Quality Control in Paper Industry— A Function of Statistical Technology

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SUMMARY

The article gives in detail the purpose of "Quality Control" in any industry and specifically in Pulp and Paper industry. In brief, method of sampling and analysis of raw materials inprocess and of final product are given. These methods of quality control (QC) when used with Statistical methods is commonly known as Statistical Quality Control (SQC), have been found to be of great value in a paper mill.

INTRODUCTION

'Quality Control' which concerns the process, the inprocess and the final products, is becoming an increasingly integral part of production in every industry. It is desired that 'Quality Control' is performed as effectively as possible with minimum possible work input. In this direction, Statistical methods commonly known as Statistical Quality Control (SQC) have been found to be valuable tools. Their application in industry gave birth to a new mode of thinking in all modern industries, including pulp and paper.

This subject was developed by Dr. W.A. Shewhart of the Research Laboratories of the Bell Telephone Company of America in his Laboratory and subsequently applied them successfully in the Western Electric Plant in America in 1924. It was during World War-II that SQC found prominence in many industries in the western countries. In India, Prof. P.C. Mahalanobis diverted his attention to this technology in 1935 and with ceaseless efforts on his part was successful in getting this technology introduced in Indian Industry with the setting up of a Committee on Statistics, Standards and Quality Control by the Council of Scientific and Industrial Research in 1944.

Japan, though started the SQC movement 5 years later than India, has spectacularly advanced in this field, whereas India's progress has been very slow. The main hurdles in the way of large scale adoption of these methods in Indian Industry could be due to India having a sellers' market in most of the products and also the resistance to change on the part of the industrial workmen, partly due to habit and partly due to lack of appreciation of this technology.

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WHAT IS QUALITY

Different persons have different conceptions of quality e.g.

(i) **To a Layman** – The best; though he is not able to measure his best, his conception of 'best' goes on changing with the better products he goes on seeing.

(ii) **To a Production man** – less rejections.

(iii) **To an Inspector**- conformance to specification.

(iv) **To Management** – more profits.

(v) **To a Salesman** – lesser customer complaints.

(vi) **To a Consumer** – fit for his use with minimum troubles.

(vii) **To a Technologist** – as an eminent Paper Maker of India late Shri P.K. Nanda used to define it, there are three things in quality viz :

- (a) Suitability to use
- (b) Durability
- (c) Appearance.

WHAT IS QUALITY CONTROL

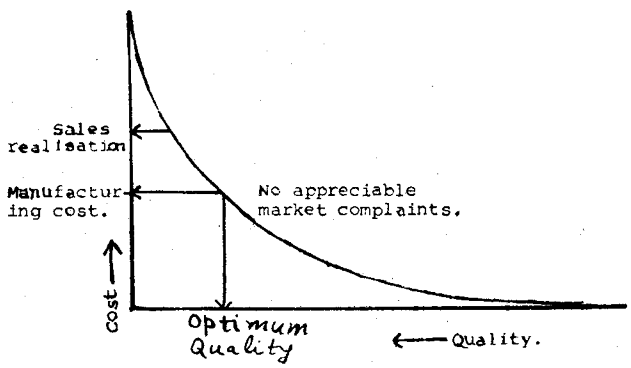
'Quality Control' means to ensure the desired product quality in respect of the above three aspects — at the optimum cost.

WHAT IS STATISTICAL QUALITY CONTROL

Use of statistical techniques to attain and sustain desired product quality at an optimum cost to the customer's satisfaction is known as Statistical Quality Control (SQC). In this context, the word quality refers not only to the quality of the product, but also to the quality of the process which includes men, machines and materials. This technology gives one the power to move from the realm of opinion to that of facts and its judicious use can mean the difference between survival and progress.

