Feasibility Study for Introduction of Alternatives to Fixed Industrial Gauging Devices Utilizing Radioisotopes

Final Report

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1.0 EXECUTIVE SUMMARY

Radioactive sources form the basis for a range of sensors used in process industries. In particular, the paper industry is a large user of sensors that contain radioactive sources for measurement of basis weight, moisture, and thickness. This work examined the potential for adoption of sensors that use alternative technologies rather than radioactive sources. Included in the work was an assessment of the barriers to adoption of alternative sources, including whether those barriers were primarily technical, cost, or institutional.

Eight criteria affecting the implementation of alternatives to radioactive sources were identified. A set of tasks were defined in order to gather information related to these criteria. These tasks included identifying contacts, collecting cost and performance information on systems, and interviewing personnel involved with the paper industry, sensor vendors (both radioactive and non-radioactive), and research organizations.

The first application targeted for study was basis weight measurement. Basis weight gauges are found in every paper mill and are an integral part of the process control instrumentation. Current typical basis weight measurement systems use radioactive sources that produce beta radiation. This application was selected based on the following criteria:

- This technology was included in the preceding work that examined the use of nuclear gauges
- radioactive sources are widely used in the paper industry for this purpose
- multiple manufacturers of basis weight gauges exist
- the industry is large and technologically mature

Contacts and interviews were performed with personnel in academia, equipment vendors, and industry groups. In general, persons involved with research organizations and instrument vendors were forthcoming with information regarding the viability of sensors that do not use radioactive sources. However, very little information was received from the paper industry itself, which seriously hampered the project.

Adoption of alternatives in the paper industry is hindered by a number of problems, including.

- Alternatives have not been shown to have equal, let alone superior, process control capabilities
- The cost-driven nature of the industry makes installing and testing prototypes of new technologies difficult unless a clear financial case can be made for the alternative.
- Research funding for alternatives is not directed towards replacement of technologies that use radioactive sources
- The production schedule in paper mills places emphasis on robust solutions requiring low maintenance, which is characteristic of most radioactive source technologies

EPA could assist adoption of alternatives by providing financial assistance to companies that

will install prototype non-radiological systems, in order to eliminate or lessen the risk of lost production for the participating mill. Concern also exists within the industry that alternative technologies in some cases do not supply the measurement accuracy required to maintain production quality standards. This is particularly true for basis weight measurement. EPA could assist adoption of alternatives by joining existing research efforts, such as the Agenda 2020 currently being conducted by the Department of Energy and the paper industry. Through these vehicles, EPA could assist research goals that will demonstrate the technical capability of alternative sensor technologies that do not use radioactive sources.

The paper industry in general would welcome replacement of systems that use radioactive sources with alternative systems that do not include radioactive sources. However, before alternatives are adopted, more research and testing into the operating advantages or disadvantages of alternatives relative to the existing installed systems must be performed. A clear advantage based on operating experience must be shown for the alternatives before the industry will adopt them.

2.0 DISCUSSION

2.1 PURPOSE

The purpose of this work was to assist the EPA in refining techniques to identify candidate industries that will benefit from using alternative technologies to using radioactive sources. Also, the work was intended to determine what efforts from EPA would assist these industries to replace technologies using nuclear sources with alternative technologies that do not use radiological sources. Four industries from the previous study were initially identified for this evaluation. These industries and applications were basis weight, thickness measurement, and moisture content determination in the paper industry; thickness determination in the plastic industry; thickness determination in the textile industry; level gauging in the beverage industry. The paper industry was subsequently identified as the primary target industry for the study.

2.2 APPROACH

Initially, eight criteria affecting implementation of alternatives were identified. These criteria, and any identified subcriteria, are listed below:

1. Industry Culture

2. Technical Feasibility
    a. Availability
    b. Effectiveness/risks
    c. Ease of use/convenience
    d. Accuracy/precision (data quality)
    e. Dimensions/physical size requirements
    f. Ability to customize
    g. Industry certification
    h. Efficiency
    i. Reliability
    j. Other impacts/needs of the manufacturing process

3. Costs
    a. Up-front costs
        i. Purchase, installation, and testing of alternative technology
        ii Disposal of fixed nuclear gauging devices
        iii. Opportunity cost/productivity loss
    b. Operation and maintenance costs
    c. Insurance
    d. Licenses
    e. Training
    f. Worker protection equipment

g. Disposal costs

4. Health/Safety of Workers

5. Public Relations/Corporate Image

6. Regulatory Burden/Legal Liability
   a. EPA
   b. OSHA
   c. NRC
   d. Other

7. Impacts on End-User
   a. Impact on prices
   b. Impact on quality

8. Other Criteria
   a. Long-term contracts
   b. Vendor services (e.g., guarantees, warranties, volume discounts)
   c. Brand/product loyalty

A number of individual tasks were initiated in order to collect the information needed to evaluate the above criteria. These were:

Task 1
Characterize a specific industry that utilizes fixed nuclear gauging devices to identify:

- Number and size of firms
- Geographic distribution of firms
- Economic impact of industry
- Type of nuclear gauging device used

Information will be gathered from publically available sources including web sites, trade publications, census data, etc. From this data, identify a number of representative firms. These firms will be contacted and interviewed in Tasks 2, 4, 5 and 6.

Task 2
Contact a small number of organizations to verify and validate the information collected in Task 1. This will provide the project team a better sense of the uses of the nuclear gauging devices and the issues associated with replacing these devices with alternative technologies. Contacts are expected to include representative firms, trade organizations, academics and vendors.

Task 3
Prepare a consultation guide used to collect information from users of nuclear devices, vendors

of the nuclear devices and vendors of the alternative technology devices. The consultation guide will facilitate the direct comparison of the technologies and the collection of data on as many criteria as possible from industry reps.

Task 4
Characterize nuclear gauging devices used by this industry (from the application identified in Task 1):

- Technical characteristics
- Number in use
- Costs (purchase, installation, maintenance, disposal)
- Regulations / Licenses

Much of the data will be collected from vendors of the nuclear devices though some may only be available from the end users. A spreadsheet will be developed to facilitate common comparisons between nuclear and non-nuclear gauges.

