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White paper

Innovative frequency hopping radio transmission probe provides robust and flexible inspection on large machine tools

Abstract

Inspection probes have become a vital contributor to manufacturing process efficiency, enabling rapid part set-up and batch changeover, plus part verification and in-process control of critical component dimensions. All spindle and turret-mounted probes need a means of signal transmission, with radio transmission being the most common on large machines and 5-axis machining centres. However, there are many challenges to the successful application of radio transmission in the factory, not least different local regulations and sources of interference from other radio-controlled equipment. In 2003, Renishaw introduced the world's first frequency hopping spread spectrum (FHSS) radio transmission for inspection probes, a robust, compact and universally applicable solution for probing on all but the smallest of machines.

Probe transmission basics

An inspection probe is used on a CNC machine tool to determine the location and orientation of parts during setting, and for inspecting the size and position of critical features for verification and process control. It does so by sensing a series of discrete points on the surface of the component. When the probe's stylus meets the surface of the part, a trigger signal is generated. This signal must be passed to the CNC so that the position of the machine at that instant can be recorded.

Figure 1 – Renishaw's RMP60 spindle probe featuring frequency hopping spread spectrum radio transmission

Since the probe is mounted in the machine's spindle when in use, the trigger signal must be sent to the CNC via a remote transmission system. There are three main transmission technologies – inductive, optical (infra-red) and radio. In each case, the probe carries a transmitter, which passes signals regarding the status of the probe to a receiver, which is hard-wired to the machine's control cabinet.

Inductive transmissions have a very short range (the receiver is mounted on the spindle nose), whilst optical and low power radio can transmit over several metres. Optical transmissions rely on line-of-sight between transmitter and receiver, whilst they also benefit from reflections inside the machine. Radio transmissions benefit from reflections too, plus significant diffraction around objects in the machine, making them ideally suited to larger machines where the probe may be inserted within the component, or 5-axis machines where line-of-sight cannot be guaranteed.

It is critical that the triggering point is repeatable, since these points are the foundation of accurate component measurement. A key design factor, then, for any probe transmission system is that it must pass the trigger signal to the CNC with a short and highly repeatable time delay. Any uncertainty in the timing of the moment of contact with the surface will translate into uncertainty of surface position (note that the speed and repeatability of the trigger latching circuitry in the CNC is also a factor here). Long delays in transmission increase the risk of damage to the probe or component.

The other critical factor in probe transmission design is the robustness and reliability of the signals that are passed. Any valid triggers must be passed to the CNC quickly so that the machine's motion can be halted, whilst interference from other devices in the factory must be rejected and worked around, without causing problems for the other devices concerned.

The radio transmission must perform the following functions:

- Regular transmission of the probe's status (probe seated / triggered and battery status) so that the CNC is constantly aware of whether the stylus has struck the component surface, or if transmission has been blocked, so that it can operate safely.
- Generation of a trigger signal at the receiver with a short fixed delay after the stylus hits the part.
- Rather than switching by mechanical means (using a switch in the shank or a centrifugal switch in the probe), it is often useful for the radio transmission to be able to send and receive probe control signals (from the CNC to the probe) to turn the probe on and off.

Factors that affect radio transmission performance and reliability

1. **Spread spectrum or fixed frequency** – what are the other devices likely to be present in the chosen frequency range, and what steps are taken to allow these devices to co-exist?
2. **Tolerance to signal interference** – where interference does occur, how can the probe continue to operate reliably?
3. **Trigger signal repeatability** – how repeatable is the signal that is transmitted to the CNC in the face of signal interference?
4. **Avoidance of 'dead spots'** – with reflections within the machine causing destructive signal interference in some locations, how can the probe's operation be maintained?
5. **Regulatory compliance** – can the same probe be used throughout the world without falling foul of local radio regulations?
6. **Power management and switching methods** – how is battery life maximised and how can the probe be switched on and off?
7. **Ease of installation** – how do sensor and receiver design affect the time and efforted needed to fit the probe system to a typical machine?

Fixed frequency radio transmission technology

Previous radio transmission probes, including Renishaw's MP16 and MP18 models, use fixed channel transmission. Within an approved low-power area of the radio spectrum (e.g. the 433 MHz band in Europe and Japan), a series of discrete channels are available. The probe and receiver are set to a specific channel during installation, which remains fixed thereafter unless another channel is manually re-selected. Within the 433 MHz band, for instance, Renishaw uses 69 such channels, each with a bandwidth of 20 KHz. This allows many probes to be used in a single factory without any risk of 'cross-talk' between probes and receivers on neighbouring machines.

Such technology has generally proved to be reliable, being limited mainly by the number of channels available within the band. However, such devices are susceptible to local interference from other radio devices in the factory that may be transmitting at the same frequencies.

Figure 2 illustrates the case where another device with greater transmission power is blocking part of a probe transmission channel. This will corrupt the signals at the probe's receiver. The only solution here is to change the probe channel until a clear part of the spectrum is found, or change the transmission band of the other device (if possible).

