Paper Quality Measurement – Past, Present and Future

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ABSTRACT

We will take you onto a journey through the progress in paper quality measurement. This starts in the early days of manual testing. Then we visit the first automatic online sensors, eventually evolving into QCS systems. The sensors became enhanced in accuracy and performance, and measurement of new sheet properties came online. At the same time, the quality measurement in the lab evolved from tedious manual procedures to large automated test systems with additional capability and vastly reduced labor. - We end the journey by taking a peek into how quality measurements might evolve into the future.

THE EARLY DAYS OF ONLINE QUALITY MEASUREMENT

Papermaking 100 years ago had few tools for online paper quality evaluation. However, the machine operators had to be skilled artists with sharpened senses for quality. The paper was visually checked, moisture was evaluated by static on the arm hair, and a piece of paper might be chewed to estimate the constituents. In the illustration below, one person senses reel building by hand, one observes paper uniformity, and the third person checks web tension with his fingers.

Figure 1 – Online quality checking, early 1900's

The reel winding and hardness was tested with a wooden stick – probably the first sensing tool for checking quality online. And this invention is still in use. This apparatus has, despite the age and simplicity, attributes of modern mobile technology. It is wireless, solid state, wearable, self-powered, and offers both audible and tactile user interface. Note –it is also made of 100% renewable materials!

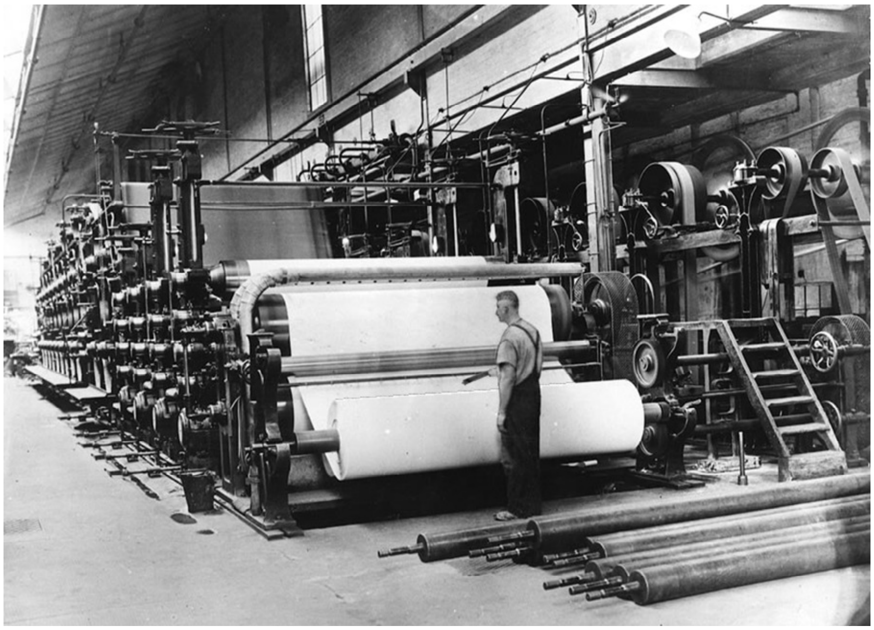

Figure 2 – One of the first tools for online quality checking – the "stick"

THE EARLY DAYS OF LABORATORY QUALITY TESTING

The laboratory test methods for paper quality 100 years ago were well ahead compared to online instruments. A large variety of lab methods had been developed by various researchers and paper makers. One key role at the time for the young TAPPI organization was to establish test standards for objective quality comparison. On the 1920 test procedure list below, we recognize quality aspects that are still important. But the emphasis on microscopical examination was more related to old time papermaking– for instance, to determine rag fiber content in the product – was a key quality issue 1920.
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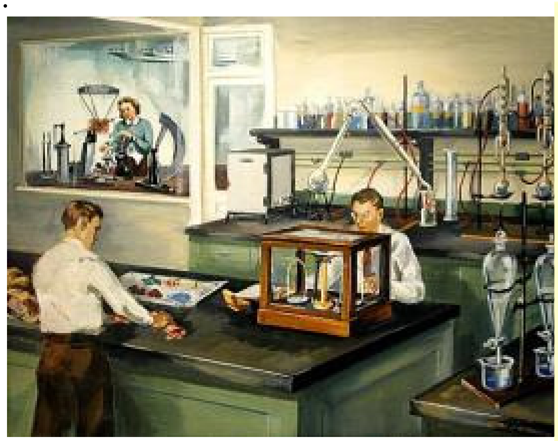

Physical Testing
Area of the sample.
Weight of the sample.
Bursting strength per unit area.
Thickness.
Bulk of a number of sheets.
Folding endurance.
Tensile strength.
Elongation at rupture.
Absorption.
Opacity.
Gloss or glare.
Translucency.
Degree of sizing.
Retention of loading.
Breaking length.

Chemical Analysis
Percent of ash.
Indicate kind of loading material – clay, plaster of Paris, heavy spar, talc. etc
Percent of paraffin.
Sizing material used.
Coating material used.
Presence of acids, free chlorine, etc.

Microscopical examination
Staining of fibers.
Reagents to analyze fibers.
Estimation of Fiber Content.
Type of fiber – rag, manila, jute, straw, coniferous, broadleaf, groundwood, etc.

Figure 3 - Paper quality testing – list from a TAPPI publication 1920

EARLY IDEAS FOR ONLINE MEASUREMENT

The urge to measure paper quality properties directly on the machine online generated several interesting ideas already 100 years ago. But most of them probably never caught on. It is still amusing to us today, to see the concepts proposed. No electronics was available – do it mechanically!

It is exactly *100 years ago* since a Mr. Orville Donaldson was granted US patent 1,135,000 for a **thickness measurement** and control system. The paper thickness is sensed mechanically by a knob sliding on top of the sheet against a roll, and the machine drive DC motor speed is automatically adjusted to keep the thickness constant. Thus, Donaldson measured caliper but regulated both MD caliper and weight with machine speed, assuming a constant stock flow. A closer look at his device reveals an integrating action by the motor driven rheostat for machine speed control and a control deadband by a gap between caliper limit contacts. We doubt that Donaldson achieved ±1 micrometer accuracy on thickness; it was possibly 100 times wider. As long as the sliding knob did not wear out.

