Innovation in action

ABB's ground breaking optical caliper sensor means papermakers can measure and control caliper on the most demanding paper grades

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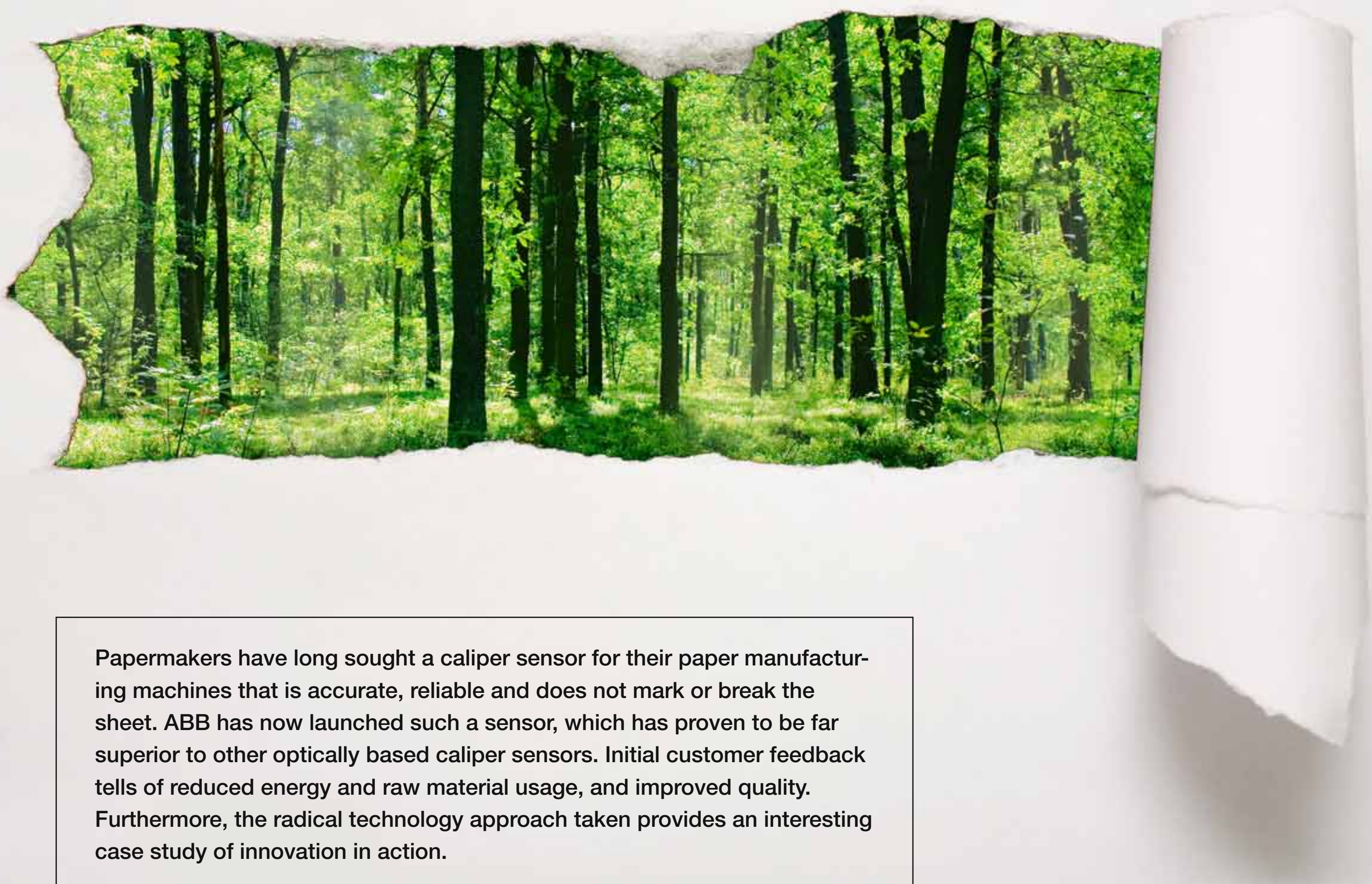

Papermakers have long sought a caliper sensor for their paper manufacturing machines that is accurate, reliable and does not mark or break the sheet. ABB has now launched such a sensor, which has proven to be far superior to other optically based caliper sensors. Initial customer feedback tells of reduced energy and raw material usage, and improved quality. Furthermore, the radical technology approach taken provides an interesting case study of innovation in action.

