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THE ROLE OF FUNDAMENTAL RESEARCH IN PAPER-MAKING QUALITY CONTROL

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Abstract

Quality control, statistical quality control, process control, total quality, are some of the phrases used to describe a function that varies considerably from one manufacturer to another and from one author to another. This paper attempts to review the changes in the concept of quality control that have resulted from the application of research programmes.

The historical scenario has three aspects. Just before the war an awareness was arising of the fact that paper was variable and that the variability had two components: along and across the machine. During the war paper had to conform to the same acceptance procedures as a raw material as did other military supplies. Thus the concept of statistical quality control was developed which, whilst recognising the need to relate property levels to the underlying variability, nevertheless used methods more adapted to discrete units of production rather than to a continous product.

It was not until after the war that major studies were undertaken, in the golden era of paper research, into the variability on the macro- and micro-scale of the paper product. This was the period of the awareness of the need for uniformity and freedom from mechanical defects, particularly in paper for high speed letterpress and gravure applications. The results of detailed study into the heterogeneity of the sheet prompted the development of instruments which would enable fundamental properties to be measured.

The result of two decades of fundamental work, not by the paper industry but by the process control industry, is the current situation of integrated measurement and control, which is described in some detail. Finally, the ability to know precisely

what is being made has resulted in the concept of total quality.

Such a survey would not be complete without some reference to the development of product quality standards and specialised tests which relate to end user requirements. These, however, whilst constituting a major factor in the industry's research programme, are, in the author's opinion, of less importance in comparison to the extraordinary developments in process control made by firms specialising in that function.

Acknowledgements are made to very many people throughout the industry who have helped in this survey.

Introduction

When I was asked to write a paper reviewing the role of fundamental research in the development of quality control I felt unable to see any connection. Dr. Corte convinced me that nevertheless I still should write the paper. I still fail to see any connection between fundamental research and quality control, but am prepared to accept that a review of the development of Q.C. is a relevant part of this Conference.

As part of my researches I sent a questionnaire to various friends in the industry. This questionnaire, and the names of those who kindly helped by replying, are attached. The replies are fascinating in that they span the whole range of the state of the art of Q.C., from the belief that current problems arise because production people are not quality orientated, to the fully integrated operation.

Perhaps the biggest difference in outlook is one I have remarked myself on translation from a U.K. to a European operation. This is the demarcation between production and quality control which gave rise, and still gives rise, to many difficulties in U.K. mills which do not exist on the Continent. The second major difference arising from the replies is that the attitude to Q.C. between those who have on-line gauging and those who do not is as different as chalk from cheese.

However, that is to prejudge the conclusions of my paper. It is after all a review paper, and therefore must begin at the beginning.

Basically, the impact and the role of Q.C. in our industry have passed through several phases.

The first was a purely mechanistic phase, during which paper was subjected to the same acceptance and variance control tests as any other material needed for the defence effort. This phase, apart from resulting in the sudden changing of the industry to a measured industry, also resulted in several people actually wondering about the variability of the product they were measuring.

The second phase I would call the great Q.C. era, when range and average charts were to be seen in every mill and when controversy raged over the meaning of 2σ and 3σ limits and over the degree of alteration to the process occasioned by an out-of-control result. This phase saw the introduction, at the same time as statistical methods, of the real mathematics of variability as a tool to study our operations.

The third phase is what I call the understanding of the process. This resulted from a lot of research and development into the way of measuring paper properties continuously. As gauges became more accurate and as computers were developed to handle the mass of data that came out, so more and more understanding of the process arose.

The final phase is where we are today, with full automatic control, and measurement techniques capable of analysing the variability of our product down to the last residual component, but with a continuing inability to control the inputs that determine the variability.

Finally, in the near future we will see integrated control ability, with links to other E.D.P. functions in the operating unit, and with total quality control achieved at the product manufacturing or paper machine operation, but still without the ability to prevent defects from reaching the customer: while in the less near future will come control of the manufacturing process itself.

In order to try to put some coherence into my presentation I intend to start with a straight historical review.

The Introduction of the Statistical Quality Control Concept

There are two basic bibliographies on the early days of statistics and statistical quality control. One I published myself in 1956[1] on the growth of statistics in the Paper Industry. The other, and by far the more important, was published by Dick Trelfa[2] in 1952. Both these bibliographies indicate the growing awareness that paper was not a homogeneous product.

The discovery had, of course, been made earlier, and one of the most interesting papers on the subject is that of Frank Hayward[3] on the weight variation on the paper machine. One can also cite Simmonds and Doughty[4], and in particular the First Report of the Paper Testing Committee, B.P.B.M.A.[5].

However, the idea of applying a science to the assessment of variability was not really introduced to our industry until the 1939/45 war, when in the U.S.A. the relatively new techniques of statistical acceptance were applied to the paper product. After all, it was only in 1939 that Shewart[6], the father of statistical quality control, had published his monograph on the "Statistical Method from the View-point of Quality Control".

Following the wider introduction of these ideas into the industry, it was in 1947 that Charles Bicking[7] published his fundamental thesis on Quality Control for the Pulp and Paper Industry. To be sure, Catlin[8] had published earlier, but the ideas did not take off until Bicking started writing, and following him Trelfa[9-11] who, while Technical Director of the Watervliet Paper Company, went a long way towards revolutionising paper peoples′ attitude to their product.

My own interest in the subject was awakened when, as a trainee in 1950, I spent some time in the paper testing laboratory and noticed that a reel of paper was defined by ten tests, whose mean only was quoted, and that a salesman could sell, and a customer accept, a large quantity of paper on the basis of one burst test.

Thanks to the support of Dr. Rance and Wiggins Teape, my own first thoughts on the subject were published in 1952[12].

I think it is very important to understand what I, and Trelfa, and Tout, and a few others, were saying at that time. The message was simple: paper is variable. Once this discovery was made, the amount of material that was written became almost infinite. Articles were published on the calculation of limits, on the corrections necessary, on the analysis of variance, on more statistical methods, and statistics, ad nauseum.

The then Technical Section of the B.P.B.M.A. formed a Statistics Committee, of which I had the honour to be the first chairman, and we put in hand the publication of test methods and the inclusion in all standards of a paragraph recognising that paper testing gave a population of results so that statistical methods had to be used to see if results really were different[13].

I think perhaps the philosophy we were trying to inculcate can best be summed up by a quote from Moon and Pearce[14] to the effect that "In general, paper-making is a process in which a reliable sample is obtained at regular but infrequent intervals".

It is interesting that at this time no thought was given by the exponents of statistical quality control, such as I, to the modification of the process. The process was as it was: it had its spread of possible results, and the aim was very much to prevent unnecessary changes being made to process variables.

I suppose the widest ranging paper on the quality control ethos was one I gave myself[15] to this body (Tech. Sec. B.P.B.M.A.) in 1956. At that time I put forward some fairly simple concepts on the use of Q.C. charts to control raw materials, process and product. Fig. 1 shows the introduction of the "Normal Distribution Concept", and Fig. 2 a "Simple Control Chart". Once again emphasis was placed on the fact that the limits were calculated to indicate the natural variability, or stability, of the process. However, the point was made throughout that the quality control supervisor was an adviser to

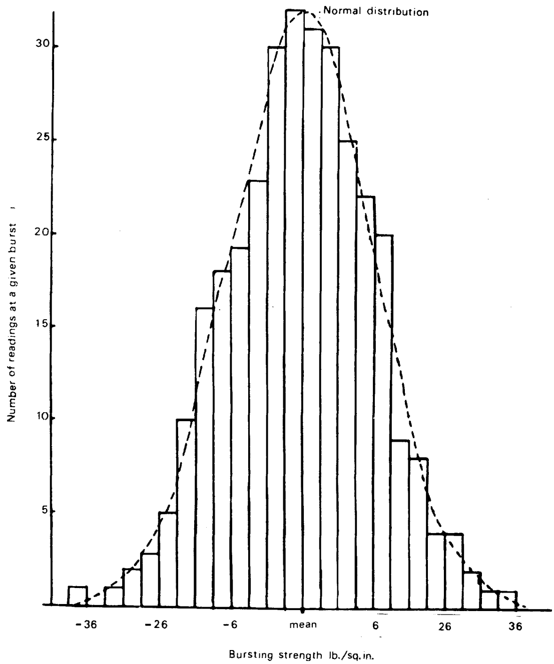

Fig 1—Results showing the 'normal' distribution.

the manager, and it was up to the manager to take action. I still think it is important that one accepts this, and also that (and I quote) "S.Q.C. charts are based on past performance and the production staff must therefore accept the limits because, by their previous production, they have set them". Another author, Gwaltney[16] put it succinctly: "Quality Control can in many ways help the production man. There are also many things Q.C. cannot do. It cannot control quality ...."

