TWENTY MAJOR DEVELOPMENTS IN SEVEN YEARS — THINKING OUTSIDE THE BOX AT THE BELOIT DOWNINGTOWN RESEARCH LAB

by

J.D. Pfeiffer[1] and R.G. Lucas[2]
[1]JDP Innovations, Inc.
Canada
[2]GL&V Inc.
USA

ABSTRACT

The Bi-Wind and the Rho-Meter hardness tester are two well-known achievements of the Beloit Corporation's Downingtown Research Lab and there were many more in the period 1964 to 1971. A small group of researchers, building on their own discoveries, saw a major shift in thinking in that seven-year period, lead by Kenneth G. Frye, appointed Manager of Research in 1964.

We acted as a harmonious group, seeking out new solutions to existing problems based on what we had previously uncovered, and what we could learn through the assimilation of technologies that could reveal new answers. We found ourselves working in fields that were unusual for a lab based on paper technology -- aerodynamics, acoustics, electronics, optics, printed circuits, lasers, microscopy, polymers, and metallurgy, to name a few. At the same time, we relied on the fundamentals of materials science, mechanics and kinematics, and machine design.

As new facts and solutions to problems were discovered, they were presented in industry seminars and publications in technical journals. Contrary to the current practices of the day, we published as it happened, not waiting until years after the fact. That in itself was unusual, as competition was secretive about what they were working on. Sometimes the knowledge spawned new products and new patents. In other cases the products came later as the understanding branched into different fields. The sequence of development will be of interest to other researchers, but of particular interest is the number of findings that were never officially published, and the number of investigations which were left incomplete when the Downingtown Laboratory abruptly closed in 1971. Some of these topics are still worthy of study by graduate students and other researchers.

CHANGES IN THE LAB AND ITS DIRECTIONS

Some research organizations go to great lengths to institute policies they hope will result in serendipity and synergism. In our case, no such policy was in place, but synergy was there in a team consisting of four research engineers, their leader, and several support personnel. The wide range of developments produced by this lab may have seemed like serendipitous discoveries to outside observers. But serendipity implies fortuitous chance and luck, and that was not part of the picture. We just did what was necessary to continue our investigations, and that opened up new vistas for us. Prior to 1964, the goal of the lab was to test things, to find out how long they would last, to measure rates of wear of dissimilar materials. The picture is familiar in labs that support large manufacturing operations. If we had been making refrigerators, the lab would have been testing to see how many times the door could be opened before it fell off.

Then, in 1964, changes happened as the new director of the research lab, Kenneth G. Frye, took over. He later admitted to us that he started out with a policy of management by directives – get those refrigerator doors tested and do it by a deadline –, however when he saw how effective we worked together, he changed to management by objectives. Then as long as our goals aligned with his, he gave us full support. Seven years later, in 1971, after a bitter labor dispute in the manufacturing section of the Downingtown plant, the parent corporation decided to close down the whole operation and move it back to Beloit, Wisconsin, with some winding operations moving to Lenox, Massachusetts.

There are several reasons for wanting to relate this story to you, 40 years later:

- We want to describe how an atmosphere can be created which supports creativity and invention.
- We want to show how management can be effective in a role which takes business pressures off the research worker
- We want to give examples of creative work by following the threads of development for several innovative projects
- We want to show how some of the questions left unanswered at the closure of the lab can still provide opportunities for further research.

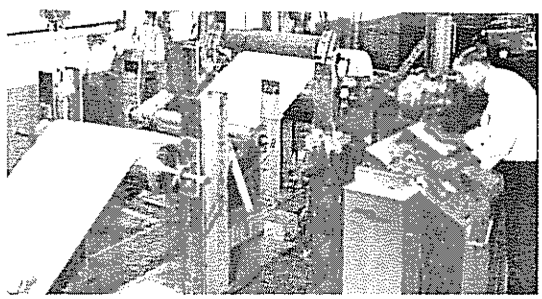


Figure 1. David Daly researching web traction, 1964.

THE FIRST IN A SERIES OF PUBLICATIONS ON BASIC FINDINGS

While some paper machinery manufacturers adopted a policy of complete secrecy about what was going on in their research laboratories, we were allowed and later encouraged to release our findings within months of obtaining the data. David A. Daly was first among us to publish on behalf of the research lab. His innate curiosity about how things worked was infectious when he spoke to us about how he observed how webs often refused to stay in traction with their carrying rolls at various paper mills he visited. He set up a laboratory study using a small single-drum winder in the lab as the motive force, with a long continuous belt of paper wrapped around the drum and threaded over various rolls. He tested a wide range of paper grades at selected tensions, speeds, angle of wrap, carrying roll diameter, and torque supplied to the roll's axis. His publication, "Factors controlling traction between webs and their carrying rolls"[1] was the first in our series of basic papers.

