Measurement and control of board quality

RUNE ANDERSON*

Paper and board products are manufactured in order to meet customer specifications and desires. These specifications and desires fall into categories of end use properties and convertibility properties. This calls for the measurement along the web as well as measurements across the web and the reel. Measurements also have to be performed in order to classify paper and board with respect to customs regulations (trade tariffs.) The set of parameters meeting the demands described, involve more basic ones such as basis weight and moisture as well as parameters describing strength properties, optical properties, printing properties, absorbent properties etc. Classical quality control has meant control of the finished paper as a delivery test and control by the buyer as an acceptance test. It has been based on sampling and measurement in the laboratory. A significant time delay from sampling to corrective actions in the process has been the characteristic feature. In order to speed up the feed-back of information to the production and to improve the quality of data, certain improvements have been made in the laboratory testing. The most prominent change has been the introduction of automated testing with computer support.

Control philosophy

It is advisable to formulate a basic strategy for the quality control.

1. Quality control has to be an integrated part of the production process from the wood department and onwards.

2. All possible efforts have to be aimed at minimizing variations within the processes.

3. As far as possible quality control should be carried out by on-line sensors and controllers with feed-back to the process.

4. Grade-change time and off production time have to be minimized. Production loss cost on a big modern board machine is substantial and amounts to thousands of dollars per hour.

5. Effective quality specification systems have to be worked out in co-operation with customers and sales department. Statistics and documentation needs, also, have to be foreseen.

In order to set a limit, I am going to concentrate on measures taken in the board mill and exclude the pulp mill.

From order to invoice

The purpose of this diagram is to show how the activities in market, production, control and economy departments are very closely linked together.

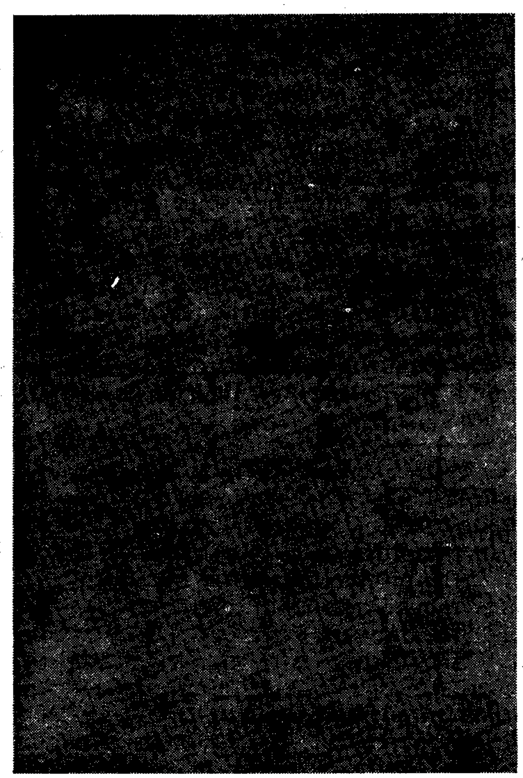

Fig. 1

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Before confirming an order the market people have to check a few things :

1. Quality specification approved ?
2. Delivery time approved ?
3. Roll width etc suitable to the machine ?

As soon as the order has been confirmed, it is registered in the computer's *order stock file*, which is available for *production planning*. The production planner puts the new order in a long term production program and later in a detailed *manufacturing programme* that is optimized wiih respect to machine trim etc.

At the time of manufacture the machine operators are well prepared and have received the necessary quality information about the new order. The computer has another file containing "*running recommendations*" as an aid to the operators to preset a number of more or less critical machine parameters. After grade change it takes some time, which has to be minimized, until the new grade is supposed to be OK. Then the operator takes a board sample from the machine reel for laboratory testing and eventual approval.

The laboratory is supplied with a special computerized system—the Autolab system—for fast testing and cmmunication with the operators and with the computer's *quality file*. In the packing station the customer reels are weighed and labelled with the necessary information. The labels, printed by a computer supported typewriter, are glued to the reels, and simultaneously the same information is collected in the computer *production file*. Then the reels usually go to the storage for some time. Shipping information about the delivered rolls are fed to the same production file and the computer then has all data for the invoice

By this system there is always a possibility to check :

*the order stock
*the production
*the storage
*the deliveries
*the quality

Purpose of quality control

The ultimate goal of quality control is to ensure *all* reels produced meet *all* quality demands and that changing from one grade to the next is carried out with a minimal production loss. In the term "quality control" I want to include *process control* carried out with measuring instruments, controllers and computers linked to the process, as well as *product control*, that might be on-line to the process. Normally the product control also is based on laboratory data and besides there is *always* a manual inspection of customer rolls.