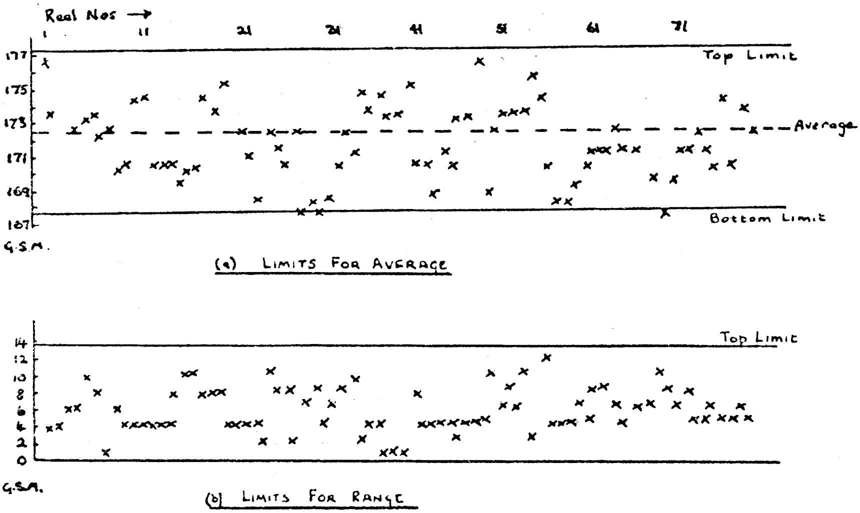

Fig 2—Rudimentary control charts.

The controversy about the value of quality control and about its place in the organisation continued for a long time. I remember an argument with Geoff Nuttall[17] on the correction necessary when a value went outside the limits.

I also like to think that an anonymous author in the Paper Maker[18] in 1960 expressed some of the true feelings of those of us working in the field, in saying "The real solution to problems of process control is the installation of modern equipment"; "The gross un-reliability of many of the test methods and the growth of statistics has brought home just how fundamentally bad many test instruments and methods are. When to this is added the high natural variability of paper ..... it is necessary to make the best of a bad job"; "Paper is more variable than it need be"; "End of reel testing is mainly valuable because of its psychological effect". In many ways this was the beginning of the end of the golden era of statistical quality control. The remark about its psychological value is very apt; however, it is interesting that even today, in my own mill, Q.C. is happy to test every reel when we make 25,000 metre reels, but unhappy at testing every second reel when we make 12,500 metre reels.

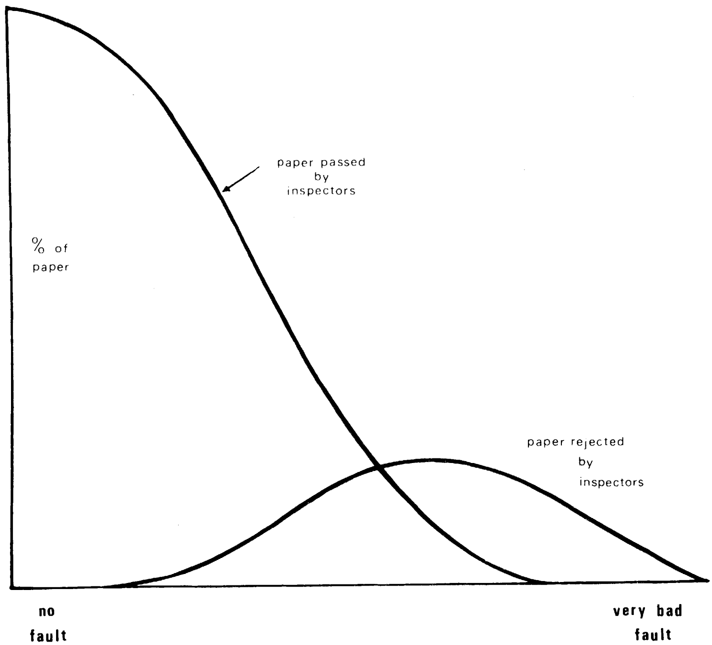

Fig 3—Results of an investigation into sorting.

Acceptance Testing

All the above deals with the application of Shewart statistical control techniques to the study of variability of paper as it is made, and the introduction of some science into the actions taken to reduce the variability of the product.

At the same time, however, it is worth recording a parallel or perhaps subsequent introduction of ideas that probably had as significant an effect. This is the idea of outgoing quality limits. Very little has been published on the subject; indeed, the only papers I know are my own[19], and certain references made by Donald Macaulay[20] whose campaign to introduce scientific Q.C. methods into the printing industry deserves wide recognition.

In the 1950s all the mills making fine paper sorted all their paper for defects. The question we asked ourselves was why this should be necessary when reeled paper was not sorted, and why the reject rate was always 15%. A full investigation was carried out in two mills, and the results were startling; some 50% of the reject was no worse than the good paper sent out, and some 30% of the good paper was as bad as that rejected. Fig. 3 shows what we found at the time. The introduction of an A.O.Q.L. scheme resulted in a substantial improvement in the outgoing quality, together with a reduction in rejects from 15% to 12%. It is rather interesting that A.O.Q.L. schemes (Charles Butcher at Reeds was another great exponent) were perhaps the only true sensible application of statistical quality control to our industry.

THE STUDY OF VARIABILITY

Simultaneously with the stochastic scientists pushing Shewart charts, others, more influenced by continuous process mathematics, were trying to find out what were the true variations occurring.

The first person who really set out the dimensions of the problem was perhaps Stanley Sergeant[21]. I may be mistaken, but this was the first recorded analysis I can find of the machine and cross direction variables on a paper machine that not only recognised stable, unstable and cyclic variations, but tracked down the causes and did something about it. I reproduce his presentation of variability in Fig. 4.

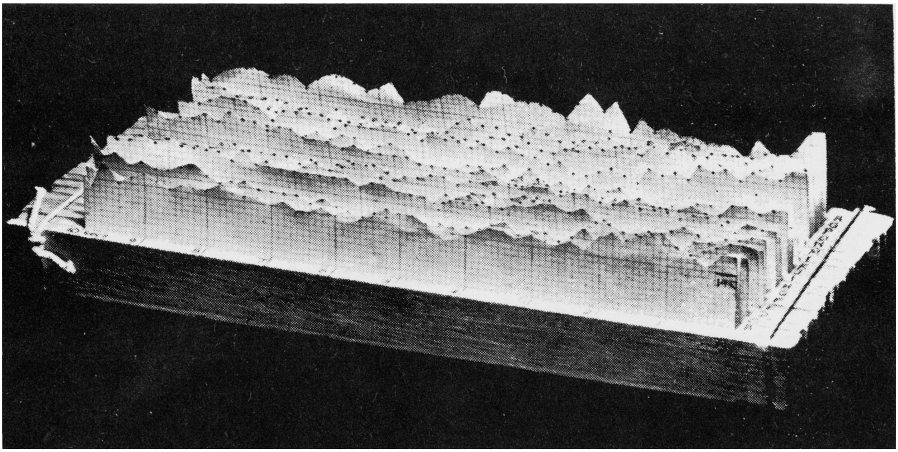

Fig 4—A contour map of the weight variation in paper.