WINDING STUDIES AND OTHER PROJECTS

Daly's work occupied weeks of testing in 1964, and in the meantime three of the rest of us were working on our own projects. Bob Lucas was studying the effects of differential drum torque on tightness of winding. The two-drum winder was a converting model with 254 mm (10-inch) diameter drums and a pivoting rider roll. The winder was equipped with heavy, wide elastomer belts coupling the two drums, running on conical pulleys for differential speed changing. Digital draw speed indicators were attached to the drums for reporting the speed difference.

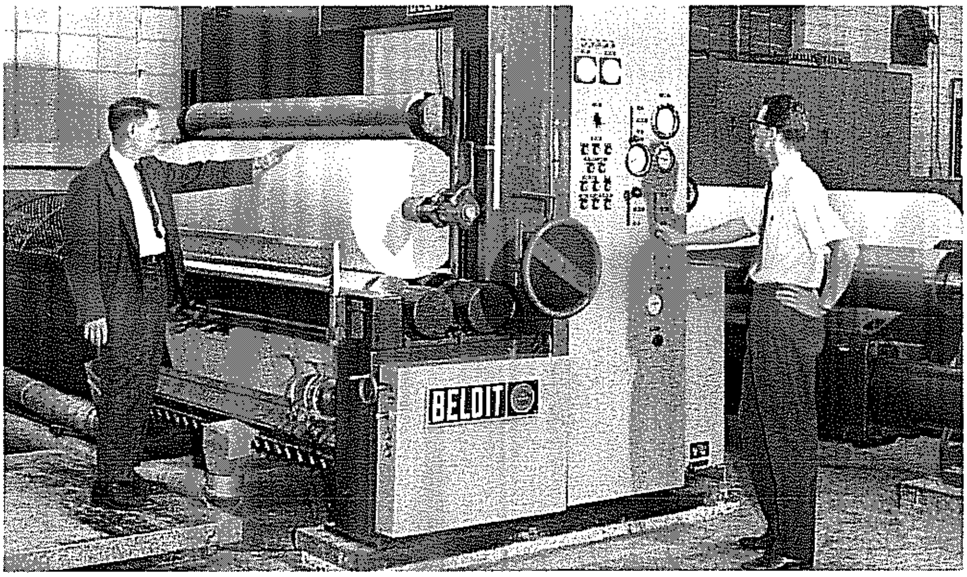


Figure 2. Kenneth G. Frye (left) and Robert Lucas at the C-10 converting winder, 1964.

HOW TO MEASURE ROLL HARDNESS

Richard Legrand was an inventor who was initially hired to work on an optical approach to scanning paper webs for defects. Pfeiffer was initially hired into the engineering department as a field service engineer, but found the challenges of research to be much more rewarding. One of his first projects in research was to assist Legrand in trying to develop a new instrument for putting a number on roll hardness. Richard's approach had been to attempt to hold a microphone in contact with a roll while sound from the impact made its way back to the microphone for analysis. His light "thumper" design had trouble in that the microphone bounced away from contact too soon for any meaningful waves to be recorded. Pfeiffer tried another approach using a heavier club instrumented with an accelerometer, which after about 5 months additional work, turned into the Rho-Meter hardness tester.

THREAD OF DEVELOPMENT – FOLLOWING THE HARDNESS TRAIL

A good researcher is never satisfied until all the questions about what he or she is doing have been answered, at least to the furthest extent possible. Questions often lead us to find parallel ways of explaining how things happen, to use modeling and simulation, and to find similarities in the natural world. If we follow the thread of development of the Rho-Meter as an example, we can see how one thing can lead to another.

Peak acceleration during impact equates to hardness

We started with the basic principle that acceleration measured during the impact of a curved steel object striking a paper roll with known initial velocity would measure hardness. This is close to the intuitive sense of hardness that anyone experiences when rapping with the knuckles on an object. Hitting a hard object such as a desktop, creates enough peak force that the pain signifies high hardness. Hitting a softer object such as a telephone directory, yields less peak force. Several questions arose about this new measurement method. Was it close to the acoustic method of sounding the roll with a club? If sound waves were travelling inside the roll, would they have time to make the trip from the surface to the core and return, before the striker bounced off the roll? The contact lasted only about 2 milliseconds. How far would an acoustic wave travel in this time interval? Answering this question led to the measurement of the speed of sound in paper, and that in turn produced further revelations.

