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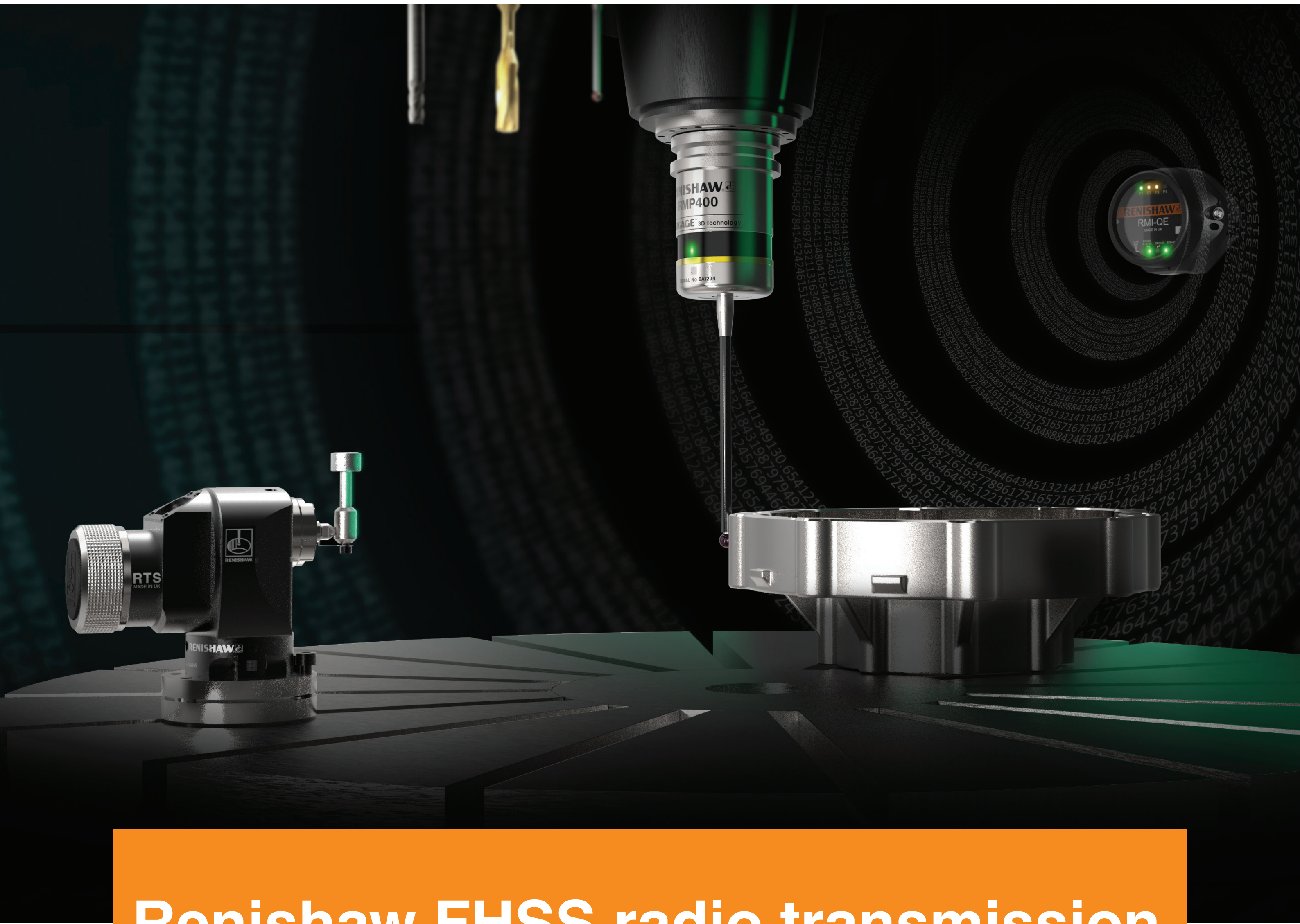

Renishaw FHSS radio transmission

Innovative frequency hopping radio transmission probe provides robust and flexible inspection on all 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 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 large machines. This technology has continued to be refined and is now presented in the 'QE' radio system – RMP and RMI-QE.