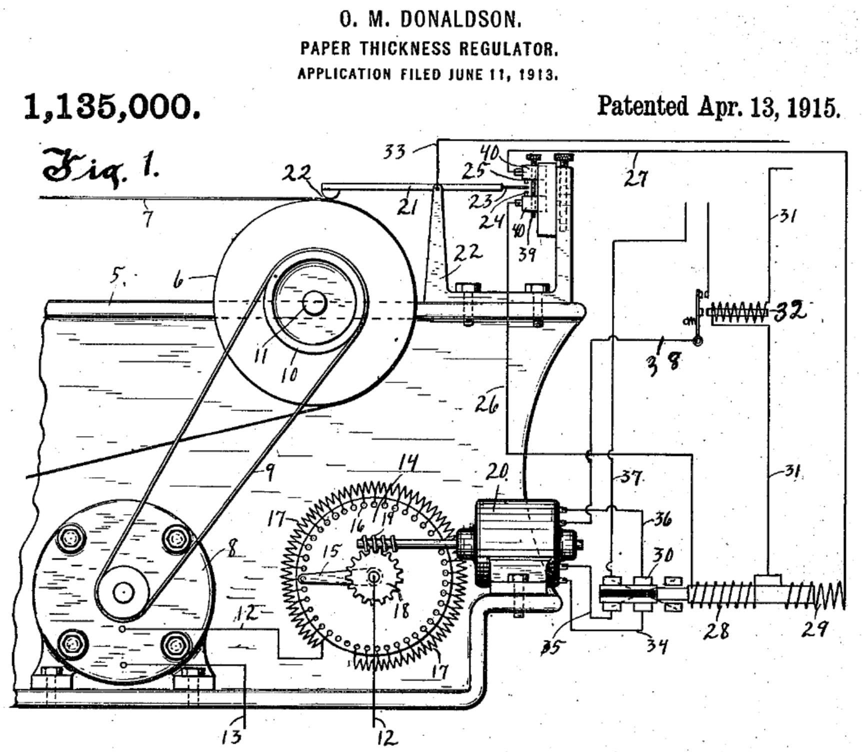

Figure 4 - Donaldson caliper measurement and MD control, patented 1915

An electric online **moisture measurement** was suggested by Louis Thompson of **General Electric**, in his US patent 1,645,077 – submitted 1925, granted 1927. He noticed that the paper dielectric insulation for arc-through is reduced at higher moisture levels. The sensor has an electrode with high voltage on the top side of the sheet while the bottom side is in contact with a grounded roll. A motor driven rheostat is utilized to repeatedly increase the voltage until arcing through the sheet. The breakdown level is registered on a voltage recorder as indication of online moisture – For the good of his health and for feeding his family, we hope Mr. Thompson was following safety rules during his on- machine test. The arc-through voltage for dry printing paper of medium thickness is typically 5,000 – 10,000 volt.

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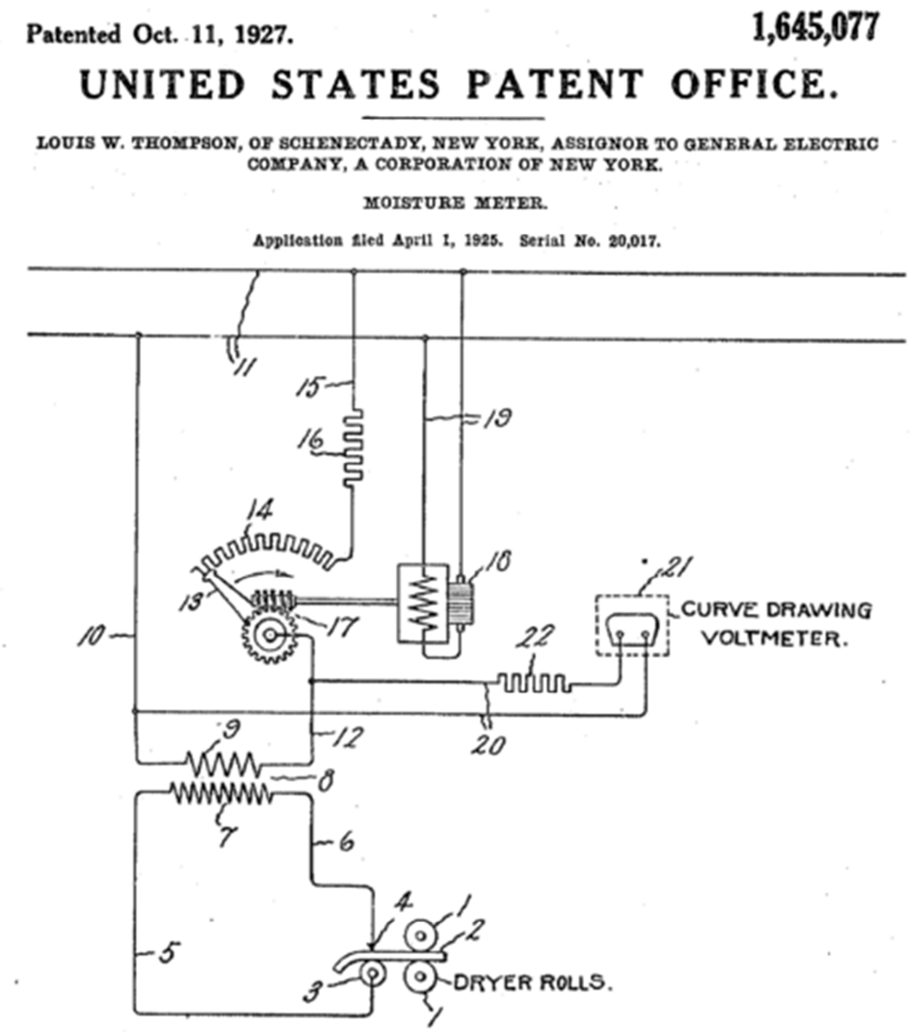


Figure 5 - Thompson's online moisture sensor patented 1927

Online **basis weight measurement** was in the early days not clearly separated from thickness – a thick sheet was also a heavyweight sheet. Therefore, thickness and basis weight were (incorrectly) sometimes interchangeable terms in literature and patents. But some sensor ideas were introduced for specifically paper weight. One of these was by Albert Allen at **Atlantic Precision Instruments**, US patent 1,824,745, granted 1931. This idea is about measuring the amount of substance in the gap by means of the influence on gap capacitance. The sensor is mounted on a C- frame, and includes a sensing gap that can be made extra wide by a lever, for threading the machine and other events. Some patent details lead us to believe that the unit was actually in use. It is also one of the first ideas we have seen for a C-frame. However, we know that paper dielectric properties are affected by several properties – basis weight, moisture, caliper, conductivity, temperature, composition… It is a fair guess that Mr. Allen had to do some daily tweaking the calibration to agree with laboratory basis weight. But he was seemingly first!

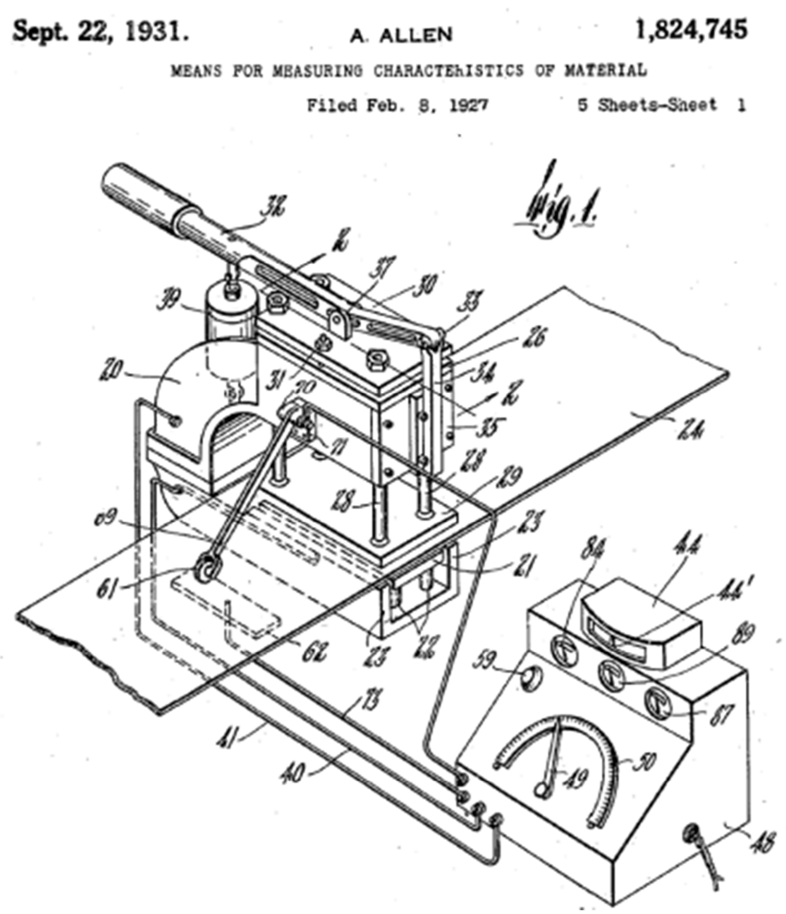


Figure 6 - Allen's online weight sensor granted 1931

THE ATOMIC AGE

It is now 116 years ago when Sir Rutherford discovered weak beta radiation emitted from natural uranium. It was also soon known that this radiation is attenuated by thin sheets, and the basis weight of the sheet is the dominating factor. That sounds promising! So why was there not a beta gauge on paper machines 100 years ago? -There were no practical means of generating this radiation or to measure it.