QUALITY V/s. COST

SQC is popularly known as the means for exercising control on factors effecting quality of the product though this is a highly restricted meaning of the term. Statistical methods play a vital role in controlling the outgoing quality to meet the customers requirement. But quality can never be divorced from cost. Theoretically, it should be possible to attain any level of quality, even a defect-free product, using the best materials, machines and men, but the cost of such a product will be too high and, therefore, prohibitive. This fact can be illustrated by the following diagram.



The management's problem is to:

(a) reduce cost per unit without prejudice to quality, or

(b) improve quality with little or no increase in cost per unit.

It is this pre-occupation of the management, where SQC plays an important role.

HOW STATISTICS IS APPLIED

SQC starts with the axiom that no two products manufactured by a process are absolutely identical. If then variability is inevitable in any manufacturing process, the question, "how much variations should be tolerated" looms large. The answer to this question leads to the meaning of control. Raw-materials are known to vary in quality and there are many small variations all through the production process. These complex causes give rise to a certain amount of variation even without any changes in the process. This is known as the inherent variability and is unavoidable. Superimposed on this, there is an additional variability due to changes in process—materials, machines, men and environment. Thus, the observed variability-consists of inherent variability which is present even in a process operating under reasonably constant conditions, and external variability due to assignable causes which could be detected and eliminated. When the assignable causes have been identified and eliminated, the process is said to have been brought under control.

SQC TOOLS

Most of the decision-making in the quality function rests on a base of statistics—the collection, analysis and interpretation of data. For the practitioner, SQC can be thought of as a kit of tools which help him to solve the industry's quality problems successfully. Detailed description of the various SQC tools is beyond the scope of this paper but some of the important ones have been briefly introduced in the following paragraphs.

SUMMARISING DATA

Sampling and testing of raw-materials, inprocess and final products is a regular feature in industry. The day-to-day tests carried out generate a large data over a period. Neither any definite conclusion on the process performance in the past can be drawn nor any forecast on its expected performance in future is possible without properly summarising this data. A data can be summarised in two ways :—

(i) WITHOUT USE OF STATISTICAL CALCULATIONS : A set of measurements can be summarised in the form of a FREQUENCY DISTRIBUTION and presented with the help of a FREQUENCY TABLE and pictorial diagrams like HISTOGRAM and FREQUENCY FOLGON etc. The data so represented give a rough idea of the average value and the process variations. As no mathematical calculations are involved, these techniques can be used even by a man having no knowledge of Statistics. In fact these techniques are in use in most of the industries.

(ii) THROUGH MEASURES OF PROCESS AVERAGE & VARIATION : A central value around which the test results cluster and variability around this value are represented by some measures of location and dispersion respectively. The measures of location and dispersion most commonly used in industry, due to their simplicity in calculation, are Arithmatic average ($\bar{x}$) and standard deviation (σ) or range of variation (R) respectively. To calculate them, one must have knowledge of preliminary mathematics only. Since the detailed description of these techiques is available in all books on Statistics, the further details of them, here, are unnecessary. Use of these techniques is illustrated with the help of an example using a hypothetical data in Appendix I.

CONTROL CHART

Dr. W.A. Shewhart introduced SQC with the concept of Control chart, which is a simple graph with a central line (also called as zero line as the variations from this line are desired to be zero) at a distance equal to the average value from the origin and two control limits at distances equal to 3σ on either of the central line.

How is the idea of Control Chart derived:—

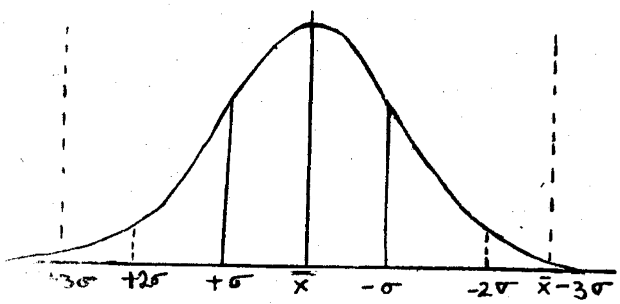
Binomial distribution is — $N(p + q)^n$

when $p \neq q$
and N is finite

a limiting case of binomial distribution is

when $p = q = \frac{1}{2}$
and $N \longrightarrow \infty$

This new distribution is known as Normal Distribution, the shape of which is given below :—



An important property of this distribution, stating that "99. 73% of all the observations lie within the range of $\bar{x} \pm 3, \sigma$" has led to the concept of control chart.

