FORCE SENSORS FOR DESIGN

IN RECENT YEARS, factors such as consumer demand and a tough economy have pushed OEMs to produce sleeker, smaller, and less costly products than in the past. This forces designers to spec or engineer parts for increasingly tight space requirements. In this difficult situation, even small components such as force sensors can play a surprisingly big role in the development of successful solutions. A patented, thin-film, flexible but accurate force sensor was developed specifically to target industry needs for a low-cost, unobtrusive, force or pressure-measurement solution. The unique technology eliminates many of the challenges plaguing engineers in the design of streamlined products.

MACHINE Design .com
BY ENGINEERS FOR ENGINEERS

Tekscan

Selecting a low-power force sensor for seamless integration and sleeker designs

MOST ENGINEERS ARE FAMILIAR with the numerous types of force sensors. These devices abound in robotics, industrial equipment, automobile safety systems, and many other areas.

The most well-known transducers for measuring force are load cells. They can use a variety of technologies to sense loads. Strain gages, piezoelectric elements, and variable capacitance are among the methods in wide use.

Load cells, however, have some drawbacks, particularly in applications where weight and size are both at a premium. Load cells can be bulky. In situations where the application of interest involves relatively lightweight elements, the load cell may weigh more than the component being tested. And some types of load cells can also be subject to ringing in certain applications because their internal elements have spring-like qualities.

In recent years, a different type of force sensor has become commercially available. The generic term for these devices is tactile sensor. The term comes from their frequent use as a means of sensing a nuanced or delicate touch, as with a robotic hand from a humanoid robot. But tactile sensors have applications extending far beyond anthropomorphic robots. They typically are built on flexible circuit material so they can be thin, light, and flexible (within reason). This opens up potential applications as, for example, sitting under a bolt head to sense the load as a technician wrenches the nut tighter, or measuring the force between two rollers directly from within the nip.

One such tactile sensor in particular targets uses that can benefit from an unobtrusive force measurement with a transducer that is also economical. Called a FlexiForce® sensor, it consists of special, proprietary piezoresistive material sandwiched between two pieces of flexible polyester with printed-

silver conductors on each inner half. The conductive traces form electrical connections to external circuits. The resulting sensor is paper thin, only about 8 mils thick.

FOCUSED ON VERSATILITY

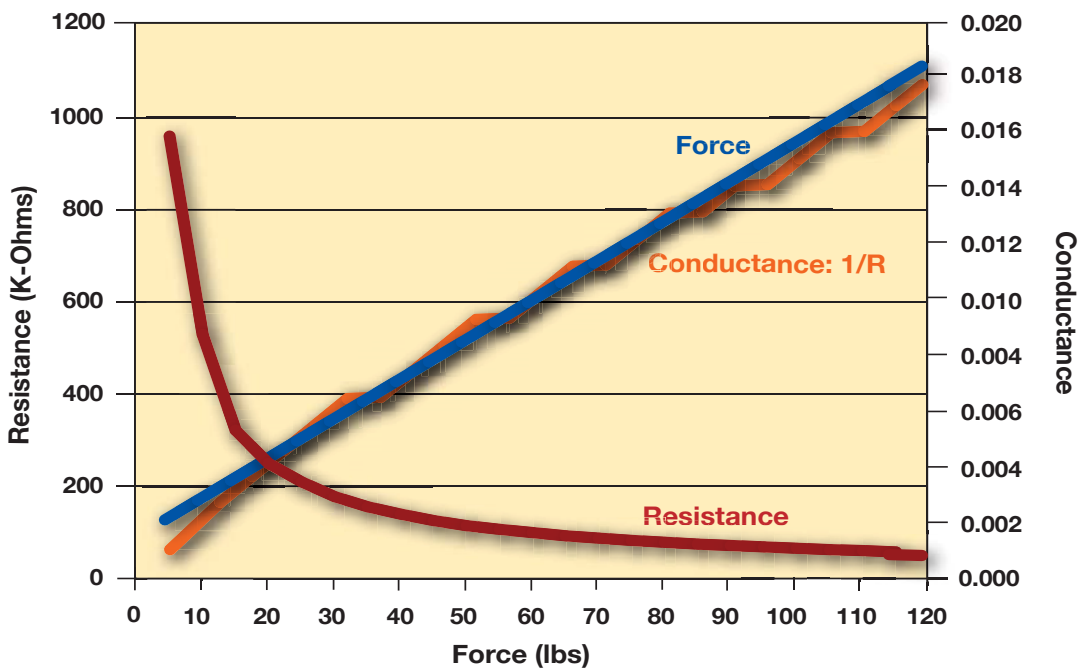
FlexiForce sensors, manufactured by Tekscan, Inc., are basically resistors that vary linearly in terms of conductance vs. force under an applied load. With no force applied, their resistance is on the order of megaohms; it is essentially an open circuit. As applied force rises, output resistance drops, eventually reaching about 10k Ω or lower, depending on the application. The output, expressed in conductance vs. force, is quite linear (linearity error < ± 3%). External circuitry to convert the output into a linear analog voltage can be relatively simple.

