hardware.

3. Literature Review

Proximity Sensors have been revolutionary when it comes to gathering health state data on equipment that is inaccessible through the usage of vibrational signals. In which those vibrational signals conserve physical characteristics of the system by using two proximity sensors (across x and y) [1-2]. For example, machinery tends to be used continuously for years, exposed to harsh environments or even extreme conditions, resulting in the wearing down the equipment. Due to the consequences of failing machinery and increasing expenditure, companies try to find the issue beforehand through the usage of proximity sensors [3]. Generally, proximity probes have been known for their usage in detecting displacement and other faults in the system. However, proximity probes have also shown their usefulness in detecting bearing damage by removing the shaft frequency as well as harmonics produced in the system [4]. Removing those frequencies allows improved detection, resulting in detecting those bearing faults. In which it can be proven that when reducing noise, proximity probes can increase their distance resolution significantly [5]. Acquiring precise data provides an even broader application of those proximity probes such as welding. It is shown that when using proximity probes, it is possible to reach exact measurements in a gap's width and alignment [6]. Furthermore, proximity sensors can also be used to determine the coating of equipment placed due to harsh conditions. As seen, it is possible to gather data from the thickness of that coating within metal plates [7]. Attributable to various applications of proximity probes, companies need different specifications to attain their required data; as a result specific proximity probes are made to fulfill that need [8].

4. Engineering Approach

There was quite a lot of guidance sought at the beginning of the senior design project with experienced engineers to determine the most appropriate approach for completing the project. Students initially acquired help from an experienced mechanical engineer in the Machine Saver Company, who guided to design the body and the probe to allow the sub-assembly to fit inside. There were quite a few challenges to overcome that involved the practicality of the UniProbe body and the ease of installation. If the UniProbe is not easy to install, it will deter customers from purchasing the probe. Therefore, we had to design the body around these challenges, as the single body length design would require an extra installation tool to install the proximity probe in the threaded hole without damaging the cable extruding from the probe body. This could increase the total cost; therefore, the UniProbe is designed with a slot on the rear so that a regular screwdriver could be used to install the proximity probe.

This approach used to test the newer twisted-shielded cable was a trial-and-error methodology combined with LCR meter testing to compare cable lengths, Capacitance, Inductance and Resistance values as the lengths varied. The design of the probe sub-assembly and coil consisted mostly of trial and error. The sponsor, Machine Saver, Inc., allowed for the use of the coil winding machine so that multiple coil configurations could be tested with the multiple proximity probe drivers available. The ability for the universal proximity probe to work correctly with currently installed hardware is a large requirement and specification set forth at the beginning of the senior design project. Machine Saver, Inc. did not specify which exact proximity probe driver must be backwards compatible; the goal was to see how many driver and probe configurations could be copied with the universal proximity probe design. The goal established by the senior design team was to make the universal proximity probe backwards compatible with the Bently Nevada 3300 xl 5/8mm 5m or 9m driver as well as the Bently Nevada 3309 5mm 5m or 7m driver, and Machine Saver's TwinProx probe driver.

Data Collection Methods: The techniques used for testing and evaluating UniProbe are quite unique but simple. Inductive proximity probes measure the distance a metallic object moves or travels. As the distance increases between the proximity probe tip and the metal, the voltage output from the processing circuit increases from 0 V to 24 V. The voltage output can be measured using a digital voltmeter. In this case, a Fluke Digital Multimeter was used to read the output from the various proximity probe drivers. To measure the distance the metallic object moves away from the proximity probe, it is imperative to use a precise micrometer. For the data collection of the UniProbe, a Mitutoyo Micrometer (0-1") with a precision measurement of 1 mil (or 0.001") was used to measure the precise movement of the metallic object.

The metallic object used for testing and evaluating the accuracy of the UniProbe output is a round stock piece of Stainless Steel 4140. Stainless Steel 4140 is a typical material that industrial shafts are manufactured out of, as it is long-lasting. However, there are many different metallic materials that industrial shafts are produced from, such as 304 stainless steel, Inconel, and many others. The stainless steel 4140 used in this testing has a polished finish to provide more accurate results. Scratches and abrasions on the surface of the metal can be detected by most inductive proximity probe sensors, so it is imperative to polish and smooth the surface if necessary. The piece of stainless steel is a round circle and approximately 2 inches in diameter and 0.25" thick.