Task 5
Characterize non-nuclear gauging devices that could replace nuclear devices (for a specific application):

- Technical characteristics
- Number in use
- Costs (purchase, installation, maintenance, disposal)
- Regulations / Licenses

Much of the data will be collected from vendors of the alternative devices though some may only be available from the end users. A spreadsheet will be developed to facilitate common comparisons between nuclear and non-nuclear gauges.

Task 6
Contact the representative firms identified in Task 1 using the guide developed in task 3. The guide will enable the interviewer to collect information on:

- Knowledge of firms regarding alternative technologies
- Barriers to utilization of alternative technologies
- Willingness of firms to elimination of nuclear gauging devices
- Criteria used by firms in selecting gauging technology
- Costs associated with use of the gauging devices
- Information that is still needed to properly evaluate feasibility of replacing nuclear gauges with non-nuclear alternatives

Task 7
Prepare draft report summarizing data collected in Tasks 1 - 6. Report also to include analysis of data collected in Tasks 4-6 and recommendations for filing in data gaps.

2.3 IMPLEMENTATION

Identification of Target Industry and Application

Under Task 1, the first industry and application identified for analysis was basis weight measurement in the paper industry. Methods for production line measurement of basis weight typically use radioactive sources that emit beta radiation. The preferred isotopes are Kr-85, Sr-90, and Pm-147. Attachment 1 contains a paper by Dr. Waller of Miami University describing these beta gauges in more detail.

This application was selected based on the following criteria:

- This technology was included in the preceding work that examined the use of nuclear gauges
- radioactive sources are widely used in the paper industry for this purpose
- multiple manufacturers of basis weight gauges exist
- the industry is large and technologically mature

The Paper Industry plays a very prominent role in both the US and world economies. This sector's global annual revenue today, from its over 300 million tons of products, exceeds 500 billion dollars, about one-third of which is attributable to the US Industry. This constitutes nearly 5% of the US manufacturing sector's contribution to GDP. The ninth largest manufacturing sector in the US, the Forest Products Industry, of which the Paper Industry is a major part, plays a vital role in most regions of the US, where it ranks among the top 10 employers in 43 of 50 states[1].

2000 Census data indicate that in NAICS Code 322 (Paper manufacturing) 5,790 establishments were operating with 553,943 employees. Within this group the following divisions occur:

(3221) Pulp, paper, & paperboard mills
(32211) Pulp mills
(32212) Paper mills
(32213) Paperboard mills

(3222) Converted paper product manufacturing
(32221) Paperboard container mfg
(32222) Paperbag & coated & treated paper mfg
(32223) Stationery product mfg

[1] From "Today's Paper Industry - Its Character and Structure", Center for Paper Business and Industry Studies, Sloan Foundation, available at http://www.paperstudies.org/industry/character.html

(32229) Other converted paper product mfg

Clearly this is a large industry that can potentially cover a wide spectrum of products.

Initial discussions with representatives from the paper industry indicated that basis weight gauges using radioactive sources are ubiquitous in the industry, with systems installed in essentially every paper mill in the US and Canada. Providing information or incentives assisting mills to replace these systems could be a cost effective method of eliminating large numbers of radioactive sources from common usage.

Validation of Information and Interviews

Tasks 2 and 3 were performed in parallel for the basis weight sensors. A short list of contacts in the paper industry, trade organizations, and research institutions (primarily universities) was developed and these personnel contacted. These initial contacts were:

Mr. Richard Campbell	Trade Association of Pulp and Paper Industry (TAPPI)
Mr. Marty Sorenson	NDC Infrared Engineering
Dr. Michael Waller	Miami University Dept. of Paper Science and Engineering

Interviews with these persons confirmed that nuclear gauges utilizing beta particles are universally used in the paper industry for measurement of basis weight. Each of these contacts also indicated that it may be difficult for representatives of regulatory agencies to get information out of the pulp and paper industry. These contacts also mentioned that the paper industry has a number of conferences coming up, including October 26-30 in Chicago and January in Montreal, which could afford excellent opportunities for free discussions with industry personnel familiar with basis weight measurement technologies. Information from these contacts was also used to develop a larger contact list.

Task 3 was initially addressed by developing a contact interview guide to be used for capturing the information needed by the project in order to determine barriers to adoption of alternatives within the industry. This guide is contained in Attachment 2.

The interviews (task 6 above) were performed using the guide as a starting point, and then asking any additional questions that may have been suggested to the interviewer during the course of the interview. A total of eight formal interviews were completed. Additional interviews were attempted, but many of the persons identified either refused to cooperate or did not return calls. The interviews that were conducted are documented in the following consultation records.

Four recurring themes were apparent from the interviews:

1. Measurements using radioactive sources are common, reliable, and accurate

2. Any replacement technology must be of equal technical competency
3. The industry would welcome alternatives to radioactive gauges as long as (2) is met
4. The industry is suspicious of EPA based on their history of relations with EPA

All persons interviewed that are involved with gauge research welcomed the concept of EPA assisting promotion of alternatives by incentives, but noted that the basis weight alternatives need further research to become technically the equal of the systems using radioactive sources.

Implementation Barriers and Cost Information

Gauge manufacturers and paper producers were contacted to gather information that would allow identification of the important reasons for adoption (or lack of adoption) of technologies that do not use radioactive sources. Attachment 4 lists the firms and organizations contacted. Initially, information about the firm or organization was gathered by visiting web sites or reviewing other generally available public information such as annual reports and publications. Contact persons were then identified, and calls placed to the contact. The information gathering process was intended to first develop data from paper industry contacts that would describe the existing or perceived barriers to implementing alternative, non-radiological basis weight measurements. This information would include:

- up-front costs, including purchase and installation
- operating costs, including maintenance
- costs associated with improvements or reductions in process control,
- changes in regulatory costs such as new or removed licensing or exposure control requirements
- new or changed liability costs, such as insurance or worker's compensation
- Any other perceived risks or benefits to adopting non-radiological methods, such as public relations

This information was not forthcoming from the industry representatives. Attempts at scheduling plant visits or tours in order to discuss these issues with industry personnel were unsuccessful. Contacts in the research and vendor community indicated that the most productive manner to reach the industry was by personal meetings at conferences and trade shows.