The US military nuclear program in the early 1940's contributed dramatically to nuclear radiation knowledge and measurement. Also, government nuclear reactors were soon producing radioactive isotopes as byproducts from making weapon materials. Such material was made available for research and industry in small quantities. This stimulated new industrial and medical applications - including gauging sheet thickness. The first patent on isotope based beta gauge for thickness measurement was applied in 1940 and granted 1941 to a Mr. Shoupp at **Westinghouse**. Several companies followed, and upstart organizations entered this new business field. The ***Atomic Age*** was here – and optimism!

One of the early upstarts making beta gauges was **Tracerlab Inc**. in Boston MA. The first permanent installation of their basis weight gauge on paper was in 1948 at Continental Paper, Ridgefield Park, NJ, making board grades. The sensor was mounted in single point ahead of the reel. We believe this was the first documented paper machine beta gauge installation.

Figure 7 - Tracerlab beta gauge 1948

Positive results from this installation were announced 1949 at the 4th TAPPI Engineering Conference in Boston, and a detailed report was published in TAPPI April 1950. - We quote some remarks of the authors, E.A. Crawford and M. Strain of Continental Paper:

"…In general the results in the use of this instrument have been most satisfactory, Mill tests of the instrument in checking its accuracy have shown it to be more accurate than necessary for production. The recording part of the instrument is showing trends or small drifts in the weight of the board which are not discernable with normal checking procedure…"

The gauge operation of Tracerlab evolved in ownership and name. The current company is EGS Gauging Inc. They are currently concentrating on most of their applications outside papermaking.

The first reported beta gauge installation **including feedback control** of stock flow was in 1952, at Don Valley Paper Co. in Toronto. The equipment "Betameter" was designed by Isotope Products Ltd, a Canadian company. The single point gauge was installed at the wet end in order to cut control delays and to provide more sensitivity by the amplified amount of water weight. At this location, there is a high water content of the web. Results show a reduction of weight variability after the wet press - from 10 lbs in manual operation on a 120 lbs wet weight sheet to 2 lbs with auto control of stock. It is mentioned that most of wet weight variability in this test originated from suction boxes. – Later, the company Isotope Products went through some changes. Some key gauging personnel went to Electronic Associates (EA), later Sentrol, and eventually a part of Metso / Valmet.

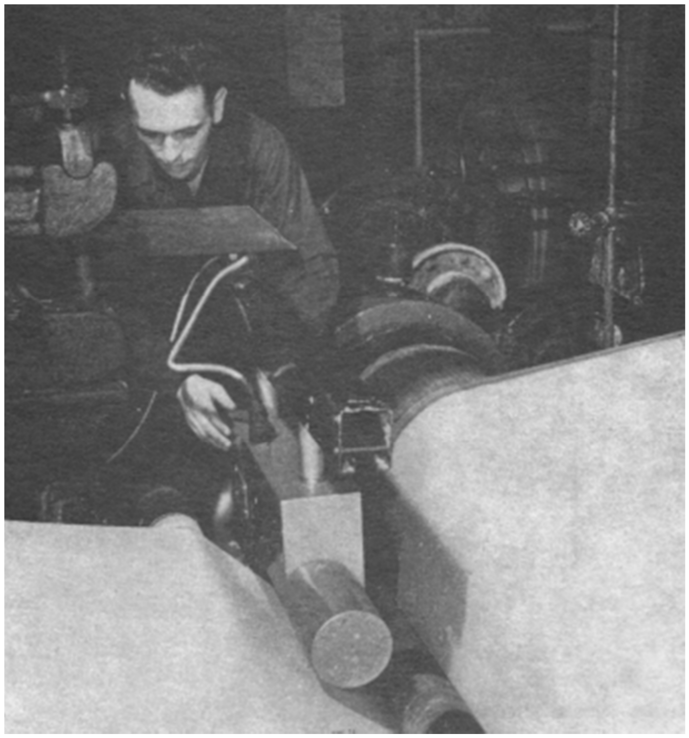
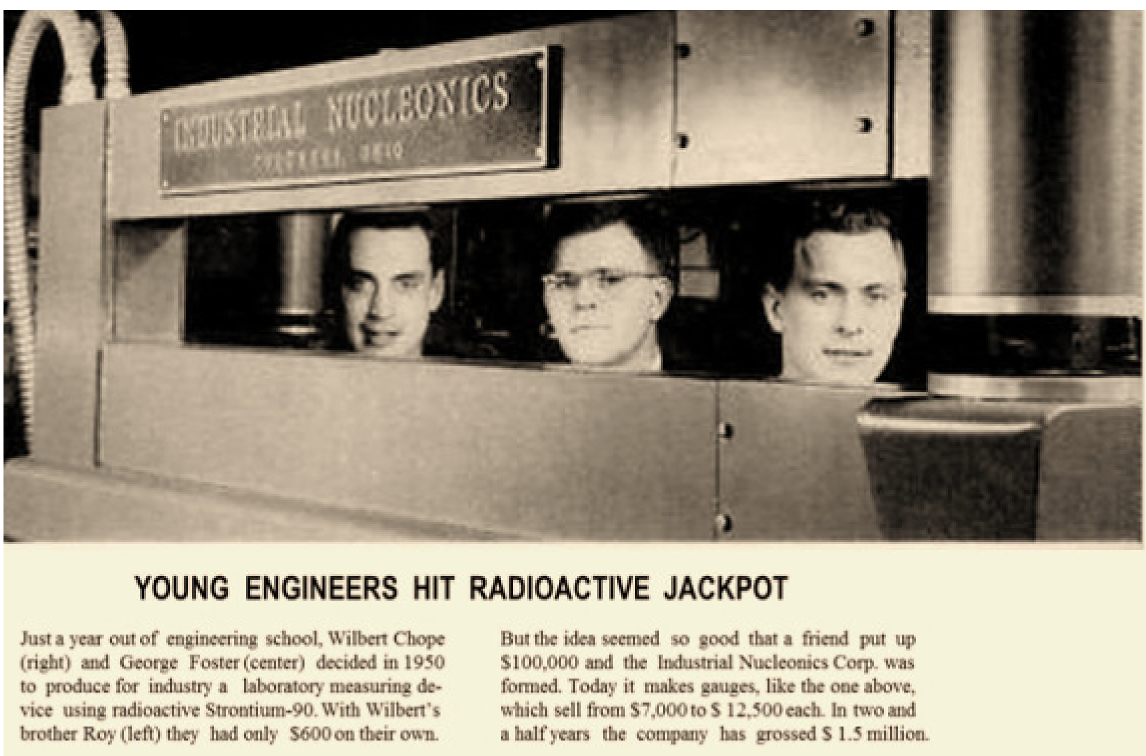


Figure 8 - Betameter installation 1952

Profile measurement with a beta gauge evolved after the initial single point installations. Some were set up in the lab to measure CD strips while some were scanning the sheet online. Tracerlab had a lab profiler in use in 1953 for newsprint testing at Southland Paper Mills, TX.