The micrometer and piece of stainless steel are fastened together in the "Static Calibrator" fixture. The static calibrator used for testing is shown in Figure 2. The probe is inserted through the collet and secured with the set screw on top. The probe tip is zeroed with a piece of 4140 stainless steel, meaning the stainless steel is in contact with the probe tip and cannot move any closer. Once the zero point is recorded, the micrometer can be turned to increase the distance the stainless steel target moves away from the probe tip. Turning it the opposite way moves the target material closer to the probe tip.

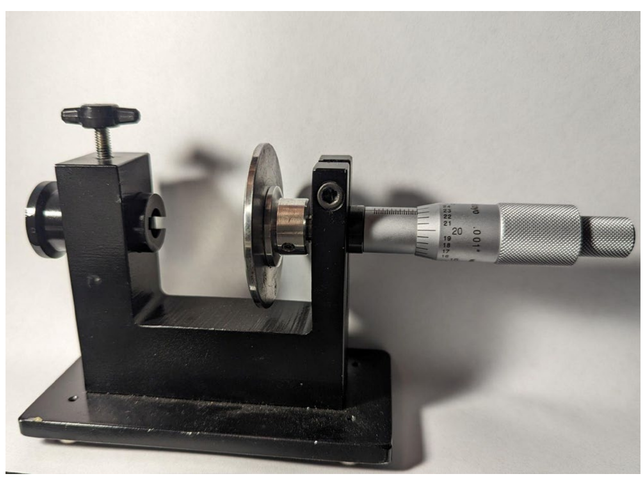

Figure 2. Static Calibrator

Data Analysis Procedures: According to the API Standard 670 documentation, the oscillator-demodulator output shall be 7.87 mV/µm (200 mV/mil) with a standard supply voltage of -24Vdc. The typical tolerance is +/- 10% of 7.87 mV/µm (200 mV/mil). However, for the

UniProbe, the goal is to have it within +/- 5% of 7.87 mV/µm (200 mV/mil) range. This measurement, of 7.87 mV/µm (200 mV/mil), is simply the slope coefficient of the line produced by the output of the oscillator-demodulator and proximity probe. To calculate the slope coefficient, the output is recorded at two different distances. For example, if the measurement taken at a distance of 254µm (10 mils) is 2.000V and the measurement taken at a distance of 1270µm (50 mils) is 10.000V then the slope or linearity is approximately 7.87 mV/µm (200 mV/mil) given by the linearity or sensitivity equation for a sensor as seen in Eq. 1.1 where $Output(Dist_2)$ is the output voltage at a distance $Dist_2$(mV), $Output(Dist_1)$ is the output voltage at distance $Dist_1$(mV) and the denominator $Dist_2 - Dist_1$ is the change in displacement in µm, or in mil (1 mil = 25.4 µm).

$$Linearity \left[\frac{mV}{\mu m}\left(\frac{mV}{mil}\right)\right] = \frac{Output(Dist_2)\text{-}Output(Dist_1)}{Dist_2\text{-}Dist_1} \qquad \text{Eq. 1.1}$$

To visualize function, the output is plotted on a distance versus Volts line graph as demonstrated in Figure 3. The output line in red is from the Oscillator-demodulator and the UniProbe connected together. The output line in blue is a demonstration of what an ideally perfect output would look like. However, when applied to the real world, the output may not be exactly zero at zero mils because the circuit does not oscillate at that low of a distance or output value.

