APPLICATION Considerations for EDDY-CURRENT Proximity Probes

The plant's rotating machinery engineer breathed a sigh of relief. After nearly half a decade of having his requests turned down, he had finally gotten capital budget approval to retrofit an aging compressor with proximity probes. He understood the value of the data they could provide, as many of the newer machines in the plant were fitted with probes and he used the information regularly to plan maintenance and diagnose mechanical problems.

However, unlike the machines in newer sections of the plant that had been supplied from the OEM with probes already installed, the machine he was now retrofitting dated back to the 1960s and did not have provisions for probes. As a result, bearing housings would have to be drilled and tapped, shaft surfaces would have to be checked for suitability, mounting brackets would have to be designed, and a host of other details would have to be properly engineered for the application at-hand. Unfortunately, the rotating machinery engineer assumed that his biggest hurdle was to obtain budget approval; the myriad of application details were ignored simply because he didn't know what he didn't know. When the items finally arrived and were installed, it was discovered during system check-out and commissioning that the transducers were calibrated to the wrong target material, that the probe holes were drilled and tapped incorrectly – introducing crosstalk and counterbore interference – and that the cable lengths were mismatched. While it eventually got sorted out, the project took three times as long as it should have and cost nearly twice as much to complete.

Nathan Littrell – Senior Systems Engineer – GE Energy – nate.littrell@ge.com
Andrew Bell – Lead Engineer – Bently Nevada Asset Condition Monitoring – GE Energy – andrew.bell@ge.com

Want to avoid a similar scenario in your plant? You can, but only when you have a firm grasp of the fundamentals of eddy-current proximity probes and application considerations that can spell the difference between failure and success when instrumenting a machine. This article is designed to help you do just that.

Principle of Operation

An eddy-current probe works by passing an alternating current through a coil of wire and measuring the coil's impedance. This impedance changes when the probe is brought near an electrically conductive material and the impedance change is proportional to the physical gap between the coil and the conductive target. The sensing electronics in turn convert this impedance change to a voltage, providing an electrical output directly proportional to physical gap.

While the operating principles are simple enough, that is where the simplicity ends. A probe must be rugged, accurate, linear, repeatable, interchangeable, and impervious to its environment. Building such a probe is daunting. Building millions of such probes is even more daunting. Advanced, proprietary manufacturing processes involving precision winding and sealing techniques have been perfected over more than 50 years to allow mass production of eddy-current probes that possess all the necessary attributes demanded by both industrial and laboratory applications.

Likewise, applying eddy-current transducers requires careful attention to detail. Only by understanding the factors that affect the probe's performance and applying the probe accordingly can one be assured that the installation will perform as specified. This article discusses each of the following nine basic factors that the installer must consider:

1. Target material
2. Target geometry
3. System length
4. Mounting considerations (e.g., counterbore, bracket resonances, installation convenience)
5. Environment (e.g., temperature, chemicals, radiation)
6. Frequency response
7. Linear range
8. Signal-to-noise ratio (e.g., device resolution, electrical runout)
9. Field wiring

1. Target Material

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The impedance change of the probe is dependent on the electrical properties of the target material. All probe systems state the material to which they are calibrated (typically AISI 4140 steel). Although some products claim to be insensitive to target material, these should be approached cautiously as there are usually performance compromises involved. The point here is that you must know the target material and verify that the probe system is calibrated appropriately, or at least that the performance deviation is known and that the transducer system can be compensated to account for this deviation. Generally, the factory should be consulted to quantify this performance deviation and to offer advice on whether the deviation would be excessive for the intended application. When the deviation is unacceptably large, transducer systems calibrated to the specific target material can be supplied.

2. Target Geometry

Typically, the eddy-current system is designed to operate with a flat target. Rotating shafts of sufficient diameter introduce no significant error, but there can be problems if the shaft is too small. The effect of an undersized shaft is that the sensor scale factor will be reduced; consequently, vibration levels will be under reported. The minimum shaft size or target diameter for flat targets should be stated on the product data sheet. Look for it and take note.

Probes used for differential expansion measurements frequently observe collars or ramped features on the shaft. The size and shape of the collars must be adequate or the probe will not function properly (Figure 1). The probe may have scale factor problems and can also pick up radial vibration of the shaft if the probe is too close. The probes used in these applications are typically larger (11, 25, and 50 mm tip diameters). The data sheet and manuals for these products contain the details for correct application.