The next, the most famous, and the definitive paper on the subject is Burkhard and Wrist[22]. For the first time the three components of variance, MD, CD, and residual, are recognised and computed, and are reprinted here as Fig. 5.

From then on the studies continued apace, depending perhaps more on the ability to measure than on the analysis, in general with the aim of analysing headbox performance.

I think it is worth suggesting that we had a great tendency to leap before we looked. In 1956 I[23] was saying that my company was using, or evaluating, beta ray gauges, beta ray profile, continuous thickness recorder, opacity recorder, dirt counter, pH controller, consistency regulator, moisture meter, and continuous formation meter. Fig. 6 is reproduced from my paper showing those at the time. Unfortunately our knowledge of the process of paper making was so defective that none of those instruments, ingenious though they may have been, was of any real benefit to the paper making.

Early nuclear grammage gauges were a vast improvement on sampling, as is shown by Rose[24] for the textile industry in 1964, and by Cameron[25] for general use in 1957.

By 1965 nearly all companies making paper with any pretension to 'research' were using on-line gauges. Unfortunately very few of those gauges gave any true idea of the property they were supposed to be measuring, and in only very few cases was the operator able to use them to control the property.

However, slowly, equipment was developed and an understanding arose of why things happened on paper machines. This was the famous era of 'computer control', when unfortunately measuring devices were so crude that the control consisted of a cascade of compensating loops.

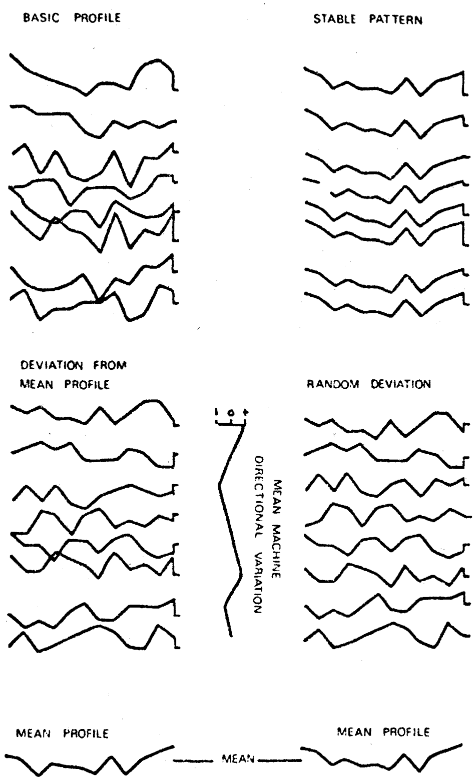

Fig 5—First presentation of components of basis weight interaction.

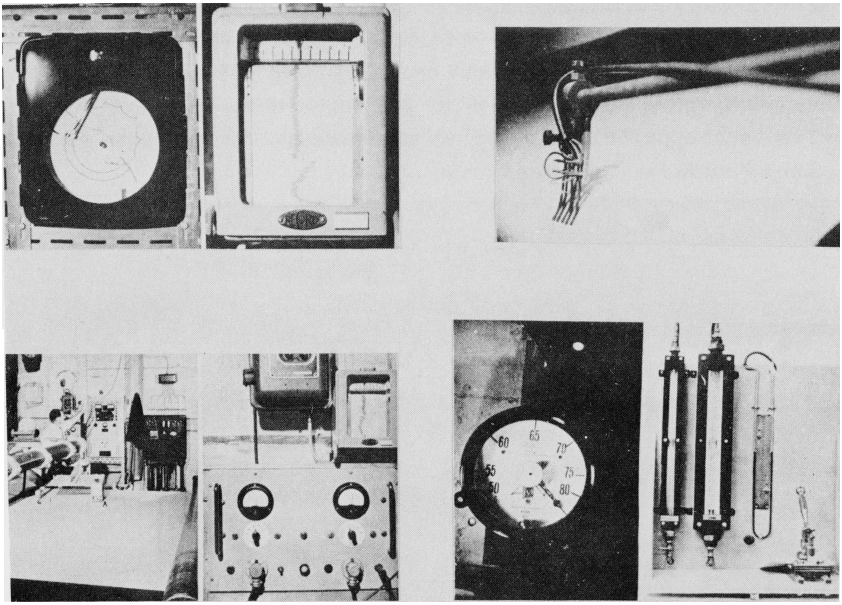

Fig 6—Early instrumentation for continous measurement.

The breakthrough started to come with the development of specialist companies whose research on sensor technology allowed them to present meaningful results that could be used. At the same time research into headbox operation and flow systems allowed at last a control function to be set up. It would be impossible to name all names, but to my mind the state of paper machine control today depends on work done by such companies as

H.M.B., Lippke, Electronics Associates of Canada, AccuRay, Measurex, Voith, Beloit, K.M.W., and many others. I have tried to pick out some highlights in the literature. I can only apologise for my omissions by saying that I am a Mill Manager, not a research man, and I am more concerned with the paper I make than with searching the literature.

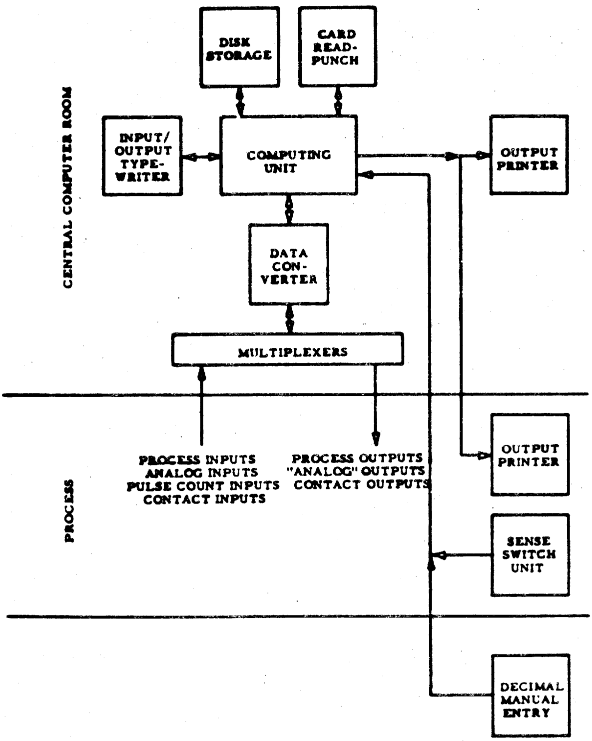

Fig 7—A process control by computer organisation.

To my mind there were two parallel approaches. One was by paper companies who bought gauges and separate computing facilities, and the other by companies such as AccuRay who combined the gauging and computing in their product.

A good example of the first approach is given in the paper by Aronsen[26] in 1966 on the problems of measuring on a multi-station coater. This study used Tracerlab Beta gauges, G.E. moisture gauges and computers, and Crown Zellerbach's own software. A second was presented to the very advanced Billerud Symposium on Integrated Computer Control in Säffle in 1966. This used an IBM 1710 SPS 11 system working on controller set points, motors and valve drives. Very little gauging equipment was used, but some 45 analogue inputs were treated. I reproduce in Figs. 7 and 8 two schematic diagrams from this excellent paper.

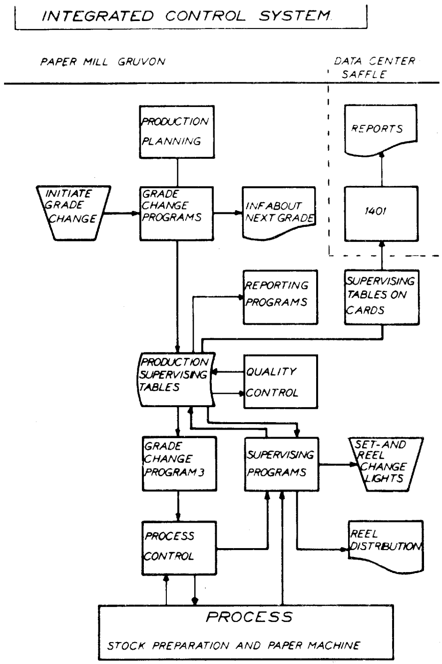

Fig 8—Details of a computer control system.