Quality cards

It is extremely important that everybody in the manufacturing and quality control areas knows exactly the quality demands of a certain order, that is, that the *quality is specified* as far as possible. The normal way of specifying the quality is by means of *quality cards*, where a number of

FROVIFORS BRUK AB

Quality control

SPECIFICATION FOR CLAY COATED UNBLEACHED LIQUID PACKAGING BOARD FOR FLEXOPRINTING

255 g/m²			Nom	Min	Max
Basis Weight		g/m²	255	247	263
Caliper		μm	370	350	390
Density		kg/m³	690		
Bending Stiffness	√MDxCD	mN	230	200	
	MD/CD ratio		2,2		
	MD	mN	340	270	
	CD	mN	155	120	
Scott Bond		J/m²	150	130	225
Surface Smoothness					
- Bendtsen	TS	ml/min	600		[illegible]
	BS	ml/min	1600		2200
Brightness	TS	% ISO	78	76	78,5
Edge Wicking		g/mh	0,20		0,22
Tensile strength	MD	kN/m	22	16	
	CD	kN/m	12	9	
Elongation	MD	%	2,2	1,7	
	CD	%	6,0	4,5	
Moisture content		%	6,0	4,5	7,5

Test Climate: 23°C, 50 % RH

Comments:

- Nom. values are target values and correspond to long run mean values.
- Min/max property values are lower resp upper limit values for [illegible] interval of the tested properties.

Fig. 2

parameters, most often physical parameters, are defined with respect to target values and tolerance limits The example shown on the picture is applicable to milk carton board, and the specified quality figures are important for that particular grade. It is, however, important to keep in mind, that some fundamental basic properties are always specified for *all* board grades. The end use of the board then determines the final appearance of the quality card. Within a certain grade there might be customers, who have very particular demands in one way or another aud the card then has to be supplemented with or even exchanged by *customer cards* tailor made for those particular customers. As in all industrial activity, there is continuous development work going, which means that quality figures all the time are subject to adjustments and to changes.

"Running recommendations"

The next step is to translate the quality and customer card figures to appropriate values for the various process parameters. That is carried out in terms of so called (machine) *"running recommendations"*, which are based on existing correlations between machine parameter figures and quality data from previous productions. These recommendations have two main objects : firstly we think that they will help us to reduce grade change time. Secondly we believed that the recommendations make all shifts crews run the machine the same way. The term "recommendations" has been chosen, because inspite of all precautions taken there are still sources of variation in the manufacturing process, which we do not rule over, for instance seasonal variations, machine equipment condition including felt and wire condition.

As the number of parameters in the board mill is very large thetask of working out these recommendations is a very heavy one. Without the assistance of the process computer, that regularly collects process figures to a *machine guide*, it would be more or less impossible. It would take too long to deal with this subject in detail. Let us just face the fact, that the "running recommendations" cover everything from pulp mixture composition, chemical additions and refining in the stock preparation system to instructions for coating air cap drying.

To sum up : Board quality is defined by quality cards—standardised or customer oriented. The practical implication on the machine is carried out by means of running recommendations.

Process Control

Today about twenty different types of on-line sensors can measure paper or board quality variables. A few are widely used for process control, others only measure board paper properties for open-loop operator actions. Several factors determine whether a board quality sensor can be used for control. First a cause-and-effect relationship must exist between the board quality variable and the process variables regulated by final control elements. As a rule such relationships are very complicated since each board quality variable always involves several process variables. Secondly, control loop factors and process dead time affect the control potential. The primary driving force behind todays developments of on-line sensors has been the objective of closed-loop computer control for one or several important variables, such as moisture and basis weight. On line monitoring of variables for quality control so far has been less common. It is however gaining attention as distributed process, production control and data acquisition systems reduce the need for accurate record keeping of quality variables.

FACTORS INFLUENCING THE CONTROL POTENTIAL OF PAPER QUALITY SENSORS

Cause Effect Relationship

Correlstation (s) Between Paper Quality Variables (s) and Controlled Process Variable (s)

Loop Factors

* Availability of Control Elements
* Deadtime of Control Loop

Sensor Factors

* Accuracy
* Reliability
* Calibration Availability and Stability
* Response Time Constant (Time Resolution)
* Spatial Resolution

Fig. 3

PROCESS DEADTIME CONTRIBUTION TO THE CONTROL POTENTIAL OF PAPER QUALITY SENSORS

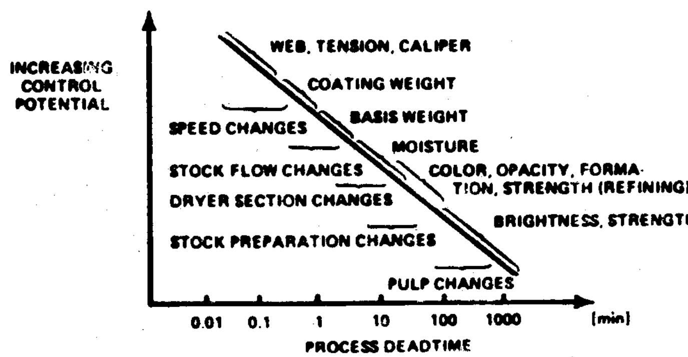

Fig 4

Basis weight

Basis weight measurement is almost exclusively based on the absorption of beta-radiation. The attenuation is nearly independent of furnish composition, for each percent of clay, for instance, a beta gauge has an error of only 0.01%. Isotope sources (Krypton 85, Steontium 90, Prometium 147) are used predominantly because they are highly stable, simple and rugged. Features to enhance accuracy and reliability are compensation for build-up of dirt and coating on the sensor heads, by standardisation at least three points in the measuring range and on gap temperature monitoring at several locations to correct the basis weight readings for air density changes.