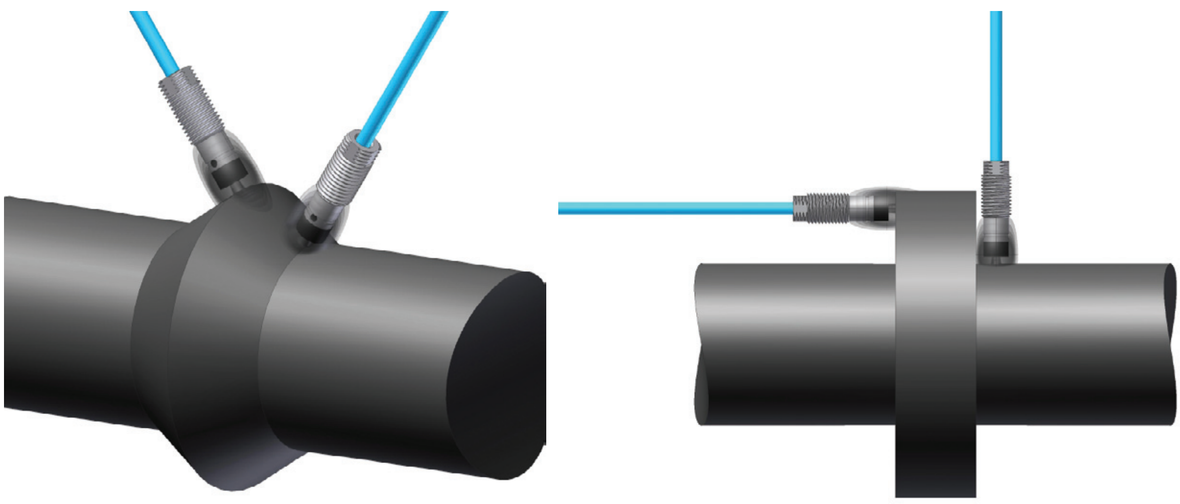

Figure 1. Differential expansion probes observing a ramp (left) or collar (right) must be selected and installed carefully to ensure that the probes observe only the intended portion of the shaft. If a radial vibration probe is installed near a collar, it must be located adequately distant from the collar to ensure it observes only the shaft —not the collar.

Crosstalk is another issue associated with the target geometry. For machines using probes in an XY configuration, the two probes can interfere with each other if they are too close. The mechanism that causes this is when the magnetic fields emanating from the probes are at approximately the same frequency (Figure 2).

The symptom is that a 'beat frequency' will be evident on the sensor output. This beat frequency is dependent on probe gap and will exhibit frequencies in the range of several hundred Hz to a few kHz.

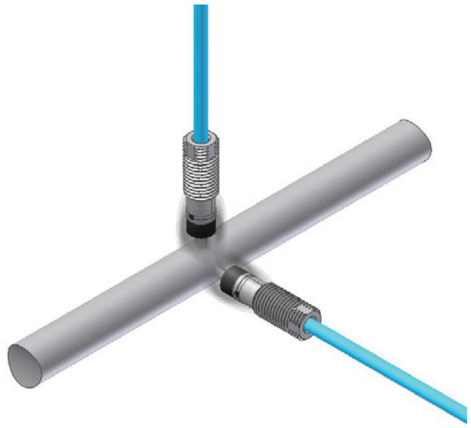

Figure 2. These two probes are located too close together, allowing the fields from each to interfere with one another. This results in so-called "crosstalk."

One solution to this problem on machines with small shafts is to displace one probe axially from the other. This separation will remove the crosstalk while still providing a useful X-Y probe pair (Figure 3).

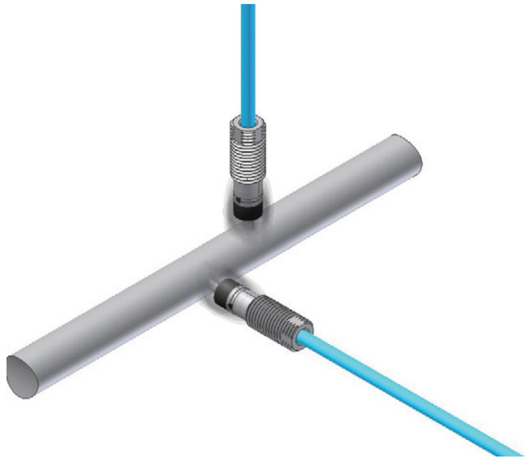

Figure 3. The probes of Figure 2 have now been offset from one another axially, preventing their fields from interfering with one another, allowing X-Y radial vibration measurements without the problem of crosstalk.

