Journal of Instrumentation Technology, 2017, Vol. 4, No. 1, 1-4
Available online at http://pubs.sciepub.com/jit/4/1/1

DOI:10.12691/jit-4-1-1

Eddy Current Digital Proximity Sensing for Vibration Detection

Frank Fang[1,*], Guoxing Yang[2]

[1]A Principal Staff in Houston, Texas, USA
[2]A Technology Innovator in Spring, Texas, USA
*Corresponding author: fang_ff_fang@yahoo.com

Abstract This document provides fundamental eddy current digital proximity sensing principle and brief comparison between digital and analog approaches. Advantages and challenges of digital proximity system are further elaborated. Then the application of digital proximity sensing in vibration monitoring is explained. At the end authors illustrate the trend of digital proximity sensing technologies.

Keywords: *eddy current, oscillation, peak detection, digitization, linearization, calibration, temperature compensation, interchangeability, vibration detection, technology trend*

Cite This Article: Frank Fang, and Guoxing Yang, "Eddy Current Digital Proximity Sensing for Vibration Detection." *Journal of Instrumentation Technology*, vol. 4, no. 1 (2017): 1-4. doi: 10.12691/jit-4-1-1.

1. Introduction

Eddy current proximity sensing is one of the most mature technologies to precisely measure linear/angular metal position, displacement, motion, compression and vibration in many applications including automotive, energy, industrial, medical and communications. As a proven contactless sensing technology, proximity sensing offers better performance and reliability at a lower cost than competing solutions. Eddy current proximity sensing has many advantages over its alternative technologies.First, it is easy to implement as the sensor neither needs to touch metal target material nor requires a coupling medium. Second, eddy current proximity sensing is suitable to a wide range of applications because of its high detection sensitivity and linearized output to the size, shape, or distance change of detecting metal material. Third, it is portable and cost effective since the sensing equipment is very small and light. Lastly, eddy current proximity sensing can be automated since its electrical characteristics can be easily controlled. Vibration detection is one of many applications where eddy current sensing is widely employed.

An eddy current proximity probe system can be modeled by a lumped parameter R-L-C "tank" circuit that is designed to run at certain frequency [1]. When oscillating current passes through a probe coil, an eddy current is generated on the surface of an electrically conductive target material. In return, this eddy current counter-affects the probe R-L-C "tank". One important phenomenon is that the resistance and inductance vary when the physical distance changes between the probe and the metal target. On the other end, a sensing electronic circuit converts this resistance or inductance change to voltage, resulting an electrical output directly proportional to the physical gap. The model of eddy current probe system is illustrated in Figure 1.

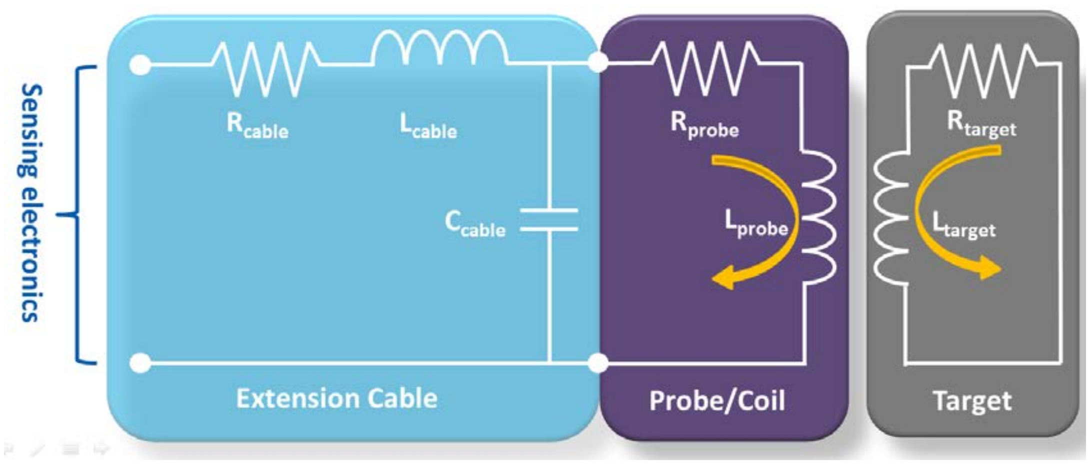

Figure 1. Model of eddy current probe system

2. Principle of Digital Proximity System

Majority of proximity probe systems are fundamentally impedance measuring devices. At its resonance frequency, the impedance is a function of the characteristics of R-L-C "tank". The relationship between impedance (Z) and inductance (L), resistance (R) and capacitance (C) is described in equation 1.