A different startup company was **Industrial Nucleonics (IN)**, founded 1950, the forerunner to ABB automation in paper industry. The IN beta gauge was an instant success and made business news in 1952, see below. “***Radioactive Jackpot”*** is a good sign of the upwards spirit of the ***Atomic Age*****!**



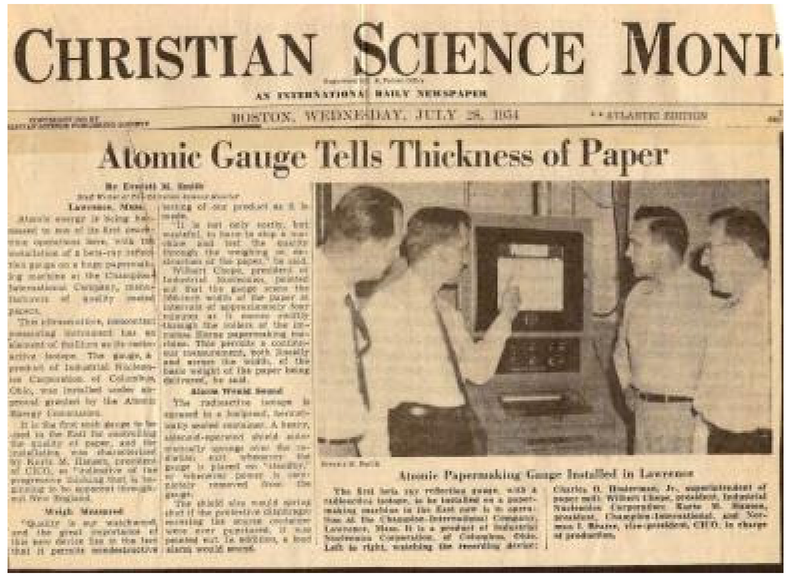
YOUNG ENGINEERS HIT RADIOACTIVE JACKPOT

Just a year out of engineering school, Wilbert Chope (right) and George Foster (center) decided in 1950 to produce for industry a laboratory measuring device using radioactive Strontium-90. With Wilbert's brother Roy (left) they had only $600 on their own.

But the idea seemed so good that a friend put up $100,000 and the Industrial Nucleonics Corp. was formed. Today it makes gauges, like the one above, which sell from $7,000 to $ 12,500 each. In two and a half years the company has grossed $ 1.5 million.

Figure 9 - Industrial Nucleonics makes business news 1952

– The first paper machine installations for a **scanning beta gauge** at the reel were made by Industrial Nucleonics in 1954. One was at Champion-International in Lawrence MA. This single-sided scanner applied a reflection beta gauge on the 166 inch wide web. Installations on less than 140 inch wide webs utilized scanning transmission gauge on U-frames in the early days. Automatic control of the stock valve was activated soon. - The news at Lawrence was proudly reported locally, another engineering triumph of the ***Atomic Age!***


CHRISTIAN SCIENCE MONI
AN INTERNATIONAL DAILY NEWSPAPER
BOSTON, WEDNESDAY, JULY 28, 1954
ATLANTIC EDITION

Atomic Gauge Tells Thickness of Paper

Atomic Papermaking Gauge Installed in Lawrence

Figure 10 –Industrial Nucleonics scanning beta gauge at Champion, Lawrence MA, 1954

DEVELOPMENT OF FIRST ONLINE MOISTURE SENSORS

While enjoying the success from the early basis weight sensors, papermakers had still the issue of keeping moisture at desired levels. This became the next priority for a reliable online measurement. Gauging firms pushed - *Set moisture to the limit in your paper - get paper price for cheap water!* The moisture sensor developments in 1950's to early 1960's were mostly focused on contacting measurement of paper electric dielectric properties. This was to a high degree driven by general advancement in radio technology during this era. - The "**Moisture Register**" hand held electronic moisture indicator gained early popularity. It is typically hand-held against the reel surface and the operator can manually walk it across, or stop at streaks for further check. It was still lacking the accuracy required for process control.

Some of the first true online moisture sensors arranged together with a beta gauge came 1956 from **Isotope Products** in Canada – the Betameter with Aquatel, a radio frequency (RF) sensor. The ownership was eventually going to Electronic Associates (EA).

Industrial Nucleonics developed the “**Moistron” RF moisture sensor** 1960, using a contacting probe lightly riding on top of the sheet. The picture below shows it attached to the beta gauge on a U-frame

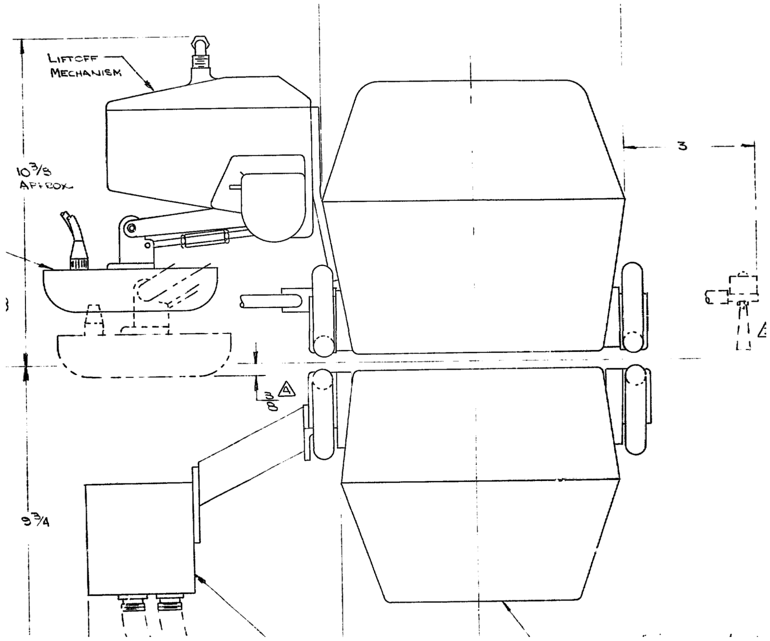


Figure 11 - Industrial Nucleonics “Moistron” sensor mounted on U-frame beta gauge 1961

But RF moisture measurement had limitations. A new competing technology using infrared light was initially developed by **General Electric**. The company **Brun Sensors** in Columbus OH introduced the Infra-Gauge in 1968. This was the first paper industry measurement of both weight *and* moisture with one IR sensor. This technology was acquired by Industrial Nucleonics and introduced for moisture measurement in the early 1970’s. It has recently re-emerged for tissue weight *and* moisture without the need for a beta gauge, today provided by most QCS suppliers. IR moisture technology “Inframike” was introduced by **EA** in Canada 1972, eventually replacing RF.

The upstart QCS company **Measurex** was founded early 1968 by David Bossen, who had left Industrial Nucleonics. Measurex developed its own IR moisture sensor using chopped light source, as part of the initial system. Its first system installation was 1969 at Simson Lee Paper, Ripon, CA.