Round about the same time the development of X - Y plotters and the ability to produce continuous cross profiles allowed the process to be studied in more detail. The PIRA Bibliography No. 627[28] lists some very interesting papers and one can see the emergence of a diagnostic method. The idea of machine, cross, and residual variations, first put forward by Burkhard and Wrist[22] was developed by Schöning and Torgensen[29], and in 1967 a survey of the situation on basis weight and moisture measurement was put out by Krumberg[30].

By 1972 the selection of computer systems was becoming a talking point, and a book was published which showed that gauging and analysis were here to stay[31].

However, even in 1974 a survey by Eric Hazlewood[32], published by Vance Publishing, indicated that on-machine control was still in the early stages of universal acceptance.

I will return to the area of on-machine control later, but meanwhile it is worth examining the role of the tester in all this.

THE TESTER

The variability of paper and the unreliability of test instruments have been recognised for a long time. Simmonds and Doughty[33] published in 1933 an awareness of the need for statistical methods. In 1931, Underhay[34] undertook a great investigation into the standardisation of the burst test.

However, the great innovators of statistical quality control tended completely to ignore the role of the tester in the 'variability' of the product. This is probably because Charles Bicking came from an industry where testing was precise, and others, like Trelfa, myself, Mardon[35] were so excited by the discovery of machine variability that we ignored the role of the tester, or else concentrated on time-study to increase their output. I suppose the nearest any of us came to realising there was a problem were Catlin[36] in 1949, and Strieby[37] also in 1949, although he was looking at chemists: I quote from my favourite anonymous article in 1960[38] " Statistics have brought home just how bad many test instruments and methods are", which was pretty scathing.

One of the early bodies to recognise the problem was the Testing Committee of the (then) Technical Section of the B.P.B.M.A. Work by PIRA[39] in particular, and by the B.P.B.M.A. Paper Testing Committee, showed that the variations between instruments were enormous, and those between testers were large. After many years of effort, the B.P.B.M.A. Standard for the Bursting Strength of Paper appeared in 1958 and stated "The average co-efficient of variation of a single result on any one tester of either type lies between 4% and 10% depending on the paper being tested". This was a major step forward at a time when paper buyers still bought on the basis of one Mullen test

The idea of standardising test instruments came out of this Committee in the early 1950s. PIRA started a members' burst test cross check using foil in 1955 and paper in 1964: and this was extended to all CEPAC members in 1976.

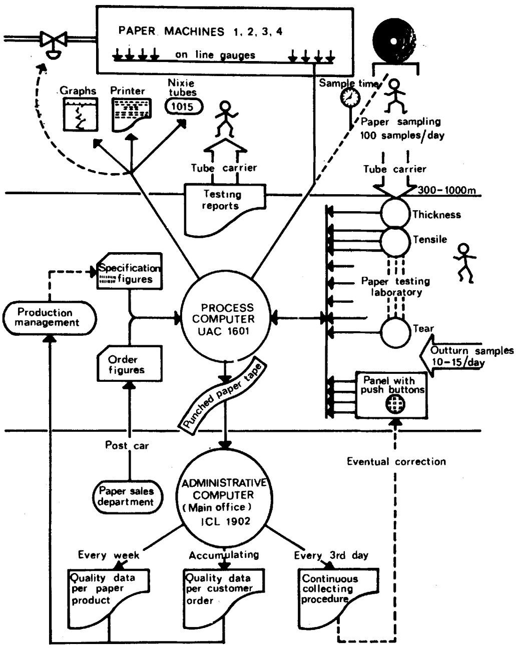

Fig 9—Computerised quality control.

However, it is worth commenting that even today many laboratories ignore the operator variability in many of the standard tests. This can be compensated for by an elaborate system of cross checking, or by the introduction of the automated laboratory. It is not my job to comment on this development, but for ideas I would strongly recommend the reading of such texts as those of Anderson and Schröder(40), Baumgarten and Göttsching(41), and Gerdin(42). Again, an advanced picture is given in Fig. 9, reproduced from Anderson and Schröder's paper.

The fully automated testing lab is slow in coming, but the software exists and write-in facilities are available on most main-stream computer control systems.

It is quite interesting that the impact of research on paper testing is practically zero. So far I have found that a lot of effort was devoted in the 1950s and 1960s to devising on-machine instruments for all sorts of properties, opacity, porosity, etc., without any attempt to develop off-line instruments that gave meaningful results. Indeed only four examples of specially developed instruments have come to my knowledge, and two of these stem from the fertile mind of John Parker[43,44], one of whose results is reproduced in Fig. 10. The others are very specialised: a new method for water and oil holding capacity of absorbent sheets, was developed by Dr Van den Akker[45] from a fundamental study of capillary theory in bibulous materials, and a way of testing filter papers was developed by Dr. Corte[46] from a study of pore size distribution in papers.

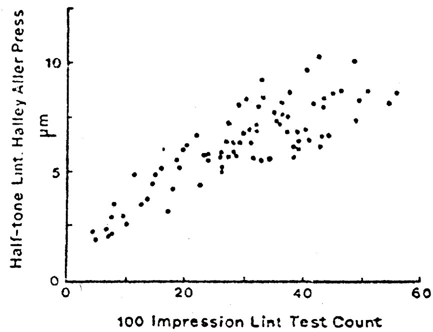

Fig 10—Lint count *versus* print quality.

However, to say this is perhaps to ignore the immense amount of work done on the fundamentals of paper as a medium for print and the utilisation of printing machines and print machine simulators to test the product. A good example of this is given by Abbott and Hendry[47] who developed the printing machine as a test instrument and correlated the results with Q.C. instruments. Such a correlation is shown overleaf in Fig. 11.

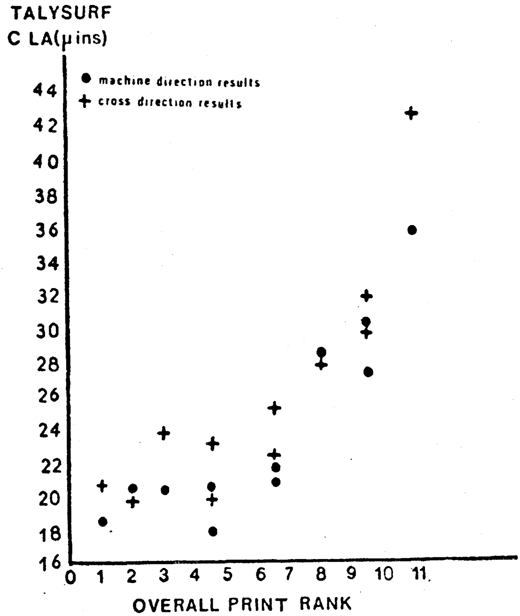

Fig 11—Talysurf profile *versus* print quality.

The philosophy of quality control

The major changes that have happened in this area, are, to my mind, firstly the impact of all the work done by companies outside our industry to introduce reliable measuring equipment for on-machine application, and secondly the realisation that quality control is the responsibility of management and not a function of the mill laboratory.

These have been paralleled by two developments:

1. The original idea of statistical quality control was based on analysing the past behaviour of the process and setting limits such that no changes were made unless results went outside those limits, thereby indicating an `out of control´ situation. The modern idea of on-machine gauging and control seeks to reduce the variances inherent in the system by positive action on machine variables.

2. The concept of total product quality, embracing all aspects of the product quality management programme. I epitomise this by saying that not only the conformity of the product to its specifications, but also its packaging and its shelf-life are part of the quality programme.

It would be invidious to try to select references to the changes in the philosophy of quality control without also saying that I have omitted many more than I have chosen.