Sound waves in paper

Testing sheets of paper arranged in a stack would be more convenient than trying to make tests of a wound roll, but we needed something to apply pressure to simulate the tightness of paper as it exists in a wound roll. Pressure applied between parallel plates by a hydraulic press would supply the compression, but how to measure the sound velocity? Pfeiffer's previous association with a company manufacturing flat capacitors for the aircraft ignition business suggested the answer. Flat capacitors that contained some void spaces would jump and throw light objects off their surfaces when charged to about 3000 volts and discharged suddenly. So we made some poor quality capacitors with intentional voids by alternating layers of aluminum foil, paper, and plastic film. One served a sound transmitter, charged by a high voltage source through resistance, and discharged by a fixed spark gap. The other was charged with 9 volts through a resistance, and served as a microphone at the other end of the stack. The pressure wave passing through resulted in a voltage change across its plates.

One of the first things noticed was that the speed of sound passing through flat sheets of paper in surface contact with each other increased as the pressure increased. Also, the speed of sound was significantly lower than the speed through solid wood fibers. The layers seemed to act as a delay line, with increased pressure shortening the delay. Looking for a parallel in another phenomenon, one might consider the compression wave traveling through a string of railroad cars when the engineer reverses that engine to take up slack in the couplings, then goes forward. The delay is provided by the masses of the railroad cars, while the spring element is in the springs coupling the cars. The mass of each paper sheet does not change, but the springs between sheet surfaces increase in number and stiffness as the pressure increases. The non-linear compression characteristics of paper were recognized in a model that uses an exponential expression to relate strain and applied stress, while the sound speed versus pressure curve could be plotted linearly on logarithmic axes.

Sound waves in wound rolls of paper

Answers often give rise to more questions. In this case, we were curious about the amount of pressure found between layers in a typical wound roll of paper. Making the measurement in roll form presented some different problems compared to stack testing in a press. However, Mr. Lucas provided a nicely trimmed, well-formed roll of 37 g/m^2 catalog paper, wound on his C-10 converting winder. The roll, about 875 mm in diameter and 127 mm wide, was supported off the floor by a steel bar passing through its center. Another sound-emitting capacitor was made in cylindrical form and inserted into the core between the supporting bar and the fiber tube core of the roll. Sound waves passing through the roll were picked up at various radius points on the roll surface, using a common phonograph pickup cartridge with a crystal element. Magnetic pickups were tried but were overloaded by the high current pulses emanating from the discharging sound capacitor. The measurement technique was unique at the time, and did not involve disturbing the winding of the roll by inserting any transducers between the layers while winding.

By relating sound velocity to radius, and decoding the graph to pressure versus radius with the aid of the stack measurements of sound velocity versus pressure, we had the pressure profile of the roll. Then by using the hoop stress formula, relating interlayer pressure, residual tension, and rate of change of pressure versus radius, we had the complete picture of roll structure. We were able for the first time to describe to paper makers what happened to all the tension wound into the roll at the expense of many kilowatts of winding power expended on pulling on the web against unwind tension: It was gone! Except for a narrow band of positive tension on the outside of the roll, most of the residual tension within the roll was negative. It was an eye-opener for the industry, and explained dozens of roll structure-related defects including starring, tension and shear bursts.

SHARING OF IDEAS IN THE DEVELOPMENT OF WINDING MACHINERY

Paper mills wanted to satisfy the market for wider, larger diameter, and heavier rolls of printing paper. From our studies of winding on two-drum winders, we knew the limitations of this type of machinery. Bob Lucas had been studying the application of differential torque between two winder drums and its effect on roll structure at various diameters. A good tight start could be made by the application of tightening torque at the start of winding, with nip force contributed by the rider roll. But as the roll weight built up on the two drums, a reverse application of torque could not forestall the eventual buildup of too much tension at large wound roll diameters. We knew that rail-supported winding was more attractive because the roll weight was supported at the core instead of at the nip. We had been doing some winding on a small single-drum winder, the same one Dave Daly had modified to drive a loop of paper at high speeds for traction studies. This winder did support the winding roll by carrying its coreshaft on rails, similar to a paper machine reel. As in all winders of this type, it is difficult to obtain a tight start on a bare core without the use of centerwind torque, and we were not thinking of adding that at the time due to its complexity. Core-supported winding was eventually shown to be limited in the maximum roll weight that could be supported by the core alone. At a later date, compromises were developed for sharing the load between the core and surface support.