Beta gauges normally are arranged for traversing across the board web and control the pulp flow value to compensate for variations in the machine direction (MD). There is still, however, a strong need for correcting the cross machine direction (CD) basis weight profile. Putting together beta-guage CD profiles versus time could result in a diagram as shown in the next figure. Normal procedure then is to try to correct for CD profile systematic deviations by manually adjusting the lip screws of the head-box. Making an optimal control on, say, 50 severally interacting slice screws is a formidable task even for an experienced operator. This task is, however, very suitable for a computer. There are today computer programs available for contributing to optimisation of lip screw settings giving a minimum of variation of the CD systematic CD profile.

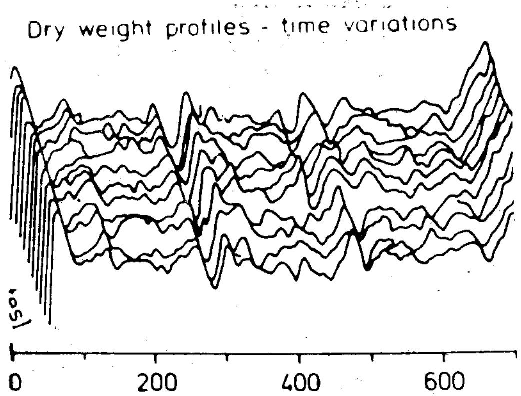

Fig. 5

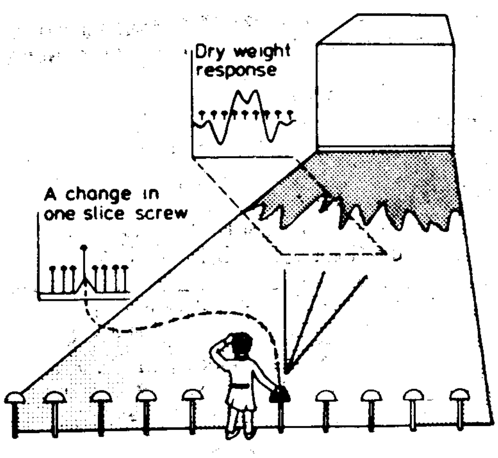

Fig. 6

Moisture content

Moisture content is probably the most important quality variable to be measured and controlled on line. Several measurement techniques span all application ranges from tissue to board : radio frequency, infrared radiation and microwave technologies.

Dielectric moisture gauges exploit the difference between the dielectric constants of water and fiber. Measurements are affected by grammage, density and composition of the board. The sensors require a good contact with the web and cannot be used at the wet end. The dielectric moisture gauges have certain disadvantages and are of minor importance today.

Infrared moisture sensors utilize the fact that water selectively absorb radiation energy in the near infrared. The infrared sensors are particularly suitable for measuring moisture at low basis weight and low moisture contents. To overcome the problem of excessive IR-absorption by heavy board, various sophisticated sensors have been developed. For instance by Accuray utilizing spherical reflecting cavities to amplify the light, or

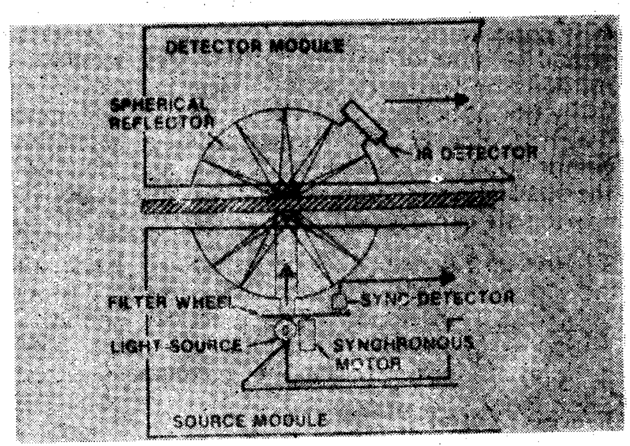

Fig. 7

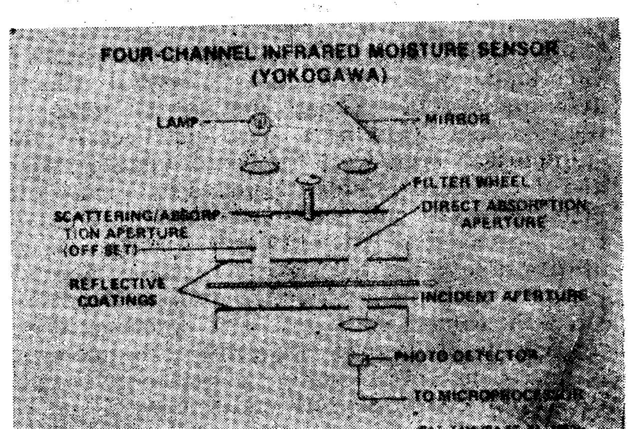

Fig. 8

by Measurex trapping the radiation between a pair of diffuse reflectors with the reflector offset from the source.

Microwave sensors utilize the fact that the specific absorption coefficient of water at microwave energies is smaller than in the IR-band. Thus the microwave energy can penetrate greater pathlengths of water for measurement of very high moisture contents. The microwaves therefore lend themselves very well for applications at the wet end of the machine for instance for measuring the moisture content of the board web after the press section or for moisture profile measurements of the press felts.