It is important to refer back to the early work of Bicking, Catlin, Trelfa and myself. I quote from Bicking[48] "The aims .... are to lead to the production of a high level of quality but not too high for economical production, to produce a uniform quality - but not one more uniform than required by end use, to make control of the machines of production easier and more positive, to reduce losses due to scrap ... and other forms of wastage ... and to allay once and for all the disputes and discontents arising from inadequate or imprecise testing", and from myself[44] "Any quality control department ... should be solely responsible to the manager ...the paper-maker should have no say whatsoever whether the paper is good or bad according to the Q.C. scheme ...", and further "the selling limits must never be put on to the S.Q.C. charts; if they are, bad workmanship is sure to result ...S.Q.C. charts are based on the performance of the mill previously and the production staff <u>must</u> therefore accept the limits because by their previous performance they have set them" and again, "The responsibility of the Q.C. supervisor must end when he has given his data to the manager"

All in all we were saying "We will tell you your process capability. All you can do is to work within it. We can never tell you how to do better, only tell you when you are not doing worse".

The change in ideas came when the vogue of `Statistical Quality Control´ was wearing out and the idea of full quality control was coming in. At the same time the sheer enormity of trying to typify a continually varying process by sampling at each hourly interval was becoming apparent.

The philosophy that began to emerge can be surmised from the following quotation from Allen(50) "The final inspection takes place in the customer's plant. The optimum number of Q.C. checks should be carried out at the machine, not in the laboratory".

We are no longer talking about S.Q.C. as understood by Juran(51) "The detection and early correction of unwanted change", but more about that of Lokki(54) "Correct quality is defined by the buyer and the amount he is prepared to pay".

During this evolution the idea of deep process analysis began to emerge, and I can recommend a study of the "Span Plan"(53) on the capability analysis of an industrial process. This was effectively a diagrammatic way of carrying out analysis of variance as shown in Fig. 12, reproduced from the text.

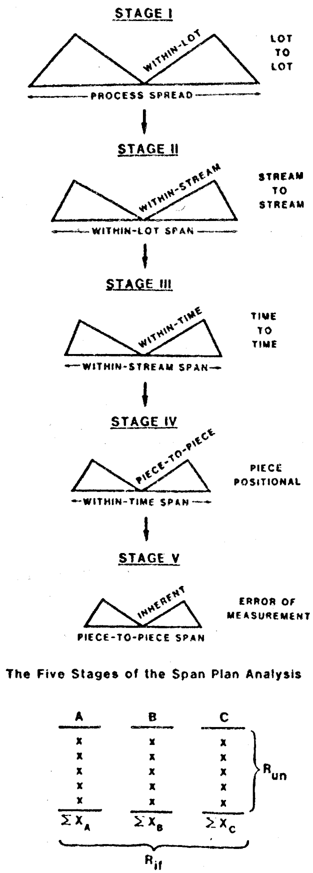

Fig 12—The span plan for capability analysis.

However, I think one must seize on two or three authors who typify the modern philosophy of quality control.

First, from Peter Daisley, famous for his development of the `seventh can´ idea, I quote "Don´t waste effort in trying to modify an existing product when a new concept is needed".

Peter Daisley has written many profound papers in his life, but one in particular contains much of his (and my) view on the reality of Q.C. today. This is a paper given to the San Salvador Institute of Overseas Trade[(54)], where he writes "In Europe we use the expression Quality Control specifically for the statistical sampling and control chart techniques used in production. When we talk about `Quality Development´ (sic) we consider not only the techniques but all the elements of quality including Techniques, Economics, Philosophy, Psychology and Administration - in fact the total system by which quality is achieved."

In a 1930´s environment the only way of achieving a norm was substantially to overshoot at a cost of say 1000 units. By 1940 Acceptance Sampling was accepted and the costs reduced to 200 units. However, these techniques were purely defensive, protecting business from the consequences of its inadequacies. By the 1950s emphasis was being given to the causes, and by the 1960s the emphasis had changed again to control the causes of quality before production.

In the same paper Peter Daisley writes further "Quality has ceased to be an optional extra, but is now recognised as an integral part of the business in which everyone has to play a part". The end result is that purchasers, be they of Peter Daisley´s `Chickenburgers´ or of Xerox paper, place contracts only with those manufacturers who have a comprehensive approved <u>quality system</u>.

Peter Daisley concludes "If a company does not have a satisfactory statement, documentation, or Quality Manual for its quality system, it is considered immature in quality and unsatisfactory for business contracts".

The second landmark in the concept of total quality is Lester Edenborough[55]. I quote from his introductory precis "Going beyond quality control, quality management integrates functions of top management and machine tender alike to break through departmental barriers". He cites the defensive attitude, whose function is only to catch bad paper, and the `offensive´ or positive approach to quality control which means putting much more effort into making things right first time.

At the same time as this concept emerges, so does that of the `quality audit´, and while many papers have been written on the subject, a very good overall view is given by Wachniak[56].

Simultaneously with the ideas of quality management, total quality, and quality audit, has emerged the concept of quality cost systems. A good summary of this is given by Oyrzanowski[57] but the companies far ahead in this field are I.T.T. and I.B.M. One ought, however, to stay a little bit closer to home, and I can do no better than to cite the 115th Technical Division Conference. Two excellent papers sum up current thinking on the integration of quality into management, those by White[58], who explains from the viewpoint of high speciality paper-making, and Hyam[59], who begins by saying that "The quality of board is often spoken of but never defined". These two authors sum up the inter-relationships necessary in achieving total quality. Williams[60] shows how the test and technological aspects are interdependent.

Again there are many, many more references, but the message is very clear: Statistical quality control, as we introduced it thirty years ago, is today only a very small part of the quality concept.

The scene today

In order to try to get an idea of the current state of thinking in quality I sent out a questionnaire, a copy of which is attached to this text. This was sent to some fifty people in our industry, of whom about thirty were kind enough to answer, whilst others helped in discussion.

The replies were remarkably diverse. Many of them are very detailed and extend to several pages of most valuable information.

What comes out every time, however, is that the biggest change in quality control activities quoted by all the respondents is the introduction of computer-based machine control systems. There is also throughout the replies a widespread recognition that there is no longer any such thing as a separate quality control function. Whether people speak of integrated quality performance, or total quality control, they all see no dissociation of quality management from production or sales management.

In looking at the replies I would prefer to start with one that is, in many ways, the most important, as it comes from a customer who is also a manufacturer. I hope Mr. Hopkins, of Rank Xerox, will not object to my starting by quoting from him, as many of his statements summarise those of the other respondents.

1. "Wherever data generated as part of an automatic process control system can be used to demonstrate product compliance, R.X. encourage this."

2. In answer to question (6), which asked about major changes in Q.C. in the last thirty years in the paper industry, Mr. Hopkins states there is "An increasing recognition of the need for quality management to be incorporated within the total business, and to replace dependance on `quality filters´ after production ...". He also noted the "Increasing numeracy within mills ....", and "A marked improvement in recognition of total quality as delivered to the customer. Q.C. used to stop at machine reels, now control techniques at the finishing and packaging stages are applied in many mills (covering qualitative attributes as well as manual or mechanical sorting)." But he notes that, while "...The recognition of a systems approach.....is emerging, the paper industry is relatively backward - too much is still expended on cure rather than on prevention."

I shall return to Mr. Hopkins later, but first will try to survey the answers to my questionnaire.

As stated earlier, a copy of the questionnaire I sent out is appended. Whilst a total analysis of the answers is beyond my ability, the main conclusion can be drawn as follows:

<u>Quality Control as discussed by myself and others thirty years ago no longer exists.</u>

What do I mean by this?

All respondents listed areas where tests are carried out, either manually or automatically. The measurements are not analysed statistically but are logged and sent to (if not taken by) the operators. In many cases they form part of an automatic control process. However, and here all correspondents were agreed, measures of stock consistency, ash, pH, valve movements, ^{o}S.R., rosin and alum solids, flow clay solids, colour addition, etc., where necessary, were taken either automatically or manually, and were <u>part of the operation of the process</u>. In general such measures were used to provide information for carrying out a control function or for providing a check on an automatic control process.