Design conference standing around a roll

One afternoon, four of us stood around a large paper roll that was resting on the floor. We often used the paper for doodling, and this time was no exception. Those present at the informal discussion were Bob Lucas, Dave Daly, Dave Pfeiffer, and Richard Legrand. We started sketching how nice it would be to combine the ability of a two drum winder to make tight starts with drum torque, if only the two drums were arranged vertically instead of horizontally, and rails were provided to support the rolls. The next possibility we saw from our sketch as it developed, was that we would not have to worry about slit separation when winding multiple roll sets, as the winding rolls could alternate on opposite sides of the two vertical drums. The web would come down over the top drum and pass between the two drums to roll sets on one side, and simply pass down into the rolls on the other side, without passing through the gap between the drums. Roll sets would never suffer from stuck slits, because the rolls were physically removed from each other on alternate sides, compared to the side-by-side configuration conventionally employed in shaftless winding.

The only question remaining was whether we could use torque between the drums to make tight starts on winding rolls on either side of the two drums. Excitedly, we began assigning speed ratios to our two drums, and lo and behold, as long as the second drum contacted by the paper had a slightly higher surface speed, the torque would have a tightening effect! We quickly placed our signatures on the surface of the roll and dated it.

Take this slip of paper and patent it!

Dave Daly expertly extracted the sheet on which we were writing with his ever-sharp pocket knife, and we had the basis for a patent application for what later came to be known as the Bi-Wind. When the final documentation came around for our signatures, Richard Legrand withheld his name, saying that he did not consider he had contributed enough to be counted as an inventor. The rest of us encouraged him to participate, but he declined.

Data collected by Dave Daly showed that a belt tie to control the drum speed ratios suffered from poor speed regulation under changing torque loads. We encouraged Soma Rohosy, who had joined the Research Department as a Designer, to incorporate a Harmonic Drive® as a differential speed control. The result was perfect for our needs. This efficient drive enabled us to control the drum speed ratio with a accuracy of 0.001% with very high mechanical efficiency. Daly, Lucas, and Pfeiffer cooperated on methods to produce tight enough starts on both sides of winder to enable building rolls of coated and supercalendered publication grade paper up to 1.5 m diameter without problems at the core. At first, the wound-in tension versus diameter was measured by a temporary setup of load cell roll and force transducers. Later, the wound-in/ wound-off tension machine (WIT-WOT machine) was completed, allowing small rolls of up to 0.3 m diameter to be brought over and analyzed for the tightness of the initial winding.

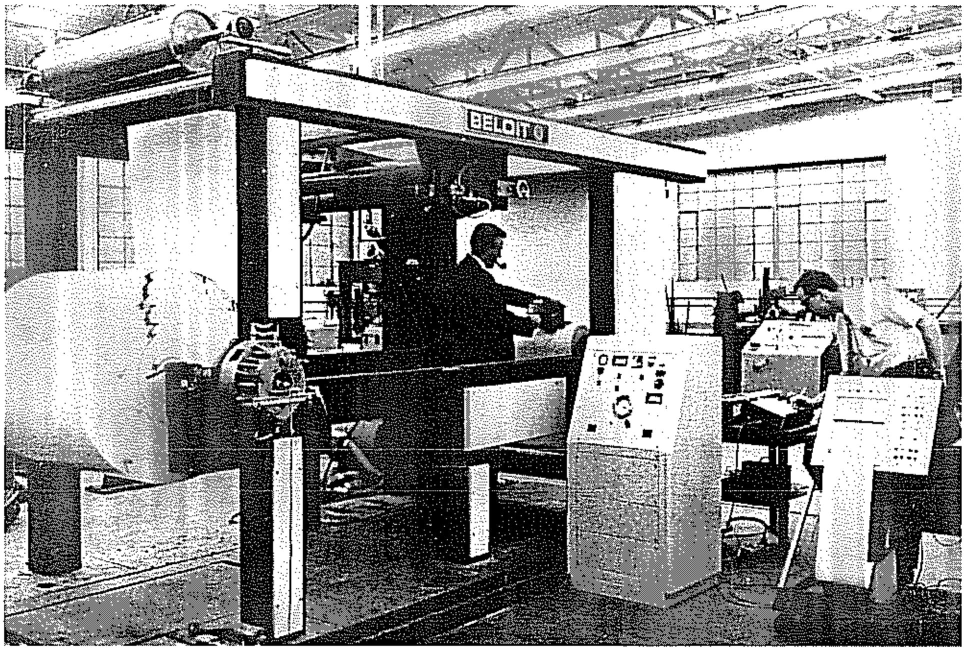
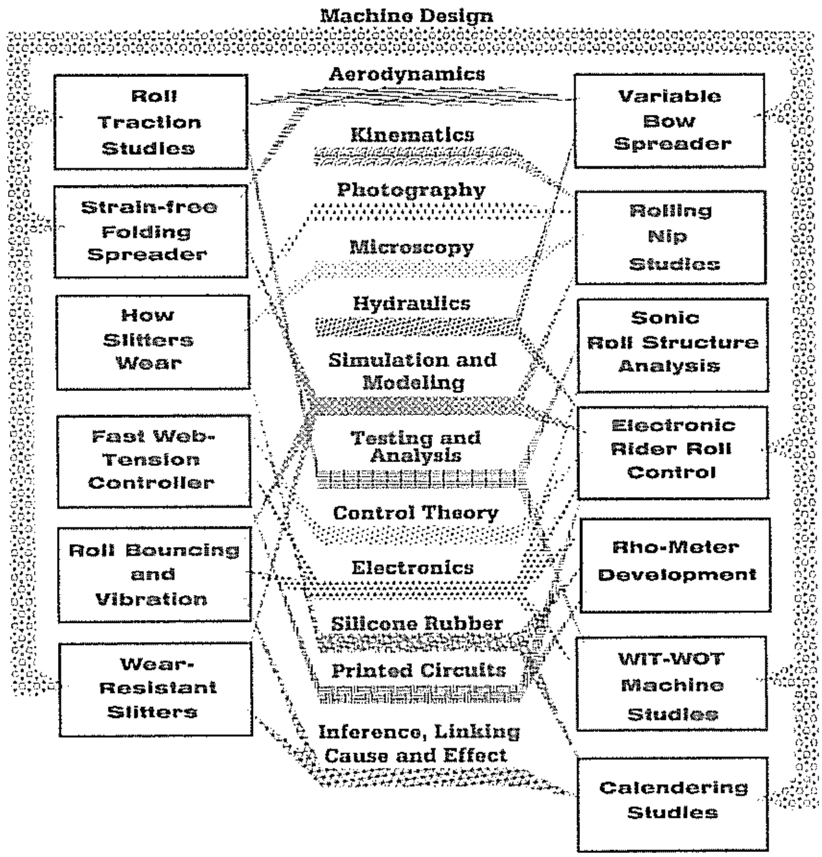