3. System Length

The probe, Proximitor* sensor, and extension cable are expressly designed to work in specific combinations. The probe and extension cable have a very tightly controlled impedance characteristic and the Proximitor sensor will only work for that specific probe/cable combination within a particular probe product family (e.g. 3300XL 11 mm). Mixing either the lengths incorrectly or parts from different product families (such as a 3300XL 8 mm probe connected to a 3300XL 11 mm extension cable) will result in problems. For this reason, the probes, Proximitor sensors, and extension cables within a particular product family are usually color coded [1].

The system length of a probe refers to the combined length of the probe and extension cable. This length must match the system length of the Proximitor sensor and is typically 5 or 9 meters. For example, a 1-meter probe must be matched with a 4 meter cable to create a 5-meter system; likewise, a half-meter probe must be matched with a 4.5-meter extension cable, and so on. The situation for 9-meter systems is analogous.

Connecting probes and cables of the wrong lengths can cause performance problems ranging from inaccuracy to a complete failure. These problems are significant and, unfortunately, common. For example, a half-meter probe connected to a 4 meter extension cable is only 4.5 meters. When connected to a 5-meter Proximitor sensor, the output will be at least 20% higher than expected. Similarly, a 5.5-meter system would have an output lower than nominal.

Also note that the lengths are considered as "electrical" lengths. The probe and extension cables are physically trimmed to meet an electrical performance characteristic. This means that the actual physical lengths can be different than the electrical length. As such, a 4.5-meter extension cable may not be exactly 4.5 meters as measured by a ruler and it is necessary to allow for nominal physical length variation when planning your system's cable runs. The length tolerance is always stated on the product data sheet. When planning the installation, be sure that the minimum physical length of the probe and cable will be sufficient to reach the Proximitor sensor.

4. Mounting Considerations

A number of physical constraints can affect the quality of the output from a proximity transducer system:

- Counterbore

Since the probe is sensitive to conductive material, any conductive machine components (other than the shaft) that are too close to the probe can affect the signal. It is common for probes to protrude directly through metal to view the target shaft. In this case, a counterbore should be employed to avoid metal too close to the probe tip (Figure 4). Any metallic machine components that protrude into the region defined by recommended counterbore spacing requirements should be removed if possible. Recommendations vary by transducer model.

This issue is similar to that discussed earlier for probes observing collar or ramps in expansion measurement applications (refer to Figure 1).

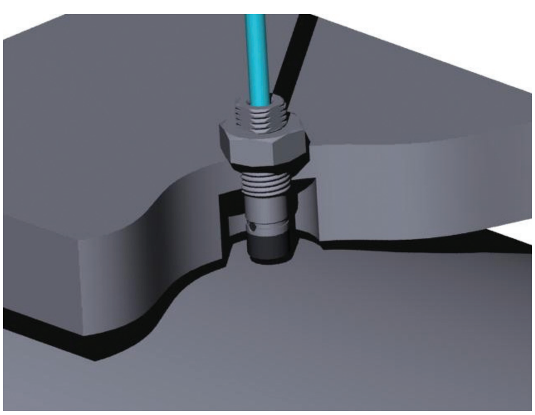

Figure 4. Cutaway rendering showing a probe with proper counterbore. This ensures that the probe's field will "see" only the rotating shaft, not the sides or back of the hole.

- Bracket Resonances

Brackets or probe mounting hardware should always be chosen to provide mounting and support that is as rigid as possible. In some instances, probes with a long metal casing (for example, a probe with five or more inches of thread) can be prone to resonance at transient or steady state operating speeds. This is due primarily to the physical behavior exhibited by a tube or pipe experiencing vibration. To avoid probe resonance, mounting features should include a support secondary to the main fitment whenever possible for installations that have more than a few inches of probe extending beyond the bracket (see Figure 5).

Figure 5. The probe on the top has a long unsupported length, resulting in mechanical resonance and erroneous readings as the probe is no longer stationary with respect to the shaft it observes. The probe on the bottom is identical, but has a mounting bracket to support and stiffen the probe "stinger." This ensures that the machine's vibration will not excite the probe mounting's resonance.

- Installation Convenience

For applications requiring long probes or installation in tight spaces, a smooth body probe should be considered. As the name implies, smooth body probes have no threads and this eliminates the need to laboriously thread the probe into a bracket. The probe may be slid into place and secured in position using a special clamping-type bracket. For threaded installations, brackets should be designed to match the thread tolerance of the probe in order to avoid binding. It is also good design practice to ensure that there is sufficient threaded material for a solid joint. A good rule of thumb is five full threads of engagement.