Visual presentation methods are rarely used in the old-fashioned sense of statistical Q.C. charts. What are widely used are instrument charts, video and print out. Only one or two of the respondents knew what was meant by A.O.Q.L. charts.

Limits are very rarely statistically calculated but more often are imposed by the customer or are the natural results of fine tuning of the system.

All respondents have computer-based control systems. In some cases these have replaced quality control procedures, but mostly the two have become complementary. In no case is there less Q.C. testing now than there was in the past.

Two items stand out in the views of the respondents.

First there is the very widespread use of computers for on-machine measurement and control.

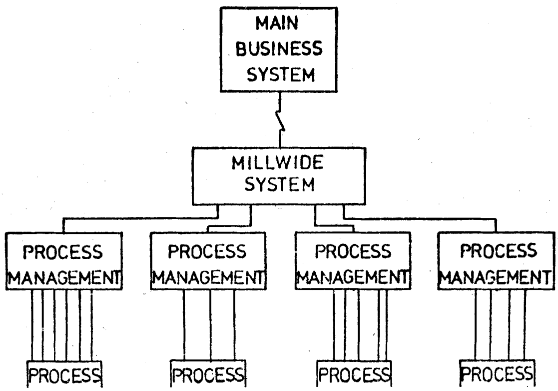

Fig 13—The overall control organisation.

Figs. 13 and 14 indicate these companies' approach.

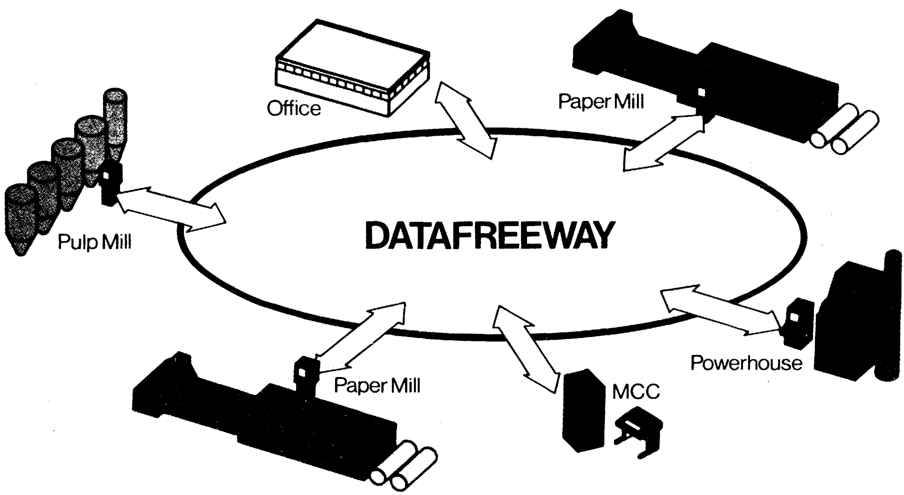

Fig 14—The link between process and administration.

Secondly there is the universality of the total quality control concept.

To illustrate this, I quote from Mr. Soemers of K.N.P., Maastricht "The last few years we emphasise the fact that quality is everybody's concern, starting with quality of market research, and ending with quality of field service. All the disciplines between both these concepts are involved in quality". And again Mr. Hopkins of Rank Xerox says "We believe that all mills must eventually control quality by establishing systems that feed information forwards to guarantee quality rather than backwards to correct unsatisfactory production".

Quality control as I see it in 1981

Let us come back to definitions.

I can do no better than repeat earlier quotations by Lokki, namely "Correct quality as defined by the buyer and the amount he is prepared to pay should be given, as far as possible, by the process of manufacture", and Daisley[(54)] "Before a contract was placed we needed a statement of company policy and procedures, explaining how quality is ensured". (This is the Quality Manual). "In the quality manual we look for clear statements of process and product standards and explicit statements on manufacturing and procedures. If a company does not have a satisfactory statement, documentation, or quality manual for its quality system it is considered immature in quality and unsatisfactory for such business contracts". Hopkins[(61)], Rank Xerox, perhaps puts together the real modern approach to a Q.C. philosophy by saying "This approach emphasises the need for specifications to establish set points on computer controlled machines with functional testing audit in the system, and a further audit being carried out on the total support systems for the central production facility".

There are also the information flows, training procedures, managerial policies, bought-in materials control, etc., all of which are necessary to maintain a `quality-tight´ system.

The two major gauging and computer control companies both now offer integrated computer monitoring and control linking the process with the accounts, with specifications, with costs, with test results, etc. There are very few machines in the world, regrettably most of them in the U.K., without computer based control systems. Quality management, or total quality control, is a requirement imposed both by customers and by competition. Papers by the two leading process control companies emphasise this[62,63].

The only thing to say is that Statistical Quality Control is dead. It is dead because it has been replaced by a degree of sophistication unthought of by those who first set about introducing a scientific concept to the vagaries of the paper-making process.

It is my belief that this review has shown how the enquiring mind has, with only small tools to begin with, sought out and elaborated the fundamental concepts of our industry. The idea that paper was variable in its properties was not easy to instil. The definition of its variabilities was part of the development of statistical quality control techniques.

We must, however, be honest. Either paper was much less variable than it is today, or we were extraordinarily lucky in the results we achieved. I would like to repeat an earlier quote, "End of reel testing has a purely psychological impact". It is fascinating to look back at the time that was spent in establishing statistical control limits[64] that were based on totally inadequate concepts and sampling and on debating the effect of reacting to out of limit properties[65]. It is doubtful if the actions and their results were then even one per cent understood.

Nevertheless, it worked. Today´s situation is the logical result of all that went before. There remain isolated mills where the debate on "to whom the Q.C. section should report" goes on, where testing and the chemist are still mistrusted. Sadly again, most of these are in the United Kingdom. But in general the aims and ideas of the early pioneers have been achieved.

Feed forward control is a fact that will be discussed elsewhere in this meeting. Limits are no longer statistically calculated but are the results of the engineering of the production unit. `Out of control´ means what it says, usually due to a process failure. Some variability is accepted, though it is but one-tenth of what it was when we started. Quality control no longer means tests and limits, but means packaging, service, presentation, customer liaison and all the aspects of total quality.

Finally, in those mills I know well, everyone accepts the need for quality, everyone accepts the quality limits, and everyone strives to make sure the product is truly Quality Controlled.

APPENDIX

QUESTIONNAIRE

1. In which paper mill areas do you use quality control techniques?
   Can you indicate where these techniques
   (a) involve the use of testers to take samples, measure, log, chart?
   (b) are techniques of automatic process control?

2. In the case of 1 (a), are the measurements used to check an automatic control process, or to provide information for carrying out a control function.

3. Do you use visual presentation methods for control of stock, machine, and paper properties?
   If so, which of these methods are in use?
   - data logging.
   - control charts.
   - instrument charts.
   - video.
   - print out.
   - AOQL charts.

4. In the event of the use of control charts, or computer print-out, are the limits imposed? If so, are they statistically calculated? If not, how are they derived?

5. Do you have any computer-based machine information or control systems?
   If so, have these replaced any quality control procedures? Which?
   Alternatively, have they increased your quality control testing requirements? Why?

6. What in your opinion, in the last thirty years, have been the major changes in the philosophy and application of quality control in the paper industry?

ACKNOWLEDGEMENTS

The following people, plus others in discussion, have helped by replying to a questionnaire (attached as an appendix to the paper) and giving their general thoughts on the development and current state of quality control in our industry.

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Transcription of Discussion

Discussion following papers given by Prof. B. Steenberg and Mr. I.F. Hendry.

Dr. R.E. Mark, ESPRI, USA

Dr. Steenberg observed in his paper that paper sheet tensile properties (strength and index) fall dramatically for basis weights below about 60 g/m^2. I would like to present here the results of some experiments that bear on this, as I am uncertain that surface effects of the fibres are necessarily entirely reponsible.