Some initial vendor cost information was received through discussion with Mr. Marty Sorenson of NDC Infrared, a vendor of radiological and non-radiological gauges. This information is included in his consultation record in Attachment 3. He noted that a typical paper mill operates for 340 days per year on a 24 hour schedule. The non-operating days consist of 1-2 day shutdowns for maintenance every 4-6 weeks. The operating schedule imposes a constraint on any replacement for accepted technologies used on the production line, because the new technology must be rapidly installable and rugged enough to require only those types of maintenance activities that can be accommodated in a 1-2 day shutdown.

Mr Sorenson also noted that prototype sensors using X-ray generators in place of radioactive sources have been developed, but testing and adoption of these replacements is problematic since the industry will only allow system installation that is proven to work. EPA could assist prototype testing of these systems through financial or other incentives to specific paper companies or mills.

Further information gathering was suspended after unsuccessful attempts to interview industry personnel. We recommend that future contact be done through industry venues such as conferences, and possibly include enlisting a university program familiar to the industry as a conduit for collecting industry data and conducting interviews.

2.4 CONCLUSIONS

This work identified the paper industry as a large user of radioactive sources for process measurement and control of basis weight, moisture content, thickness, and other properties. The most prevalent use of radioactive sources is for basis weight measurement, but any one of these measurements may be performed using systems that include radioactive sources. Adoption of alternatives in the paper industry is hindered by a number of problems, including.

- Alternatives have not been shown to have equal, let alone superior, process control capabilities
- The cost-driven nature of the industry makes installing and testing prototypes of new technologies difficult unless a clear financial case can be made for the alternative.
- Research funding for alternatives is not directed towards replacement of technologies that use radioactive sources
- The production schedule in paper mills places emphasis on robust solutions requiring low maintenance, which is characteristic of most radioactive source technologies

EPA could assist adoption of alternatives by providing financial assistance to companies that will install prototype non-radiological systems, in order to eliminate or lessen the risk of lost production for the participating mill. Concern also exists within the industry that alternative technologies in some cases do not supply the measurement accuracy required to maintain production quality standards. This is particularly true for basis weight measurement. EPA could assist adoption of alternatives by joining existing research efforts, such as the Agenda 2020 currently being conducted by the Department of Energy and the paper industry. Through these vehicles, EPA could assist research goals that will demonstrate the technical capability of alternative sensor technologies that do not use radioactive sources.

The paper industry in general would welcome replacement of systems that use radioactive sources with alternative systems that do not include radioactive sources. However, before alternatives are adopted, more research and testing into the operating advantages or disadvantages of alternatives relative to the existing installed systems must be performed. A clear advantage based on operating experience must be shown for the alternatives before the

industry will adopt them.

3.0. CONSULTATION RECORDS

Organization: Technical Association of the Pulp and Paper Industry (TAPPI)

Contact: Mr. Richard Campbell

Contact Phone: (202) 463-5159

Date: July 29, 2003

Consultation Summary

- Mr. Campbell suggested that we contact Tom Grant of the American Forest and Paper Association at (914) 776-6697. Mr. Grant might be able to provide specific information on the use of nuclear gauging devices in the paper industry.

- Mr. Campbell indicated that the 2003 TAPPI Fall Technical Conference will take place in Chicago, Illinois between October 26 and 30, 2003. He further indicated that one of the sessions of the conference could be on "census and controls."

- Mr. Campbell requested that we send him an e-mail describing our project and the information we want to collect. He indicated that, once he received the e-mail, he would forward it to TAPPI members. Based on the responses received, he would let us know if any of the TAPPI members would be interested in talking with us.

Follow-Up Activities

- Per Mr. Campbell's request, we sent him an e-mail, on August 5, 2003, describing the project and the data we would like to collect.

- Per Mr. Campbell's suggestion, we contacted Mr. Tom Grant on August 8, 2003. Refer to the consultation record for additional information.

- On August 8, 2003, we contacted Mr. Campbell to confirm that he had received our August 5, 2003 e-mail. Mr. Campbell indicated that he had received the e-mail and had forwarded it to TAPPI members. Mr. Campbell also indicated that he had received only one response and that he would forward that e-mail response to us. The response was from Mr. Bill Thorp of Georgia Pacific. Mr. Campbell suggested we follow-up directly with Mr. Thorp [(678) 428-4832]. Finally, Mr. Campbell indicated that he did not expect to receive any additional responses. However, he believed that Mr. Thorp was the best person to talk to about nuclear gauging devices in the paper industry and the replacement of these

devices with alternative technologies.

- On August 8, 2003, we received an e-mail from Mr. Campbell containing Mr. Thorp's response. We then contacted Mr. Thorp on August 15, 2003. Refer to the consultation record for additional information.

Organization: American Forest and Paper Association

Contact: Mr. Tom Grant

Contact Phone: (914) 776-6697

Date: August 8, 2003

Consultation Summary

- Mr. Grant indicated that he is not familiar with the use of nuclear gauging devices.
- Mr. Grant suggested we contact Mr. Bill Thorp of Georgia Pacific. He indicated that Georgia Pacific has numerous census and control equipment.
- Mr. Grant also suggested we contact Mr. Gideon Vargas of DOE's Office of Industrial Technologies.

Follow-Up Activities

- We contacted Mr. Thorp on August 15, 2003. Refer to the consultation record for additional information.
- We have contacted Mr. Vargas on several occasions. However, we have not been able to speak with him.

Organization: Georgia Pacific

Contact: Mr. Bill Thorp

Contact Phone: (678) 428-4832

Date: August 15, 2003

Consultation Summary

- Mr. Thorp indicated that all information on the paper industry's nuclear gauging devices is available through the Federal government, since all devices must be registered with the U.S. Nuclear Regulatory Commission (NRC).

- Mr. Thorp suggested we contact nuclear gauging device manufacturers (e.g., Honeywell in Phoenix, Arizona) to collect technical and cost information on these devices.