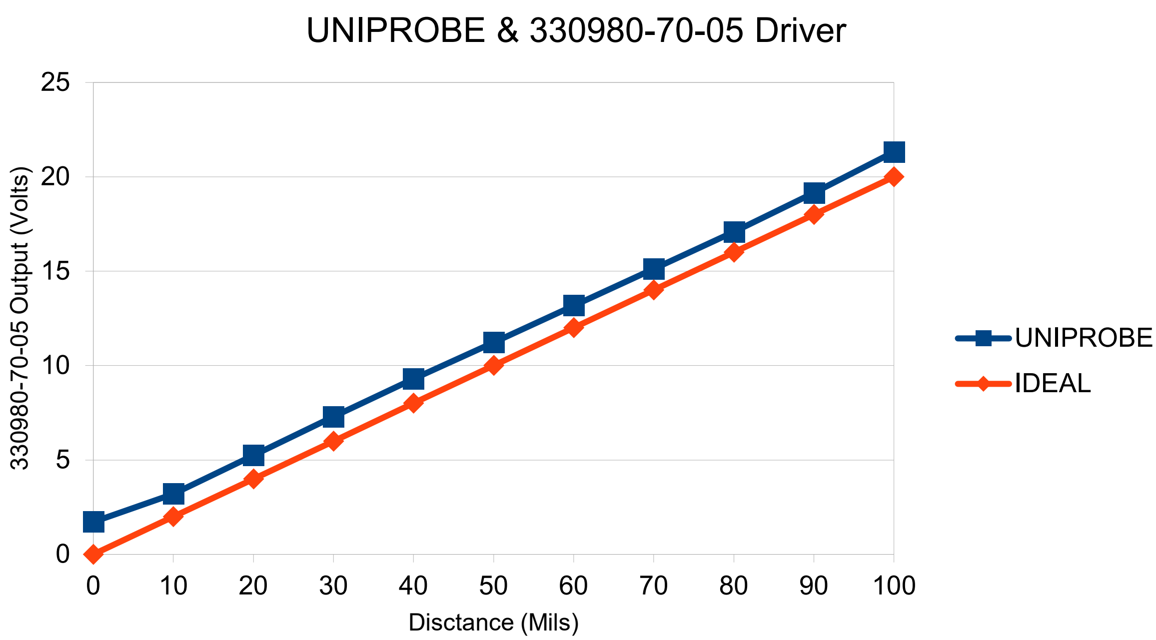

Figure 3. Oscillator-Demodulator and UniProbe output using the Eq. 1.1

Data Quality and Control: To ensure data quality and control when designing the UniProbe or universal inductive proximity sensor, it is imperative to ensure an accurate and linear response. It is also important to ensure the equipment used for testing is calibrated and accurate. The static calibrator was tested with multiple different proximity probes and proximity probe drivers or oscillator-demodulators to ensure the output is accurate and it is calibrated precisely. The proximity probe drivers used in the testing of the UniProbe are the standards used to manufacture other proximity probe systems provided by Machine Saver, Inc. but originally produced by

Bently Nevada, Metrix Instruments, as well as Machine Saver's Manufactured in the U.S.A TwinProx driver.

Ethics and Ethical Considerations: When designing a universal inductive proximity sensor, there are many ethical considerations to be aware of as the engineering work progresses. There are a few safety considerations, such as ensuring the sensor's electromagnetic fields do not interfere with nearby equipment. It is also important that there is no radiated or emitted noise from the circuit designed. On top of that, it is important to be aware of the environmental impact and minimize the electronic waste produced. Lastly, it is important to promote sustainable design practices and reduce the carbon footprint when designing and manufacturing millions of sensor products.

When designing an inductive proximity probe, we must also be aware of the sensor's energy consumption; there are tight tolerances per the API standard 670 documentation. Ensuring the sensor meets the industry standards is mandatory. Another goal of this project is to provide clear documentation and support for Machine Saver, Inc. to continue with this project into the future. As such it is imperative to be transparent and provide clear information about the sensor's functionality and limitations.

5. Methodology and System Design

The API standard 670 is the minimum requirements for a machinery protection system (MPS) measuring radial shaft vibration, casing vibration, shaft axial position, shaft rotational speed, piston rod, drop, phase reference, overspeed, surge detection and critical machinery temperatures. According to the American Petroleum Institute (API) standard 670 Machinery Protection Systems documentation, a proximity probe consists of a tip, a probe body, an integral coaxial cable or triaxial cable, and a connector. The probe tip used in the design of the Universal Proximity Probe will use a 5mm (or 0.22"). This 5mm probe tip is one of the standard sizes specified by the API Standard 670 documentation. The probe tip is currently used to match 5mm 3300xl, 0.190" 3000 series as well as the 3309 Narrow Side View proximity probe systems. Utilizing the smaller 5mm probe tip with a magnetic ferrite to enhance the eddy current magnetic field will allow for the most accurate measurements, bearing in mind that there should be no interference from metallic materials near the eddy current magnetic field.

