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THE PURE AND APPLIED SCIENCE OF PULMAC ZERO-SPAN TECHNOLOGY

(Improving mill productivity by harmonizing science, technology and people)

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INTRODUCTION

Any industrial process, including the manufacture of pulp and paper, is determined by what goes in to the process (input variables), the transformation process itself (throughput variables), and what comes out (output variables). Process control systems apply known cause and effect relationships between important input, throughput, and output variables to produce output of acceptable quality at an acceptable cost. The ideal paper producing system would require an operator simply to dial in the grade and required tonnage. The automated process control system would then take over to continuously monitor input variables at each process stage and match changes with the appropriate setting adjustments to throughput variables. Paper production would then be realized at optimum machine speeds without production losses due to broke, wet-web breaks, unnecessary use of reinforcing pulps, and unnecessary refining energy input. But actual papermachine systems often fall short of the ideal for several reasons. One important factor, though, is that data gathered for process control is usually drawn from measurements that are much more indirect indicators of fundamental properties than what with applied Pulmac zero-span technology, is now quite possible.

Annergren distinguished four different sources for data collection in the hierarchical structure of paper, extending upwards from the molecular level, through to the fiber-wall, fiber, and fiber-network levels.[1] To these, one can add that of fibre-in-suspension, or pulp situated between individual fibres and the fibre network. And it is pulp that is the dominant level of analysis in process control. For example, at the digester and bleach plant it's a pulp's Kappa number in the former instance and a pulp's brightness in the latter that is deemed important. In the stock prep area, refiner energy input is adjusted based on a pulp's measured freeness. But it is increasingly evident that measures of pulp quality are not sensitive to important factors affecting both the papermachine and final product quality at the reel[2]. Consequently and more attention is being given one level down to the fibre, as the more valid primary source. Fibre shape is now commonly measured by optical sensors reporting on fibre length, coarseness, and curl. Yet pulp strength as determined by conventional laboratory handsheet tests still dominates. But there is a growing volume of scientific literature suggesting that fiber quality determinants are primary indicators of a pulp's papermaking potential and should be the focus of attention for process control and quality assurance.[3]

As Annergren[4] and Cowan[5] have both suggested, what is needed is a common system of measurement that will be sensitive to changes in the key fibre properties that establish what is generally referred to as pulp strength. With such a system in place it becomes a straightforward technical matter to associate input fibre properties with throughput process settings (temperature, chemicals, and time) and quality indicators such as kappa number, brightness, and freeness together with paper quality measurements at the reel. Once these associations are established then process optimization in the production of both pulp and paper becomes just one more straightforward technical matter. Fortunately such a system exists. The fibre strength, length, and bonding potential indices that can be generated by the Pulmac Z-Span Testing system provide a rapid and reliable means to specify pulp strength entering and exiting each process stage.

WHAT DOES THE ZERO-SPAN TEST MEASURE?

Interest in zero-span testing first makes an appearance in the literature with Hoffman-Jacobsen back in 1925.[6] There is an obvious theoretical means to measure average fibre tensile strength: replicate on an extremely small scale a conventional tensile tester and eliminate any initial span between the clamps. In this manner all fibres secured by one set of clamps would also be secured by the other. The total failure load would be the sum of the failure loads of each of the fibers crossing the clamping line. This value divided by the number of clamped fibres would yield the average intrinsic individual fibre strength. But it is not a simple technical matter to manufacture a necessarily massive, very much macroscopic, zero-span clamp assembly that will provide for sensitive measurement of the physical strength properties of essentially microscopic particles. Largely because of this difficulty, little attention was paid to a practical zero-span test, despite the views expressed by Clarke and, later, Van den Akker et al in the 1940's and 1950's that a zero-span test would likely provide a good indicator of average fibre strength.[7] Things changed in the 1970's when Wavell Cowan developed a practical zero-span testing device through Pulmac Instruments Ltd of Montreal, Canada. This device offered a feasible means to acquire zero and short span tensile data in both laboratory and industrial settings.[8] The way was now open for the scientist to investigate what such a device actually measures and for the technologist to determine and substantiate practical applications.