Figure 12 - First Measurex scanner 1969 (covers removed)

DEVELOPMENT OF ONLINE CALIPER MEASUREMENT

Caliper measurement and related sensors for improved reel building is the next overall priority for improving paper quality. But to make this measurement practical took long time. Difficult challenges came up with accuracy on thin sheets at high machine speed – and without damaging the sheet.

In the 1960's, there were still no universal caliper sensors available from QCS suppliers. Therefore, some papermakers made their own. For example, A. Thompson at **Great Northern Paper Co**. in Millinocket, ME, had one solution with sliding shoes patented 1966. A different caliper design with rollers was patented 1969 by J. Kahoun, at **Consolidated Bathurst** in Wisconsin Rapids, WI

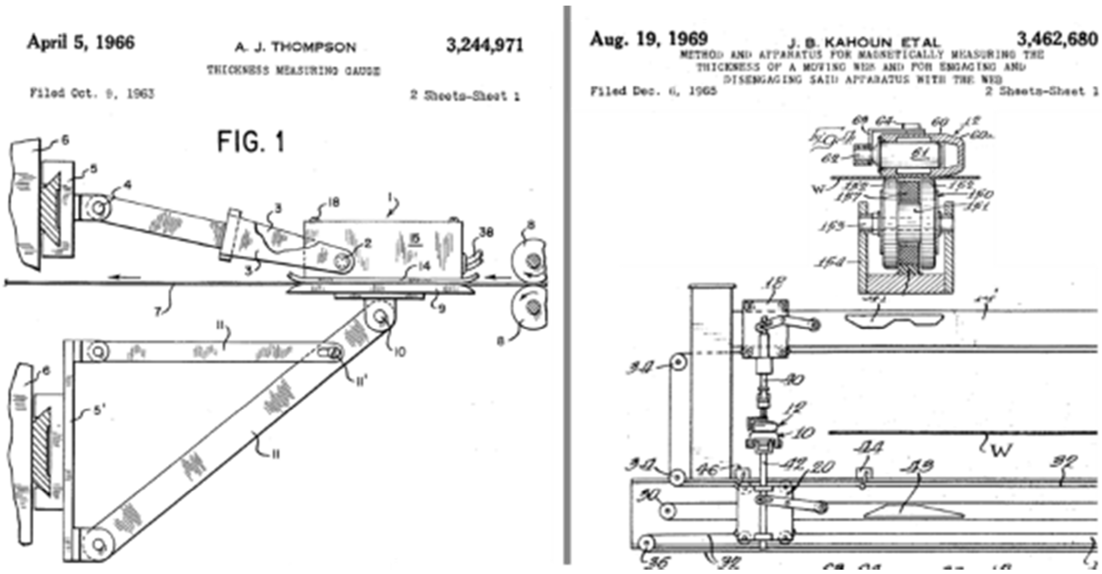


Figure 13 - Caliper sensors by papermakers - 1960's

A different reel building method initially owned by Consolidated Bathurst was the reel hardness sensor, the "**Backtenders Friend".** By measuring hardness profile of the moving solid reel surface, the issues about contacting a free running fragile web at high speed were eliminated. This solution is also providing true reel hardness rather than caliper - which is one important component for hardness. This approach was more successful than the early caliper sensors. It resulted in products sold by **Sentrol** (former EA) 1973, and in 1977 by **AccuRay Corporation** (former Industrial Nucleonics). It is based on a sensing roll in contact with the reel and mounted on a dedicated scanner, usually below the reel. But it has limitations for some installations – i.e., obstructing operator access, in the way for broke, and subject to impact. This has limited the market - the new generation caliper sensors are more universally applied.

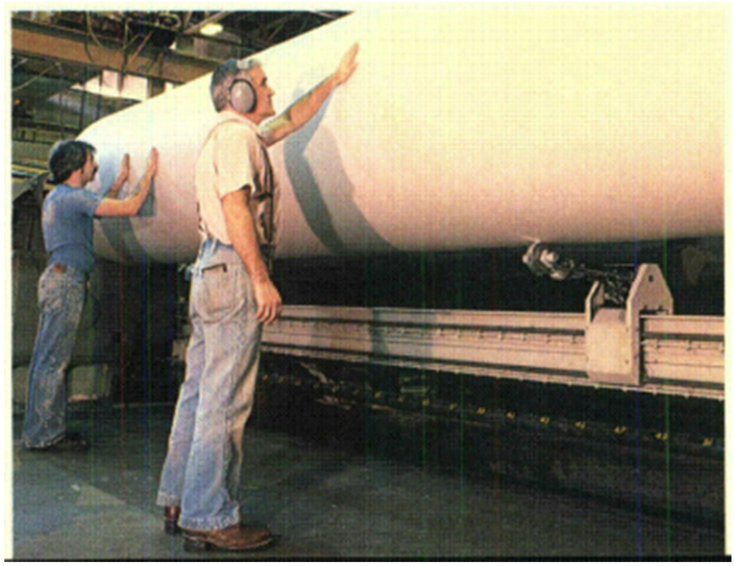


Figure 14- Backtenders Friend – early version

The early generation of caliper sensors from the emerging QCS suppliers included the EA Calitel introduced 1965, initially with rollers and evolving to a sliding plate. Measurex came out 1973 with a dual sided contacting sensor - initially “five buttons on a diaphragm”. A few years later, this evolved to light flexible arms with contacting plates. Industrial Nucleonics introduced in 1973 a single sided contacting, air bearing caliper developed by Indev. In the late 1980’s, this evolved to dual-sided contacting versions, and a fully non-contacting dual air bearing licensed from Scandev, Sweden. But the accuracy and sheet runnability was still not satisfactory for some applications. The light contacting **GT caliper** was introduced in 1996, and eventually became an industry workhorse. As evident in the picture below, the moving mass in this design is probably reduced by two orders of magnitude, or more, as compared to the early caliper sensors described on previous page.

Figure 15 - Lightweight GT contacting caliper

NON-SCANNING MEASUREMENTS

QCS measurements evolved, and the great value of a full profile instead of single point measurement was soon established. Considering some of the mechanical difficulties with scanners at the time, thoughts came up about elimination of the moving scanner heads and measuring the web with a cross-machine directional (CD) array of stationary sensors. This technique would measure full width of a running sheet continuously instead of a narrow diagonal trace from scanning sensors. Scanning and. non-scanning principles are illustrated below. Ideally, full-width stationary sensor arrays can see two-dimensional variability simultaneously. However, there are pros and cons of both scanning and non-scanning measurement techniques.