The functional block diagram of a common inductive proximity sensor is shown in Figure 4. The difference between the common block diagram shown and the UNIPROBE design is that the entire cable and sensing core are one piece in the UniProbe. In a typical proximity probe installation, the proximity probe is only 1 meter in length, and an extension cable is required to connect the sensing core to the processing circuit. The UniProbe will extend approximately 7 meters in length, allowing for plenty of cable length to connect the sensing core to the processing circuit.

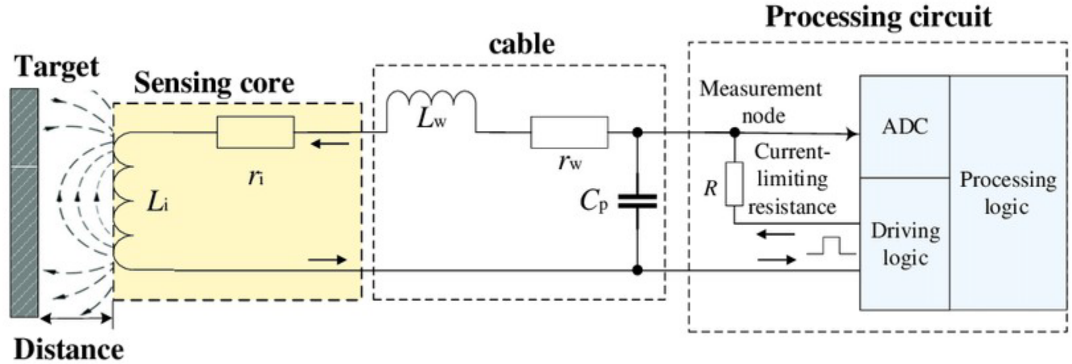

Figure 4. Functional Block Diagram of a Generic Inductive Proximity Sensor [1-2]

The API standard 670 documentation declares that the reverse mount probe, with an integral hex nut probe body approximately 25mm (1in.) in length should be used, unless otherwise specified. The reverse mount probe is not usable in rod drop applications so to make a universal probe a forward mount probe body design must be used in order to accommodate any machine casing. The forward mount probe body design is not flawed; the API Standard 670 documentation only calls for the reverse mount so that it can standardize within the documentation. At no point does the API 670 determine that forward mount probe bodies are unusable. Forward mount probe bodies are more typical in the real world at least from an anecdotal point of view. The sponsor, Machine Saver Inc., has certainly sold and distributed more forward-mount probe bodies than reverse-mount probe bodies, which leads to the UNIPROBE design leaning towards a forward-mount probe body style.

It is quite impractical to expect the UniProbe to mount into any machine casing as physics does not quite support this yet. There is simply no way to mount a ⅜-24 threaded body into a ¼-28 threaded hole. The hole is simply too small for the body. That is why the UniProbe uses a subassembly that can be used with any probe body. The proposed UniProbe design contains a 1.5 inch ⅜-24 inch body, which will allow the customer to use a single probe body length. This probe body design can be manufactured with the following thread sizes: ¼-28 UNF, M8x1 Metric, M6x1 Metric, and M10x1 Metric. The UniProbe body design includes two divots in the threading to allow space for two rubber O-rings. The O-rings act as a stopper to reduce the ability for the UniProbe to back out of the machine casing or recede further into the threaded hole. The O-rings limit the ability for the probe body to loosen from the high vibration seen during typical machine uses. As well as on O-ring to stop the probe from moving out of its intended position, the UniProbe has a designed stop nut which is mounted onto the back of the UniProbe body. The stop-nut can be threaded into the machine casing to mount directly onto the back of the UniProbe body, the force of the nut pushing it will keep the universal probe from receding out of the machine casing.

As a specification requirement from the sponsor company, Machine Saver, Inc., one goal was to replace the coaxial or triaxial cable specified by the API standard 670 with a newer lower cost twisted shielded pair cable option. The newer twisted-shielded cable pair option is easier to manufacture which in turn decreases the overall cost to produce a proximity probe as well as an overall reduced cost for the consumer.

6. Implementation of the Universal Probe

Implementing the design was certainly a challenge. In the earlier preliminary planning discussion with one of the more senior engineers, it was brought to the concern that perhaps the twisted shielded pair cable varied too much in inductance and capacitance as the length is varied. To test this theory, multiple cable lengths were tested with an LCR meter to determine the capacitance per foot and to determine how much variation is seen between the different distances. Table 1 contains the data acquired during this testing. The data in Table 1. suggest that there is some variation as the distance is increased. As the distance or length of the cable increases, the pf/ft decreases in somewhat of a curved shape. The decrease and increase are not exactly linear, which made linearization of the universal proximity probe even more of a challenge.