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.

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 stop 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 desirable 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.

Figure 1: Renishaw RMP60-QE

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 effort needed to fit the probe system to a typical machine?

Fixed frequency radio transmission technology

'Legacy' 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), 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 used 69 such channels, each with a bandwidth of 20 kHz. This allowed 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 and have now been superseded by spread spectrum devices.

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).

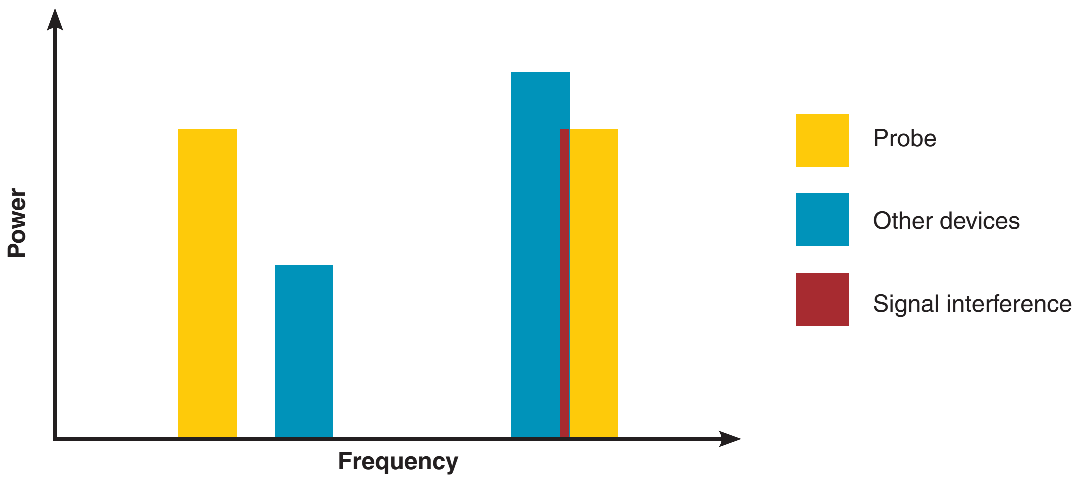

Figure 2: Probes and other devices on fixed channels must not overlap

Spread spectrum radio technology

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

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 Spectrum (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 'QE' radio probe system).

3. **Chirp Spread Spectrum (CSS)** - a spread spectrum technique that uses wideband linear frequency modulated signals (chirps). It is mostly used for long range data transmission applications (such as LoRaWAN) and when two-way ranging or distance monitoring is required.

4. **Ultra-Wide Band (UWB)** - a technology that uses nanosecond pulses broadcast across a wide bandwidth (>500MHz) to achieve short-range, high-bandwidth communications, with the added capability of precise ranging. This technology is increasing being used within mobile phone devices and is predominately used for the tracking of 'tags'.

Frequency Hopping - The Industrial Choice

Renishaw's latest generation machine tool probing system (QE) uses hybrid FHSS modulation, operating in the ISM band between 2.402 and 2.481 GHz, providing 39 channels, each with 2 MHz bandwidth. The system consists of at least two parts - the metrology probe (e.g. RMP60) which is mounted in the machine spindle or on the machine bed, and the RMI-QE 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 spread spectrum systems, as well as other devices such as microwave ovens that also operate in this frequency band. Frequency hopping system are designed to be tolerant of transmission collisions (from other devices) and simply retransmit on a different frequency/channel while preserving timing and metrology. FHSS allows a greater number of 'high power' co-located system to operate in the same vicinity compared to most other types of spread spectrum methods. This makes it ideal for large scale manufacturing sites.