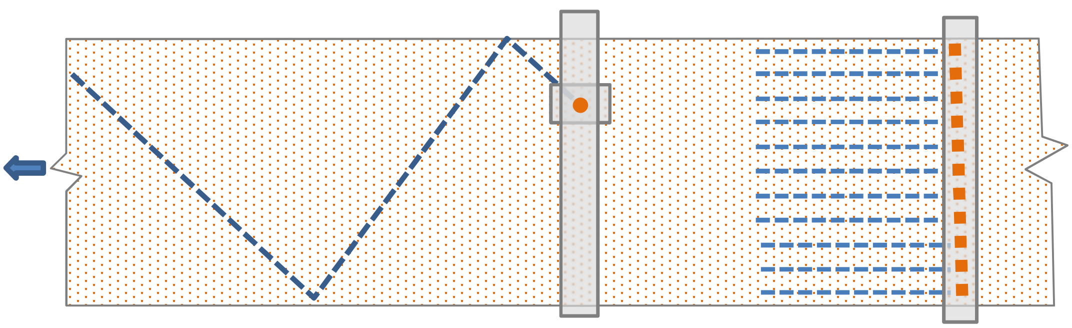
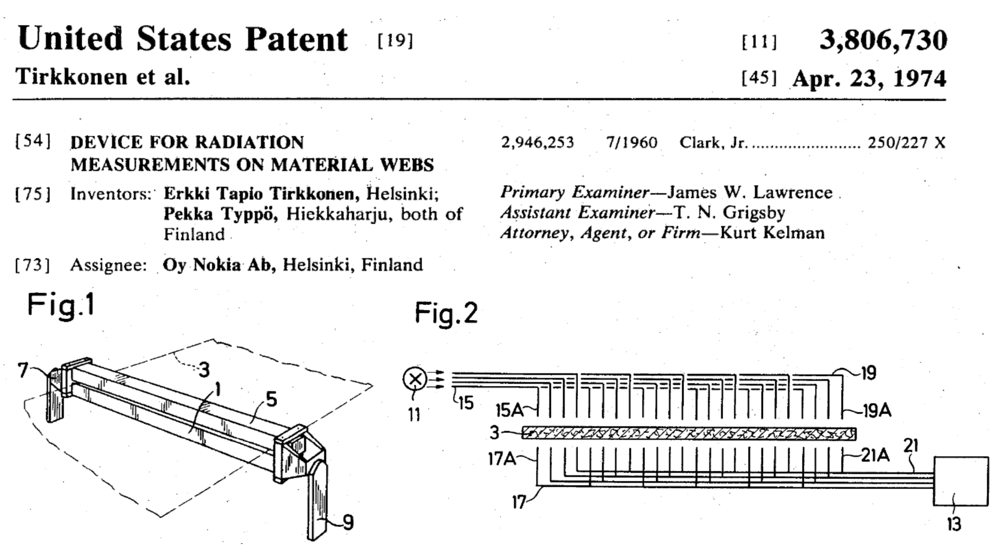


Figure 16 - Scanning sensor vs. a non-scanning sensor array

In the early days of QCS sensors, non-scanning was just installing a few standard single point sensors at fixed CD locations – like one near front side, one near back side. But this is not sufficient for obtaining the sheet profile, and not economic feasible for several points across the sheet.

One of the first new ideas was a system with stationary light guides on each side of the sheet, patented by E. Tirkkonen and P. Typpö of **Nokia**. Their first filing was done 1971 in Finland, and US patent was granted 1974. The device is intended to measure weight and moisture profiles optically or IR, by several light apertures across the web, by means of light guide tubes of polished aluminum. - We could not locate any further records of the invention – but this idea was published already 40 years ago!



United States Patent [19] [11] **3,806,730**

Tirkkonen et al. [45] **Apr. 23, 1974**

[54] **DEVICE FOR RADIATION MEASUREMENTS ON MATERIAL WEBS**

[75] Inventors: **Erkki Tapio Tirkkonen**, Helsinki; **Pekka Typpö**, Hiekkaharju, both of Finland

[73] Assignee: **Oy Nokia Ab, Helsinki, Finland**

2,946,253 7/1960 Clark, Jr. .... 250/227 X

Primary Examiner—James W. Lawrence
Assistant Examiner—T. N. Grigsby
Attorney, Agent, or Firm—Kurt Kelman

Figure 17 - Early idea by Tirkkonen and Typpö for non-scanning full sheet measurement

Several serious attempts have been made for non-scanning QCS, but most ran into the following limitations

Product cost is one of the key issues. This is because many CD profile points are usually demanded, **Measurement accuracy** is another one. A scanning sensor is typically going off sheet periodically to diagnose itself, standardize, calibrate and eliminate the influence of dust, dirt, etc. This is a complex task for hundreds of fixed measurement points, with paper running in between for days in dual sided sensors. **Expandability** to measurement of several quality properties is also a key consideration. For instance, there is not yet any method to get BW or caliper array sensors even near the accuracy of today's scanning sensors. This implies the need for at least one scanner, adding to cost for a non-scanning one. **Controllability** is also a key factor. By the nature of typical paper MD and CD variability, there is not typically any huge performance gain to justify the large cost for an instantaneous profile for control.

Even though these limitations are real, non-scanning measurement still holds great potentials in the future.

QCS BASIC QUALITY SENSORS OF TODAY

We have offered you a glimpse into the early history of the three basic sensors - basis weight, moisture and caliper. But the work on these sensors did not stop. Machine speed increased, better control solutions came along, and the permitted quality deviation tightened. Therefore, the basic sensors have changed in tune with the needs. As one example - the infrared sensor shown below, measures moisture and fiber weight continuously at 5000 samples per second.

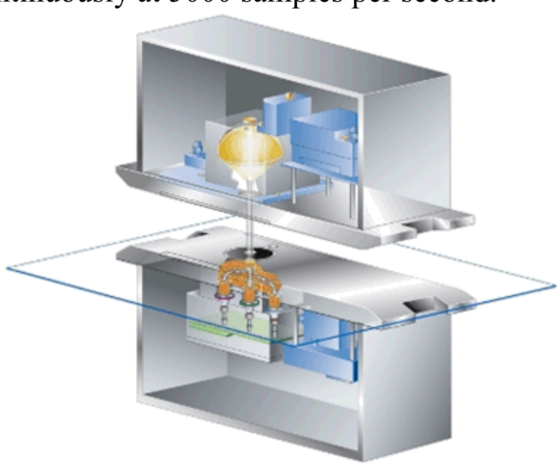


Figure 18 The HPIR sensor – measuring moisture and fiber weight at 5 kHz

Another dramatic example of major new designs for basic measurements is optical caliper. This has long been a papermaker's dream – measure thickness by light, get high accuracy, but don't touch the paper. Early developments utilized fully non-contacting dual-sided laser triangulators, where Measurex introduced the first paper industry application 1999. Voith announced a different dual-sided optical sensor 2010. However, these methods generated a new learning curve – the need for precise sheet stability control. Instead, today several QCS suppliers offer single-sided optical with single-sided contacting, for improved sheet stability control. The illustration below is for a chromatic aberration caliper sensor, a method to reduce errors from light penetration into the sheet – a key accuracy issue on optical caliper measurement.

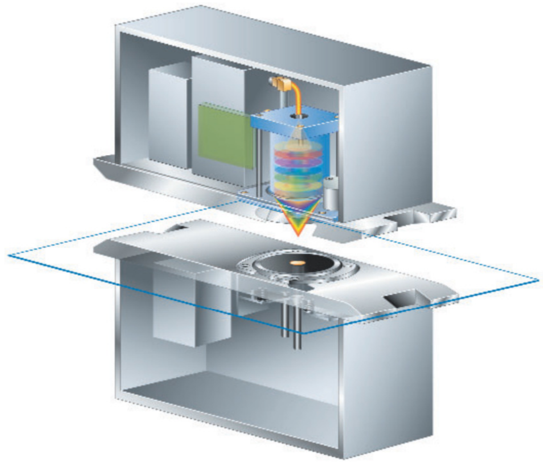


Figure 19 Optical caliper based on chromatic aberration

ADDITIONAL SHEET QUALITY PROPERTIES MEASURED ONLINE

The first group of sensors for additional sheet properties came on-line in early 1970's to late 80's. In 1975, AccuRay introduced a novel **X-ray ash sensor**. From this group, **color** is a complex property to measure and difficult to control manually, but soon got industry acceptance when automatic controls were available. In 1985, the **Macbeth ColorEye II** single point color was integrated in AccuRay QCS. Additional quality sensors have remained a mainstay of QCS systems, with selection depending on paper quality needs. The sensors have also evolved with new technologies over the years and process applications have expanded. As one example, color measurement was initially applied to mostly colored sheets but has today gained wide acceptance for white paper with specified optical parameters.