5. Environmental Considerations

A key consideration when selecting probes is the temperature for each location on the machine that will be occupied by the sensors. The temperature ratings of the probe tip, cable, and Proximitor sensor are all different and should be considered separately. The machine temperatures must be within the rated temperature limits of the probe, extension cable, and Proximitor sensor during idle, startup, shutdown, and (especially) base running conditions.

The system must also be undamaged by any of the process gases or liquids present. Standard probes commonly feature PolyPhenylene Sulfide (PPS) or Poly Ether Ether Ketone (PEEK) tips and are widely compatible with steam and petroleum products. If the environment contains anhydrous ammonia (NH_3) or other reactive substances, probes manufactured with a ceramic tip can be used to resist corrosion or degradation. The ceramic tip probes are also excellent for highly pressurized applications where the probe is required to seal differential pressure.

For nuclear power plant or research applications involving exposure to radiation, specially designed probes are available which can withstand Gamma radiation.

6. Frequency Response

Typical machinery vibration monitoring applications require the probe to provide vibration data at one or two times the running speed of the machine. This is normally well within the ability of the probe to respond. Occasionally there are machines that run very fast or have a need to monitor at a higher multiple of the running speed (e.g., blade pass frequencies for pumps or turbines). The response of the proximity probe will be attenuated at higher frequencies. Check the data sheet of the probe to find the maximum frequency response. This can be particularly important for speed sensing applications when a sharp trigger is required and multiple harmonics of running speed are required to give a crisp square wave output [2].

THERE ARE MANY CONSIDERATIONS WHEN SELECTING EDDY-CURRENT PROXIMITY PROBES AND DESIGNING THE INSTALLATION. AT FIRST GLANCE, IT MAY SEEM THAT MUCH OF THE INFORMATION INCLUDED IN THE DATASHEET IS EXTRANEOUS, BUT—AS DISCUSSED IN THIS ARTICLE—THIS INFORMATION IS PRESENTED FOR GOOD REASON.

7. Linear Range

For a vibration measurement, it is critical that the probe has enough range to measure the motion of the shaft. To pick the correct probe, estimate the maximum peak-to-peak vibration level that is expected and choose a probe that has at least that much linear range. When installing the probe it is important to gap the probe in the middle of the linear range in order that the vibration will "fit" into the probe's linear range. It is good practice to select a probe that has more linear range than is strictly required by the application to allow for some flexibility when gapping the probe. Figure 6 shows the typical voltage response versus gap for a probe system. The probe must stay in the linear range at all times in order to provide a valid measurement.

The consequence of choosing a probe with insufficient linear range or gapping the probe incorrectly is that the monitor system will enter a "NOT OK" condition or there will be data errors instead of protecting the machine.

For a thrust or differential expansion measurement, it is even more critical that the probe has the ability to measure the entire motion of the shaft. The selection process is similar in that the probe is chosen based on the expected shaft movement. The difference with a thrust application is that the gapping of the probe needs to be considered relative to the often asymmetrical motion of the shaft. A complete discussion of gapping for thrust is beyond the scope of this article, but suffice to say that careful attention must be paid to ensure that the probe will remain in the linear range during all operating conditions [3,4,5].

The consequence of an error in application of probes for thrust or expansion measurements is severe as it will typically mean that the machine can fail in a manner that allows rotating and non-rotating parts to contact, such as blades and casings.

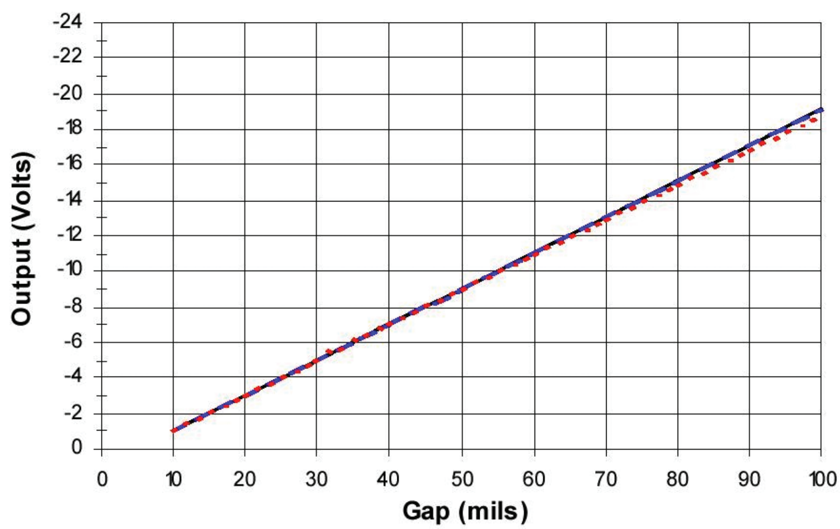

Figure 6. Actual probe voltage versus gap response (red) overlaid on expected output (blue) showing that the probe response is highly linear.