The determination of tensile strength depends upon a precise measurement of sheet thickness. We have compared `thickness´ measurements made in four different ways (for sheets of 15 and 30 g/m^2).

The four different techniques we used were

a. Digitising scans of a series of photomicrographs of a resin saturated sheet (we had first to find a resin that didn´t cause swelling).

b. Measuring with a spring loaded stylus connected to an LVDT.

c. Mercury immersion.

d. Conventional caliper measaurement.

We found that for the lighter sheets all four methods gave different answers, in the order a, b, c, d, whereas for the heavier sheets conventional caliper determination gave an answer substantially higher than the others which were all approximately equal.

Thus it seems possible that the values of tensile strength reported in the literature may be underestimated, relying as they do on caliper determination.

The position is different for the specific tensile strength, the tensile index, since it may be calculated in three separate ways, of which only one depends upon thickness determination.

Firstly, the tensile strength can be divided by the volumetric density: secondly, the breaking force can be divided by the linear density: or thirdly, the breaking force per unit width can be divided by the basis weight.

Of these only the first route depends upon sheet thickness, while the other two do not.

Thus it is necessary to seek an explanation for the reported reduction of tensile index at low basis weights other than the uncertainty in sheet thickness.

A possible physical explanation is as follows.

The distance between fibre bonds is substantially greater in 15 g/m^2 paper than in 60 g/m^2. Thus there is likely to be much more lateral instability in compressed fibres in the lighter sheet than in the heavier. This could certainly be expected to reduce the tensile index, irrespective of any surface effects.

Thus, while fibre surface effects may contribute significantly to the reported reductions in tensile properties of lightweight sheets, it is by no means necessary to assume that these effects are alone responsible.

Prof. B. Steenberg.

Fibre surface effects are manifestations of buckling instabilities of compressed fibres. Results of experiments with fibrous network models reported at the Second Fundamental Research Symposium(4) showed that both compression and tension caused surface fibres to loosen and project out from the sheet. The increase in thicknesss during stressing is well known, for example, in multiwall paper.

Mr. A. de Ruvo, STFI, Sweden

I am interested to see that in your review you have dispensed with the hydrogen bond model of paper structures. This gives me some comfort, though others may be a little frustrated.

Prof. B. Steenberg.

Though I have not included the hydrogen bond model, I do not intend to imply that it is dispensed with. I have only discounted its usefulness in predicting the unknown properties of paper. I doubt neither the hydrogen bond nor its importance. However, I do not see its relevance to practical paper-making, for the reason that the hydrogen bond itself is not amenable to experimentation. The old deuteration experiments on virgin pulp and paper made from it were very useful, but, to my knowledge, no such experiments are being conducted at present. There are lots of calculations being made, but these are not being supported by new experiments, and rely on data from the literature.

Dr. A.H. Nissan, Westvaco, USA.

I have some hitherto unpublished results that may go some way to answering Prof. Steenberg's criticisms.

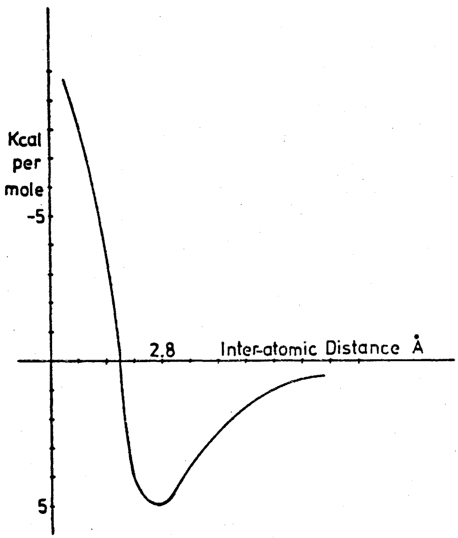

Fig 1

The results come from experiments performed at the Forest Products Research Laboratory, Madison, Wisconsin, by Dr. Von L. Byrd which have been confirmed by Dr. John Glomb, at the Westvaco Research Centre, Covington, Virginia.

Consider the potential energy function for a hydrogen bond, shown in figure 1.

This illustrates that the equilibrium distance, Re, for the O-H-O structure is approximately 2.8-2.9 Å, at which range the bond energy is 4.5 - 5.0 kcal/mole of H-bonds. There is a force constant k_r which measures how easy it is to rupture the bond, which has been measured frequently over the past twenty years by spectroscopic means. The average value obtained from all these determinations is

$$(1.5 \pm 0.1) \times 10^4 \text{ dynes/cm. at } 0^\circ C.$$

Dr Schuster of the University of Vienna has kindly supplied me with the latest quantum mechanical estimates for the potential based on the two best calculations known to him, from which a value of

$$(1.45 \pm 0.2) \times 10^4 \text{ dynes/cm}$$

is obtained.

Thus quantum mechanics and spectroscopy may be said to give a combined value for k_r of

$$(1.5 \pm 0.2) \times 10^4 \text{ dynes/cm}$$

The hydrogen bond theory referred to by Prof. Steenberg may be summarised by the equation

$$E = k_r . N^{1/3}$$

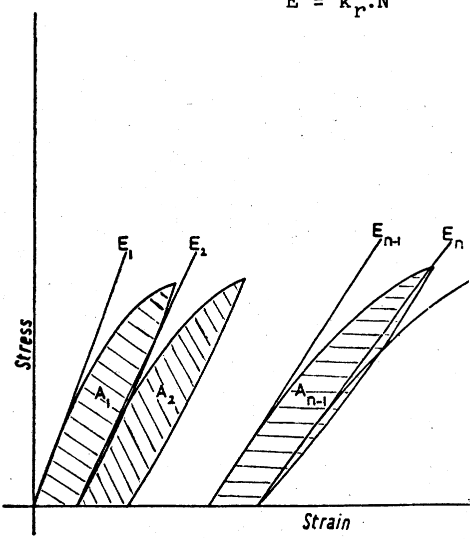

Fig 2

where N is the number of H bonds per cubic centimetre of paper, and E is the Young's modulus.

Now consider the set of curves for cyclic stress-strain loading shown in figure 2.

The total energy absorbed per cycle, TEA, represented by the area under the hysteresis loop, A, can be expressed in terms of energy per unit volume, This is the irreversible energy dissipated in a stress-strain cycle.

Dividing this number by the energy necessary to break one bond, given above as

4.75 kcal/mole of H-bonds ($3.3x10^{-13}$ ergs/bond),

gives an estimate of the number of hydrogen bonds (M) broken during the cycle. Thus

$$M = TEA/(3.3x10^{-13})\ \text{bonds/cm}^3$$

If the sample is subjected to a number of cycles (n), then the sum of all the TEA values is related to the total number of bonds per cm^3 broken during all the cycles (T) by the expression

$$T = \sum_{i=1}^{n-1} (TEA)_i/(3.3x10^{-13})$$

The initial and final values of Young's modules, E_1 and E_n, are given by the equations

$$E_1 = k_r .\ N_1^{1/3}$$

$$\text{and } E_n = k_r .\ (N_1-T)^{1/3}$$

Since determinations of values of Young's modulus are only accurate to $\pm3\%$, it is necessary to break as many bonds as possible in order to be able to distinguish between E_1 and E_n.

To achieve this the experimentalists repeated the stress-strain cycles some twenty times at increasing strains. By summing the TEA value from each hysteresis loop they were able to calculate the value of k_r directly from the rheology of paper sheets.

I am indebted to Dr. V.L. Byrd and to Dr. J. Glomb for their permission to quote their experimental results for the values of k_r, namely

($1.25x10^4$) dynes/cm and ($1.5x10^4$) dynes/cm

respectively, with an average value from the seven samples at the two laboratories of $(1.32\pm0.2)x10^4$ dynes/ cm.

This experiment includes no adjustable parameters and is a truly predictive experiment with exact relationships between the various parameters. We need more work of this kind to confirm the results beyond reasonable doubt and to try to answer the many very intriguing questions in paper rheology.