It is claimed that microwave sensors are not affected by additives, pH and freeness variations.

Caliper

Because of density variations of paper and board, caliper sensors with contacting or semicontacting measurement heads have to be used. Sensors using the magnetic reluctance principle measure the current passing through a reactor, with the total impedance directly related to the distance between the top and the bottom plate of the reactor. Semi-contacting sensors have been developed to avoid polishing or scratching action on coated board surfaces. The upper sensor head floats on an air cushion of approximately 0.25 mm thickness above the upper surface. Slight vacuum applied to the bottom reference plate establishes one-sided sheet contact. Such gauges, produced by Accuray and Lippke, eliminate the compressibility effect and claim fewer sheet breaks.

Sensors for basis weight, moisture content and sometimes also caliper are normally built together in compact units traversing the board web at critical positions, for instance before and after coating stations, before the Yankee cylinder and before the size press. Sensor signals are normally presented on colour videos as CD-profiles and trend diagrams for basis weight, moisture content and caliper. Furthermore the computerized measurement systems have programs for presenting quality statistics, production summaries etc.

Other quality variables

Other types of sensors utilizing X-ray absorption or back scattering technique or optical methods have been applied for the measurement on-line of such different quality variables as filler content, coating weight, smoothness, opacity, colour and brightness. There are also on-line sensors available on the market for the measurement of sheet porosity, web tension and reel hardness. Today considerable development work is going on for utilizing ultrasonic velocity measurements in paper or board for on-line sensing of mechanical strength variables (tensile strength).

The field of on-line measuring on the board machine is still at the beginning and much development has to be done with regard to reliability and repeatability of sensors. Besides there are still a great number of quality variables which can only be determined in a physical testing laboratory, for instance

— tearing strength
— compressibility
— degree of sizing
— printability variables

Product control

It is often advantageous to equip a big modern board machine with extensive on-line measuring sensors for quality variables for continuous control of processes and for information of the product. The reason for that is evident : The operators then have the manufacturing process in their hands and can carry out eventual adjustments without loss of time. Besides, the product information obtained this way gives a much safer base for quality judgement of customer's reels than can ever be had by laboratory examination of sheet samples taken at tambour shifts.

There are, however, a few disadvantages with on-line sensors mentioned above

— they have to be calibrated rather frequently; otherwise they may give false information
— they are sensitive to mechanical damage for in tance by the board web at break
— they cannot measure all desired board quality varibles Therefore it is necessary to have a well equipped testing laboratory in connection with the board machine. The laboratory ought to have facilities for :
  — "wet end testing", which normally means pulp testing, freeness and consistency testing etc
  — chemical tests, including coating colour examination, ash content testing etc
  — physical testing of board.

The levels of all physical property values of board depend on the moisture content of the board and thus of the air where conditioning and testing is made. To obtain reproducible testing values all testing has to be carried out in a specified atmosphere. According to ISO standard testing shall be made at 50% RH and 23°C.

Tensile Properties

Among several existing methods of measuring strength properties of paper and board the tensile tests have a central position.

In a tensile test a test piece of specified length and width is subjected to an increasing

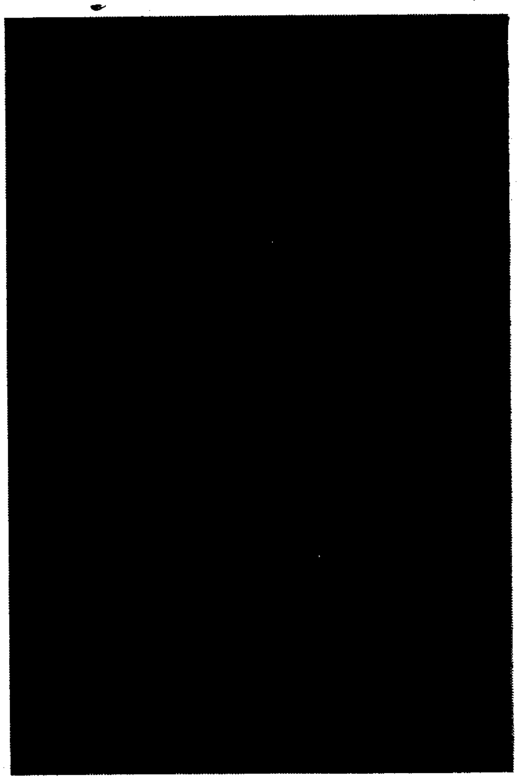

Fig. 9

pulling force parallel to the plane of the test piece until it breaks. From a tensile test we can for instance obtain values for tensile strength, stretch and tensile energy absorption (TEA). All these properties can be evaluated from a force-elongation curve (or stress-strain curve) obtained from a tensile instrument designed to record the tensile force continuously while straining a test piece at a constant rate of elongation until it breaks.

The diagram shows a stress-strains curve. By integrating the area under the curve we obtain the TEA-value of the tested strip.

The original Schopper tester is wellknown but can only evaluate tensile strength and elongation.