Figure 3: Renishaw RMI-QE receiver / interface

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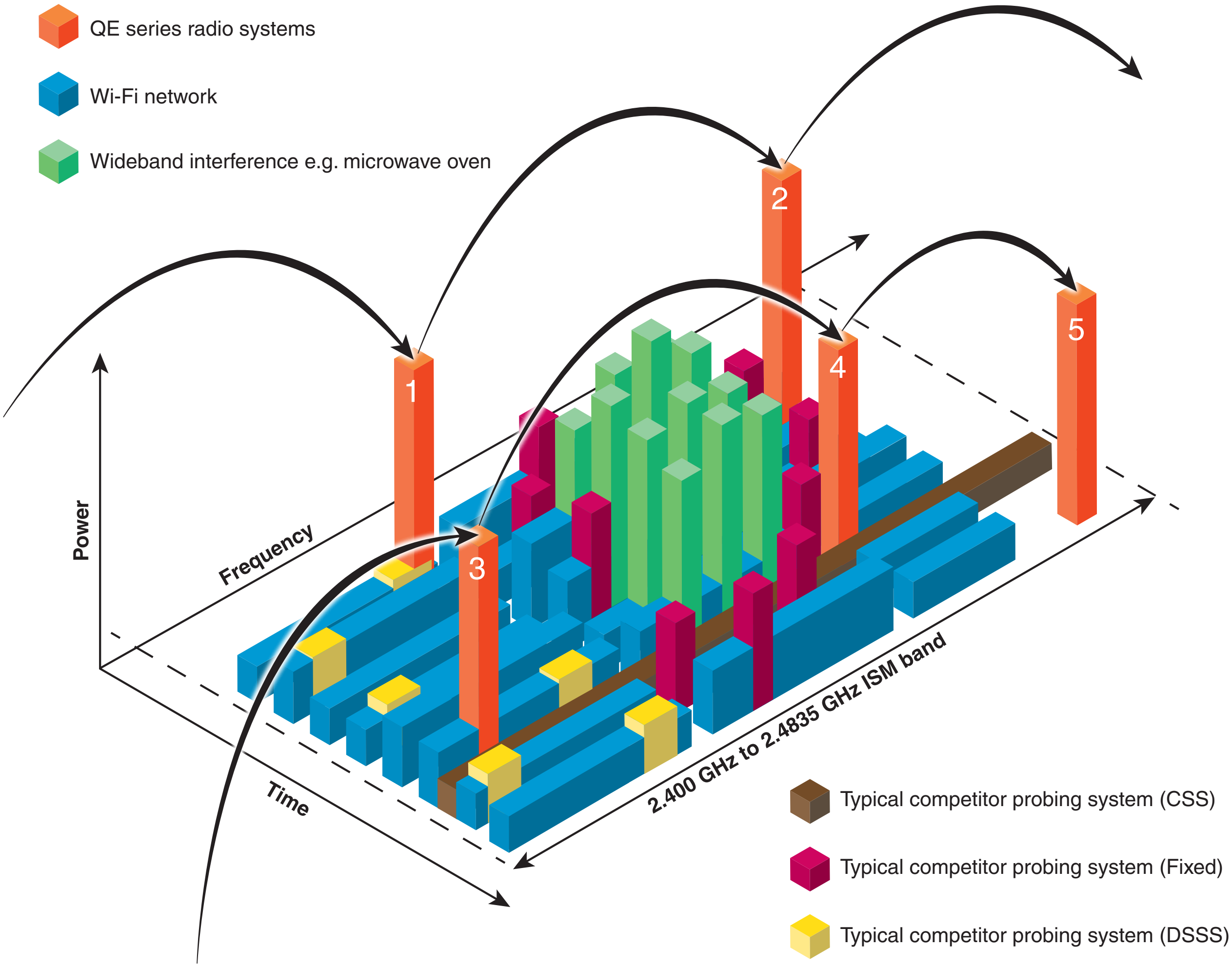