Prof. B. Steenberg.

My paper is a critical review of the available literature. I am very glad to have seen this information, and look forward to reading about it when published.

Dr. L. Eriksson, STFI, Sweden

I would like to add a comment to Mr. Hendry's paper.

A lot of research is needed before we can hope to achieve any sophistication in quality control and it is my belief that the current proposals for mill-wide control systems from the major suppliers are not appropriate. The full inter-relation between process and product variables must be understood, and while it is not it remains an area demanding research effort.

Mr. I.F. Hendry, Wiggins Teape, UK

I entirely agree. Indeed an earlier speaker asked for suggestions on topics for fruitful research. I suggest that by spending a month in a paper mill any research worker would accumulate so many problems that he wouldn't know where to start.

Mr. A. Ibrahim.

I fully agree that a great deal remains to be done in trying to understand the entire paper making process. However, I do believe that some of the modern control equipment available provides helpful information. We, the control equipment manufacturers, certainly do not believe we have all the answers, but our aim is to provide tools to discover what is happening throughout the process.

Mr. B. Radvan, Wiggins Teape, UK.

I keep thinking of Professor Tabor's remark about respectable and less respectable research. Though his remark referred to research into the physics of the solid and liquid states, I wonder if the same problem doesn't affect the areas covered by Mr. Hendry's paper.

Mr. I.F. Hendry.

I have my own comments to add here. Peter Wrist and I were both up at Cambridge together, and even shared a tutor. Since then Peter has done the `respectable' research, while I have done the `less respectable' work.

Prof. K.I. Ebeling, Helsinki University of Technology

Mr. Hendry, does part of the success of the integrated control system derive from the acute financial conditions which prevailed in the paper making industry throughout the 1960's and 1970's? Under those conditions, even the slightest process improvement, implemented all year round, gave rise to enormous financial returns. Against such a background, it is easy to understand both the rapid penetration of these systems, and the research effort that was mounted to make the sensors reliable.

Dr. H.F. Rance.

I am of the opinion that the development of accurate and reliable sensors was responsible for the rapid spread of control instrumentation.

Mr. I.F. Hendry

Obviously the consideration of a rapid return on investment did play a large part in the acceptance of control technology, but, as Dr. Rance has implied, there was no return on the early substance and moisture gauges, because of the difficulties in making them work. It was only the advent of reliable measurements that allowed the closing of the control loops.

Mr. I.K. Kartovaara, Enso-Gutzeit Oy, Finland.

Practically all quality control is based on the simple calculation of an arithmetic average. This is acceptable provided that the underlying distribution of the variable in question does not change with time. But in general the use of other types of statistics in quality and process measurement should be considered.

Mr. I.F. Hendry

I fully agree. But surely that is already done by modern on-machine gauging systems, where the statistics used are considerably more complex than simple means and standard deviations? Continuously updated analyses of variance, regression, and Fourier analysis are all possible in modern control packages. The widespread use of computers in these applications has made available far more advanced statistics than ever were in the days of hand calculation.

I think these new techniques are used to advantage.

Mr. P. Wrist, The Mead Corporation, USA

I would like to make three general observations on the proceedings so far.

Firstly, on the question of whether or not fundamental research should be directed, we have heard arguments both for and against. My feeling is that while either approach can lead to useful results, some direction is necessary if efficient use is to be made of limited resources. Referring to my own experience, Dr. Wahren described how my fundamental work on table roll drainage was strongly directed with a short term deadline. Similarly, in the second company I worked for, the management's clearly stated intention of being the world's fastest newsprint producer, allied to its policy of posting results daily, ensured that fundamental research was performed only when immediately applicable. And again later, when my research into the factors affecting fibre dispersion uniformity, and sheet formation and structure, was quite general, there was always a specific, known application for the results. This, I believe, focussed my investigations admirably.

Thus it has been my experience that the chances of new knowledge's finding early application are considerably improved if fundamental research is directed, and if the researcher is kept aware of what the direction is.

Secondly, I want to draw attention to the considerable value of team-work. As Dr. Mardon mentioned, there was a number of research teams working on various aspects of paper manufacturing in the early 1950's, each of which interacted with the others to some extent. I certainly recognise the enormous help I received from others, both within and outside the teams of which I was a member, whether at St. Winifred's, at Baie Comeau, or at Chillicothe. In the case of the development of drainage foils, it was certainly not enough to understand how the suction was created: it was absolutely essential to work alongside other teams, especially in the area of materials development, if use was to be made of the knowledge. The first foils were stainless, and could be used only with plastic wires. The development of ceramic foils for use with wires of any material came only later.

Finally, I think we should all recognise the role of competition in fundamental research. There was a number of Cambridge graduates beginning in industry at the same time as I. One in particular was very active in my areas, and provided me with a lot of competition. He began in Wiggins Teape, followed me to Canada, and later followed me to the USA. In today's proceedings he has already beaten me to the punch. As you may by now have realised, my long standing competitior is Jasper Mardon, whose continued rivalry has provided my work with a tremendous stimulus.

The following contribution was received after the Symposium.

Dr. A.H. Nissan

After the session several colleagues expressed their desire to repeat these experiments and to study other factors. These comments may be of some use to those people wishing to do this.

We found it necessary to take some of the following precautions:

1 Mechanical conditioning: It is necessary to stress the sample to a strain of some 0.1 - 0.2 % and destrain it to zero a few times before the series of loops is measured.

The first rising limb of the first loop is affected by many special factors and is usually not reproducible. (Indeed, as Dr. Corte has pointed out, this limb can take the shape of a J curve, showing strain hardening.)

In practice the first curve is of great importance, but for our purposes it introduces too many transient and irrelevant factors, and should be eliminated. Otherwise E_2 may be found equal to or even exceeding E_1.

2 Conditions should be isothermal: This means a very slow rate of straining and destraining, otherwise temperature (and even humidity) effects will intrude, again making E_2 values unreliable, even exceeding E_1.

In those of our experiments where the loops were taken to high strains, the rate of destraining was maintained so low that it took twenty minutes to complete a loop.

3 Signal to noise ratio: A single loop will rarely produce an effect much larger than a standard deviation in the measurements of E, so we found it necessary to conduct 15 to 20 loops per sample to improve the signal to noise ratio.

4 Protocol: We found the following protocol useful.

Supposing we performed 16 loops, so that we had a collection of measurements of E from the beginning of each loop, ie E_1, E_2, ..., E_{16}, then we formed the following pairs:

$E_1 - E_{16}$, $E_1 - E_{15}$, $E_1 - E_{14}$, $E_1 - E_{13}$, $E_1 - E_{12}$;
$E_2 - E_{16}$, $E_2 - E_{15}$,....,$E_2 - E_{12}$; up to ..,$E_5 - E_{12}$.
Thus we obtained twenty five calculations in five sub-groups.

By calculating the means and standard deviations for all the sub-groups and careful examination of each pair, aberrant results could be detected. These were not discarded. The mean of the twenty five calculations was only slightly affected by gross errors.

By reporting the means, the number of calculations, and the standard deviations, all statistical parameters for later evaluation of consistencies and precision become available.

Before calculations of T can be used for studying fatigue, creep, stress relaxation, etc., the following questions about k_r must be answered (hence the delay in our publication of the results so far obtained).

Would values of k_r obtained rheologically from news-print, paper from semi-chemical pulp, unbleached kraft, bleached board, glassine, and regenerated cellulose show regular deviation from the values obtained spectroscopically and quantum mechanically?

What are the effects of radical changes in the process of making the sheet, for example, press-drying?

What are the effects of physical parameters, temperature and humidity, and of chemical parameters, pH and various ionic concentrations (structure making and structure breaking salts)?

Accurate, precise, and reproducible answers to these questions from many different papers tested in different laboratories will prove far more useful in bridging the gap between the H-bond continuum approach and the discontinuous structuralist methods than the useless polemics on irrelevant issues so far raised.

After all, the two descriptions are complementary, not mutually exclusive.

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