Figure 3. Pfeiffer and Lucas at the WIT-WOT machine, 1967. The unwinding roll was an attempt to reconstruct a painted line on the roll face, after two rewindings.

CROSS-FERTILIZATION

In the sharing of ideas between research workers of diverse backgrounds, each brings in some unique aspect of problem solving that the others can appreciate. David Daly had a natural ability to connect cause and effect. Bob Lucas was particularly strong in machine design, materials, and hydraulics and pneumatics. David Pfeiffer and Richard Legrand brought in capabilities in electronics and optics. We never stopped learning or teaching each other as new challenges arose. Daly practiced chemistry when removing the stabilizer from methacrylate resin when potting paper samples for microtoming (another technique he learned), Pfeiffer designed and etched double-sided printed circuit boards. Lucas designed efficient core chucks and ball bearing support for arbors that would carry the maximum overturning moment in a minimum of space, and put together hydraulic load cells to accurately monitor and control web tension. And that's just what went on in one week. The next week, it was always something different. The chart on the next page illustrates a number of supporting disciplines that were employed to support a selected number of our projects.

Disciplines and Techniques involved in a selected number of Laboratory Projects



THE ROLE OF MANAGEMENT IN GUIDING THE RESEARCH TEAM

We have not said very much about how Ken Frye was helping us through his changed policy of management by objectives. It is not that we did not have meetings, we did, and the tone of the meetings as recollected seemed to be that of pep talks, with encouragement to keep on what we doing. As far as accomplishments, we seemed to be doing that well. Ken Frye saw that support was always provided when we needed it. Mechanical design help was available through Soma Rohosy, a full-time member of the department. He made large contributions toward the design of the WIT-WOT machine, web-driven slitters, and other winder designs. Our lab supervisor, Ken Seidel, saw that everything was built, erected, aligned and made totally functional in record time. Ken Seidel often provided us with liaison to the field, as he was often sent to the paper mills of our clients when no one else seemed to be able to solve their problems. What he brought back was a great help to us when we heard how he fixed those problems. Thanks to what Ken Seidel absorbed through his association with the research department staff, and his own abilities, he became a highly sought-after independent service expert. He ran a highly successful consulting service for years after he left the company.