8. Signal-to-Noise Ratio

Eddy-current proximity probes are amazingly accurate devices, but they do not have infinite resolution. There is always a noise floor for any electrical device below which any measurement is not reliable. Typically this value is several tens of millivolts for a proximity probe system. Check the data sheet of the product and consider the resolution required of the system.

"Electrical Runout" is another problem that may be encountered in an installation. This phenomenon is caused by variation in the material properties of the shaft appearing as a spurious vibration signal. The magnitude of electrical runout can be quite high depending on the quality of the shaft material. The causes and cures of electrical runout have been discussed in previous ORBIT articles [6,7].

9. Field Wiring

Proximity sensors are low-voltage devices—the output of a typical sensor is usually only a few volts. As such, it is important to maintain a clean signal path to the monitoring system. Magnetic fields from power cabling and transformers can cause a significant voltage to be induced in the sensor system, introducing noise that can cause erroneous readings. Cabling for sensors should always be routed away from power cables. If the instrumentation field wiring must cross power cables it should cross perpendicular to the power cables in order to avoid coupling the electromagnetic field.

The frequency response of the sensor is also strongly affected by the amount of capacitance in the wiring between the sensors and the monitor [8]. Extra capacitance on the output of the sensor acts as a filter and reduces the magnitude of the high frequency components of the signal. DC and low frequency components are not affected. Reference Figure 7 to see a graph showing the effects of added capacitance.

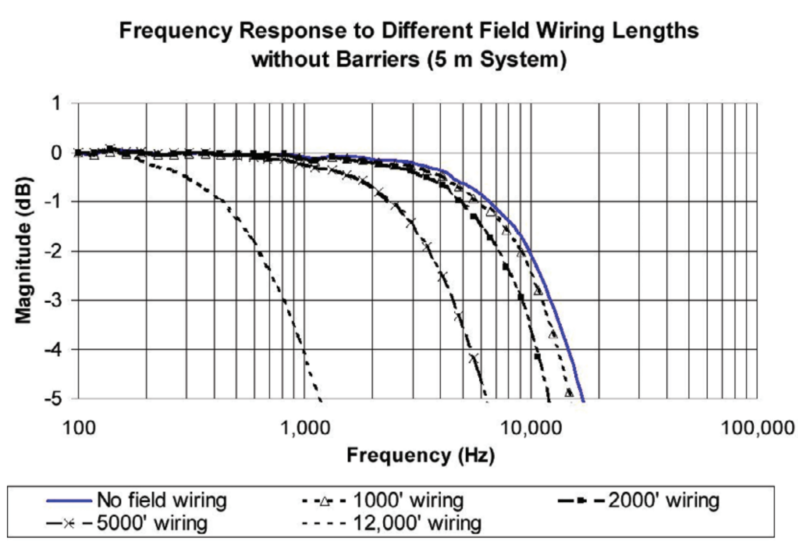

Figure 7. Added capacitance of long field wiring lengths will affect the frequency response of the probe system, behaving essentially as a low-pass filter. This effect must be carefully considered, particularly when the probe system will be required to detect very high frequencies, such as observing a toothed wheel or detecting vibration harmonics on a high-speed machine such as a turbo-expander.

In summary, long wire runs can cause attenuation of high frequency signals in addition to increased risk of noise. Long runs of instrumentation cabling should be avoided whenever possible by locating the monitor near the machine. Digital communication from the monitor to the control room via IP-based ethernet or other protocols is not as susceptible to noise issues.

Conclusion

Eddy-current proximity probes offer excellent sensitivity and robust performance when installed correctly. However, there are many considerations when selecting probes and designing the installation. At first glance, it may seem that much of the information included in the datasheet is extraneous, but—as discussed in this article—this information is presented for good reason.

An abundance of resources exist in addition to the product datasheet and this article, as noted in the references at right, and the reader is strongly encouraged to make use of these items. In addition, your local GE Energy sales professional specializing in the Bently Nevada* product line has deep knowledge of application considerations and pitfalls, and can be a valuable asset when planning your installation.

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