Innovation in production

One could be forgiven for thinking that paper, invented thousands of years ago, is one of the simplest products in the world to manufacture. Yet the modern production of even one sheet of photocopy paper involves an almost unimaginable array of technology – especially where the quality control system (QCS) on the papermaking machine is concerned. ABB is one of the top providers of such QCS technology to papermakers.

Central to a papermaker's operation is a scanning platform through which the paper web passes. This scanner holds an assembly of sensors that measure the principal properties – moisture and weight – of the paper as they move across the sheet. A sophisticated set of control algorithms then generates instructions for the papermaking machine to regulate the process.

Along with moisture and weight, accurate caliper (ie, the thickness of the paper) measurement and control are critical for defining paper. However, reliable caliper measurement has proven elusive.

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Past imperfect

Traditionally, accurate caliper measurement has been achieved using dual-sided contacting caliper sensors, the current industry standard. These run small "skis" over the paper and record the thickness change to within a 1 µm accuracy. Even though paper may look flat, on a microscopic level many paper grades actually look more like a mountain range! The caliper, by definition, is the paper thickness when some of the "peaks" have been lightly compressed and it is a need-to-have measurement for almost every papermaker.

Some types of paper present tremendous challenges for these contacting skis, and paper sheet damage, inaccurate measurement and poor control can often result. This prompted ABB to pioneer non-contacting air-bearing sensors in the late 1960s. These offered simplicity but had marginal accuracy and resolution performance on high-speed machines.

More recently, QCS suppliers have focused on optical caliper sensors, usually utilizing the laser triangulation technique. This method has shown promise but is plagued by substantial errors caused by instability in a fast moving sheet, tilt effects from a non-flat sheet, sensor alignment, surface topography effects, and not least, laser light penetration into the semi-translucent paper body.

ABB has chosen quite a different, non-laser optical approach, one that provides greatly improved measurement accuracy and stability. This new sensor, the latest in its 50-year history of pioneering online paper quality measurements, finally provides papermakers with a precision tool to measure and control caliper on even the most demanding paper grades.

Laser triangulation limitations

Laser triangulation has found acceptance in industries such as metals, rubber and plastics. It compares a physical gap and a laser triangulation distance measurement to the free sheet surface. Triangulation works by focusing a laser beam onto the paper and following the position of the reflected light 1a. The distance from the sheet surface can then be determined by analyzing where this image is formed.

Triangulation works extremely well for surfaces that have no penetration issues, such as metals. However, if the light penetrates into the bulk material, as can be the case with paper, then the method will have difficulties determining the true surface location and hence give a false distance measurement 1b. Grade and process-dependent calibrations or other compensation may also be required as well. Some laser sensors may also need to operate in tandem with a periodically engaged contacting caliper sensor to refresh the laser sensor for both absolute and profile shape calibration.

Light penetration can be easily demonstrated by measuring five different paper-grade sheets – taped together – using a dual-sided contacting versus a dual-sided laser triangulation caliper sensor 2. The agreement on the fine paper grades ranges from approximately 1 µm to about 10 µm. Often, the quality specification of these paper grades calls for a caliper variation of no greater than ±1 µm, so such variations in agreement can pose real problems as grades are changed on a single machine, or even as process conditions change. In addition, there are enormous discrepancies when paper grades change more extensively, such as the 30 to 50 µm offsets recorded for the card stock and kraft grades, for example.

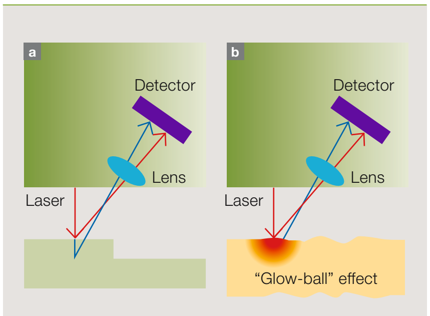
Along with moisture and weight, accurate caliper measurement, which has often proven elusive, is critical for defining paper.