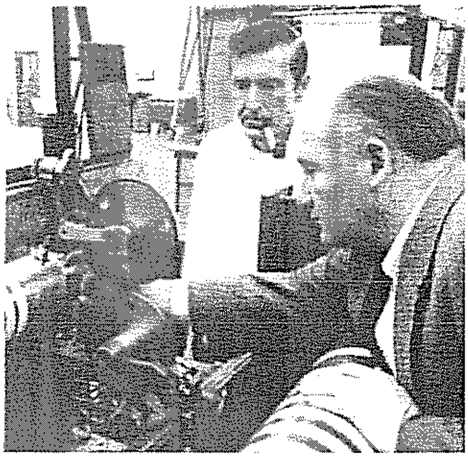


Figure 4. David Daly and Soma Rohosy with web-driven slitters running on air bearings. (1968)

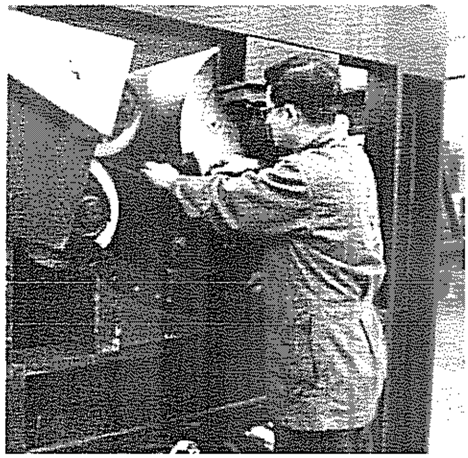


Figure . Ken Seidel at an experimental board sheeter (1968).

Ken Frye provided other support by bringing in personnel from the engineering department as required for special jobs. But one of the most important functions was to shield those in the research department from upper management. The service of protecting us in the lab from pressures brought from above was not an easy job, and we only learned what was happening in later years. But not having top management breathing down our necks was appreciated, as it allowed us to get on with our work.

Still another service provided by Mr. Frye was to relieve us from having to do lengthy justifications for capital expenses whenever we needed new equipment. We needed lots of new equipment. Everything we were working on was brand new developmental equipment that was fresh off the drawing board, and we needed it built in a hurry. No problem, most of it was put through the shop as a 'breakdown order'. For those not familiar with the term, this is emergency service for clients whose machinery has experienced a sudden failure or breakdown. The shop always set the priorities so that these orders were handled in haste, pushing scheduled work out of the way to minimize the client's downtime waiting for the repair. By operating under the shield of breakdown orders, we avoided lengthy justifications, as the need is obvious, since it is for a breakdown. Also, a large experimental machine could be assembled from pieces, instead of making a capital equipment request.

<u>The need for good PR</u>

Ken Frye always insisted on having a duplicate set of slides made for him when we made our own presentations. We were a little suspicious of his motivation for doing this, but as it turned out, the value of his dispersing our findings in research wherever he visited was significant. He helped us become the focal point for the industry to look for breakthroughs and find answers to their problems. Of course, the sales department also welcomed these efforts. At one time, a Beloit Corporation vice-president was visiting the Downingtown Lab. This vice-president was well acquainted with the research investments of the corporation in its worldwide facilities. During his visit he was overheard to say to Mr. Frye that there is no doubt that our laboratory is "where the action is".

TWENTY MAJOR DEVELOPMENTS

As promised, here is the list. A number of the developments have already been covered while discussing threads of development, and those are shown in regular typeface. Developments not yet mentioned in detail are shown *in italics.*

1. Factors controlling traction between webs and their carrying rolls
2. How and when to apply drum differential torque to create optimum roll structure.
3. A portable instrument to accurately measure roll hardness
4. Revealing pressure and residual tension in typical wound roll of paper by sonic analysis
5. *Detailed study of slitter blades and how wear profiles develop; what makes a dusty cut.*
6. *Spreader roll with variable bow radius*
7. *Finely-grooved first drums for paper winders*
8. *Rolling nip studies; production of WIT by nips, and instant centers*
9. Bi-wind two-drum vertical winder arrangement
10. Harmonic drive system for vernier control of winder drum speed differential
11. *Wound-in, wound-off tension measurement (WIT-WOT machine)*
12. *Finely-grooved paper carrying rolls*
13. *Fast-responding electronic web tension controller*
14. *Strain-free, folding web spreader*
15. *Electronic rider roll control system with constant drum nip force*
16. *Improved adjustable winding stations with cantilever chucking of roll ends*
17. *Web slitters with sharpness retention, web-driven*
18. *Segmental tension sensing table rolls for wide winders*
19. *Studies on bouncing and vibration, measurement of bounce modes*
20. *Replication of surfaces to explain calender finishing action*

Stopping the list at just 20 developments required some restraint on our part. We could have added a half-dozen more, but then the title would have to be changed. Some studies were never completed at the time the laboratory closed. We have listed those as suggestions for further work on the following two pages. And following that is a list of the patents and publications arising out of the work done in the seven years.

OPPORTUNITIES FOR FURTHER STUDY AND RESEARCH, AND UNPUBLISHED PREVIOUS WORK

We realize that the chance of no one working on any of the topics listed below in forty years is very slight. However, we present the following research ideas in the hope that at least some aspect of the topics has not yet been fully developed.