Opacity
Brightness
Formation
Gloss
Color
Ash
Direct coat weight

The second group of other quality sensors came later. And additions to this list will come!

Fiber orientation
Porosity
Press moisture
Forming section dewatering
Coating gel point
Smoothness / Surface topography
Strength / mechanical properties

From this list, the last two items: measurement of **smoothness** and **strength** properties, face extra challenges to measuring on-line with good correlation to an existing standard lab method. As well known, there are several strong-established lab methods in use to determine various aspects of either smoothness or strength. These different lab methods do not necessarily correlate strongly to each other, and use varies depending on paper grade. Therefore, **online sensors** have similar issues. If on-line measurement is progressing, we might see new or modified lab standards - if this adds end user value.

ABB introduced dual-sided online fiber orientation measurement by lasers in 1999, an industry first. Other QCS suppliers have followed several years later, mainly with imaging methods.

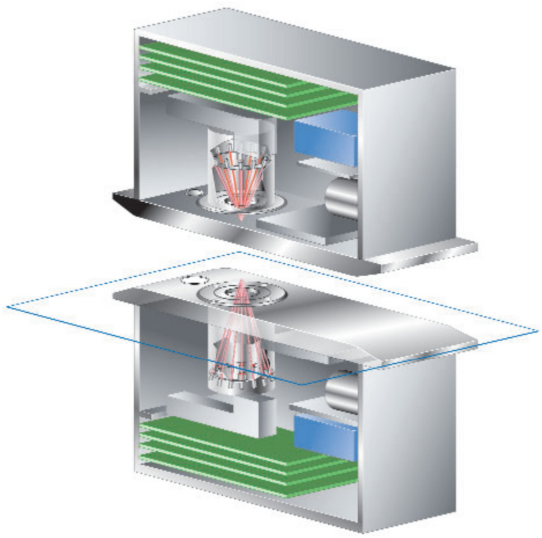


Figure 20 Laser based dual-sided fiber orientation sensor

QCS MEASUREMENT SYSTEMS TODAY

There is today a wide span of QCS measurement capability depending on the process and grades being produced. A tissue machine may have a single scanner providing weight and moisture profiles, while a major coated board machine may have up to 6~9 scanners generating dozens of profiles including calculated variables like coat weight measurement. Furthermore, some of the more critical papermaking processes cannot run for too long period of time without QCS measurements. This has driven the improved hardware designs with extra robustness and reliability for high availability due to the multitude of measurement sensors and scanners that may be present in a system.

The illustration below shows a board machine QCS measurements 1948 vs. 2015 - *a dramatic progress!*

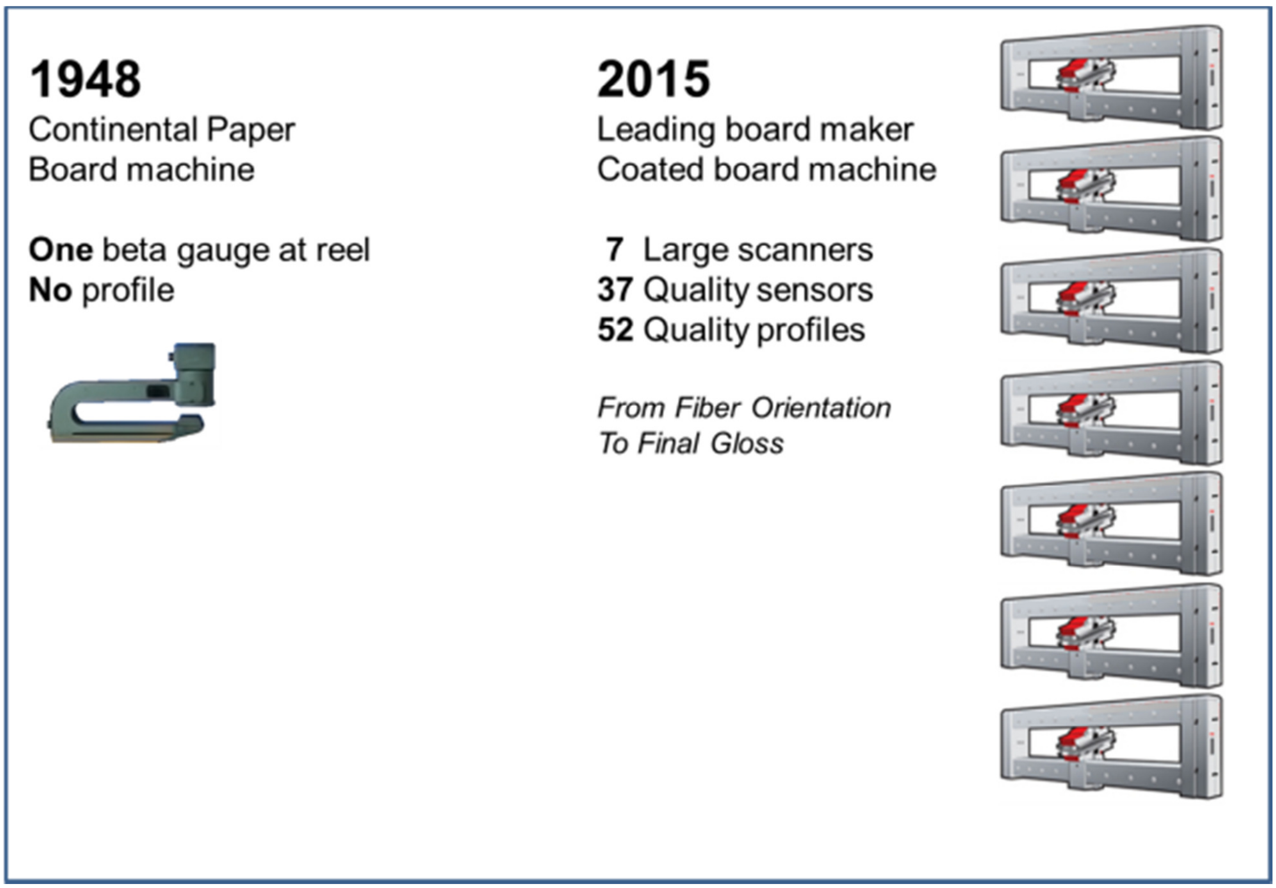


Figure 21 – QCS measurement evolution 1948 to 2015

TOTAL PAPER QUALITY INFORMATION

We have now seen how QCS measurements have evolved to automatically provide large amounts of online paper quality information. But there are additional quality information sources to consider:

-The modern paper test laboratory has also evolved to an automated operation. This provides additional paper quality information and end user critical test results. It also performs destructive testing of samples – which obviously cannot be performed on running paper. Furthermore, the laboratory can today automatically measure such properties on a cross direction strip from the reel, and can in one single run generate profiles of several test parameters.

- Web imaging technology is an essential tool to find and classify various sheet defects, and provides information about other properties like formation. This technology has evolved in speed and precision of detection, and provides today extremely high bandwidth information of even very small sheet details.