On some thin paper grades, laser sensor caliper errors can approach 50 percent of the sheet thickness.[1] To compensate, time-consuming fiber and filler-dependent calibrations have to be made.

Seeking a better method

Efforts to overcome many of these problems yielded only limited success.

1 Laser triangulation principle: The position of the reflected light changes as the sheet thickness varies a. In b, the glow-ball effect causes measurement uncertainty in some paper grades



Footnote

[1] All these issues have been verified by other researchers [1,2,3].

However, because customer demand for a laser-based system was so high, ABB decided to embark on its own laser sensor development project.

Using its in-depth knowledge of light scattering from paper, ABB quickly concluded that even an enhanced laser triangulation technique was not the best tool for precision caliper measurement. A parallel study carried out to investigate the potential of technologies from other industries uncovered one technique that attracted much attention – an optical confocal displacement technique.

ABB's non-laser optical approach provides papermakers with a precision tool to measure and control caliper on even the most demanding paper grades.

An initial evaluation showed it had the required micrometer resolution and other performance parameters. Its ability to measure rough paper surfaces on a dirty, humid and vibrating paper machine, however, was unknown as it had only ever been used in a stable laboratory environment. Laboratory tests finally proved that technology was indeed robust enough and it became the focus of the development project.

Optical principle

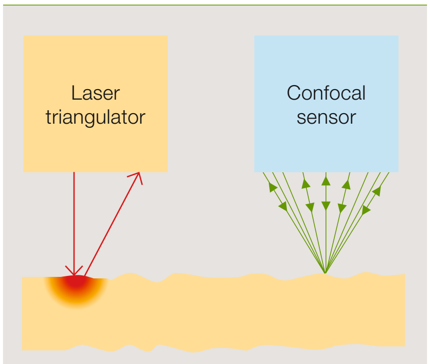
The confocal method works by projecting a small spot of broadband light (12 µm) from a high-power white LED source, via fiber optics and through a lens system, onto the sheet surface 3. The lens system is designed to provide a high level of chromatic aberration, ie, the light is split into its component colors as it passes through the lens system. Each individual color is positioned at various distances from the lens. The reflected light from the sheet of paper is returned via the projected light path, ie, through the lens and the optical fiber. This shared optical path is one of the features that makes this a more accurate method than laser triangulation.

The variance in the height of paper surfaces is measured using wavelengths. To begin with, the various peaks present on the paper surface will pass through the focal point of a specific color. For example, when the paper surface passes through the focal point of the green light, then green light becomes the dominant wavelength received by the spectrometer detector. Special algorithms in the detector correlate this dominant reflected wavelength to the distance to the paper surface; a dedicated digital signal processor evaluates the received spectra at 4,000 measurements per second 4. A large numerical aperture ensures that dust in the beam path does not influence the measurement. An advantage of using wavelength to measure distance is that it is unaffected by slight changes in the intensity of reflected light caused by paper color and brightness.

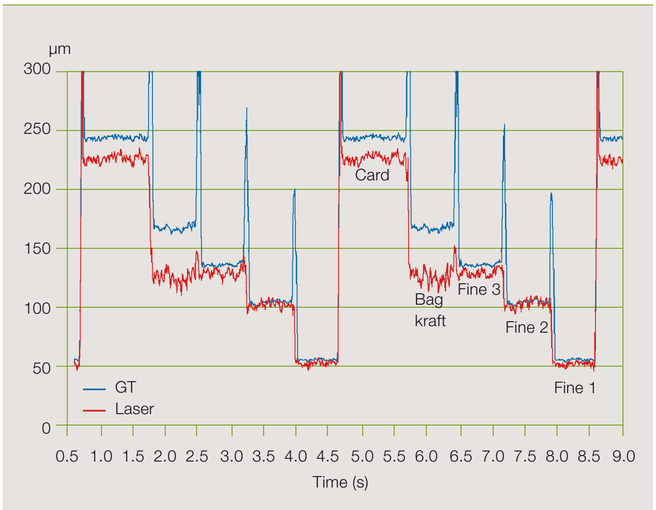
The confocal optical caliper sensor uses wavelengths to measure the height variations of paper surfaces.