1. Tailor the paper to the printing process – then develop the machinery to make it

This was one of David Daly's projects when the Downingtown lab closed. Offset, letterpress, and rotogravure each have their own requirements for received the printed image. The surface of the sheet , as well as the bulk properties through the sheet are important. In the intervening years, the development of papers for the Small Office, Home Office (SOHO) has seen a renewal of interest in specialty papers for ink jet and laser. These products command high prices, but to our knowledge, the tailoring of machinery to make the products has focused mainly on the coating process.

2. The LearMeter

Paper grades notorious for bouncing and vibration have one property that differentiates them from non-vibrating grades – the layers of the former papers lock together tightly due to pressure in the positive tension band, causing them to retain a pattern formed radially as the vibration takes place. In slippery grades the layers slide against each other and erase the memory of the deformed state. A small test device was made to bend a deck of sheets and measure the ability to slide against each other as the deck was bent. Spring clamps were placed over the pile in two places to simulate radial pressure. The term LearMeter was the result of shortening laminar shear to "lear". The prototype of the meter is no longer in existence, but it could be reconstructed from the remembered details. It measured the angular deflection of the paper pile in response to an increasing moment force applied.

3. Study of wound-in tension due to a rolling nip in the presence of torque.

Study the strain fields in multiple layers under the nip as the rolling nip passes by under various conditions including high tension developed in the top sheet, little or no tension developed in the top sheet, torque transmitted simultaneously through the nip, in CW and CCW moments. Micro-photographic studies taken of a simulation of paper webs on a larger scale indicated that the half-sinusoidal nip penetration strain field in the material was tilted ahead or behind the axis of symmetry by the direction of applied torque.

4. Tension fan-out angle on various grades of paper

David Daly noticed that when a tachometer wheel was pressed into a tensioned web in his traction studies, some webs such as calendered kraft paper showed a narrow angle, while lightweight coated and supercalendered publication grade formed an angular pattern approaching 60 degrees wide, downstream on the contact point. He investigated further to see if this signified the downstream distance that would be required for a local tension disturbance to be distributed across the whole web. (Bob Lucas noticed similar effects during his studies on spreading multiple slit webs.) Is it possible to expand on this finding and resolve tension variations across a web?

5. Thin films retarding wear

A thin film of cellulose, probably only a few molecules thick, coats the blades of slitters when cutting paper. This greatly reduces the metallic friction and wear of the knives. Trim slitters, running with no paper to cut for long periods of time lose this film and begin to wear as soon as it is gone, which is why mills have to sharpen their trim slitters much more frequently.

6. Nip mechanics in laminating and rubber-covered roll construction.

How pressure and shear are transmitted through the covering into the roll body. What happens at the interface of a web passing through the interface between the roll and a backup roll? How is this modified by the presence of layers being laminated, with a binder or adhesive or fill of greatly differing viscosity? How layers of differing hardness may be arranged in a backup roll for rotogravure printing so that shear forces across the ink-printing cylinder-backup roll interface are reduced to avoid smearing the image.

7. Sonic analysis

Improved setup for sonic measurement of roll structure using sound impulses radiating outward from the core. Ron Swanson worked on sound measurement using impulses sent into the roll from the surface with considerable success. The work was done at the Web Handling Research Center is the mid-1990's. However, to obtain a detailed picture of the roll under test, one could develop a specialized setup for producing the pulses, piezo-electrically or by capacitor discharge. Then by using more accurate methods for measuring the time delay for the wave to arrive at various diameters of the roll, more exact readings of the instantaneous velocity of the sound wave at any radius could be obtained. The circular symmetry of the setup would ensure that no apologies would be needed for waves passing along oblique paths, and would minimize internal reflections. Deflection of a laser beam focused on the roll surface could be detected easily, as the passage of the sound wave can be felt with the fingers.

8. Continuous measurement of the MD modulus of a web

We tested dozens of rolls of paper on the WIT-WOT machine for a mill client experiencing severe registration error transients in a color printing operation. We measured and recorded 23 different paper parameters during these tests, but the 24th parameter, which we did not measure, was the culprit. Something affecting the modulus of elasticity of the paper occurred in the formation on the paper machine. The cause was found by eliminating all of the other possible reasons for the registration to be suddenly affected. The transient was traced back to a surge in stock chest levels, and it was quickly eliminated. We could have set up a bridle-roll arrangement measuring tension under a fixed draw speed ratio difference to record the modulus fluctuation, but we didn't. Ultrasound is another way to measure a sonic modulus, having been done for years. But ultrasound may not transfer directly into what the printing press sees.