In a 1975 monograph, Cowan elaborated further on the article he and Cowdrey had published the year before[9] on the nature of zero and short span tensile testing.[10] He proposed that short span curves would provide information about average fibre strength and length as well as their inter-fibre bonding potential. By measuring in both the machine and the cross directions from paper samples drawn along the reel, information could also be gathered regarding fibre alignment and changes in the distributions of all these properties from edge to edge along the reel.

What is being measured through zero and short span testing is quite straightforward. In a conventional tensile test, load is passed from one clamp to the other through a bonded network of fibres and results provide information about the bonded network, not about the fibres themselves. In a tensile tester capable of performing a zero and/or near zero-span (i.e. short span) test the gap between clamps is so small that a region is created (zero-span region) where individual fibers are firmly secured by both clamps and the failure load can be interpreted to be providing information about average individual fibre properties, as opposed to collective properties of the interlocked fibre network. As the initial gap extends out from zero to various short spans, the limits of the zero-span region are approached and the load at failure drops as the number of individual fibres spanning the gap drops off.

There are competing views in the literature about whether these tests should be performed on dry or re-wetted sheets in order to obtain a truer picture of fibre properties. Seth recommended the dry test as did Batchelor.[11] These views were based on comparisons with single fibre tensile tests. Cowan, on the other hand, favoured the wet test. He postulated that, when re-wet, hydrogen bonds that would otherwise contribute to the total resistance to tensile loading would be eliminated. Mohlin et al[12] came down on the side of Cowan regarding the wet test, but with slightly different explicative reasoning. They acknowledged that the dry test could be valid when measuring strength properties of carefully controlled laboratory-produced pulps. But they determined that, with industrial processes, significant localized fiber degradation, or defects, would be invariably present to which the wet but not the dry zero-span test is sensitive. In the dry zero-span test, hydrogen bonds apparently overcome these surface defects by bridging load across or around defects either by, in effect, cementing them in the former case or by transferring and distributing load to adjacent fibres in the latter. For relatively defect free laboratory-produced pulps, such ‘repairs’ would be unnecessary. In several studies, the impact of increased inter-fibre bonding was indeed found to be unimportant in the wet zero-span test.[13] Mohlin did determine that the wet zero-span test is very sensitive to changes in the degree of fibre degradation causing localized defects on the fibre wall, fibre length, and fiber shape (kink,curl). Furthermore, Mohlin corroborated Cowan’s earlier findings that the wet zero-span test correlates well with tear at a given tensile value. [14]

APPLYING THE ZERO-SPAN APPROACH

So what does this mean in practical terms? There are three important conclusions to be drawn. First, there does remain some ambiguity in the literature regarding what is actually occurring during the zero-span test. This is likely due to the fact that the samples being tested are not ideal two dimensional isotropic forms. They have a third dimension which prevents absolute zero-span conditions from ever being realized. The simple act of compression during clamping, forces the opposing clamps slightly apart in the horizontal plane. This negates Cowan’s premise that at zero-span all fibres initially clamped on one side are also clamped at the other. Furthermore, because the sample has thickness fiber arrangement will have a vertical component and, therefore, load transfer will also have a vertical component, as opposed to the strictly horizontal premise of theory. This variance from the theoretical ideal suggests that much of the ambiguity in the literature may arise from the circumstance that network effects in the zero-span region are non-negligible and can never be completely discounted. It is up to further research to improve the theoretical explicative model.

However, there are two other conclusions that are directly and unambiguously pertinent to industrial practices in the manufacture of pulp and paper. The wet zero-span test is very sensitive to changes in average individual fibre strength as limited by the degree of fibre degradation causing localized defects on the fibre wall. If fiber kink and curl are first removed in sample preparation, then wet zero-span changes in a given pulp will be associated with changes in the frequency of localized fibre defects which are, in turned, caused by variations in chemical pulping and mechanical refining conditions. The wet zero-span test also correlates very well with changes in tear at a given tensile and tensile at a given freeness.[15] Indeed, Cowan has shown that if dry and wet short-span tests are recorded providing information on fibre length and bonding potential, tear and tensile - traditional measures of pulp strength - can be predicted with meaningful accuracy.[16] In the end, a zero and short-span tensile testing program makes it possible to monitor fibre strength, length and bonding potential across pulping processes in near real time and so monitor the stability of pulping processes.[17] Armed with this knowledge, it is also possible to have a more precise indication of a given pulp’s papermaking potential. This capability offers industry a powerful process and quality control tool; a claim supported by case studies and reports found in the literature.