Figure 4: FHSS probe transmission co-existing with other radio traffic

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 using 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-QE is receiving information from the correct probe and not from one on a neighbouring machine. Further security features include authentication, data integrity assessment and interference detection. Every system operates with a unique hopping pattern to ensure co-existence with other Renishaw systems on adjacent machines. The bespoke protocol has been designed to combat interference by using a series of retransmissions when a communication does not get through, while preserving overall system latency and metrology performance. If the RMI-QE does not receive a valid signal from the RMP after a series of 'retries', it will assert the error output to bring the machine to a safe halt.

To interfere with the radio probe transmission, another signal must coincide with the same channel at the same time and overwhelm the radio probe signal. The 2.4 GHz band is reserved for low power transmission, meaning few devices are likely to be within range of the RMI-QE at any point. An interfering signal could potentially corrupt the data packet of the communication. If one transmission is blocked by another device, it would need to hop with the same channel sequence at the same time interval as the probe to continuously block its communications. The probability of this occurring is very small.

Trigger signal repeatability

When a probe trigger occurs, 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 5 ms ± 1 µs after the stylus strikes the surface and triggers the probe. Since the delay is repeatable, it is easily removed through probe calibration.

Avoiding transmission 'dead spots'

Radio transmissions pass between the probe and RMI-QE 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 paths (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.

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.

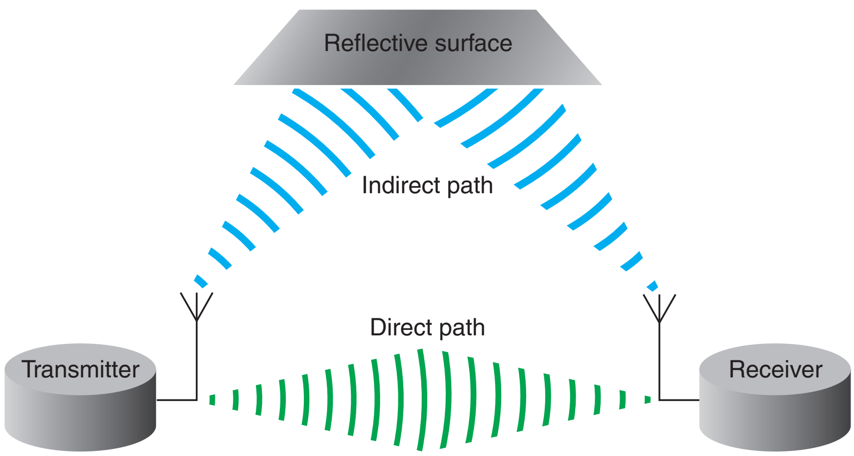

Figure 5: radio waves reflect off surfaces inside the machine tool and can interfere with waves travelling on a direct path to the receiver. Frequency hopping avoids 'dead spots' by regularly switching channels

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 38) 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 38, 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 paths 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 has found nearly universal approval around the world and many spread spectrum and low-power broadband devices are now commercially available that utilise this spectrum. 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 probe, 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 2.5 mW during normal 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 QE probe can be activated by means of a radio start signal, a centrifugal switch or a shank switch (RMP60 and RMP600). In radio turn-on mode, the probe is activated by a signal from the RMI-QE, using the system'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 interface and allowing faster installations by simplifying or removing the need for conduit routings. Reliable operation with a single interface/antenna is another benefit of FHSS systems.

The range of probe sizes available (24mm, 40mm and 63mm diameters with lengths of 31mm, 50mm and 76mm respectively) makes the QE probes 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 continues to provide reliable transmission and co-existence with other radio devices in the increasingly noisy industrial factory environment. It is a universal solution that complies with changing radio regulations around the world and is the benchmark for performance and reliability of radio transmission probes throughout manufacturing industry.

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