STRESS STRAIN CURVE

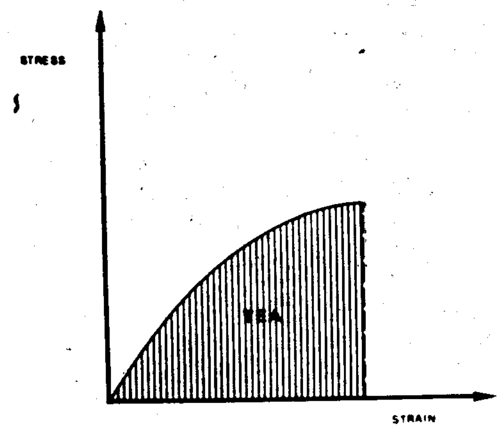

Fig. 10

Fig. 11

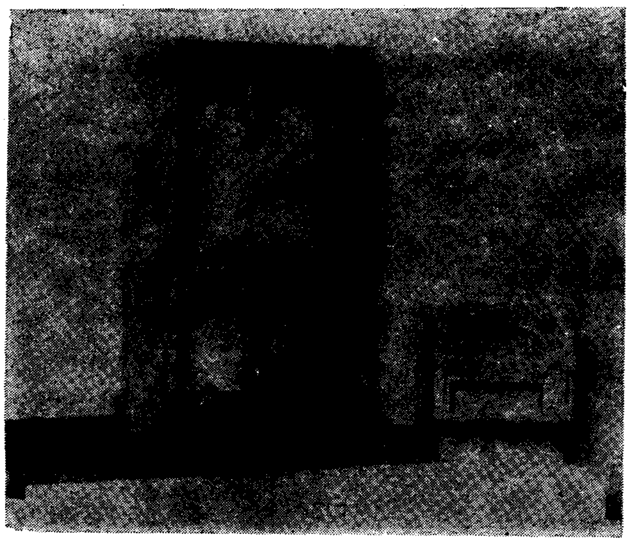

Fig. 12

Modern electronic testers equipped with micro processors can measure TEA and tensile stiffness as well and there are different computer programs available for hysteresis and cycling testing. Further more the instrument will automatically compensate for errors due to slack or forced clamping. The overall precision is excellent.

There are also flat horizontal bench models available with automatic clamping which of caurse are very handy to operate.

When testing board, the tensile value gives a good picture of the quality with respect to fiber furnish, refining and wet end conditions, etc.

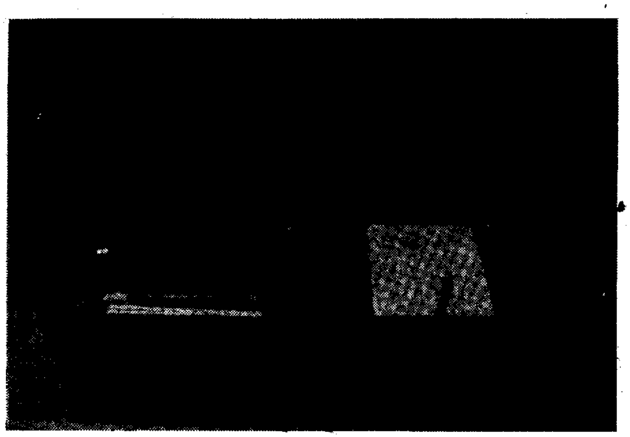

Fig. 13

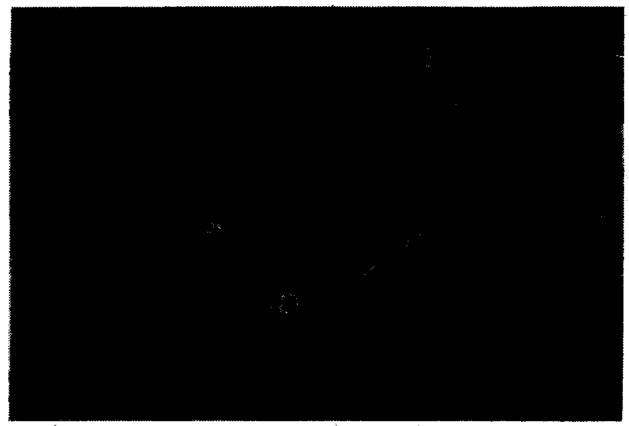

Fig. 14

Stiffness

There are several principles of testing bending stiffness. According to the method most

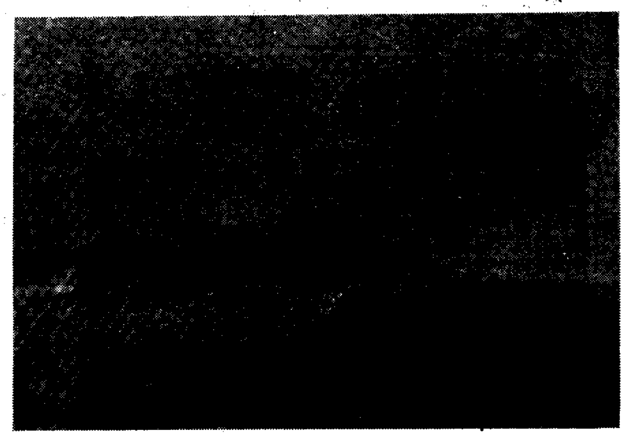

Fig. 15

common today we measure the *force*, which a clamped test piece of standardized length and width exerts to a force sensor, when the clamp is turned 15°. The board testing test piece length normally is 50 mm and width 38 mm. The figure shows the instrument with the clamp and the force sensor. The bending angle as well as the test piece size can be varied for other materials to be tested. Bending stiffness is a very important quality parameter for most board grades, for instance for folding carton board and for liquid packaging board. Stiffness figures correlate very well with the "in use" strength of filled board packages as has been found out by practical handling trials. Board converters normally specify bending stiffness values carefully and use this parameter very actively in their quality evaluation.