- Mr. Thorp indicated that he has been part of Agenda 2020, a joint venture between the American Forest and Paper Association and DOE's Office of Industrial Technology. The principal mission of Agenda 2020 is to maximize the efficiency and effectiveness by which the paper industry executes pre-competitive collaborative research and to ensure that programs that are undertaken are properly focused on the issues which address the industry's most pressing technology needs. Agenda 2020 has looked at the issue of replacing nuclear gauging devices in the paper industry for the past five years. They have not been successful in identifying a technology that could replace the nuclear gauging devices.

- Mr. Thorp stated that the paper industry would like to replace the nuclear gauging devices with other types of technologies. However, nuclear gauging devices are the best available technology that exist at this time.

- Mr. Thorp indicated that DOE has done research on the replacement of nuclear gauging devices in the paper industry. All reports are publicly available. Mr. Thorp suggested we contact Elmer Fleishman of the Idaho National Engineering Laboratory [(208) 526-9023] to obtain additional information on DOE's research.

- Mr. Thorp indicated that replacement research would cost about $10 million. The paper industry would be interested in receiving EPA's support (i.e., funding) for this research.

Follow-Up Activities

- We contacted NRC's Public Documents Room to obtain a list of nuclear gauging device licensees. A list of these licensees is provided in the attached "NRC Gauge Lic.wpd" file. Descriptions of the NRC program codes contained in this file are provided in the "ProgramCodes.wpd" file. Note that we have not reviewed the list of licensees to identify licensees in the paper industry.

- Per Mr. Thorp's suggestion, we contacted Mr. Fleishman on August 15, 2003. Refer to the consultation record for additional information.

Organization: Idaho National Engineering Laboratory

Contact: Mr. Elmer Fleishman

Contact Phone: (208) 526-9023

Date: August 15, 2003

Consultation Summary

- Mr. Fleishman indicated that DOE has sponsored research on basis weight devices. This research shows that beta-emitters are the best available technology that exists at this time for measuring paper's basis weight.

- Mr. Fleishman indicated that other types of devices used to measure basis weight employ optical methods (e.g., infrared). However, these methods do not produce reliable results, since light scattering changes based on the composition of the paper. Thus, the nuclear (i.e., beta) source is still needed.

- Mr. Fleishman indicated that, when using infrared devices, use of the radiation source is avoided. However, because paper absorbs a lot of water (i.e., moisture), there is a lot of interference. Thus, to obtain a reliable measurement, calculations need to be performed to subtract the moisture content. As a result, the basis weight measurement is not reliable.

- Mr. Fleishman indicated that the paper industry would like to replace nuclear gauging devices with other types of technologies in order not to deal with radioactive sources.

- Mr. Fleishman indicated that DOE's Office of Scientific and Technical Information has a database, the Energy Citations Database, in which it catalogues DOE's scientific and technical information. This database is can be accessed at: http://www.osti.gov/energycitations/.

- Mr. Fleishman suggested we contact Mr. Gideon Vargas of DOE's Office of Industrial Technology [(202) 586-0082] to obtain additional information on DOE's research on basis weight devices.

Follow-Up Activities

- Per Mr. Fleishman's suggestion, we queried DOE's Energy Citations Database to identify reports on basis weight devices. Potentially relevant citations identified through this query include:

  -- Tomimasu, H et al. *Comparison of Four Paper Imaging Techniques: Beta-Radiography, Electrography, Light Transmission, and Soft X-Radiography*. July 1991.

  -- Hall, MS et al. *Commercialization of On-Machine Sensors to Measure Paper Mechanical Properties: Final Report*. September 1994.

  -- Bossen, DA et al. *Basis Weight Gauging Apparatus, System, and Method*. September 1973.

- We have contacted Mr. Vargas on several occasions. However, we have not been able to speak with him.

Organization: NDC Infrared Engineering

Contact: Mr. Marty Sorenson

Contact Phone: (847) 291-4956

Date: September 11, 2003

Consultation Summary

General Information

- Mr. Sorenson indicated that there are 1,160 paper mills in North America. These paper mills make about $600/minute in profit.

- Mr. Sorenson indicated that paper mills are in operation 24 hours/day, 7 days/week, 340 days/year. The rest of the time they close operations to conduct maintenance and repair activities. They also install new equipment during this period of time.

- Mr. Sorenson indicated that paper mills conduct maintenance and repair activities every 4 to 6 weeks. These activities take 1 to 2 days. During this time, the basis weight device is replaced. The device is then calibrated at start-up.

Nuclear Gauging Devices

- Mr. Sorenson indicated that NDC produces beta-emitter devices for paper basis weight measurement. Other manufacturers of this type of device include Honeywell (USA).

- Mr. Sorenson indicated that the beta-emitter device is standard. However, the frame is custom made, based on the size of the paper.

- Mr. Sorenson noted that, unlike other companies, NDC does not require that customers purchase control equipment, monitoring equipment, or operation and maintenance (O&M) services along with the basis weight devices. NDC recognizes that paper mills already have control/monitoring equipment. Thus, they only need to replace the basis weight device. Other companies require paper mills to purchase control equipment, monitoring equipment, and O&M services. This requires having a full-time person on site to monitor the process.

- Mr. Sorenson provided the following cost information for an NDC basis weight (beta-emitter) device. This cost information is applicable to a typical paper

processing machine, a machine that processes 150-inch paper.

Device/Service	Cost
Beta-emitter basis weight measuring device (includes radiation safety and device operation training)	$250,000/unit
O&M services, on-call basis (no parts)	$1,100/day
O&M services contract (covers emergency calls, quarterly service, parts, replacement and disposal of device)	$20,000 to $25,000/year
Spare parts package (for paper mills that would like to repair the devices themselves)	$30,000 to $40,000/package
Replacement and disposal of device	$6,000/replacement

· Mr. Sorenson indicated that nuclear devices present a danger only when it is being repaired. In those instances, workers wear monitoring equipment to determine how much radiation they are being exposed to. There is no need for personal protective equipment while the paper mill is in operation. Due to the use of radiation devices, paper mills need an NRC license.

Non-Nuclear Gauging Devices

· Mr. Sorenson indicated that NDC has a new type of equipment to measure paper basis weight. This equipment relies on X radiation. When using this equipment, nuclear energy is emitted only when making a measurement. Thus, an NRC license is not needed.