Table 1. Twisted Shielded Pair Cable Capacitance per Foot over different distances

Cable Length (in.)	Capacitance (pF)	Calculated (pF/ft)
390	745.42	22.94
378	721.87	22.92
366	698.41	22.9
354	674.99	22.88
342	651.36	22.85
330	626.88	22.8
318	621.73	23.46
315	616.42	23.48

The next step to determine how to make a linear output universal proximity probe was to measure the inductance and capacitance of the complete UNIPROBE system and compare it to the standard proximity probe driver system, such as the Bently Nevada 3309 NSV system. Table 2 and Table 3 compare the inductance and capacitance of the total cable lengths of the UniProbe system measured at different lengths to match as closely as possible to the Standard Bently Nevada 3309 NSV 7m system. Figure 4 and Figure 5 exhibit the plotted data for the twisted shielded pair cable over different distances. Figure 4 displays the inductance line graph of the twisted shielded pair cable as the length of the cable is increased. Figure 5 displays the capacitance line graph of the twisted shielded pair cable as the length of the cable is increased.

Table 2. Standard Bently Nevada 3309 NSV 7m system capacitance and inductance.

Bently Nevada 3309 NSV 7m proximity system		
Length (ft.)	Ls (mH)	Cs (pF)
26.1	93.165	-271.92

Table 3. Twisted Shielded Pair capacitance and Inductance compared to distance.

Twisted Shielded Pair Cable		
Length (ft.)	**Ls (mH)**	**Cs (pF)**
3	-367.731	68.89
9.5	-119.116	212.68
21	87.887	-288.26
26	151.777	-166.91
31	288.74	-87.74
36	-212.913	118.99

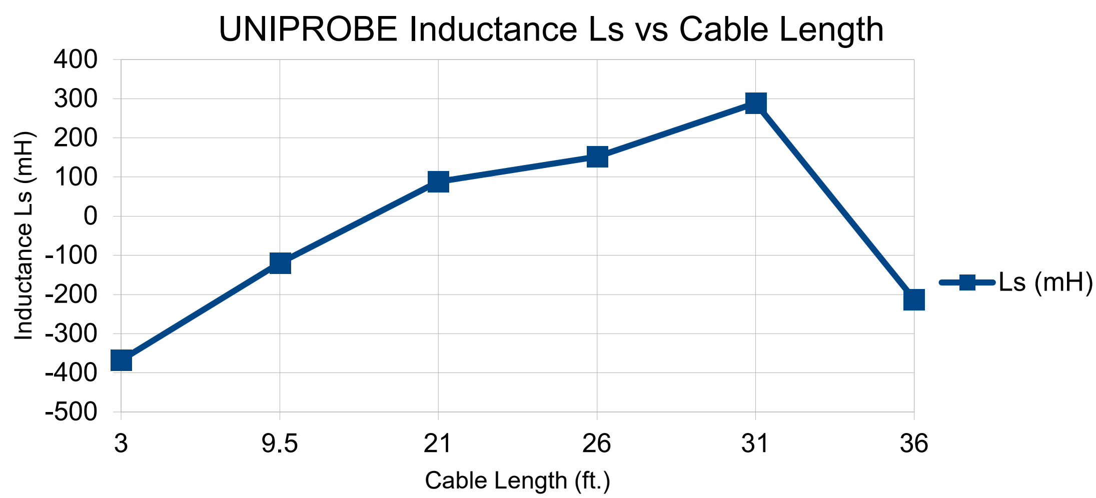

Figure 5. Twisted shielded pair inductance vs. cable length.