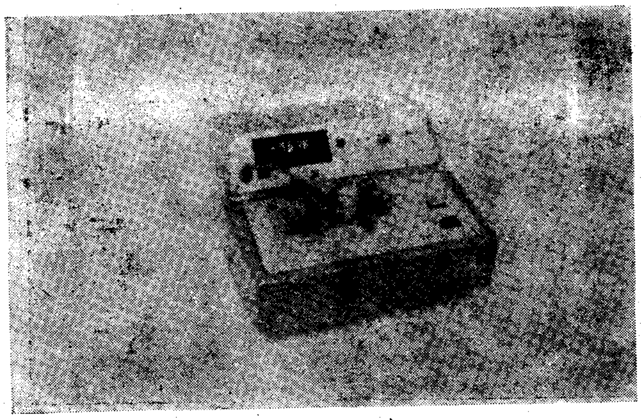

Fig. 16

Board stiffness le el is influenced by several quality and machine parameters for instance by basis weight, density, refining and pulp quality.

Tear

Tear according to Elmendorf is the force

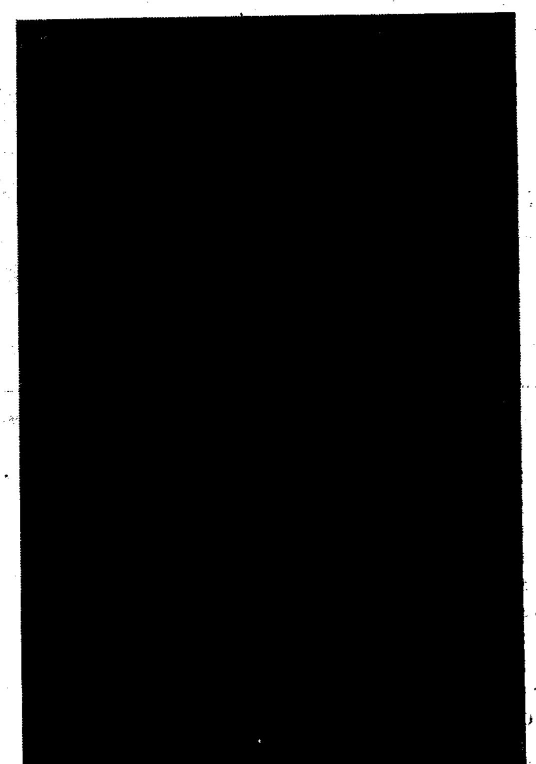

Fig. 17

required to continue the tearing of specified test pieces, which have an initial cut. The Elmendorf tearing test procedure involves the use of a pendulum-impulse apparatus according to the

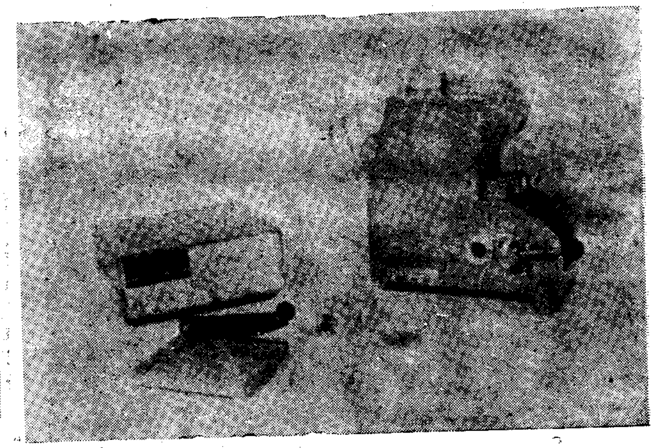

Fig. 18

figure. A set of test pieces is clamped in a vertical position between parallell jaws, one stationary and one moveable, fitted to a pendulum. An initial cut is made in the set of test pieces, which is then torn through a given distance when the pendulum is released and swing freely. The tearing work is equal to the decrease of the pendulum potential energy and can be estimated from a scale.

Tearing strength is an empirical property, which-like tensile-correlates with pulp quality, freeness and with some machine parameters. It has practical importance for board that are subjected to tearing strains during converting (for instance slitting operation) or in end use. "Carrier Board" for wrap around packages is an example of such board grades where a high tearing strength in both dry and wet condition is of importance.

Bursting strength

Bursting strength is a composite property effected by various fundamental characteristics of the sheet, principally tensile strength and elongation.

The most common instrument for measuring bursting strength is the Mullen apparatus, where a test piece is clamped between two concentric plates, each having a circular opening in the centre. Pressure is applied to the under side of the test piece by a rubbar diaphragm, which is expanded by hydraulic pressure. The bursting strength is the maximum pressure required to burst a test piece.