· Mr. Sorenson indicated that NDC is currently looking for a location at which they could conduct a comparison study. That is, NDC would like to have a beta-emitter device and the X-ray device operating next to each other in order to compare their efficiency. However, finding this location might be difficult since the paper industry first needs to believe that the new equipment will work. NDC would be interested in obtaining EPA funding to conduct this comparative study and demonstrate that the new equipment works.

· Mr. Sorenson indicated that the paper industry is extremely interested in the replacement of nuclear devices. However, the industry does not want to spend money on something that might not work. In addition, at this time, the paper industry is a very tight industry to spend capital.

- Mr. Sorenson indicated that the costs associated with this equipment are comparable to the costs associated with the beta-emitter device. However, licensing costs would not be incurred.

Follow-Up Activities

- None

Organization: Miami University Department of Paper Science and Engineering

Contact: Dr. Michael Waller

Contact Phone: (513) 529-2205

Date: August 06, 2003

Consultation Summary

- Dr. Waller indicated that various technologies are used in the paper producing industries and film (including plastics) industries. His research shows that beta-emitters are the best available technology that exists at this time for measuring the basis weight of paper.

- Dr. Waller stated that other, non-radiological types of devices are used primarily to measure thickness, including laser gauges, optical gauges, and electronic gauges. However, for basis weight, nuclear gauges are the method of choice. Nuclear gauges are considered a well known and accepted technology that provide good results.

- Dr. Waller noted that although some competing technologies to nuclear basis and moisture gauges have been developed, there has been little market penetration by the competing technologies. He stated that it is conceivable that every manufacturer of thin film material, including paper, plastics, and foils, uses nuclear gauges.

- Dr. Waller supplied TEA with a paper he is presenting at the TAPPI conference in late October 2003 in Chicago. This paper describes new control methods for basis weight measurement. Although it briefly mentions a non-nuclear alternative to basis weight measurement, the implication is that nuclear gauges supply a very well tested and useful method for control measurement.

- Dr. Waller stated that if technically capable alternatives to nuclear gauges were developed, the thin film industry would likely adopt them..

- Dr. Waller suggested we attend the TAPPI conference October 26-30 in Chicago, IL.

Follow-Up Activities

- Per Dr. Waller's suggestion, TEA looked up the agenda and enrollment information for the TAPPI conference. Of particular interest at the conference are the three Department of Energy sessions relating to new

- Dr. Waller's paper is attached to this report.

Organization: Honeymoon Paper

Contact: Mr. Dale Ziegler

Contact Phone: (513) 755-7200

Date: August 07, 2003

Consultation Summary

- Mr. Ziegler indicated that he spent many years in pulp and paper plants but was not familiar with the technologies used for basis weight measurement. He was of the opinion that many plant personnel in the industry would understand the reason for basis weight measurements but may be unfamiliar with the actual technologies involved.

- Mr. Ziegler recommended that we contact Ms. Heather Andre of International Paper at (513) 248-6606. TEA left many messages for Ms. Andre but these were never returned.

- Mr. Ziegler contacted several of his colleagues in the paper industry to see if TEA could arrange tours of paper facilities in order to observe the technologies for performing basis weight measurements, and to interview the plant engineers regarding the technologies available and their potential for adoption. Mr Ziegler forewarned TEA it was highly unlikely that any paper facility would voluntarily allow persons working with EPA into the plants. TEA was not successful in arranging any tours or on-site interviews.

Follow-Up Activities

- TEA will continue to work with Mr. Ziegler to arrange tours, and will continue to attempt an interview with Ms. Andre.

Organization: Western Michigan University Department of Paper Engineering

Contact: Dr. John Cameron

Contact Phone: (269) 276-3508

Date: August 06, 2003

Consultation Summary

- Dr. Cameron suggested that almost all paper machines (mills) use beta gauges to measure mass (basis weight). He does not believe there is a viable alternative at this time to beta gauges for measuring the basis weight of paper.

- Dr. Cameron stated that other, non-radiological types of devices are used primarily to make other, complimentary measurements. For instance, infrared technology can be used to measure temperature, and ultrasound technologies can be used to measure material properties of the paper.

- Dr. Cameron indicated that the industry primarily used nuclear gauges from two major suppliers in the U.S. One company, Measurex, he was familiar with but the other company he could not recall.

- Dr. Cameron re-iterated to TEA that beta gauge technology is universally used, is reliable, and is not considered a problem in the industry. He believed that if research money were available, the industry would be interested in alternative non-nuclear methods if the alternatives could be shown to be cost effective.

Follow-Up Activities

- None to this contact

4.0 CONTACT LISTS

Manufacturers

Jensen Barker www.jensen-barker.com
Papermaking equipment and technology (not basis weight gauges)

Mohawk Paper www.mohawkpaper.com
Explanation of paper making process and use of quality sensors in the process

Globalspec http://sensors-transducers.globalspec.com
Web sensing & scanning systems. List of vendors of web (e.g. paper) measurement systems.

Polysort www.polysort.com
Listing of laboratory, test and measurement equipment (including basis weight gauges)

Honeywell www.acs.honeywell.com
Measurement products and sensors for the pulp and paper industries, including basis weight measurement

ADVANZ www.advanzgauge.com/
Manufacturer of measurement control systems for continuous web applications, including basis weight measurement

ATI Adaptive Technologies www.atigauge.com/
Gauges for measurement solutions, including beta and gamma gauges

Electronic Systems SPA www.electronicsystems.it
Manufacturer and supplier of quality control systems, including basis weight measurement

Invensys Process Systems www.invensysips.com
Process automation and advanced technologies, including non-nuclear basis weight measurement

NDC Infrared www.ndcinfrared.com/
Manufacturer and supplier of quality control sensors, including basis weight sensors

Oryx Systems www.oryxsystems.com/
Thickness gauges for measurement control

GE Panametrics www.gepower.com/dhtml/panametrics/en_us/index.jsp
Ultrasonic testing and measurement equipment, including thickness gauges

Automation Industries www.automationindustriescorp.com/
Process automation and quality measurement systems, including thickness gauges (wood products but not paper)