A special spectral shape analysis algorithm further improves the agreement between sensor and laboratory, even for sheets with pronounced surface topography. This algorithm simulates the slight compression of the peaks that would be observed when measuring caliper on an offline laboratory instrument.

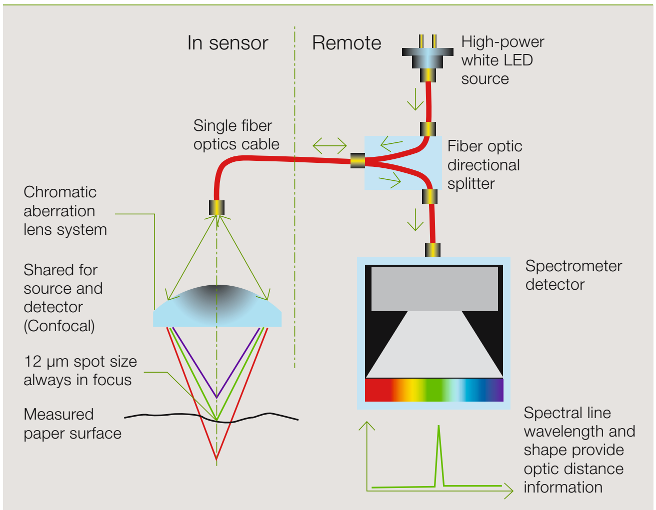
3 A confocal sensor vastly reduces errors from light penetration that may occur with laser triangulation



2 The performance of laser triangulation versus contacting caliper (GT) on card, bag and three fine writing paper grades



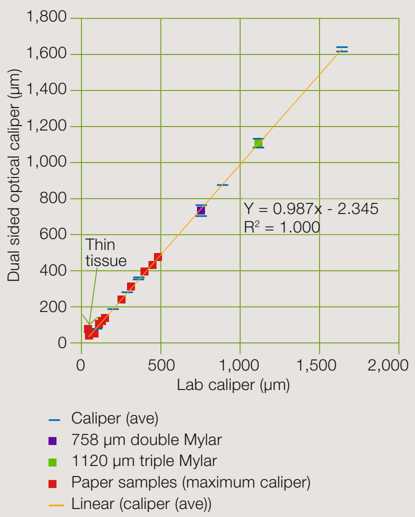
4 Confocal optical caliper sensor principle



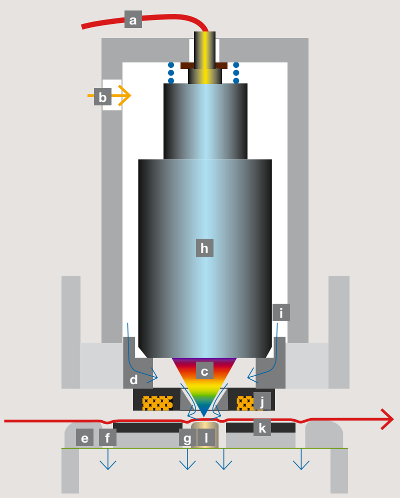
Innovation in production

The sensor output for a variety of demanding paper grades and Mylar samples, all with the same calibration constants, is shown in 5.[2] The grades of the paper samples used included tissue,[3] SC-A, coated, uncoated, linerboard, newsprint, card stock, and glossy calendered grades. The fascinating thing about the graph is that it is very linear over a wide range of samples, implying that the measurement does not require any grade-dependent calibration. In other words, ABB's optical caliper sensor is the only one on the market today that can measure caliper for all paper grades with only a single calibration!

5 Confocal sensor reading for a variety of sample types and thickness levels, with the same calibration



6 Simplified sensor cross section



- a Fiber optic to remote processor
- b Temperature controlled air
- c Chromatic light cone
- d Ceramic spacer
- e Sheet stabilizer
- f Outer vacuum
- g Inner vacuum
- h Lens system (optic probe)
- i Air purge
- j Coaxial ferrite sensing coil
- k Ferrite target
- l Optic target

Engineering confocal technology to accurately measure paper caliper online in the extremely hostile environment of a paper mill is a major breakthrough.