APM Maryvale Study: APM Maryvale in Australia started up production of uncoated woodfree fine paper in 1987 from locally-produced eucalyptus and imported softwood kraft. Initially Maryvale could only successfully run a eucalyptus – softwood ratio of 80:20. The intention was to be able to emulate producers in Brazil and operate at 100% eucalyptus as soon as possible following start-up.[18] Maryvale attributed their inability to run at 100% eucalyptus to poor pulp quality and poor papermachine performance. A study was commissioned to acquire zero and short span tensile data in order to isolate and quantify causal factors with a view to maximizing the papermaking potential of the eucalyptus pulp. Archived handsheets and current pulp samples were tested from old and new chip supplies, from different wood ratios, and from known periods of good or poor wet-end runnability and sheet reactivity. Pulp quality had hitherto been controlled mainly by cooking to constant Kappa. Viscosity and freeness were also reported, but together with Kappa number, these quality indicators failed to correlate well with paper quality at the reel. Conventional laboratory handsheet testing was far too time-consuming to be useful for process control purposes while the Pulmac Zero-Span approach offered a means to rapidly acquire data on the fundamental fibre properties that could enable prediction of both runnability and paper quality at the reel.

Correlations between fibre quality and refiner energy input and wet-end breaks were investigated. Pulp samples were drawn from weekly periods of good, or ‘hard’ pulp (i.e. on-target porosity achieved as a result of refining which also improved strength characteristics) and poor or ‘soft’ (no refining energy input because porosity is already at or below target) pulp production. For the purposes of the study, if a pulp lot had received no input refiner energy for at least 24 hours in the week, it qualified as soft, otherwise it was designated as hard. The study determined a strong relationship between the wet zero-span result (FS) and the production of hard or soft pulp with 69% of hard pulp characterized by an FS number above 110 Nm/g and no soft pulp production at all above that benchmark. Based on this result Maryvale could establish 110 FS as the threshold to control off-machine porosity.

Similar results were obtained when examining wet-end break frequency and pulps from old and new chips. Poor runnability was defined as a week of one or more wet-end breaks per day. Here the L number (fibre length index defined as wet short span to wet zero-span ratio multiplied by 100) was found to be the relevant indicator as 83% of high break periods occurred when the L number fell below 32.5. This benchmark could then be used to minimize softwood use without incurring loss of runnability. Old chip pulp was found to have lower FS and L values than new chip pulp at 143 and 36.9 versus 170 and 40.6.

A zero-span examination of archived daily handsheets drawn from 1987/88 and in 1989/90 was also undertaken. 38% of the samples drawn from 1987/88 were below the target 32.5 L number as opposed to no samples at all below target L number in the latter period. FS number was below the 110 target in 38% of the 1987/88 samples while this improved to 16% below target in 1989/90. This data showed a marked overall improvement from the earlier to the latter period which was attributed to the 1989 upgrade of the bleach plant. The periods of low L number value corresponded to higher frequencies of wet-end breaks and preceded periods of higher percentages of softwood content as would be expected.

These findings confirm Cowan's earlier empirical work. As a result of this study APM Maryvale found they could rely on Pulmac zero-span data to minimize softwood kraft consumption and to control the wood mix ratios leading to the digester.

Weyerhaeuser Longview: Weyerhaeuser started up its 1200 tonne per day Longview, Washington kraft fibreline in 1995. It operates a continuous digester, oxygen delignification reactor, and three-stage bleach plant and supplies pulp for bleached paperboard, fine paper and as a reinforcement pulp in newsprint. Process Engineer Ruth Stanaway applied Pulmac zero-span data to improve pulp strength to meet the more rigid strength requirements of their newsprint customer. Traditional reliance on viscosity as an indicator of pulp strength proved insufficient in the ranges needed for newsprint. This customer required pulp quality reported as tear at 5 km breaking length tensile. With a correlation coefficient of .85, composite zero-span data (FS * L * B – see endnote 17) was clearly strongly related to tear. Fibre strength values were then monitored through the control room and changes in values were associated with observed process changes. Eventually the mill was able to preemptively adjust process settings in order to maintain fibre strength numbers on target. Over time, the mill's newsprint customer learned to decrease softwood use as fibre strength increased and so minimize the kraft ratio.[19]