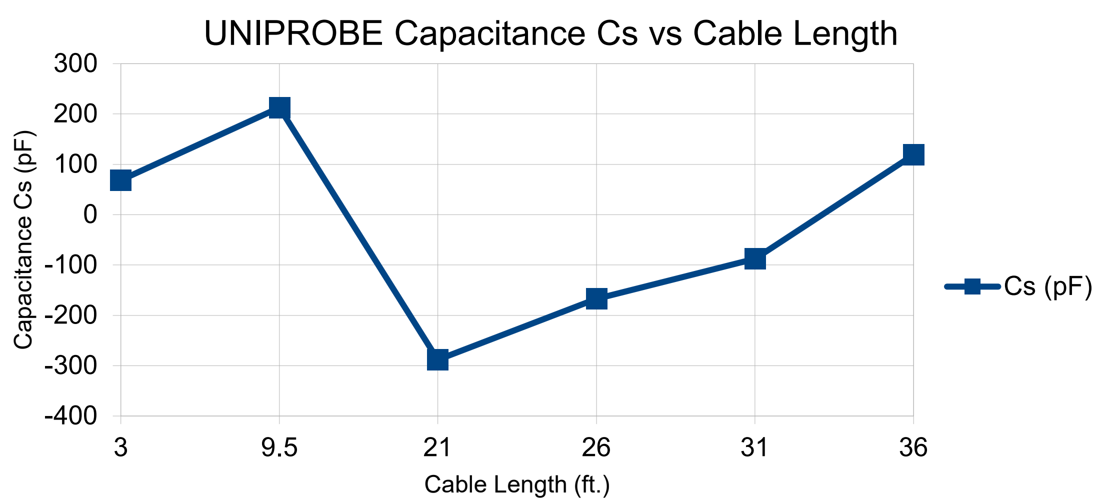

Figure 6. Twisted shielded pair capacitance vs. cable length

Once the cable capacitance and Inductance were matched to our Standard Bently Nevada 3309 NSV 7m Probe driver system, getting the output linear was simple. All that was left to do was to attach the coil that is epoxied in the cap to the cable and attach a connector to make the output connection to the Bently Nevada probe driver systems easier. Then, finally, test the UniProbe for backwards compatibility to other probe driver systems.

7. Test Results and Analysis

The experimental results were quite impressive. The UniProbe was linear the first time it was measured against the Bently Nevada 3309 NSV 7m probe system as shown in Table 4. The linearity was well within the specifications of +/-10% of 7.87 mV/µm (200 mV/mil). The plotted graph to match the data in Table 4 can be found earlier as shown in Figure 2. UniProbe was also tested against other Bently Nevada proximity probe drivers to determine the linearity and backward compatibility. The results from the Bently Nevada 3300xl 9m test are documented in Table 5 and are also within the specification of +/-10% of 7.87 mV/µm (200 mV/mil).

Table 4. UniProbe & Bently Nevada 330980-70-05 Probe Driver

Distance (Mils)	**UNIPROBE OUTPUT (volts)**	**Ideal Output (volts)**
0	1.716	0
10	3.194	2
20	5.25	4
30	7.29	6
40	9.3	8
50	11.23	10
60	13.18	12
70	15.12	14
80	17.09	16
90	19.15	18
100	21.32	20
Linearity (mV/Mil) =	199.45	200

Once it was determined that UniProbe would be backwards compatible to Bently Nevada standard hardware, the testing progressed to testing UniProbe against the Machine Saver Twinprox as well as testing UniProbe at different frequencies to ensure accuracy no matter how slow or fast the machine is. To measure this, the UniProbe was connected to the Machine Saver TwinProx module and put on a rotor kit that mimics the movement of a metallic shaft. The rotor kit can vary the speed which in turn changes the frequency or RPMs of the machine shaft. UniProbe output was measured at multiple different frequencies such as 1000 RPM shown in Figure 7, and 2000 RPM shown in Figure 8.

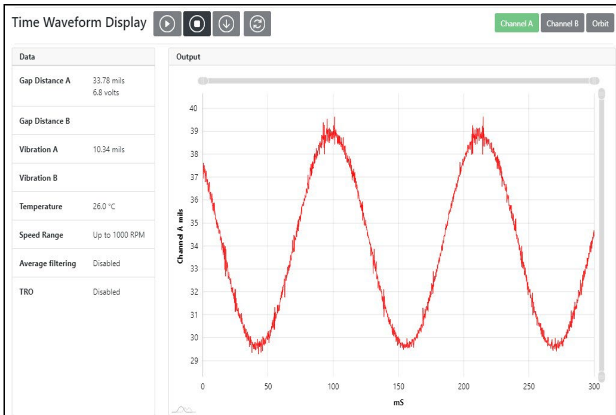

Figure 7. UniProbe & Machine Saver TwinProx Output on a rotating shaft at 1000 RPM