Engineering challenges

The underlying confocal technology described above is not new. The breakthrough, however, is being able to engineer it to accurately measure paper caliper online in the extremely hostile environment of a paper mill. Besides the hot, humid and dusty conditions and the fact that paper moves at motorway speeds, a paper machine vibrates at magnitudes several times greater than the actual paper thickness.

One of the critical challenges then was to keep the sheet stable while measuring the gap distance. This difference is the reference distance between the top and bottom halves of the sensor, one on each side of the paper sheet and 10 mm apart.

Air gap and sheet stabilization

An accurate measurement of the sensor air gap is just as important as the optical measurement. A cross-section through the two sensor heads is shown in 6. The reference distance between the top and bottom heads is sensed by a specially designed magnetic inductance technology, which has proven to be exceptionally accurate and stable. The difference between this primary magnetic gap measurement and the optical distance measurement determines the caliper measurement.

Furthermore, there is a secondary magnetic sensor for 3-axis head alignment diagnostics and compensation. This feature makes the mechanical setup both easy to use and robust for the customer and enhances profile accuracy by multi-axis residual error correction.

An accurately positioned and flattened sheet is also essential for any optical caliper measurement. This is achieved by a sheet stabilizer located in the head of one of the sensors. The stabi-

The unique aerodynamic design means that even after six months continuous running there is little dust build up inside the vacuum chambers

Factbox ABB QCS: a long pedigree in paper sensing

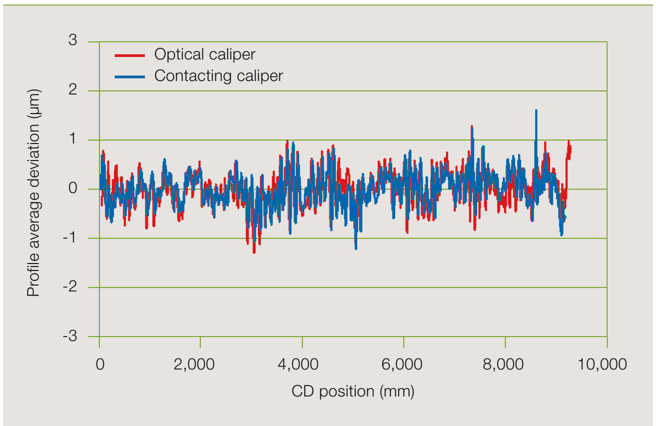
ABB QCS has a long and distinguished history. Formed just over 50 years ago in Ohio, one of its earliest achievements, a paper basis weight sensor, represented the first-ever commercial use of radioactivity. Ever since, ABB QCS has been responsible for one innovation after another in paper sensing and production control.

Today, the company helps papermakers sense and control their processes. As well as sensors (basis weight, moisture, fiber orientation, ash, and coating, all mounted on a steel scanning frame), other products include advanced control software and actuators.

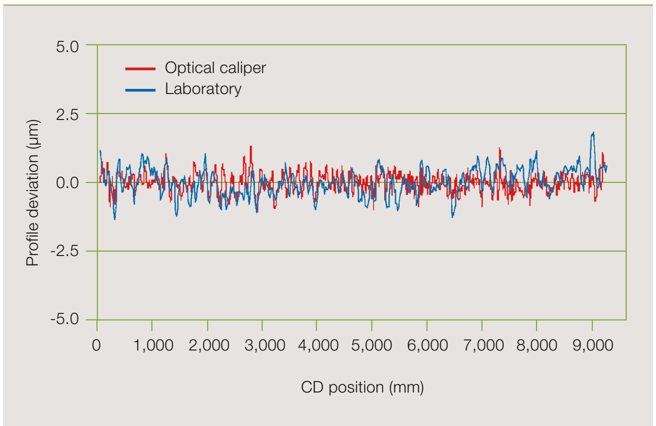
Footnotes

2) The test was performed in a lab environment and may not include all possible disturbances that can occur in a production environment.