Analytical Technologies, LLC www.filmthickness.com/index.html
Non-contact, non-destructive thickness measurement (optics)

SolveTech www.gauging.com/index.htm
Non-contact, non-nuclear thickness gauging systems

Trade Organizations

American Forest & Paper Association
www.afandpa.org
1-800-878-8878
1111 19th Street, NW, Suite 800
Washington, DC 20036

TAPPI
'the leading technical association for the worldwide pulp, paper and converting industry.'
www.tappi.org
(770) 446-1400
15 Technology Parkway South
Norcross, GA 30092

APMA: **American Paper Machinery Association**
www.papermachinery.org
(703) 538-1787
201 Park Washington Court
Falls Church, VA 22046-4527

NCASI: **National Council for Air and Stream Improvement, Inc.**
'Environmental resource for the forest products industry since 1943'
www.ncasi.org
(919) 558-1999
P.O. Box 13318
Research Triangle Park, NC 27709-3318

Alkaline Paper Advocate
http://palimsest.stanford.edu/byorg/abbey/ap/ap09/ap09-4/ap09-404.html
Listing of fine paper mills in the US

Desktop Publishing http://desktoppub.about.com/cs/papermills
List of paper mills and manufacturers

Pulp and Paper Companies

Appleton
825 E. Wisconsin Avenue
P.O. Box 359
Appleton, WI 54912-0359
(920) 734-9841
www.appletonideas.com

Products: carbonless paper, thermal paper, security paper, etc.

Atlas
3725 East 10th Court
Hialeah, FL 33013
(305) 835-8046
www.atlaspapermills.com

Products: tissue and towels from 100% recycled paper, tissue paper

Badger Paper Mills, Inc.
200 West Front Street
P.O. Box 149
Peshtigo, WI 54157-0149
(715) 582-4551
www.badgerpaper.com

Products: virgin and recycled papers and printed and waxed packaging products

Boise
1111 West Jefferson StreetP.O. Box 50Boise, ID 83728-0001(208) 384-6161
www.bc.com
Products: office papers, printing & converting papers, newsprint, packaging, market pulp

Burrows Paper Division
730 East Mill Street
Little Falls, NY 13365
(315) 823-2300
www.burrowspaper.com
Products: array of paper grades for a variety of end-uses

International Paper

International Paper Plaza
400 Atlantic Street
Stamford, CT 06921
(203) 541-8000
www.internationalpaper.com
Products: coated papers, consumer packaging, industrial papers, industrial packaging, printing & communication papers

5.0 INTERVIEW GUIDE

1. Open with a general description of project and purpose

- Trinity Engineering Associates is conducting a study on behalf of the U.S. Environmental Protection Agency (EPA) to gather information about the technical and economic issues associated with use of alternative technologies to the radiological gauges presently used to measure the basis weight of paper in paper mills.

- The EPA's Clean Materials Team is responsible for assessing incidences of lost radioactive sources that enter into consumer metal supplies and the public domain. When industrial devices and consumer products containing radioactive sources fall out of regulatory control, possibility of source breach and subsequent harmful exposures and significant economic impacts to the industries involved.

- One approach to minimizing incidences of lost sources is to provide viable alternative technologies to the use of radioactive sources. One of EPA's current efforts in this regard is a study to assess alternative technologies to the radiological gauges used in paper mills to measure the basis weight of paper. As part of this study, we'd like to ask you some questions about your experience with radiological gauges and other alternative systems used measure basis weight.

- The answers you give will provided only to EPA for the purposes of this study, and will not be disclosed to any third parties, including trade organizations, commercial companies, or government agencies, other than EPA.

2. Use following question tree to determine extent of use of alternative technologies, and reasons for/against adoption of alternatives

3. Closing Questions

- _ Can I get some contact information from you, including:
  - _ Name
  - _ Company
  - _ Position
  - _ Phone Number
  - _ Mailing Address
  - _ e-Mail Address
- _ Is there anyone else that you know of at your company or in the industry that would we could contact for additional information?
- _ Is it alright to contact you later by phone or e-mail if we have any further questions?
- _ Is there anything else you'd like to add?

Thank you for taking the time to talk to share your experiences and knowledge today.

4. Document call in consultation report

Attachment 1
Paper by Dr. Michael Waller

BASIS WEIGHT GAUGES: WHAT'S NEW?

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KEYWORDS

Basis weight, papermaking, sensors, radiometry

ABSTRACT

The paper discusses the technological underpinnings and features of present-day scanning basis weight gauges for papermaking. In addition, the signal produced by the sensor will be incorporated into a discussion of the process control system for the paper machine. While the purpose of the gauge is to measure machine-direction (MD) and cross-direction (CD) properties, the incorporation of the gauge's signal into the larger control system is especially pertinent since the gauge can only measure a compromise element of a true property attribute. Some mention will also be made of non-scanning, full-sheet gauges.

HISTORY AND PROGNOSIS

In the early 1980's, Walbaum and Lisnyansky gave an excellent review of many of the on-line instruments for paper quality measurements [1]. In the same time period, Pfeifer described on-line sensors for the measurement of basis weight [2,3]. Certain books, which are typically thought of as text or reference books, also contain discussions of basis weight gauges, such as that by Smook [4]. One recent and excellent reference for papermaking quality gauges of all types is Chapter 4 of Book 14, Process Control, of the Papermaking and Technology Series, published in cooperation with the Finnish Paper Engineers' Association and TAPPI. The chapter is edited by Leiviska and authored by Jouni Tornberg [5].

Post World War II electronic technology had severe limitations by today's standards. Measuring instruments and recorders were galvanometric devices. Audio frequency recorders used steel wire as the recording medium. Calculators were electromechanical, occupying about ½ cubic foot to provide addition of 10 digit numbers. Amplifiers used vacuum tubes, having a

life of 1000 hours. Two vacuum tubes per bit of digital information were required, with a power consumption of about 2 watts/bit.