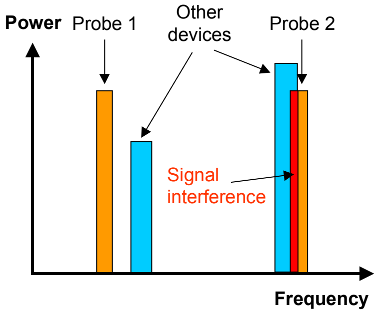

Figure 2 – probes and other devices on fixed channels must not overlap

Frequency hopping spread spectrum radio transmission

Spread spectrum transmissions achieve greater robustness than single channel transmissions by distributing their signals across a wider frequency range. There are two main spread spectrum technologies:

1. **Direct sequence spread spectrum** (DSSS)– where a signal is sent at low power over a broad range of frequencies simultaneously (as used in WiFi wireless networks).
2. **Frequency hopping spread sprectrum** (FHSS) – where a signal is transmitted at a relatively high power at a coded series of different frequencies, known to both transmitter and receiver (as used in 'bluetooth' devices, and in Renishaw's RMP60 radio probe system).

Renishaw's RMP60 is a FHSS device operating in a band between 2.402 and 2.481 GHz, providing 79 channels, each with 1 MHz bandwidth. The system consists of two modules – the RMP transmission module that is integral with the probe and mounted in the machine spindle, and the RMI receiver / interface that is connected to the CNC and mounted somewhere on the static machine structure.

FHSS transmission involves both transmitter and receiver 'hopping' from one channel to another, using all the channels available within the band over time. This allows them to co-exist with other FHSS and DSSS systems, as well as other devices such as microwave ovens that also operate in this frequency band. Frequency hopping reduces the chance of an unwanted receiver monitoring and intercepting the message from the probe, and increases the chance of getting the message through to the correct receiver in the presence of other radio traffic.

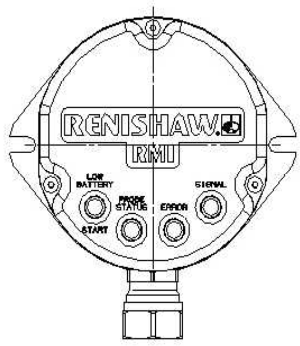

Figure 3 – RMI radio receiver and interface

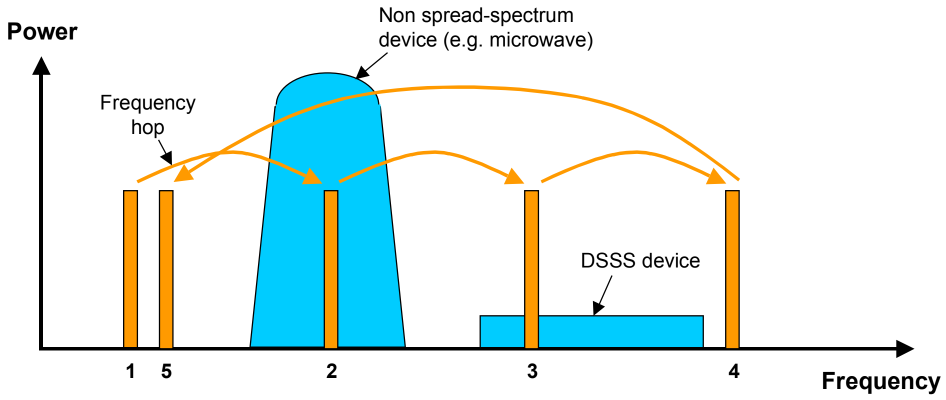

Figure 4 – FHSS probe transmission co-existing with other radio traffic

Figure 4 illustrates the FHSS probe transmission hopping between a sequence of frequencies throughout the 2.4 GHz band:

1. At the first frequency, the spectrum is clear and the transmission from probe to receiver succeeds.
2. After the first hop, the frequency switches to a channel that falls within a frequency range that is occupied by another device with higher transmission power. In this case, the probe transmission will be overwhelmed and will not get through.
3. Now the frequency has shifted to a point where it overlaps with a DSSS device, transmitting over a wide frequency range but at low power. The probe transmission has sufficient power to get through, whilst the DSSS device still has plenty of bandwidth in which to transmit its messages.
4. Clear frequency – transmission successful.
5. Probe continues one of many possible hopping sequences that will visit all the available channels over time.

Tolerance to signal interference

FHSS systems expect to operate in a noisy environment, containing other spread spectrum and fixed frequency devices. Renishaw's communication protocol features a unique probe ID to ensure that the RMI is receiving information from the correct probe and not from one on a neighbouring machine. Further security features include signal encoding and noise detection, a range of different channel hopping sequences, and transmission retries in the event of significant signal interference. If the RMI does not receive a valid signal from the RMP after a series of retries, it asserts its probe open and error outputs to bring the machine to a halt.

To interfere with the radio probe transmission, another signal will need to coincide with the same channel at the same time and must overwhelm the radio probe signal. This is unlikely since the 2.4 GHz band is reserved for low power transmission, so that the number of devices that are likely to be in range of the RMI at any point is probably low. The most likely impact of an interfering signal is to corrupt a few bits of the communication. If one message is blocked by another device, it would then need to hop with the same channel sequence at the same time interval as the probe to continuously block its communications. Realistically, the chance of this happening is very small.