An instrument for testing the bursting strength of board is shown in the figure. This

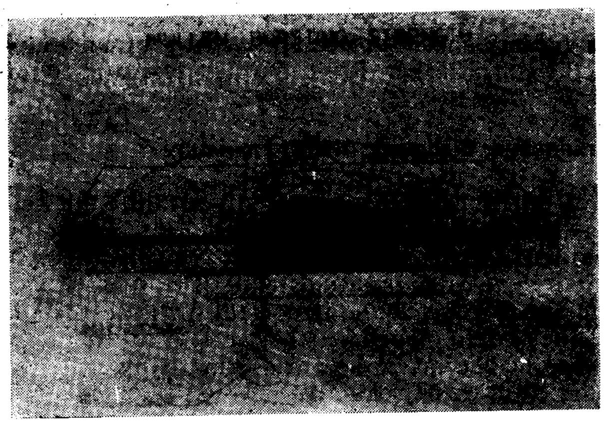

Fig. 19

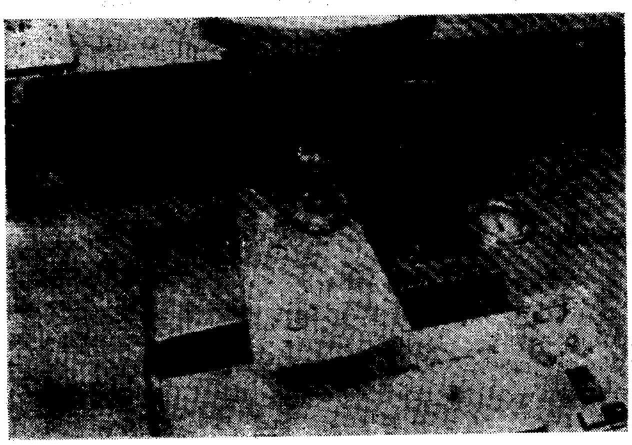

Fig. 20

instrument is heavier built than the paper burst tester, with larger diaphragm opening, larger clamping plates and higher pumping rate.

The main improvement since the original Mullen was invented is the replacement of the hydraulic pressure gauge by an electronic pressure transducer. It has been found in inter-laboratory tests that the hydraulic pressure gauge is an influential error source. These gauges require dynamic calibration which is not the case for the electronic ones as they are independent of the rate of pressure increase, Also the electropnematic clamping device is important in order to obtain high and repeatable clamping pressure, which is particularly necessary for heavy basis weights. The pressure is easy to adjust which is of value when testing light paper qualities. Also the influence to the readings from the diaphragm tension due to heavy variation between different diaphragms is important to take in account.

Traditionally the burst test has been of significant importance in paper and board industry. Also today the bursting strength is considered to be of great importance as a control test in board mills and is also used for combined container board both corrugated and solid fibre.

Ply bond (z strength)

For all board–and in particular multiply board–the z-strength or ply bond strength is very important. The basic principle of this test is to apply a force at right angle to the plane of a test piece. The z-strength is defined as the maximum force required to split the sample.

There are several methods to make this test in practice. One of them is the so called Scott Bond test. A test piece is fastened with two-sided tape between a L-shaped aluminium angle and a metal plate in the Scott Bond apparatus. A pendulum hits the angle and the piece splits. The loss of energy of the pendulum indicates the work required to split the test piece and is equal to the Scott Bond value.

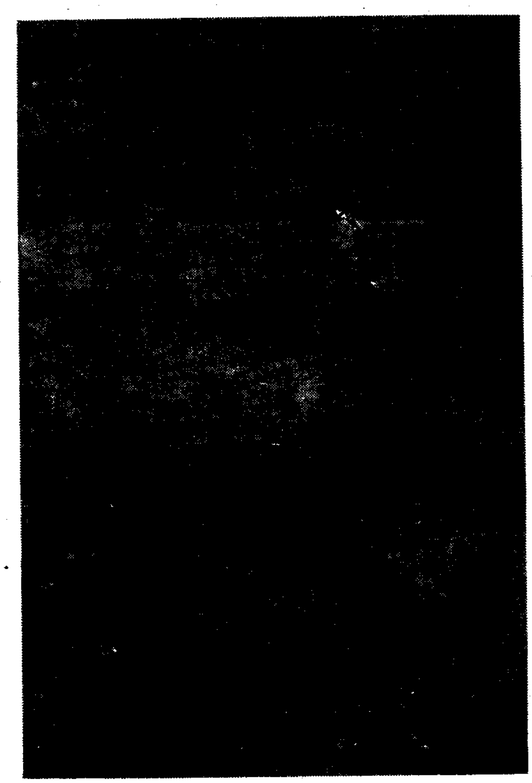

Fig. 21

The diagram shows a Scott Bond instrument.

For multiply board the z-strength is influenced by pulp quality (lignin and hemi cellulose content), refining, chemical additives (e.g. starch) and by wire section conditions (retention and wet web dryness).

Ply bond strength is of importance at converting, for instance at printing, PE-coating, scoring, and heat sealing operations.

Fig. 22

Smoothness-Bendtsen

The Bendtsen figure is the volume of air in cm^3 per minute of a specified over pressure leaking out between the board surface and a specified metal ring.