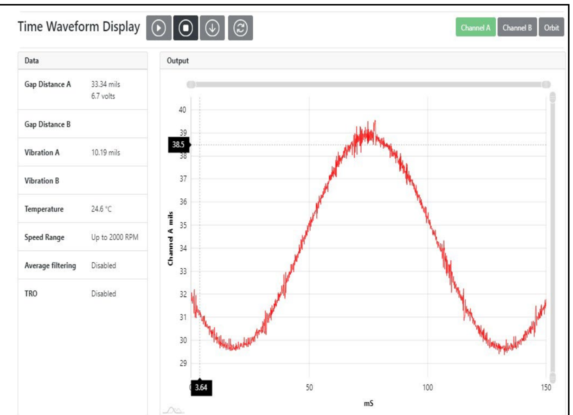

Figure 8. UniProbe & Machine Saver TwinProx Output on a rotating shaft at 2000 RPM

Table 5. UniProbe & Bently Nevada 3300xl 9m probe driver system

UNIPROBE vs Bently Nevada P/N: 330180-90-05 (S/N: 01II00SK2)								
Cable Length in. (m)	420 (10.668)	408 (10.363)	384 (9.754)	360 (9.144)	348 (8.839)	336 (8.534)	334 (8.484)	IDEAL
0	0.602	0.601	0.601	0.601	0.601	0.601	0.601	0
10	0.602	0.602	0.602	0.709	0.928	1.136	1.198	2
20	1.287	1.535	2.036	2.591	2.899	3.18	3.252	4
30	2.781	3.092	3.732	4.465	4.856	5.248	5.34	6
40	4.141	4.509	5.316	6.281	6.78	7.29	7.43	8
50	5.353	5.792	6.79	7.97	8.63	9.28	9.45	10
60	6.407	6.92	8.11	9.57	10.4	11.26	11.49	12
70	7.33	7.91	9.29	11.06	12.07	13.19	13.47	14
80	8.12	8.77	10.36	12.44	13.65	15.07	15.46	16
90	8.79	9.49	11.26	13.69	15.17	16.95	17.43	18
100	9.34	10.12	12.07	14.81	16.59	18.79	19.42	20
Linearity (mV/Mil)	102.4	111.1	133.2	162.3	178	197.7	202.9	200

The API Standard 670 documentation states that the cable used should be coaxial or triaxial cable. However, there is no other evidence to suggest that a twisted shielded pair cable could not be used for machinery protection systems. That is why UniProbe is designed with the twisted shielded pair cable as specified by Machine Saver, Inc. It is important to sometimes try to break boundaries and expand the rules.

The cost of the coaxial cable can be anywhere in the range of $2-$2.50 per foot. Whereas the Twisted shielded pair cable can be anywhere from $1.50-$1.80 per foot depending on the distances when ordered. With a standard seven meter cable or 22 to 23 ft cable extending from the proximity probe, the cost of the coaxial cable would be approximately $44-$55. With a standard seven meter cable or 22 to 23 ft cable extending from the proximity probe, the cost of the new twisted shielded pair cable would be approximately $33-$39.60. Switching to the low-cost twisted shielded pair cable can result in significant cost savings. With an estimated savings of anywhere between $4.40-$22 over the current coaxial cable per unit it is a no-brainer to switch to the lower cost. The proposed twisted shielded pair cable offers additional benefits including reduced material costs, increased flexibility and improved reliability. With a shorter payback period this switch represents a smart economic decision with a strong return on investment (ROI).

8.1 Assessment

ETEC 4199 Senior Design I and ETEC 4399 Senior Design II courses at Sam Houston State University include all the student learning outcomes (SLOs) developed in the Electronics and Computer Engineering Technology and Mechanical Engineering Technology programs. SLO3 requires students to function effectively as a member as well as a leader on technical teams. The corresponding Performance Indicators (PIs) for SLO3 is (a) Use appropriate context, conventions, and mechanics, (b) Use credible sources, evidence, and structure, and (c) Demonstrate oral presentation skills. The senior design project presented in this paper is one of the nine senior design projects completed in the 2024-2025 academic year. Three in-class presentations in Senior Design I provided valuable feedback from other student teams and faculty to the project design and implementation. The multidisciplinary team members met with both faculty advisors weekly face-to-face or via Zoom meetings outside of regular class hours for progress and resolving design challenges. Engineering Technology programs contain five Student Learning Outcomes (SLOs) and their corresponding fourteen Key Performance Indicators (KPIs) that are all measured for completed capstone projects. Out of five SLOs, assessment results for SLO3 entitled as “Apply written, oral, and graphical communication in broadly defined technical and non-technical environments; and an ability to identify and use appropriate technical literature ” is shown on Table 6. Some of the Industrial Advisory Board (IAB) Members attend both the midterm and final Senior Design Seminars to evaluate the projects and provide very effective feedback.