-Total paper quality information is a combination of *QCS measurement, lab test, and web imaging.* All this information is available for the operator and for automatic controls. However, a smart data reduction, combination, grouping and presentation is essential because of the vast amount of information available. See illustration below.

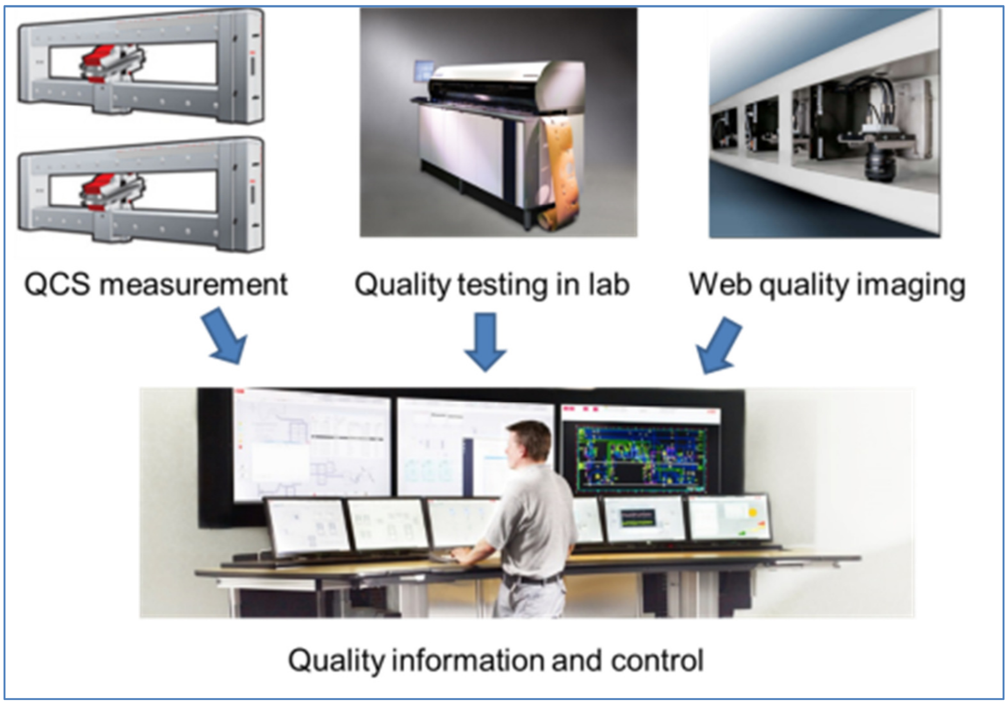


Figure 22 - Total paper quality information

FUTURE QCS MEASUREMENT TECHNOLOGY – SOME IDEAS

Online quality measurements have exploded from a single point beta gauge to detailed profile measurement of dozens of sheet quality parameters and distributed sensors from the wet end to reel. Add to this, advanced lab test equipment automatically measuring an additional plethora of paper quality parameters and web inspection catching every sheet defect. There is indeed plentiful of quality information! So how might this evolve in the future? Here is a vision:

Quality information fusion

With this vast amount of information available, it takes efforts to find and understand the quality information quickly, when needed for a papermaker's specific task. It might even feel overwhelming. We anticipate this will be solved by smart information fusion of QCS measurements, lab measurements, process measurements and web inspection. It will condense the information, automatically selected for the task at hand. This takes a wide range of know-how in each of these areas from the supplier!

New quality measurements - with the paper customer in mind

The paper customer may favor certain paper sourcing based on performance observations –but not so much the standard quality information provided by the paper producer. Observations may include i.e., roll runnability, high speed print results, converting machinery jams, cleanliness, or sheeting results. We think that more online measurements will arrive to better measure, predict and quantify end-use quality. It will involve new sensors, new measurement locations in the process, and merging various data for a benchmark index.

Personal quality viewer

We foresee a future where new sensor and information technology will be merged to empower the operator to get hands-free process insight -wherever the person works. It might, for instance, be smart head worn devices that superimpose quality data the operator's view of the process. These viewers can be wireless devices in the QCS system, and may also have direct sensing included for some properties.

Imagine…
Standing at the reel and see the caliper profile!
Adjusting at the wet end and simultaneously see the quality at the reel!
Viewing a cut paper sample and read color values L* a* b*!
Looking at any roll after the winder - see a fused compact summary of all quality info for that roll!

Figure 23 - A futuristic idea– Personal Quality Viewer – See the profile on the reel!

Figure 24 - A futuristic idea: See quality data, superimposed on a paper sheet or on a roll!

CONCLUSIONS

We have now traveled through the dynamic history of QCS measurements from early history to today. We also have offered some ideas of what the future may bring. The capability progress up to now and the outlook for continuing progress the future, are certainly fascinating subjects. But we also see simplicity coming back in the future, by empowering the operator to directly view all pertinent quality aspects- in real time, anywhere, and hands-free.

A final thought … will we come back to the apparent simplicity of making quality paper making 100 years ago, but with friendly tools that make the true paper quality improved by orders of magnitude?

REFERENCES - PATENTS

The table below shows some interesting historic patents about pioneering QCS measurement of paper quality - **from the early days up to mid -1970's**. The list is far from exhaustive but it will hopefully convey the general history. And some of them are quite amusing to read, in view of modern technology! The really dynamic evolution of QCS measurements started only when the right tools came available, for instance nuclear, electronics, computers and optics technology. -The evolution **after the 1970's** has produced a very large amount of additional measurement patents not shown below. There has been a significant widening of QCS scope - and there are hundreds of more recent QCS measurement patents. Understandably, we cannot cover all important QCS measurement patents in this report.

US Pat. no.	Inventor	Filed	Short description
812,042	Hudson	1902	Roller thickness sensor
1,135,000	Donaldson	1913	Thickness sensor with control
1,509,869	Harvey	1923	Online moisture measurement
1,645,077	Thompson	1925	Online electric moisture sensor
1,824,745	Allen	1927	Capacitive basis weight sensor
1,882,962	Sawford	1928	Optical thickness sensor
1,969,536	Winne	1932	Caliper sensor with feedback control
2,264,725	Shoupp	1940	Beta gauge for rolling mill
2,488,269	Clapp	1948	Beta gauge for paper, etc.
2,552,189	Kuehni	1946	Weighing running paper web with air
2,618,751	Fearnside	1950	Beta gauge for paper
2,790,945	Chope	1952	Beta gauge with standardize
2,909,660	Alexander	1957	Beta gauge with CD control of BW
2,920,272	Erdman	1957	RF moisture sensor
3,244,971	Thompson	1963	Caliper sensor with dual sliding shoes
3,435,241	Hickey	1964	Formation sensor w dual detectors
3,462,680	Kahoun	1965	Traversing roller caliper sensor
3,525,929	Mounce	1967	EA roller caliper sensor
3,597,616	Brunton	1969	IR moisture sensor
3,617,872	Horn	1969	Indev airbearing caliper
3,641,349	Dahlin	1969	IR moisture sensor with chopper
3,806,730	Tirkkonen	1971	Non scanning profile, BW and moisture
3,822,588	Knight	1972	Backtenders friend hardness sensor
3,827,808	Cho	1973	Opacity sensor
3,828,248	Wennerberg	1972	Button caliper sensor
3,936,189	DeRemigis	1974	Opacity color brightness sensor
4,081,676	Buchnea	1976	Ash sensor

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