Pulmac fibre strength measurements could then be applied back through the bleach plant to optimize its performance. By lowering the stock temperature in the bleach plant operators were able to decrease losses in fibre strength across the Do tower. Cooking to higher kappa at the digester brought further improvement to fibre strength. Earlier attempts to cook to higher Kappa had proved unsuccessful because of the need to increase ClO_2 dosage in the bleach plant. Pulmac Z-Span data has been useful throughout in providing rapid and reliable strength information necessary to implement incremental steps towards improved process optimization.[20]

Sappi Muskegon: A similar experience was reported by Lynn Berry, quality manager for the Muskegon Business System. The bottom line was improved by millions of dollars per year by incorporating a Pulmac zero-span testing system that helped bring down product variation, thus reducing downtime and lowering material costs. [21] Before implementing the zero-span testing program, the mill had monitored viscosity, residual alkali, and sulphidity every two hours together with frequent measurements of kappa, brightness, and dirt. With all this data, they still lacked the confidence they needed to adequately predict a pulp's papermaking potential in terms of runnability, formation, and in machine strength requirements. Frequent wet-end breaks on the papermachine were attributed to high strength variations which also led to reliance on premium materials such as titanium dioxide and high softwood ratio furnish. According to Berry, the rapid feedback provided by zero-span testing permitted the mill to gain a greater understanding of the effects of process variables on fibre strength and to make positive changes that substantially reduced process variability. Wet zero-span values were raised by 10% while standard deviation was reduced from 6.5% to 3.2%. Confidence in fibre strength through the bleach plant allowed brightness to be increased two points to 90 which permitted the total substitution of titanium dioxide with less expensive calcium carbonate. In another initiative made possible through zero-span testing, the Muskegon mill was able to lower softwood consumption by 10% on a grade run on one of their papermachines.[22]

TOWARDS PROCESS OPTIMIZATION THROUGH APPLIED ZERO-SPAN TESTING

A pulp mill has three overriding production objectives. One, it must reduce pulp quality variability to a minimum. This is quite a challenge when producing hundreds of tonnes of pulp per day, especially if fibre is being drawn from various sources of supply. Two, it must optimize its production so that its pulp will be as economical as it is uniform in quality. This also presents a significant challenge, given the infinite sources of variability in pulp production and complex interplay of key process variables. Three, since perfect uniformity of quality is impractical, a pulp mill must have the means to differentiate pulp lots with sufficient precision in order to optimize furnish blends for the paper side or to match lots of different quality characteristics with customers or usages requiring corresponding quality specifications. The experiences of the Maryvale, Longview, and Muskegon mills shows that equipped with a Pulmac Zero-span testing system and the will to make it work, these objectives can be achieved with greater precision and certainty than was possible with other approaches

The fiber parameter which best characterizes the papermaking quality of pulp leaving the pulping/bleaching process is the wet zero-span, or FS, number. Pulps with FS numbers more than 4% below normal will begin to cause problems on the papermachine and by the time the FS number falls to 10% below normal, papermaking problems of one kind or another will crop up 70%-90% of the time.[23] A Zero-Span program can characterize all pulp production on a routine basis in terms of its FS number. These numbers may then be used not only to provide feedback information as a means to reduce variability and to optimize pulp production, but also to ensure that all clients or papermachine operators will receive pulp that will perform as expected on the papermachine. Zeroing in on the FS number during start-up of a new fibreline can also help normalize operations in a speedy timeframe while building, from day one, the baseline fiber quality numbers that will likely prove helpful in detecting, isolating, and correcting process upsets.

Define Normal and Problem Variability: Once a Zero-Span testing capability is operational, routine shift testing should begin immediately. The resulting data base will enable quick determination of the average FS number and the extent of its normal variation across key production stages. This data base is organized into pulp strength histograms of pulp production versus FS number. The variability in the FS number picked up by the pulp strength histogram will be caused by the interaction of process variables such as chemical concentrations, temperature, reaction time, and refiner condition, and with variations in wood quality such as chip size and uniformity, moisture content, and species mix.