$$Z = \frac{L}{RC} \quad (1)$$

Where L and R change with the gap between the probe tip and the target material.

American Petroleum Institute (API) standard 670 governs the minimum requirement for a machinery protection system (MPS) measuring shaft vibration and position. The standard requires that the output voltage of sensing electronics is linear and within ±5% of 200 mV/mil in the entire operating range (10 mil to 90 mil) of a proximity probe system (one mil equals one thousandth inch).

The task of the sensing electronics is to measure the impedance change and generate an output voltage. If a linear relationship exists between the change in impedance and change in gap, it would be very easy for sensing electronics to directly map the gap change to the output voltage. However, the fact is that the impedance to gap change curve is nonlinear or logarithmic. After the gap reaches certain distance, the probe no longer "sees" the target and further changes in gap don't affect the impedance. A typical curve of impedance change vs. gap change is shown in Figure 2.

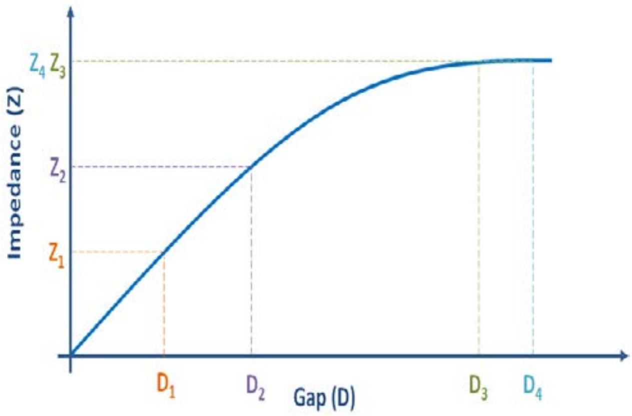

Figure 2. Impedance change vs. gap change

2.1. Analog Approach

The challenge then is how to linearize the observed change in impedance so that its generated output voltage is linear and proportional to the gap over as wide a range as possible. A pure analog circuit may be used to exactly compensate the nonlinearity to linearity as shown in Figure 3.

However, it is not an easy task to perform the needed compensation. First, the circuit components have to be properly selected. Second, a particular set of components works for only a single combination of probe tip diameter, cable length, and target material [2].

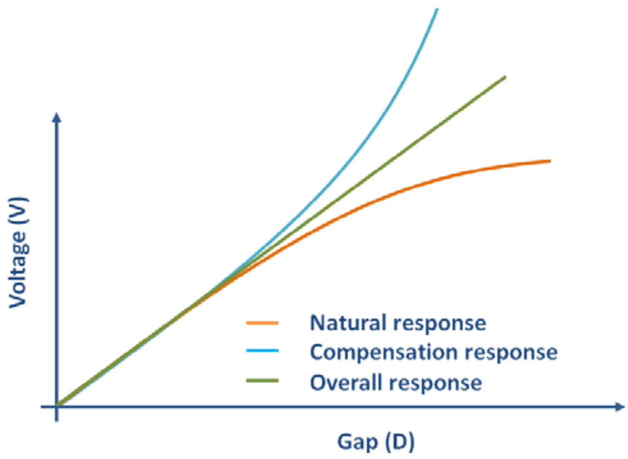

Figure 3. Hardware compensation of a nonlinear curve

2.2. Digital Approach

A digital way to linearize the nonlinear impedance input is to create an algorithm in software. By applying the smart algorithm, each individual input is directly mapped to an output. It is easy and straight forward. The function block diagram of the digital approach is illustrated in Figure 4.