3) The reading from the thin tissue grade was higher than normal because unbounded individual fibers were physically extending outside the sheet boundaries.



7 Online performance on fully recycled newsprint grade



8 Optical caliper performance on 100 percent recycled newsprint

lizer contains a ferrite target for the primary magnetic gap measurement and an optical target onto which the optics are focused [4]. Sheet control is achieved by a very light vacuum, which gently smoothes the sheet and removes any wrinkles in the optical measurement zone without marking the sheet or allowing the buildup of coating or contaminants. As a result, the optical caliper sensor is applicable to demanding grades, such as newsprint, coated, super calendered, and fully-recycled grades.

The super smooth ceramic coatings and hard materials used in the sheet stabilizer plate prevent any buildup and sheet marking, and provide excellent wear resistance. The large vacuum zones are designed to prevent the accumulation of fillers and coating, thereby reducing or even eliminating the need for frequent maintenance cleaning.

Measurement results

The first test results taken from a real papermaking machine were exceptional. They were in agreement with a contacting caliper sensor installed in parallel, showing a deviation of less than ±1 µm. In addition, amazing small-scale variability became visible.

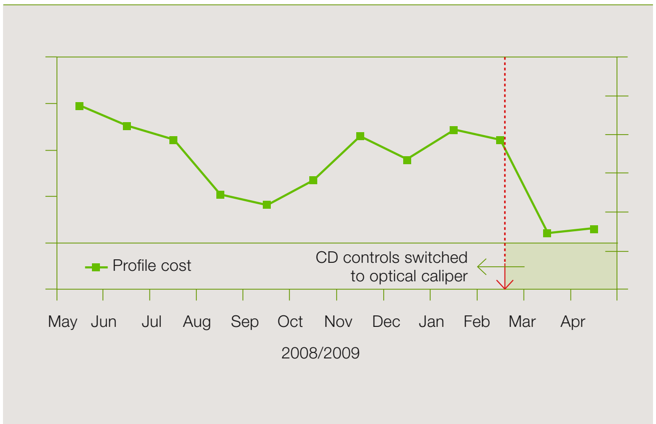
With ABB's optical caliper sensor, one customer has experienced a 55 percent drop in caliper-related poor quality costs.

The first permanent installation was on a large, 100 percent recycled furnished newsprint machine that produces a 9.3 meter wide sheet running at 1,700 m/min. This process can cause problems for contacting sensors, such as occasional buildup on the sensors or other mechanical factors that may cause measurement degradation, or even sheet handling problems. The optical caliper was installed in December 2008 and has been used in the production process since January 2009. Just one month later it was used for live CD (cross direction) caliper control! Since then, the customer has reported improved reel building and a reduction in profile variation. Furthermore, the sensor requires little maintenance in this process – the sheet stabilizer plate is periodically cleaned only as a precaution.

The performance of the optical caliper is compared with that of the contacting caliper in 7. In this example, the profile deviation between contacting and optical measurement is better than 0.5 µm. Sensor profile agreement with the customer's laboratory has also improved dramatically; the graph in 8 shows an agreement of better than ±1 µm.