Many of today's gauges have evolved from basic concepts that are 50 years old. These gauges and the associated larger systems differ mainly in the development of transistors and use of digital computers, making the gauges more consistent, accurate and reliable. These gauges, along with the communication and manipulation of information in process systems, are allowing real-time process optimization. Smart gauges with built-in intelligence are now interfaced to data highways, communicating with optical fiber links to process simulators for real-time optimization.

Much has changed in the past 50 years: from the first on-line gauges installed in the 1950's, to the first computers installed on paper machines in the 1960's, to the Plant Information Systems of today. Even 20 years ago, computer control of basis weight was thought of more as a necessity than a luxury. The early 80's provided on-line CD profile control systems - regarded as one of the most important breakthroughs in paper machine automation.

As suggested by Pfeifer [2], the basis weight gauge has evolved in three stages. First there was an exploratory period where many approaches were developed and tested. A maturation period followed when the successful approaches emerged. Finally, today's refinement period occurred when the matured technology was tuned for a variety of applications.

SCANNING GAUGES

Scanning gauges, mounted at the dry end of the paper machine, have for many years been the standard method for measuring basis weight, and ultimately providing a control signal for stock flow. These scanning gauges produce sparse information about the characteristics of the sheet and suffer from the features of being able to discover only very low frequency disturbances with large dead times in the control loop. Accordingly, much effort has gone into developments to improve this situation, and only lately certain technological breakthroughs have emerged that offer great promise for alleviating many of the problems inherent in scanning gauges.

Gauge development

Basis weight is defined as the mass of material per unit area. Occasionally called areal density, the favored unit of measure is g/m^2. Not infrequently, the unit of measure might be $lbm/3000\ ft^2$ or sometimes $/1000\ ft^2$. While the on-line measurement of basis weight might be considered to be in the refinement period for the single-point or scanning nuclear radiation gauges, that is not necessarily the case for full-sheet imaging technology, which might be classified in the exploratory period (not discussed here).

As has been true for many years, the primary method for weight measurement is the beta-gauge transmission technique. (For non-woven applications, the gamma backscatter technique is also used [6]. Another technique is based on filtered blackbody radiation in the far infrared region [7]. Neither of these techniques will be discussed here.) Beta particles from the source head are collimated and focused toward the sheet, attenuated in a nearly exponential fashion which is almost independent of furnish (and coating), and detected in the detector head on the other side of the sheet. Detection using Geiger-Mueller tubes, proportional counters, scintillator/ photomultiplier tubes and solid-state detectors was attempted during the exploration period of 50 years ago. The ionization chamber has emerged as the optimal detector because of its high stability, ruggedness, and ability to be efficiently sized to detect radiation distributed over the relatively large radiation beam.

Efforts early in the exploratory stage were directed toward compensating for mis-alignments of sources and detector and sheet passline (position of the sheet between the heads). Arrangements for focussing the radiation consisting of multiple sources, blocking plates and configured detector apertures were suggested by Faulkner [8] and Hansen [9] in order to promote signal insensitivity for small sheet movement and lateral and z-direction head movement. Z-direction insensitivity is particularly significant, since the carrier beams for the scanning gauge can deflect in response to the hotter operating conditions as opposed to those at start-up. To address this problem, consider placing a small disk slightly larger than a round source aperture on the face of the much larger ionization chamber. If the chamber is very close to the source head, the disk blocks most of the radiation, and a very small detector signal results. A similar small signal also results if the detector/disk combination is moved far away (in the z-direction). Thus there must be a place where the signal is at a maximum. With suitable radiation focusing disks and tuning efforts, devices using this technology featured a plateau of signal strength for displacements of about 0.1", as shown in Figure 1. The work involved was highly empirical in nature since the interaction of beta radiation with the sheet is both absorption and scattering, and mathematical models for attenuation are approximate and very geometry-dependent.

Figure 1 – Signal Strength vs. Z-Direction Displacement for a Gauge with Z-Direction Insensitivity

The maturation and refinement periods saw the incorporation of the gaseous krypton-85 radioisotope for mid-range basis weights and better methods of compensation (discussed later) so that the gauge's output remained relatively insensitive to passline variation, temperature changes, head misalignment, and furnish variation, a need particularly important for recycled fiber use. Heavier basis weights have seen the use of strontium-90, whereas promethium-147 is the isotope of choice for lighter weight sheets.

Additional development work optimized performance in dusty environments and greatly improved accuracy for lightweight products to 0.25% [10]. The measurement of lightweight products is especially sensitive to air temperature, since the basis weight of air is about 10 g/m^2 for an air gap of 10 mm. Multiple scan averaging and suitable Kalman signal filtering have produced 0.1 g/m^2 two-sigma repeatability for 150 g/m^2 sheets with a spot size of 13 mm and a 1 ms response time [11]. Other work concentrated on improving construction techniques by borrowing technology from the aerospace industry, and changing the sliding shutter to a rotating drum assembly for better emission containment and reduction of air gap [12]. A schematic of a typical modern basis weight transmission gauge is shown below in Figure 2 [13].

Figure 2 – A modern beta-ray transmission gauge. Courtesy of ABB, Inc.

A non-radioactive source basis weight gauge for more specialized applications is depicted below in Figure 3. While not used for paper applications, it is commonly used for polymer film and sheet. This gauge with its unique geometry uses the principle of characteristic infrared (IR) energy absorption of one or more materials in the moving web. As shown in Figure 3, an IR source (tungsten lamp) and reflector is positioned below the sheet. A chopper periodically interrupts the broadband IR beam which then passes through the sheet and into the detector assembly consisting of beam splitters, filters, lenses and as many as twelve photodetectors (four are shown). Optimal filter wavelength/bandwidth combinations are claimed to make it possible to discriminate between the various polymers in a coextrusion [14].

Figure 3 – The IRPlus® Infrared Sensor. Redrawn from a Honeywell-Measurex Corporation brochure [14].