FlexiForce sensors come in one standard shape off-the-shelf for testing/proof of concept and are available in several lengths. But these sensors can also be fabricated in custom form factors with relative ease for OEM applications.

Similarly, the range of force these sensors handle can be customized as well. They can also be quite sensitive to applied force. A FlexiForce sensor can register a light touch of only 5 gm, though recommendations are to load at least 80% of the device's sensing area with 40 gm or more for best results. It is also possible to adjust the sensor's dynamic range by tweaking its external drive circuit. These adjustments are as easy as a turn on a potentiometer.

Also available are "matrix" sensors, which come in a variety of standard shapes and sizes. These sensors are often referred to as "sensor mats." The mats can be built with sensing locations as small as 0.0009 sq-in. or covering areas up to 256 sq-in. These packages are considered

100-lb Sensor



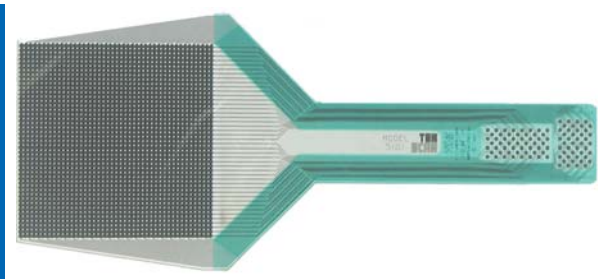
FlexiForce sensors are basically resistors that vary linearly in terms of conductance vs. force under an applied load.

pressure-mapping systems and are designed to be used with Tekscan's patented electronics and software to display areas of high and low pressure across the surface of the sensor. They typically find use in R&D, test & measurement, and quality assurance applications.

This sort of versatility lets tactile sensors play a role in a number of imaginative uses. The first generation of thin-film force sensors emerged in the 1980s. Developed by Tekscan for the dental industry, they let clinicians measure the force and pressure distribution of a patient's bite with respect to time. This was an advancement over a check with mere carbon paper, which could only gauge peak pressure with no time reference.

Since the 1980s, the technology has been further refined, and applications have emerged in such areas as conformal ergonomics, large metal-stamping machines, small electronic connections, and even soft rubber door seals. Often, shoe manufacturers use FlexiForce sensors to gauge the amount of force exerted by heels and toes to design a more comfortable shoe insole.

FlexiForce sensors are 100% factory-tested. Thus, they tend to be specified in applications that can't tolerate failures. And, they are built in the United States, an advantage for custom sensor designs that incorporate a significant amount of intellectual property.



Tekscan also offers a variety of matrix sensors, which are used with patented software and electronics for real-time pressure mapping over a given area.

COMPARING CAPABILITIES

It is useful to compare FlexiForce sensors with other types of tactile sensor technologies. One design uses a piezoresistive material, similar to that of FlexiForce sensors, sandwiched between flexible plastic sheets, but puts both conductive areas on the same substrate. A point to note about this design is that the output depends on the sensor area over which the force is distributed. A force acting on a large percentage of sensor area will produce a lower reading than the same amount of force concentrated on a smaller area. In this regard, such sensors behave as pressure sensors rather than as force sensors.

Another type of tactile sensor uses capacitance as the sensing mechanism. The typical makeup is that of overlapping row and column electrodes separated by an elastic dielectric material. Compressing the dielectric between a particular intersection of row and column plates reduces the plate spacing and provides a response proportional to displacement.

One difficulty with capacitive tactile sensors is that they generally must be driven with a high-frequency ac signal. This is because the displacement change with applied force is relatively small, and so is the change in capacitance. The electronics needed to convert capacitance change to force can be somewhat complicated. In contrast, FlexiForce sensors are driven with dc. They can be used with Tekscan's Economical Load and Force (ELF) system to sample and record data at rates of up to 5.7 kHz.