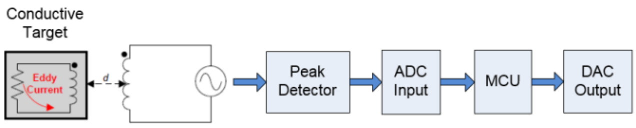

Figure 4. Function diagram of a digital proximity system

The digital proximity system is composed of 5 key components.

Oscillation: The circuit of R-L-C "tank" which provides sustained oscillations at the required frequency.

Peak Detector: The circuit to capture the peak-to-peak value of oscillations when the gap is changing.

ADC (Analog-to-Digital Convertor): The circuit to convert the detected analog peak value to digital format and feed it into a Microcontroller Unit (MCU).

MCU: The heart of the digital proximity system that runs the algorithm and transforms the digitized nonlinear input data to a linear digital value for voltage output.

DAC (Digital-to-Analog Convertor): The circuit to convert the digital value to analog voltage output.

2.2.1. Advantages of the Digital Proximity System

The digital proximity system is able to combine the performance of a full API 670 compliance with the flexibility of digital configurability for a variety of probe tip diameters, manufacturers, extension cable lengths, target materials, and linear ranges [3]. It offers huge advantages over the analog alternative in the following ways.

- Oscillation parameters of the R-L-C "tank" can be adjusted to achieve an optimized dynamic nonlinear range to meet the requirements of different materials and system lengths.
- Peak detector output can be regulated to suit ADC's input requirements in system design.

- High resolution ADC can be used to achieve high accuracy.
- Smart algorithm in software is flexible so that the system can be calibrated either at factory or in the field by customers.
- DAC output can be in either current or voltage.

2.2.2. Challenges of the digital proximity system

Although the digital proximity system possesses some ideal benefits comparing to the analog alternative, there are still some challenges that must be overcome before turning it into a practical solution.

Temperature compensation: The algorithm table is normally working well at room temperature. However, electrical characteristics can change dramatically as temperature varies. Thus, the actual nonlinear curve will drift away from the one that is used to create the original linearization table. Measured results can be far off from API 670 standard if a proper temperature compensation algorithm is not implemented.

Interchangeability: The R-L-C "tank" is critical to the digital proximity system. However, due to tolerance in manufacturing process, it is almost impossible to make two probes, cables, or sensing electronics exactly the same. If any component of a system is swapped with another, the L, C, or R discrepancy may cause the actual nonlinear curve to deviate from the one that is used to create the original linearization table. Some extra smart mechanism must be applied if full interchangeability is desired for the system.

3. Digital Proximity Sensing for Vibration Detection

Vibration analysis is fundamental in a predictive maintenance program and it is widely used for detecting and monitoring incipient and severe faults in machinery parts, such as bearings, shafts, couplings, rotors, and motors. Such wide varieties of applications engage a broad range of conductive materials, require varying machine-to-sensor distance, and demand extensive types of sensor diameters. Eddy current proximity sensing is suitable to all these requirements. And with proper design, the oscillation frequency of eddy current sensing can be optimized to fit the surface depth of any target conductive materials. In addition, the nature of inductive sensing makes it even more superior to other proximity sensing technologies.

Digital proximity sensing is basically a position measuring technology. It is useful in any application requiring the measurement or monitoring of the position of a conductive target, especially in a dirty environment. However, because of the high precision and fine vicinity of its measurement, more often digital proximity sensing is used to measure the dynamics of a continuously moving target, such as a vibrating element [4]. With proper hardware design, software linearization scheme and compensation algorithm, a digital proximity system can detect a target in less than one mil and generate incremental scale factor (ISF) of 1.0±5% V per 10 mil in a wide range from 10 mil to 200 mil. Figure 5 below demonstrates an excellent performance and interchangeability of such a system. Monitoring vibration so precisely in such a micro level is definitely an assurance of asset protection and enhanced efficiency for operations.