Gauges of Today

The gauges of today incorporate features that provide insensitivity to variations in air gap temperature, furnish composition, sheet passline, head alignment and head z-direction separation. As mentioned earlier, all gauges use focussing systems of one sort or another to provide signal insensitivity to head mis-alignment and z-direction separation changes. While this technique is passive, an active technique for addressing z-direction separation was devised in the late 1960's by Hans Müller Barbieri AG of Wettswill, Switzerland [15], and marketed as part of the ASEA PAPERMAC™ system [16]. This gauge had an oscillator coil in one head, and an induced voltage pick-up coil in the other head that produced a varying signal as the distance between the heads changed. The coil's signal was then used to correct the (unfortunately) changed signal received by the detector to account for changes in head separation without a perceived change in basis weight. Improvements on this distance correction system have been incorporated in modern gauges offered by the manufacturers [17].

In addition to providing head separation insensitivity and/or automatic correction, the manufacturers have been developing other solutions for variations in air gap temperature, sheet passline, and furnish composition. Modern gauges have rotating shutters which allows the distance between source and detector to be made smaller. Greater insensitivity to air gap temperature changes is the result, including an improvement in signal-to-noise ratio. Several manufacturers offer gauges which have rectangularly-shaped apertures in the source head. This results in a fan of radiation in the machine direction which is wider than the detector head, but very narrow in the cross-machine direction, as shown in the ray diagrams of Figure 4. This feature allows good MD streak detection (ca. 1 cm) and results in insensitivity to variations in sheet passline and furnish composition [18]. In addition, all manufacturers have incorporated well-controlled constant-temperature air curtains to eliminate variations in air gap temperature while providing self-cleaning of the gauge.

Figure 4 - Ray Diagrams in the Machine and Cross Direction

HANDLING THE SCANNED SIGNAL - OLD AND NEW METHODS

Now that we have a signal from our scanning gauge, what is to be done with it? The average of many scans is used to provide routine basis weight control, in spite of the long dead time between the stock pump and dry end. Model-based CD control is used to evaluate controllability and provide on-line diagnostics aimed at greater production efficiency. The basis weight sensor signal which before addressed only quality issues now forms part of a much larger system, one term for which is an Integrated Monitoring System (IMS) [19]. The value of an IMS system is its ability to associate high

frequency quality disturbances with, for example, process pulsations in real time, made possible by the high frequency response of current basis weight sensors, about 1 kHz.

Providing accurate profiles from a scanning gauge in a timely fashion is a challenging objective. Faster scanning and computing will help, but the difficult task of separating the MD and CD variability has been with us for many years and will be discussed next.

Variance and frequency response

Scanning gauges all have the feature of MD/CD interaction because of the diagonal path across the sheet. This shortcoming has been recognized by many investigators who have presented various methods for partitioning the MD and CD variances, one of which is based on Kalman filtering. The relationships between variance statistics, autocovariance functions and the power spectrum are well described in several sources, and are of great importance when comparing statistics from various machines [20]. Common present practice is to identify orthogonal variance components as MD (averages of CD strips or individual scan averages), CD (variance of the averages at individual CD positions), and residual (the rest, which consists of short-term MD, random, covariance, interactive and measurement error). Of great significance is the assumption that any data set is representative of a population of random variations, that each measurement is independent of the others, that the measurements are independent of the data acquisition methods, and that the process is stationary. Unfortunately, none of these assumptions is strictly true, which makes the comparison of results and claims for control performance questionable.

The process generally used to estimate CD profiles from the time-sampled data is Data Box Averaging. Since the signal is averaged over fixed time zones, the effect of the averaging on CD variations depends only on the width of the zone and is independent of scan speed. For MD variations the ratio of sheet speed to scan speed is important, in addition to the width of the zone. Thus, when comparing results, one needs a stationary process to justify analyzing MD and CD components as orthogonal and independent of each other, in addition to statistical and spectral analysis computations being made in spatial rather than temporal terms. Data box width and scan speed are significant and important criteria for comparison purposes [21]. Smaller data box widths and higher scan speeds have followed along a time path, yielding better resolution and identification of variation.

Mapping, process models and actuators

We now finally come to generating a signal which will cause an effect – the actuator at the wet end of the machine, whether it be a slice actuator or a valve in a dilution headbox. Measurement is carried out at some distance from the actuators, and the effects of sheet wander and shrinkage are concerns for appropriate control, in addition

to the actual effect which actuators have on the process. The filtering of MD data allows control to be accomplished for overall weight by adjusting the stock delivery. CD control needs to be accomplished by relating the measurement array to the actuator array, showing how each actuator is projected through the sheet to the scanner. This "mapping" of databoxes to actuators takes into account sheet wander and shrinkage, but also creates errors which are frequently associated with standing-wave instabilities across the sheet [22]. One method of dealing with the distortion of information which occurs with the reconstruction of profiles from scanned data is to use a technique based on the Generalized Sampling Theorem (GST). This is especially useful for higher control bandwidths but suffers from the fact that the best results are obtained with data from either side of the plane of reconstruction [23].

One newer method of data manipulation, whereby two dimensional properties of the sheet can be extracted efficiently for the purposes of process monitoring, control and optimization, is by the use of extensions of a special form of Principle Component Analysis (PCA) known as the Karhunen-Loeve (KL) approximation. This procedure extracts the dominant features of stochastic spaciotemporal data by separating the information content from the random components. As a by-product, significant data compression results [24].

The current industrial practice for aligning CD actuators and scanners is to perform a bump test by moving a few selected actuators across the sheet. This process usually requires collecting many scans of data because of noisy data and varying machine processing performance, including sheet shrinkage and wander. Various investigators have investigated solutions to this mapping problem mainly from the standpoint of theoretical considerations [25,26].

CONCLUSION AND EPILOG

What's new? Well, for one person, new may be something which to another is "old hat." The use of radioactive sources in basis weight gauges is certainly not new, nor is the desire to provide a more accurate, stable and responsive gauge. What is new are some of the methods for achieving insensitivity to things which can cause gauge errors: start-up temperature versus continuing operation, air temperature fluctuations, furnish changes, passline variations and dust accumulation.

Still, the dry end scanning gauge operates with the handicaps of imperfect information and a large of dead time which limits frequency response. At least one manufacturer has developed a system for measuring basis weight without scanning by mounting an array of CCD cameras across the paper machine. Another manufacturer has developed a system which can detect changes in basis weight shortly after the headbox, perhaps in full-sheet fashion. The scanning gauge at the dry end may indeed be on its way to being replaced.

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