Types of Control Chart:

There are three types of control charts, viz :

(i) control chart for variables : $\bar{x}$-R and
$\bar{x}$-σ types

(ii) control charts for Attributes :

(a) Control Chart for Number of Defective P

(b) Control Chart for Number of defects C

(iii) Cusum Control Chart.

Normally control charts are maintained for averages rather than individual readings because of the fact that averages are more sensitive to change than are individuals. This point is illustrated by the following diagrams.

INDUSTRIAL EXPERIMENTATION

It is always desired in an industry to improve quality and reduce cost per unit. This generally requires changes in process. However, in order to prevent upsetting the entire process, it is essential that any modification in the existing methods should be tried first on a small scale. Thus experimentation becomes inevitable.

Generally an experiment is required for verification of a certain theory formulated relating to a process. The object, generally, is to study the effect of various process variables on the desired quality characteristic, there are many spots in the Paper Mills where this tool can be utilized for improved working with regards to quality and cost.

Advantages of well-planned experiments are :—

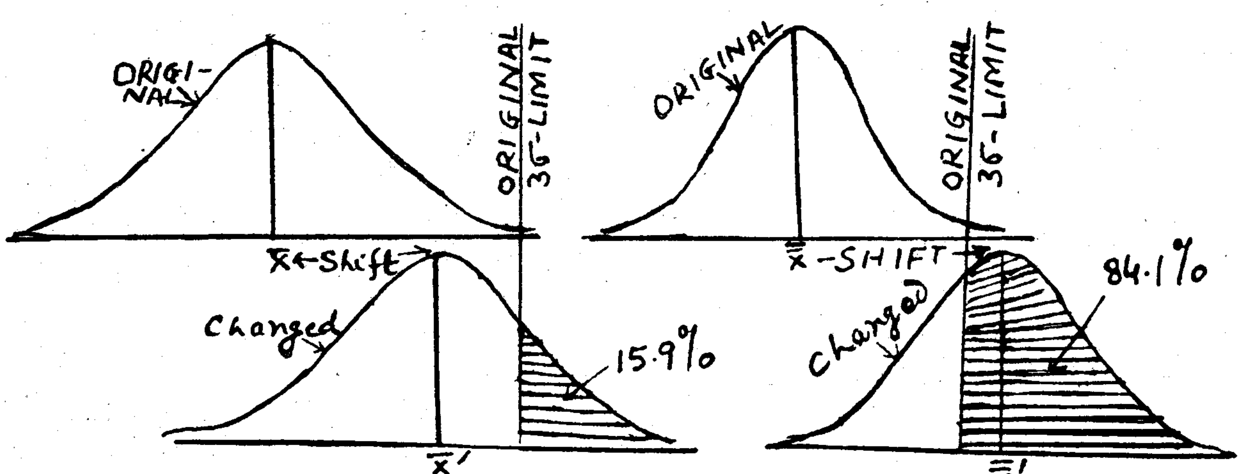
i. The questions on hand are attempted to be answered through clear planning and examination of all relevant details.

ii. Answers are obtained with pre-determined confidence for minimum experimental efforts in terms of money and time.

iii. Effect of various factors singly or jointly are evaluated in quantitative terms without entanglement or confusion.

SAMPLING

(a) Sampling as one of the SQC tools, plays a very vital role in control activities. It is impossible to measure every item of a population, containing a large number of items, due to various factors like cost, work fatigue and destructive testing etc. Therefore, usually a small number of items is selected from a complete population and information representing the population is gathered. Reliability of these informations would depend upon the appropriateness of the samples in representing the popluation.