UNPUBLISHED RESEARCH

"The modes of natural vibration of bulky kraft rolls", D.A. Daly and J.D. Pfeiffer, Beloit Research Papers

"Surface winding 0.00125-inch blown polyethylene, Progress report", D.A. Daly, May 6, 1970. – Trials at 1220 m/min (4000 fpm).

PATENTS AND PUBLICATIONS RESULTING FROM THE WORK DONE AT THE DOWNINGTOWN RESEARCH LAB IN THE PERIOD 1964 TO 1971

The following are U.S. patent numbers. Several of the inventions were patented in other countries as well.

1. 3,383,064 **Rewinder for paper and the like**, (The Bi-Wind) DA Daly, RG Lucas, JD Pfeiffer, filed 1-17-1966, issued 5-14-1968.
2. 3,424,267 **Hardness Tester** (The Rho-Meter) JD Pfeiffer, filed 12-13-1965, issued 2-4-1969.

3. 3,463,377 **Web Separator** (the folding spreader) RG Lucas, filed 11-9-1966, issued 8-26, 1969.
4. 3,599,889 **Electronic Rider Roll Control System** JD Pfeiffer, filed 12-16-1969, issued 8-17, 1971.
5. 3,645,433 **Spreader Roll** RG Lucas, KG Frye, filed 12-16, 1967, issued 2-29, 1972.
6. 3,650,491 **Electronic Web Tension Measurement & Control System** JD Pfeiffer, filed 12-16-1969, issued 3-21-1972.
7. 3,682,032 **Slitter with Sharpness Retention Ability** JD Pfeiffer, filed 12-16-1969, issued 8-8-1972.
8. 3,685,379 **Slitter Blade Mounting Assembly** RG Lucas, KG Frye, SM Rohosy, filed 12-16-1969, issued 8-22, 1972.
9. 3,687,388 **Wound-In Tension Measurement & Control** JD Pfeiffer, filed 12-12, 1969, issued 8-29, 1972.
10. 3,785,232 **Web Support Table** KG Frye, RG Lucas, KL Seidel, SM Rohosy, filed 12-16-1969, issued 1-15, 1974.
11. 3,792,820 **Web Rewinder** RG Lucas, filed 3-1-1972, issued 2-19, 1974.
12. 3,797,772 **Expandable Chuck** RG Lucas, filed 3-1-1972, issued 3-19, 1974.
13. 3,848,304 **Variable Curvature Beam** RG Lucas filed 1-7-1973, issued 11-19, 1974.

PUBLICATIONS

1. Daly, D.A., "Factors controlling traction between webs and their carrying rolls" TAPPI J, 48(9), 1965, p. 88A
2. Pfeiffer, J.D., "Internal Pressures in a Wound Roll of Paper" JD Pfeiffer TAPPI J 49(8), Aug. 1966, pp. 342-347.
3. Frye, K.G., "Winding Variables and Their Effect on Roll Hardness and Roll Quality," TAPPI J, 50(7), pp. 81A-86A.
4. Daly, D.A., "Study of Defects in Wound Rolls leads to better Winding Control," Paper Trade J, Dec. 4, 1967, p. 46.
5. Daly, D.A., "How Paper Rolls on a Winder Generate Vibration," Paper Trade J, Dec 11, 1967, p. 48.
6. Pfeiffer, J.D., "The Mechanics of a Rolling Nip on Paper Webs," TAPPI J, 51(8), pp. 77A-85A.
7. Daly, D.A., "The Shear Slitter Yields to Laboratory Study," CPPA 54th Annual Meeting, Jan. 1968.
8. Daly, D.A., "Surface Winder Vibration and/or Bouncing of Rewinding Roll," Paper Trade J.
9. Daly, D.A., "Shipping Roll Defects," Paper Trade J.
10. Lucas, R.G., "Internal gearing in a roll of paper," TAPPI Fin. & Conv Proc., Oct., 1974.
11. Pfeiffer, J.D., "Nip forces and their effect on wound-in tension," TAPPI J, 60(2), pp. 115-117.
12. Pfeiffer, J.D., "Wound-off tension measurement in paper rolls," TAPPI J, 60(3), pp. 106-108.

Twenty Major Developments in Seven Years

J. D. Pfeiffer[1] **& R. G. Lucas**[2], [1]JDP Innovations, Inc., CANADA & [2]GL&V USA, Inc., USA

Name & Affiliation	**Question**
	No time for questions.

Since there was not enough time for questions after the presentation, some of the slides illustrating problems still unsolved at the close of the laboratory in 1971 were not shown. If you would like to have copies of the slides not shown, please contact the authors at jdpinnov@aol.com or bob.lucas@glv.com.