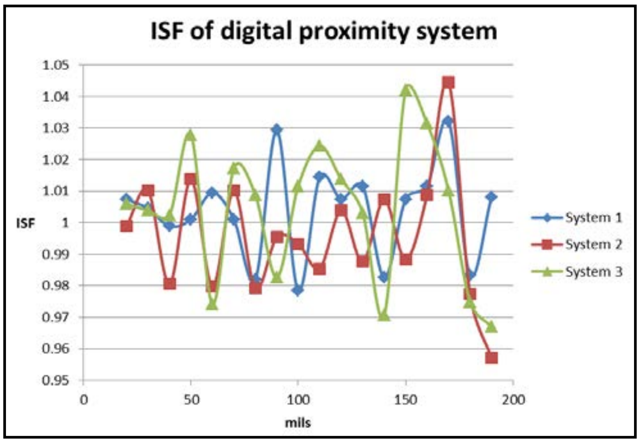

Figure 5. Linear output of digital proximity systems

4. Trend of Digital Proximity Technology

We are at the edge of a revolution, where technologies are evolving and thriving like never before. Brands are banking on advanced integrated circuit (IC) technology, Internet of things (IoT), and embedded intelligence to create winning strategies and achieve competitive advantages.

The integrated circuit is in its nanotechnology era. The IC size is becoming smaller and smaller each year. On the contrary, the capacity and density of IC keep increasing bigger and bigger. The cost to performance ratio will continue to go down. The modern sophisticated IC technology allows different types of sensors to be integrated with both digital and analog circuits in one single silicon. To take advantage of this, the oscillation, peak detector, and ADC of the digital proximity system can be consolidated into a single chip. This revolutionary design will deliver better performance, better reliability, and greater flexibility than existing solutions, and at a lower system cost. Texas Instruments (TI) is the leader in this industry. Its LDC1x series devices offer great opportunities for creative and innovative system design in the proximity sensing world [5]. However, the LDC1x devices have to be optimized or customized to suit different application requirements.

The IoT is far beyond the traditional concept of connecting typical devices such as computers and smartphones to the Internet. Any standalone Internet-connected device that can be monitored and/or controlled from a remote location could be an IoT device. As the IoT market grows exponentially in the coming years [6], including the digital proximity system in the IoT device list could generate incredible potential in brand development and customer attraction. Cloud computing enables all features of the digital proximity system to be accessible from mobile devices using native or web apps.

As discussed earlier, certain intelligent algorithm is required to make the system flexible, configurable, reliable and repeatable. This is not a trivial task. Especially when probe interchangeability and temperature variation are in consideration, the challenge is even bigger since the algorithm needs to transform a diversified nonlinear input to a unified linear output. It is, therefore worth to develop proprietary intelligence to gain supreme performance and customer satisfaction in this area.

5. Conclusion

Eddy current sensing is a noncontact technology capable of high-resolution measurement of position and/or the change of position of any conductive target. Digital proximity sensing combines complex electronic designs with advanced mathematical algorithms to achieve high performance for precision displacement and vibration measurement in today's industrial operations. Integrating other cutting-edge technologies such as IC and IoT into a digital proximity sensing system will generate incredible potential to the evolution and applications of digital proximity sensing technology.

References

[1] Du, Winncy, Resistive, Capacitive, Inductive, and Magnetic Sensor Technologies, CRC Press, Boca Raton, 2014, 211-214.

[2] Silva, Clarence, W., Sensor Systems: Fundamentals and Applications, CRC Press, Boca Raton, 2016, 453-455.

[3] American Petroleum Institute, API Standard 670 Machinery Protection Systems (5th edition), 2014, Available: www.api.org/pubs, [Accessed March 20, 2017].

[4] Silva, Clarence, W., Vibration: Fundamentals and Practice (2nd edition), CRC Press, Boca Raton, 2007, 485-490.

[5] Texas Instruments, A revolution in sensing, Available: http://www.ti.com/lsds/ti/sensing-products/inductive-sensing/inductive-sensing-overview.page. [Accessed March 20, 2017].

[6] Intel, IoT: Changing the Way We Live and Work, Available: http://www.intel.com/content/www/us/en/internet-of-things/overview.html?cid=sem43700010315448786&intel_term=iot&gclid=CImLwcvk5dICFYW1wAodEMAIIw&gclsrc=aw.ds/ [Accessed March 20, 2017].