Simple drive electronics plus a thin profile make FlexiForce sensors candidates for several areas of use. The standard version of the sensor has an active sensing diameter of 0.375 in. In many cases, designers will prototype with a standard sensor to prove a concept, then devise a custom version. Custom sensors can have nearly any shape, even with irregular features. Sensors can also be attached to stiffer

continued on page 6

Standard and Custom Single-Point Force and Load Sensors

MODEL A201 FLEXIFORCE STANDARD, off-the-shelf sensors come four in a box. For customized versions, Tekscan accepts orders ranging from 10 items to millions, depending on factors that include sensor size and shape.

Physical Properties FlexiForce Standard Model A201

Thickness	0.008 in. (0.208 mm)
Length	7.75 in (197 mm) Optional trimmed lengths: 6 in. (152 mm), 4 in. (102 mm), or 2 in. (51 mm)
Width	0.55 in. (14 mm)
Sensing Area	0.375 in. (9.53 mm) diameter
Connector	3-pin Male Square Pin (center pin is inactive)
Substrate	Polyester (ex: Mylar)

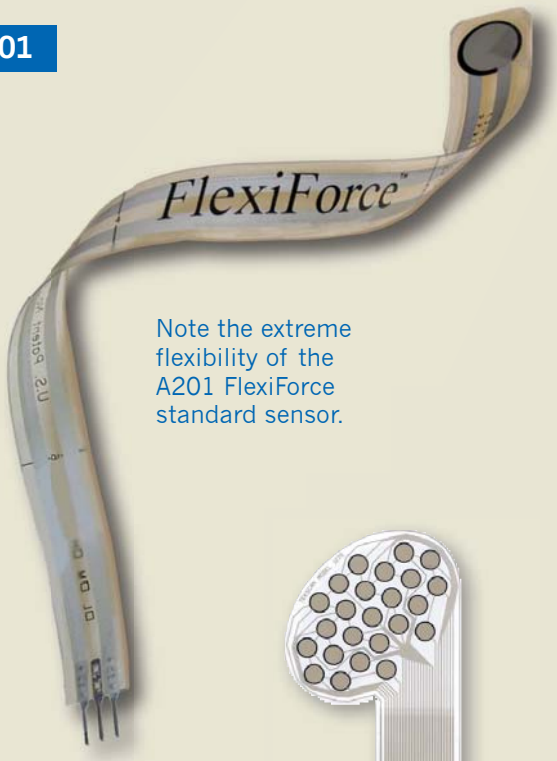
Standard Force Ranges

0 - 1 lb (4.4 N)
0 - 25 lbs (111 N)
0 - 100 lbs (445 N)

To measure up to 1,000 lbs, apply a lower drive voltage and reduce the resistance of the feed-back resistor (see circuit on page 7).

Typical Performance

Linearity (Error)	< ±3%
Repeatability	< ± 2.5% of Full Scale
Hysteresis	< 4.5% of Full Scale
Drift	< 5% per Logarithmic Time Scale
Response Time	< 5µsec
Operating Temperature	15°F - 140°F (-9°C - 60°C)



Note the extreme flexibility of the A201 FlexiForce standard sensor.

Custom versions of FlexiForce sensors can include sensors with more than one sensing element.

New HT201 High-Temperature Force & Load Sensors: 15°F to 400°F (-9°C to 204°C)

continued from page 4

substrates such as hard plastic or metal if the application environment demands it.

Standard sensors are offered in the range of 0 to 1, 0 to 25, and 0 to 100 lbs. Overloads up to 10,000 psi (plastic limit) won't harm the sensors. For measuring forces between or outside of these ranges, a simple op-amp circuit can be constructed (see circuit on page 7). By adjusting the feedback resistor of the op-amp circuit, or adjusting the drive voltage to the sensor, the force range can be fine-tuned up to 10 times in either direction for keying in on specific force ranges.

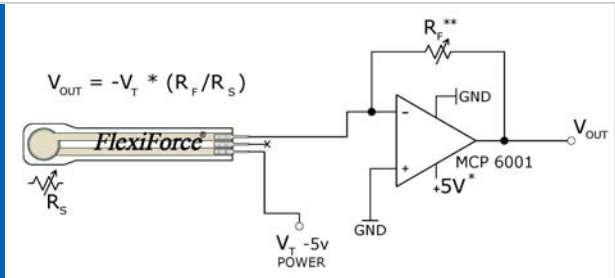
From infusion pumps to palpation proficiency

MORE RECENT MARKETS taking off for thin-film sensors include the medical device industry. Novel devices measure forces exerted by tools during surgery for a more sensitive tactile response and accurate simulations; certify axial stabilization of tendons and evenness of tissues in joints during surgery to facilitate proper recovery; and obtain feedback from forces exerted on infusion and syringe pumps to ensure they are functioning properly.