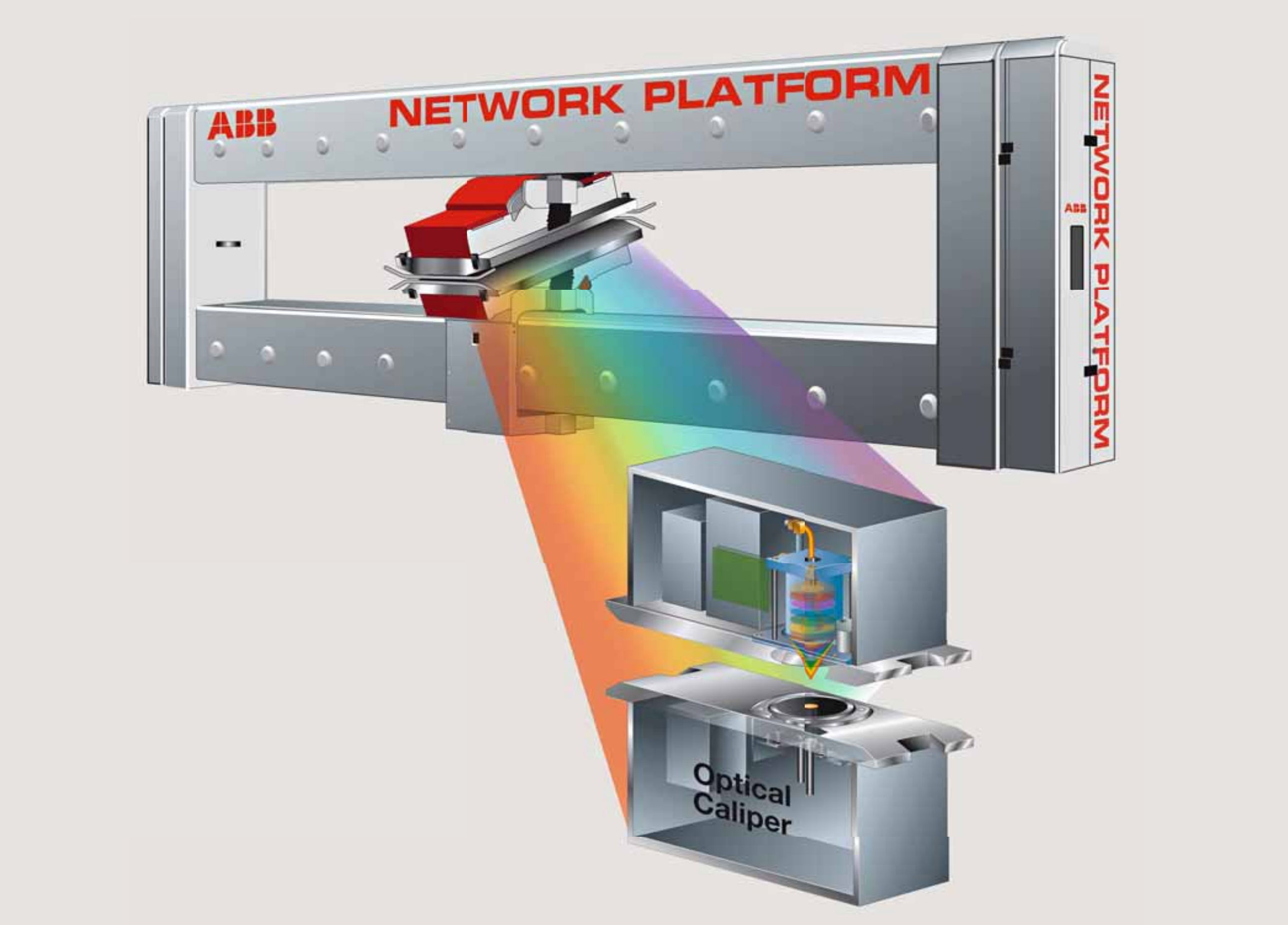
ABB's Network Platforms are the industry's strongest and smartest scanners, providing the process information necessary to optimize product quality.

9 Real mill data: The cost of poor caliper to the customer has more than halved since using the ABB optical caliper sensor to measure and control the customer's process.



Innovation in production

ABB's Network Platform NP1200 equipped with the new optical caliper sensor



Customer benefits

The benefits to the customer are best described using real data from a real customer running one of the first optical caliper sensors 9. The graph shows a 55 percent drop in caliper-related poor quality costs! Such a dramatic reduction in turn leads to significant savings in the amount of raw material needed, and the energy and chemicals used.

ABB's optical caliper controls the paper quality to within 1µm when several different grades are being manufactured, and it is not sensitive to calender pressure, speed and tension profiles across the machine.

Papermakers can now buy a caliper sensor that is accurate, reliable and does not mark or break the sheet.

Stora Enso Eilenburg in Sachsen, Germany has reported it is "very satisfied" with ABB's optical caliper sensor. The company says the sensor "is working with CD caliper control" and that there are "no problems on the paper edges and no waste paper on the winder."

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