Fig. 23

The Bendtsen smoothness figure is an indication of the printability of the board (low Bendtson—better printability). For high class printing - rotogravure and to some extent litho printing—the Bendtsen test fails in accuracy and importance and has to be replaced by other testing methods. (Parker Print Surface test and Heliotest).

Grammage, thickness, density, moisture

These basic parameters do certainly not need any comment. I will just point out that laboratory testing instruments are getting more and more sophisticated and automated. The quality variables mentioned are so important for the running of the board machine that more or less every board maker has on-line measuring sensors incorporated in their machines.

In addition to above mentioned conventional procedures for determining the characteristics of board, there are a number of specialized procedures which have been adopted as standards or routine control. For further information the American TAPPI and ASTM standards and the Swedish SCAN Standards could be recommended. The British Technical Section also lists a large number of testing methods for board, which are proposed British Standards.

Autolab

During recent years antomated laboratory testing with computer support has been made commercial. The Swedish company Lorentzen & Wettre markets their Autolab system where laboratory testing instruments are equipped with electrical signal outputs which are made available

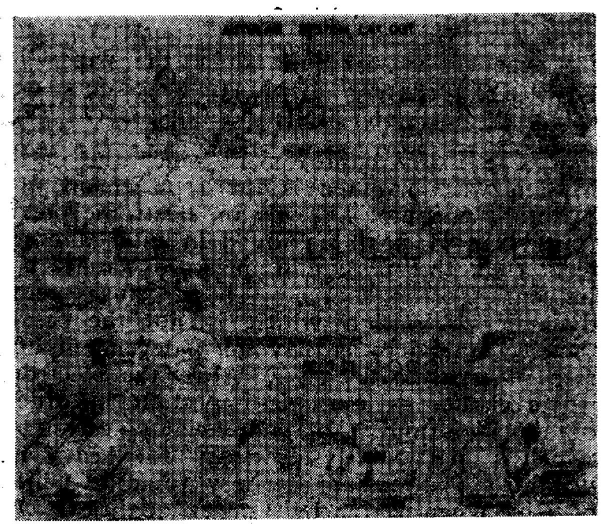

Fig. 24

for computer treatment. The system has made possible a considerable speed-up of the feed-back of information to the production. Further the accuracy of laboratory data has been improved and systems for test reports and statistics have been simplified.

Manual inspection

It is just as important that the board mill has appropriate routines for board web and customer reel inspection as fulfilment of quality variable specifications. When it is a matter of visual inspection, we have to put high demands on the whole machine staff including winding and packing m achine operators as well as shipping people. Errors may come up along all links of this chain, and it is extremely important that all employees are alert and report and correct everything that is not normal.

I shall give some examples of common defects that almost inevitably cause customer claims :

1. Impurities in the web

- Knots and rejects from the pulp mill (bad screen and centricleaner operation)
- "Slime deposits" caused by microbiological activity in the wet end system (poor cleaning)
- Pulp lumps (poor cleaning; defects in wire section)
- Condensate drop (defects in ventilation and air caps)
- Calender spots (moisture and formation problems)

2. Coating defects

- Blade and air knife streaks
- Impressions drom dirty rolls
- "Orange-peel" appearance (improper air-knife conditions)

There are today available, on the market, automated web inspection systems based on optical methods (still partly under development).

3. Reel quality

- Folds "screw", "ridges" often caused by CD variations of basis weight, caliper and moisture)
- Reel hardeness CD variations (basis weight, caliper and moisture CD variations; bad calender control)
- Cutting dust (bad winder knives)
- Rolls out of round (winder operation)
- Pore core quality
- Damages in wrapping
- Poor reel labelling

The list could be made larger. There is no harm in reminding that customers first contact with the board product will reveal if there is something wrong with the reel. It is not unfair to question that the first impression of the board reel could indicate the quality of the product itself.

Customer claims

Handling of customer claims properly is *important*. Market, quality control and production have all to feel their responsibility. There are some points in this respect which are worthwhile mentioning :

- claims have to be dealt with *immediately*
- analyse reasons-technical, personal and organizational-and correct as fast as possible
- make periodical surveys and look for trends; find out what is important
- try to realize that visual damages and defects normally are the big part of all claims
- find the people responsible, discuss and make corrections
- it is often a good idea to visit the customer
- there ought to be some limited number of claims. If not, the reason may be that the internal quality control is too severe. Try to correlate claim frequency with rejection frequency

Conclusion

With today's technology, with its big and expensive production units and specialized market demands quality control is getting more and more important.

What I have particularly tried to emphasize is the following :

—*The integration aspect*, that is to create systems that bring market, production and quality control departments together; to eliminate "department thinking" and create the feeling thas everybody works for the same goal.

—*The measurement and control philosophy*, that is, as far as possible, utilize on-line quality measuring sensors with fast information feed-back to the operators. Laboratory tests shall as far as is practically possible be used for level control and calibration

—*The rationalization aspect*, to use such equiupment for mannual quality control operations that these operations can be carried out in the fastest and most accurate way (example Autolab)

—*The staff's responsibility*, Behind the most sophisticated computer and instrument systems there is always the individual man. In the long run the success of a mill is dependent on the support of individuals.