In another case, a National Cancer Institute-sponsored project in the late 1970s began to use technology to standardize breast examination. The problem: Most breast lesions are palpable and discovered by hand, not X-ray, which works on bone and not on soft tissue. At the time, it was routine for tumors the size of golf balls to go unnoticed, not a good situation when the larger the tumor, the more chance of malignancy. Over time, the group developed MammaCare®, now recognized as the medical and scientific standard for clinical breast examination efficiency.

Over the years, the group developed many design iterations to come up with what today is called the Palpation Proficiency and Assessment Device (PAD), which comprises tactually accurate breast models instrumented with custom FlexiForce sensors. The sensors locate and relay over 1,000 levels of examination pressure within each square centimeter by way of a digital signal processor. The device lets MammaCare confidently certify clinicians who have demonstrated examination skill. The complete solution also included electronics, hardware, firmware, and Windows drivers designed and produced by SSI Wireless.

The MammaCare breast model, containing small simulated tumors, sits on the surface of a pad containing an array of FlexiForce sensors. The sensors provide force feedback data used to measure the performance quality of a clinician's breast examination skills. These data are used to certify breast examination proficiency.



Typical drive circuit for sensor.

SIZING UP APPLICATIONS

Light weight and size aren't the only reasons for employing FlexiForce sensors. Durability was a key driver for Sensor Wireless, a Canadian manufacturer of wireless monitoring gear for large bottling plants. To help their clients reduce breakage during production, Sensor Wireless needed a custom force sensor integrated into its system which would determine forces applied to bottles by production line rails, robotic grippers, and adjacent bottles.

Once Sensor Wireless customers receive an order, they consult with Sensor Wireless, which replicates the bottle in question and then wraps a sensor around the form. The sensor is combined with a wireless transmitter by Sensor Wireless and is placed around the bottle, explains Director of Production and R&D Tom MacDonald. The proprietary electronics that enable wireless capability go inside the bottle. Readings of sidewall forces on the test bottle transmit from the FlexiForce sensor through an RF signal to a Palm handheld, so line operators can see the forces in real time.

Before a custom FlexiForce sensor was developed for their application, a lot of line adjustments entailed workers "guessing-and-checking," a difficult way to find problems, notes MacDonald. "But now," he says, "an operator just needs to isolate a section of line and run the test bottle through it anywhere from five to 10 times to get a force profile. The operator repeats this process for the whole line, quickly pinpointing the problem and adjusting the equipment accordingly. The monitoring device eliminates a lot of line downtime because adjustments just take a few minutes."

Bottling lines can run at speeds of 1,200 bottles a minute. At these speeds, there are a lot of bottle collisions associated with corralling and other handling operations. Only a durable sensor can withstand this sort of treatment, says MacDonald. Some of the company's customers have been using the same monitoring device for 2 ½ to 3 years now.

Durability also tops the list for SSI Wireless, a U.S. engineering firm and business unit of SSI Embedded Systems. According to President Michele Mordacq, a recent project, a prototype wireless inventory-control system, involved single-point sensors in a custom arrangement that fits on a shelving unit in a grocery store. When a shelf becomes empty, the system sends e-mails to company personnel listing items that need restocking.

"From all the available force-sensing technologies, we selected the FlexiForce as the best combination of durability, price, and accuracy," says Mordacq. "In questioning different sensor

A FlexiForce thin-film sensor wrapped around a test "bottle" captures sidewall forces exerted on the form. Internal electronics send this data wirelessly to a Palm handheld, letting line operators see the effects of their adjustments in real time.

manufacturers, we liked the availability of an off-the-shelf, single-point sensor because we could easily purchase a few and then build test samples to see if a system would work. For the inventory equipment, highly accurate devices such as medical scales cost too much, and that level of accuracy was unnecessary anyway. As long as measurements lay within a few ounces, it was good enough. Load cells proved too big because they interfered with system operation."

Mordacq says the thin-film sensors can also provide users a way to reduce costs such as maintenance because the devices let companies remotely monitor equipment in the field and take corrective action earlier. It's common to send out technicians to measure pressure, temperature, motor turns, and the like to diagnose equipment problems, Mordacq explains. This process is costly and time-consuming. So SSI Wireless is combining FlexiForce sensors with electronics to build a device that will provide a remote view for diagnostics. Tekscan worked with the firm during the effort to help iron out development issues.

Mordacq also says the capability to interact with a force-sensor manufacturer with strategic technological partners is important because this arrangement can help designers cope with unfamiliar disciplines. Mechanical engineers, for example, must increasingly deal with different fields, such as electronics.