Pulp mills typically have reasonable control over process input variables, and generally know when process upsets occur. On the other hand, variations in wood quality are largely invisible to the production operation. This means that the changes in FS number that are driven by changes in wood quality are largely unpredictable and therefore beyond the scope of normal process control strategies. Variations in the FS number driven by changing wood quality are referred to in our program as *normal variability*. Normal variability could well account for as much as ± 6% spread in the FS number about the mean value. The larger swings in process variables are generally triggered by production upsets or are an unintended consequence of necessary process adjustments done to accommodate changes in user-defined pulp quality requirements. These larger swings are referred to as *problem variability*.

While production remains in the range of normal variability, the Zero-Span program serves to apply the FS label to the pulp strength quality indicator in frequent intervals and to generate more and more data that can be later correlated with concurrent process changes that are also recorded. These correlations build the knowledge base that can provide greater insights regarding the complex cause and effect relationships that uniquely characterize any pulping operation. When production ranges into the problem variability area, Zero-Span testing and analysis can be put to immediate work isolating and correcting the root cause. With the accumulated knowledge base already established, this correcting process will itself become more and more routine. And, as an added benefit, optimization strategies will become more and more apparent and their implementation increasingly certain and controlled as was the experience with the three mills cases reported above. Still, while timely feedback will greatly assist efforts to quickly identify and reverse negative quality trends, production upsets will occur from time to time and will produce some quantities of reject quality pulp. Two possible strategies can be visualized for dealing with such pulps. First they can be segregated and sold as off-quality. But an alternative that will fetch a higher per ton price, is to recover such pulps prior to drying and to bleed them back into normal production at a low fixed rate. The resulting blended pulp lot will exhibit acceptable FS numbers and uniformity and can be sold at the premium rate.

Optimization: With few exceptions, the overall productivity of any papermaking operation depends far more on the uniformity of the furnish quality than it does on any particular quality parameter. This is because papermachine operation is adjusted to run reliably with a given furnish. When furnish quality departs from target range, those adjustments become out of tune. A furnish is materially unchanged if its FS value is held within a range of ±4% from a defining normal value. Should the FS number drift outside this range, problems will be experienced on the papermachine. So maintaining the FS number within 4% of the mean value will define a target quality for pulp that will perform with satisfactory runnability on any client papermachine.

The zero-span approach will allow a mill to introduce a value added marketing strategy based not only on its ability to ensure steady quality, but also on its ability to match pulp quality with real papermaking need. Very few papermachine operations really gain any useful advantage by seeking to maximize the strength of the pulps they use. In fact for many grades of paper a lower FS pulp may well have characteristics (e.g. more flexible, easier to beat fibers) which actually enhance its performance over a higher FS pulp. Zero-span testing will permit quality labeling of all production in terms of a small number of categories each of which will consist of pulp with a specified uniformity. Approximately 90% of pulp production will fall into one or other of these categories. By focusing the sales effort on matching the right pulp to the customer's actual needs, and then guaranteeing on-going uniformity of quality, all categories of pulp can be sold at market, and possibly even at premium price.

HARMONIZING SCIENCE, TECHNOLOGY, AND PEOPLE

Zero and short span tensile testing offers a means to monitor fiber quality with a much greater degree of precision than is possible through conventional laboratory physical property testing. The science is clear on that. Practical applications of this approach reported in the literature and outlined above give ample evidence that the systematic implementation of a zero and short span tensile testing program will deliver improved operating efficiencies resulting in lowered production costs and improved customer satisfaction. While a general approach towards optimizing production has been discussed, it might be appropriate in these concluding paragraphs to provide some indication as to potential savings that could be realized from a typical papermachine system.

The current operating strategy employed on many papermachines is to “center-line” the processing conditions (refiner settings, blend percentages, papermachine settings) by grade. This benchmark is generally defined by averaging historical performance data. Variances at the reel from target properties signal process adjustments often determined through trial and error experiences of shift operators and supervisors. The dry line, couch vacuum, and other sensors are then used as a between-reel guide to the operational settings and employment of tickler refiners. Since undetected fiber quality changes in a papermachine furnish are generally found to account for some 50-80% of papermachine upsets, there is clearly a very significant cost saving potential that can be realized, if this changing fibre quality can be rapidly sensed and compensated.

