

# A High-Precision Noncontact Electronic Gap Measurement Gauge

The first portable capacitive gap measurement tool, originally developed for aircraft manufacturing, now has a digital output that expands its range of applications.

**Bryan Manning and Robert L. Foster, Capacitec**

Shims and feeler gauges, the tools traditionally used in gap measurement, exhibit only marginal accuracy when the tolerance must be better than 0.001 in. (0.025 mm). Plastic shims can vary in thickness by 0.0003 in. (0.0076 mm), and feeler gauge data tend to be subjective—the “feel” will vary from one user to the next.

A second problem with contact measurement methods is that their accuracy is reduced over time. The constant rubbing against hard surfaces during the measurement process causes wear on the shims and feeler gauges, and can also damage the highly polished surfaces found in some applications. Third, shims are often removed after setup and there is no way to be sure that the gap is still within spec.

A major U.S. diesel engine manufacturer undertook a study of these problems because fuel economy, guaranteed under service warranty, varied widely with the final adjustments made to fixed gaps on the spring-load-adjusted intake and exhaust valves. Metal shims were used to make these tweaks. The desired gap sizes were ~0.015 in. (0.38 mm) for the intake and ~0.030 in. (0.76 mm) for the exhaust valves. The results of the study indicated that there was a sizable discrepancy in the measurement results among six technicians, all of whom were using the same tools and trying to set the same gaps. The gap sizes varied from one another by amounts ranging from 0.001 in. (0.025 mm) to 0.006 in. (0.015 mm), with an average variation of 0.003 in. (0.076 mm) or 10% of reading for the

Several trends in quality and process control are pushing QC personnel toward increased documentation and recording of the measurements they perform. QC schemes such as SPC and TQM have become more rigorous. ISO 9000 represents a new set of manufacturing standards. Once measurements are obtained, they must be transferred into the local quality system. Manually writing down the information on X/R charts, for example, and then inputting it to an SPC data program on a PC offers yet another opportunity for error. Automatically gathering and transferring these data electronically to the appropriate quality program would save time and money—and improve the quality of the recorded data.

## Advancing the Technology

Noncontact capacitive sensors and sensor systems have been used by industry to measure gaps since the 1960s, and by the nuclear fuel industry since 1978 to measure gaps between fuel rods. Even though the sensors of that time could be as thin as 0.020 in. (0.50 mm), they ran into trouble trying to measure gap sizes <0.040 in. (1.0 mm).

This limitation, and the lack of system

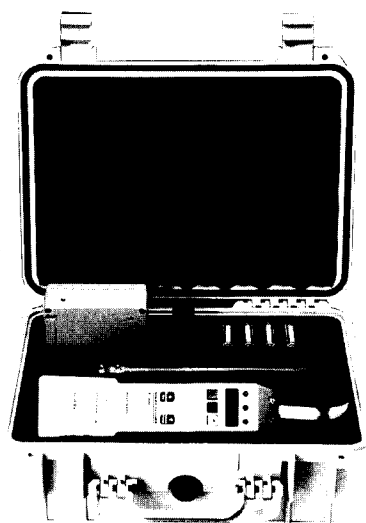


Photo 1. Each Gapman kit is shipped in a waterproof industrial case that also contains standard components such as a battery charger, RS-232 and ground cables, and a 3-point gap calibration block. Additional optional components are available for special applications.

eral acceptance even though interest in it remained alive in the aerospace, semiconductor, automotive, and industrial arenas.

In the late 1980s, Capacitec and Boeing Aircraft began a cooperative development program that resulted in the design of the world's first portable thin gap measurement instrument, the analog Gapman. Introduced in 1993, and sold for a number of applications, this device satisfied many of the customers'

requirements, including portability, improved repeatability, and interface to SPC data loggers.

## Customer-Driven Product Development

The analog Gapman was a major step toward portable gap measurement, but needed further development to expand its range of applications. Capacitec therefore invested in an extensive customer-driven product development program. Before any product designs were drawn up, a 10-page survey was sent to and completed by more than 50 potential users. In addition, dozens of customers were interviewed at trade shows and beta site meetings. The result was a prioritized list of key requirements for

held gap measurement instrument:

#### Easy to Use

Simple to operate even for new or unskilled employees

Preset to the specific application

Effortless interface with quality control systems

#### Flexible

One instrument for multiple measurement locations

Reaches gaps very difficult to access

Precise on all conductive surfaces

#### Reduces Cost

Low cost per measurement

Longer process/equipment uptime

Eliminates startup scrap

Eliminates scratches on product

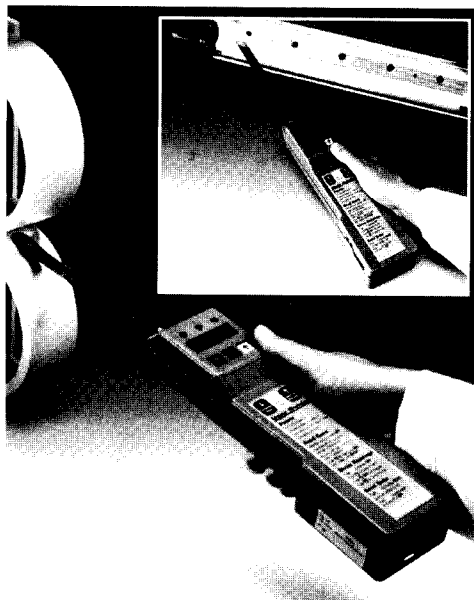
With this input, Capacitec finalized the product design to include the following key features:

- Factory preset to customer spec.
- Digital output (RS-232)
- Ergonomic design
- Easy connections
- Preprogrammed setup
- Audible/visual feedback on reading
- Long battery life
- Quick-change gap sensors
- Minimum of buttons
- Good tip sheet

### The Digital Gapman

The new digital Gapman, introduced in late 1996, is a high-precision, noncontact, portable electronic gap measurement gauge (see Photo 1). It features two capacitive sensors, one on either side of a wand, for position-compensated measurement and insertion into gaps as small as 0.009 in. (0.22 mm). The measurement technique uses the capacitive principle of measurement physics as applied to determining the distance between two capacitor plates. The target, which is earth grounded, forms one plate and the sensor the other.

Each of the two sensors on the wand is interfaced to a built-in instrumentation amplifier. When the detected capacitance is input to the amplifier, the output can be linearly ratioed to digital units and then to engineering metric or English units as related to the gap between each sensor and its target. (The gap may range from touch to some full scale dimension.) The dual sensors' guard rings are driven to alleviate degrading fringing effects that would reduce the sensor's measurement range. The air gaps of the two sensors are added to the overall sensor thickness to arrive at the true gap.



**Photo 2.** The Gapman is shown measuring a 0.7 mm gap between a small roller diameter and a 0.5 mm sharp edge (inset). A special linear calibration for the roller diameter and the knife edge was supplied for this application. The automatic mode used to measure the gap between two large-diameter rollers takes the minimum gap reading and peak holds it on the digital display.

Measurement is noninvasive and unaffected by alloy variations, and therefore not subject to the dramatic rises in error rates that alloy variations can create when other measurement processes are used. Unlike inductive or eddy current sensors, which cannot be used in high magnetic fields, capacitive sensors are immune to magnetic flux changes as well as to materials that change magnetic susceptibility.

### Typical Applications

Capacitec's thin sensor technology has replaced traditional gap measurement methods in a range of applications, including:

**Coatings.** In the photographic film and adhesive label industries, 3–6-ft-long parallel stainless steel plates called coaters are used in the coating process. These plates have a machined air gap of between 0.012 in. (0.3 mm) and 0.020 in. (0.5 mm), which must be maintained to 1  $\mu$ m or better repeatability across the full length to achieve coating uniformity. The Gapman is used to test alignment before production and to maintain alignment after weekly maintenance procedures.

**Plastic Extrusion.** Similar to coaters, plastic extrusion dies used to make plastic sheet, mesh, and other products have high-precision thin gaps typically <0.020 in. (0.5 mm). At Cincinnati Milacron, a well-known manufacturer of high-precision plastic extrusion

equipment, maintaining accurate gaps is critical to ensuring product quality. Gap ranges of 0.020 in. (0.5 mm) to 0.10 in. (2.5 mm) are maintained with an accuracy of 0.0002 in. (0.005 mm) at gap temperatures of 100°F–150°F. According to Hayes Striplin, product manager for the plastic sheet extrusion line, the company uses our noncontact industrial gap wands 0.040 in. thick (1.0 mm) to adjust the ends of two long extrusion rolls to spec; it then checks sag at the middle gap with the Gapman.

**Structural Assembly.** At Boeing, the Gapman is used to measure and control gaps on commercial aircraft skins and structural components. Typical gaps range from 0.009 in. (0.22 mm) to 0.125 in. (3.2 mm). During assembly of the Boeing 777 tail section, a Gapman is used to measure gaps 8 in. inside the sub-assembly. The device is also used to measure gaps between metallic and non-metallic (composite) materials in advanced design and military aircraft.

**Photocopiers.** Xerox Corp. has since 1982 used Capacitec thin gap technology extensively in the production of its photocopiers. In printing press and photocopier applications, the Gapman is used to control and set the paper paths to gaps within 0.001 in. (0.3 mm) to 0.002 in. (0.6 mm) windows in blind locations 24 in. (0.61 m) inside the photocopier (see Photo 2). In large-scale printers, the precise alignment of printer heads is critical to print quality. A Gapman is used by a major East Coast manufacturer of printers to set nominal gaps between 0.028 in. (0.7 mm) to 0.032 in. (0.8 mm).

**Packaging Materials.** During manufacture of polystyrene foam dinnerware and prepared food packaging, the gap between the two halves of the foam mold must be measured. This procedure helps ensure high-quality foam plate production, eliminates startup scrap, and prevents thin-walled packaging products from failing in the field. During scheduled setup and maintenance, a Gapman monitors these molds for wear.

**Other.** Additional applications include battery component gaps; rotor-to-stator air gaps in electric motors; polyester film roller gaps; PC board lamination presses; and die gaps on large automotive metal forming presses.

Gapman is registered by Capacitec. ■

**Bryan Manning** is a marketing consultant, and **Robert L. Foster** is Director of Engineering, Capacitec, PO Box 819, 87 Fitchburg Rd., Ayer, MA 01432; 508-772-6033, fax 508-772-6036.