Trigger signal repeatability

When a probe trigger occurs, then it is vital that this is transmitted to the CNC in a repeatable manner. A short delay is included in the transmission process to allow for retries in the face of signal interference, and the duration of this delay is highly repeatable. A trigger signal is issued to the CNC 10 ms ± 10 μs after the stylus strikes the surface and triggers the probe. Since the delay is repeatable, it is easily removed through probe calibration.

As explained earlier, the CNC's latching circuit will introduce a further, small repeatability error deriving from its scale resolution and the speed of its electronics, which is added to the probe and transmission repeatability to form the total system repeatability.

Avoiding transmission 'dead spots'

Radio waves pass between the RMP and RMI units directly, but also via reflections within the machine (refer to Figure 5). Single wavelength radio transmissions can suffer from nulls or 'dead spots', where there is destructive interference between the direct and indirect waves (total interference occurs where the indirect wave is of the same amplitude as the direct wave and is 180 degrees out of phase with it). Significant interference can cause the amplitude seen at the receiving unit to fall below its sensitivity threshold.

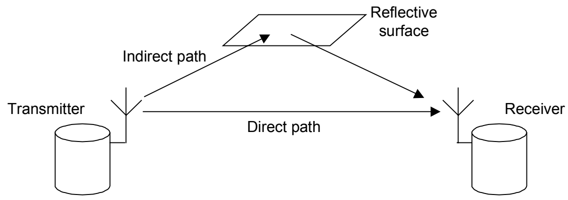

Figure 5 – radio waves reflect off surfaces inside the machine tool and can interfere with waves travelling on a direct path to the receiver. Frequency hopping avoids 'dead spots' by regularly switching channels.

Where this problem exists, changing the channel on a fixed wavelength system generally only has the effect of moving the null to a different part of the machine. Many fixed wavelength systems use two receivers, orientated at 90 degrees to each other to reduce the likelihood of nulls at the receiver.

A frequency hopping system avoids 'dead spots' by regularly changing channels. The 2.4 GHz frequency band provides a range of wavelengths from 0.121 m (channel 78) to 0.124 m (channel 00). Generally the reflected path is substantially longer than the direct path (at least 2.5 wavelengths longer). In this case, if there is a complete null on channel 78, the attenuation on channel 00 will be just 6 dB, so transmission can be performed successfully where nulls exist at any one wavelength. Only one receiver is needed for robust performance.

In practice, of course, there will be many reflected signals with different path lengths, making closely located nulls at successive channel frequencies very unlikely. Furthermore, reflected waves will be reduced in amplitude, thereby reducing the likelihood of total destructive interference at any one wavelength.

Regulatory compliance

Spread spectrum systems are favoured by radio regulations in most markets, since they allow many systems to coexist in the same spectral range with reliable communication. The 2.4 GHz band, in particular, has found nearly universal approval around the world and many spread spectrum and low-power broadband devices are now commercially available. This enables a single design of radio transmission to be used in all major industrial countries, simplifying regulatory concerns for machine builders who supply systems to many different markets. By contrast, fixed frequency systems occupy different frequency bands in US, European and Asian markets to comply with local laws.

Power management and turn-on methods

Low power consumption is desirable in the RMP, since it is powered by batteries. During operation, the probe minimises the drain on the battery by transmitting periodically, except when a trigger is sensed. In between the periodic communications, the probe unit consumes minimal power – sufficient just to run the probe interface and its microprocessor. During transmission, however, the power consumption increases as the battery must power the radio modem and its controlling electronics. Emitted radio power (ERP) is limited to 1 mW during transmission, and channel hopping is used to ensure robust communication over a range of up to 15 m, rather than resorting to greater transmission power.

The RMP60 system can be activated by means of a radio start signal, a centrifugal switch or a shank switch. In radio turn-on mode, the probe is activated by a signal from the RMI, using the probe’s unique ID. This method has the advantage of avoiding the use of high power start signals that can affect neighbouring probe systems and other radio devices in the vicinity.

Ease of installation

The minimal time and effort needed to install the probe system is a major benefit of radio systems compared to optical transmissions, especially on larger machines. Radio systems allow for greater flexibility in the positioning and orientation of the receiver, simplifying conduit routings for faster installation. Reliable operation with a single receiver is another benefit of FHSS systems.

The RMP60’s compact size (63 mm diameter and 76 mm length) makes it ideal for large machines and smaller multi-spindle or 5-axis machines. Ideally, an inspection probe should be as short as the shortest tool assembly on the machine, so that it can probe surfaces produced by that tool near the upper limit of the machine’s Z travel.

Conclusions

Renishaw’s pioneering application of spread spectrum radio transmission to machine tool probes has produced a compact system that is easy to apply, yet which provides reliable transmission, co-existing happily with other radio devices in the increasingly noisy factory environment. It is a universal solution that is in line with changing radio regulations around the world, and is set to broaden the appeal of radio transmission probes throughout manufacturing industry.