The prototype Real Time Wireless Inventory Reporting system developed by SSI Wireless uses force sensors from Tekscan to determine when shelves need restocking.

"Tekscan partnered with us to help turn its Economical Load & Force (ELF) system for force measurement into a wireless device," says Mordacq. "We brought in our hardware and software experience in wireless communications and network protocols as well as experi-

Biggest challenges

A WIDE RANGE OF FORCE-SENSING technologies is available, making it difficult to select the best one. Research from MACHINE DESIGN magazine's "2008 Sensors Market Overview Report" lists the biggest challenges designers face when dealing with a sensor manufacturer. Topping the list is lack of technical assistance.

When designers have technical questions, they want to speak with application engineers who understand their processes and can quickly address their questions. They also want to collaborate with a company that sells quality products and can efficiently handle their orders, whether they are buying a single sensor or millions of sensors. What's more, designers expect timely delivery of sensors.

Companies that need help in selecting and integrating standard or custom sensors into their solutions can work closely with the Tekscan technical team throughout the design process. As Mark Goldstein, Ph.D., a member of the research team that founded MammaCare®, says, "Work is spectacular, and more exceptional than I thought it would be. The sensors work great. They can detect the slightest pressure accurately. It is way beyond my expectations."

ence in the development of Windows desktop applications. Our two companies continue to work together on other solutions, a recent example coming from the aforementioned wireless shelf-inventory system."

A quick turnaround on custom devices along with a sensor manufacturer that knows OEM processes inside-out were factors important to Cervitrol, a Swedish engineering firm that helps companies in the design of new solutions. A recent project involved the design of an instrument for measuring pressures between a steel and rubber plate in commercial printing equipment. The instrument lets operators see forces in real time to quickly and easily adjust the machinery.

"We had already used the standard flexible sensor in other jobs and product trials in the past, so we were familiar with its large dynamic range and excellent linearity and accuracy," says Thomas Eisner, design engineer. "But the instrument design," he continues, "required our working closely with the manufacturer. The design needed a much smaller sensing area than the standard sensor provides, so it was necessary to ensure such a small area could, in fact, detect force. The application involved a load range of about 10 to 100 psi and a long surface requiring an even pressure distribution through a line along the surface. An eight-week turnaround on the custom sensor and good advice from the manufacturer helped smooth our product-development processes."

CONCLUSION

Good things come in small packages, as OEMs that have adopted thin-film piezoresistive flexible force sensors (FlexiForce) can attest. Such technology, with its very thin and flexible capabilities, is easy to integrate into a myriad of designs.

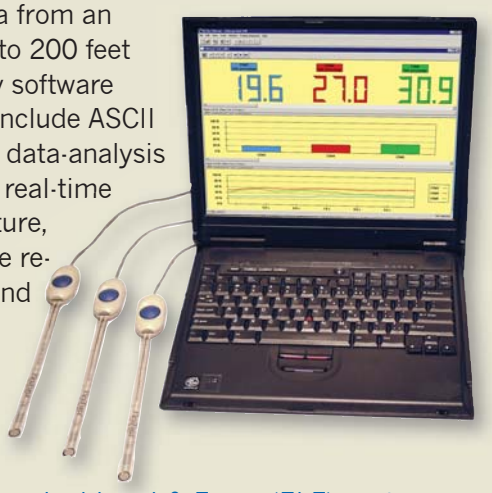
OEMs find that these low-cost, off-the-shelf sensors provide them an easy and quick way to prototype products. The durable design also works well in end solutions, providing a wide resistance range, high linearity, low drift, and low power consumption. What's more, the user-friendly, single-cell sensors don't need complex electronics to achieve an output.

Given these characteristics, OEMs can employ this technology in a range of applications. They will find that these sensors play a key role in developing sleeker, smaller designs. ■

Turn a laptop into a force-measurement system

IN ADDITION TO THE WIRED version shown here, Tekscan's wireless, inexpensive Economical Load & Force (ELF) system provides a USB-powered Hub, a battery-operated transmitter, three sensors (one in each of the available force ranges), and software that turns a laptop or PC into a force-measurement instrument.

The wireless system can capture and store force data from an event up to 200 feet away. Key software features include ASCII output to data-analysis software, real-time data capture, and movie recording and saving.



The Economical Load & Force (ELF) system from Tekscan gives users an inexpensive, pre-built way to try out a force-measurement system. Wireless systems are also available.

For more information on using thin-film, flexible force sensors in product design, visit www.tekscan.com; phone 800.248.3669 in the United States or +1.617.464.4500 internationally; or email marketing@tekscan.com.

Tekscan