A hypothetical papermachine system will serve to illustrate the potential cost savings. A communications paper mill was seeking to avoid closure by improving overall profitability. Having heard of the successes reported at APM Maryvale, Weyerhaeuser Longview and Sappi Muskegon, they decided to acquire Pulmac Zero-Span technology themselves and put it to work. Their Number 4 papermachine was producing various grades of printing paper at 400 tons per day at full capacity. Like Maryvale, it had been making paper from a blend of locally pulped eucalyptus reinforced with imported softwood kraft. In order to maintain strength and runnability targets the furnish was generally kept at an 80:20 hardwood to softwood ratio. Over the past several years the papermachine had experienced total production losses of just under 1200 tons per month due to quality rejects at the reel and downtime at grade change-overs, breaks, and wash-ups. The zero-span testing program was established with a view to reducing the number of reject rolls and improving downtime statistics.

Following the Maryvale approach very carefully, the first step was to establish benchmark ranges for furnish quality, papermachine performance, and paper quality. Accordingly, samples were taken out of archives for zero-span testing. Samples were drawn from periods of known good performance and the resulting average FS, L and B numbers were set as operating benchmarks. Samples were also drawn from periods of known operating and quality problems. The fibre quality numbers produced in this part of the program were found to frequently range more than 6% from the benchmark figures in at least one of the three fibre quality numbers and that these periods produced most of the production downtime and rejected rolls. It took almost a month of testing to arrive at this new starting point. With the database now established it would be possible to identify problem sources in terms of fiber quality numbers and to develop standard procedures to maintain these numbers within the 6% range of the established benchmarks.

This they did and the savings were quickly realized. Before the Pulmac zero-span benchmarks had been established 346 tons per month was recycled as broke due to quality defects at the reel. This number decreased dramatically to 276 tons per month broke after successful identification and implementation of the new standard procedures. At an average gross margin of $320 per ton this alone added over a quarter million dollars per year to the gross profit generated by the team at Number 4. It generally takes time and associated lost production to settle down after a grade change. By using Pulmac fibre quality numbers Number 4 papermachine operators were able to accomplish this much more rapidly, increasing production a further 46 tons per month. Similarly production gains of another 96 tons per month were achieved by reducing time lost due to breaks and washups contributing another half million gross profit. It did take another six months to reach this new productivity highpoint, however, and six months after that to realize the savings of over one million dollars on this one papermachine.

But the team at Number 4 Papermachine was not done yet. The final stage in the program to achieve productivity gains was to use the knowledge gained in the first year to optimize running conditions in the second. The targets set were to reduce basis weight by 1%, and substitute with $CACO_3$, to reduce the softwood content by half, and to increase machine speed by 1%. These targets were achieved with one more year of experience. The reduction in softwood reduced the furnish cost by $40 per ton. Reducing basis weight by 1% and substituting with CACO3 reduced furnish cost another $3.65 per ton. Increasing machine speed by 1% resulted in increasing annual output by 1,345 tons. Taken together these productivity gains increased the gross margin to almost $400 per ton and the annual tonnage by 3,144 tons per year.

4 Papermachine

Period	**Annual Tonnage**	**Gross Margin**	**Gross Profit**
Pre Pulmac	131,912	$320	$42,211,840
Pulmac + 2 Years	135,801	$364	$49,431,564
Difference / %	3,144 / + 2%	$75 / +23%	$7,219,724 / +17%

In this hypothetical situation in just two years a team of well-motivated papermachine operators increased the gross profitability of # 4 Papermachine by 17%, contributing over eleven million dollars to the mill's overall profitability. Given an initial capital expense of $200,000 to purchase the equipment, training, and program support from Pulmac and a further $100,000 per year in manpower costs to prepare and test samples, the mill would have achieved 100% return on investment after just the eighteen months. These results, while seemingly extraordinary, are not outside the possible with a highly motivated team. But even much more limited productivity gains will still achieve significant improvements to the bottom line of a pulp or paper mill. Given the scientific evidence supporting the utility of Pulmac Zero-Span technology combined with the documented experience in several mill settings, the pertinent question is no longer why should your mill acquire this capability, rather it is why your mill has not already done so.

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