Table 6. Sample assessment selected for SLO3

Key Performance Indicators	Unsatisfactory < 60%	Developing 60-69%	Satisfactory 70-79%	Exemplary ≥ 80%
a) Use appropriate context, conventions, and mechanics (Pre- Proposal + Mid-Report)	0%	0%	10%	90%
b) Use credible sources, evidence, and structure (Final Technical Report)	0%	0%	20%	80%
c) Demonstrate oral presentation skills (Final + Mid Presentation)	0%	0%	15%	85%

8.2 Student Roles and Multidisciplinary Collaboration

The UniProbe project was executed by a team of students from the Electronics and Computer Engineering Technology and Mechanical Engineering Technology programs. This diversity allowed the team to address the complex intersection of mechanical mounting and high-frequency electrical sensing. Team Responsibilities and Task Distribution:

Electronics Engineering Students:

- Conducted LCR meter testing to analyze the non-linear capacitance and inductance of the twisted shielded pair cable.
- Performed the trial-and-error coil winding process using the sponsor's equipment to match the impedance of Bently Nevada and Machine Saver drivers.
- Managed data collection using digital multimeters and calculated the linearity coefficients to ensure API 670 compliance.

Mechanical Engineering Students:

- Designed the universal probe body and subassembly to ensure it could be manufactured in multiple thread sizes, such as M8x1 and 1/4-28 UNF.
- Integrated the "slot on the rear" design, allowing for installation with a standard screwdriver to avoid cable damage.
- Developed the O-ring and stop-nut mounting system to maintain probe stability during high-vibration machine operation.

Project Management and Communication

To meet the objectives of Senior Design I and II, the team followed a structured professional workflow:

Weekly Consultations: The team met weekly with faculty advisors and industry mentors from Machine Saver, Inc. via face-to-face and Zoom meetings to resolve design challenges.

Milestone Tracking: Progress was monitored through a Gantt chart, moving from conceptual modeling and simulation in the Fall semester to construction and testing in the Spring.

Peer Review: Three in-class presentations allowed the team to receive and incorporate feedback from other student teams and faculty, mimicking a professional engineering review board.

9. Conclusion

This project was one of nine senior design projects completed during the 2024–2025 academic year. A comprehensive project proposal—including problem definition, literature review, conceptual design, modeling, simulation, a Gantt chart, and a proposed bill of materials—was prepared and approved as part of the one-credit-hour Senior Design I course in the Fall 2024 semester. The three-credit-hour Senior Design II course in the Spring 2025 semester focused on finalizing the design, producing 3D-printed mechanisms, acquiring required components, and completing construction, implementation, and testing.

In conclusion, the UniProbe universal inductive proximity probe solution simplifies the ordering process for customers, eliminating the confusion of selecting the correct part number, probe body length, threading, cable length, and system type. With UNIPROBE's streamlined approach, customers only need to choose the type of threading their machine uses, making it easy to get the right part. Additionally, the sensor is designed to be backwards compatible with existing industry leader systems, ensuring seamless integration with already installed hardware.

Future work for UniProbe will include finding a way to seal out the pressure at the bearing cap. The UniProbe cable will hang out of the probe body hole in the machine casing. The stop-nut and O-rings should help keep the probe stationary, but to make sure the pressure is sealed into the machine and not lost where the probe body threaded into the machine casing it is imperative to find a cable grip that can seal out the required pressure as well as allowing the cable to pass through the machine casing threaded holes. Another area of testing to improve the accuracy of the UNIPROBE would be testing different target materials such as 304 stainless steel, Inconel, and Aluminum [even though it is most likely not going to work with aluminum as there is not enough carbon material in the aluminum]. With a wider range of target materials tested, it would verify the accuracy of UniProbe as truly universal product.

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