(a) For individual values

(b) For average of 4.

The simplest form of sampling is called Random Sampling. A Random Sample is defined as a sample in which every individual of the original population has an equal chance of being represented.

Another form of sampling useful in industry is Stratified Sampling. For example, when a number of machines are producing same variety paper, sample taken from a lot wherein the production of all the machines are put together, gives an estimate of proportion of defective products in the lot, but nothing is known about the working of individual machines. In this case, therefore, it would be necessary to take random samples from the different machines separately. This is called stratification according to machines.

To draw Random Sample from a lot, table of Random Numbers is used with great advantage.

(b) Sampling of incoming raw-materials and products is also very common in industry for acceptance or rejection. This, known as acceptance sampling, is of two types :

(i) Sampling for Acceptance of a lot formed by a large number of Units - A specified number of units is drawn from a lot. The sample units are checked either by go-no-go criteria or by variable measurements. The lot is accepted if the sample contains defectives maximum to a pre-determined number otherwise rejected.

(ii) Sampling for Acceptance of a lot in bulk form - there are cases where a lot or consignment does not contain definite sub-units. E.g. a consignment of lime, where it is desired to estimate the percentage of CaO content, with some agreed precision, the bulk sampling procedure may be employed. Intuitive reasoning will show that it is proper to select a few wagons first and then from each wagon a few sub-samples from different areas within a wagon rather than collecting all samples from any particular wagon or one sample each from several wagons. Statistical theory of Bulk Sampling in such cases takes care of various aspects like variation between wagons and within the wagon, and cost of sampling and analysis. The following equation shows the relationship for variation of the estimated CaO content with the variation in actual CaO content between the wagons and within a wagon.

$$\text{Variance } (\bar{\bar{x}}) = \frac{(M-m)}{(M-1)m} \sigma b^2 + \frac{\sigma w^2}{m\,n}$$

Where M = No. of wagons in the consignment

m = Number of wagons in the sample

n = No. of secondary samples within a wagon

σb^2 = variance between wagons

σw^2 = variance within a wagon

Precision of the estimate can be controlled through appropriate choice of m and n.

REGRESSION & CORRELATION ANALYSIS

In experimental work as well as in-plant operations, it is of considerable importance to know by how much the level of one characteristic changes with the change in level of other characteristic. Correlation and Regression analysis helps to determine the mathematical function of the form of $Y=a+bx$ expressing the average values of the secondary variable for different values of the first. Following are some of the areas in a Paper Mill where these techniques can be used with great benefits :

(i) Effect of pulp consistency on paper substance.

(ii) Effect of M/c. speed on paper substance.

(iii) Effect of various factors in bleaching on pulp brightness.

(iv) Effect of ash content of paper on its strength characteristics and the like.

These relationships help to :—

(i) decide substitution of existing testing procedures by quicker and cheaper methods.

(ii) determine levels at which the process conditions have to be maintained in order to achieve desired effects.

(iii) determine the effect of more rigorous control of particular operating conditions on the product quality.

CAUSE AND EFFECT ANALYSIS

Defects just do not happen by chance, but they have definite causes which can be traced. The causes, though numerous, follow a certain law or principle and exhibit the phenomenon of 'vital few' and 'trivial many'. Often a single dominant cause is of far greater importance than all the rest put together. Location or identification of such causes often becomes a complex problem especially when there are large number of sources.

Prof. K. Ishikawa of Tokyo University has developed unique "Cause and Effect Diagram" which maps out all the variables present in the process affecting a particular characteristic. The authors at their Mills have, with the help of experts from SQC Unit of Indian Statistical Institute, Calcutta, developed a Cause and Effect Diagram for paper substance as reproduced in Diagram-II.

TEST OF SIGNIFICANCE

In industry the samples of raw-materials inprocess and final products are drawn and tested to infer about the lot characteristics. To check, whether or not the sample results represent the lot, statistical techniques known as tests of significance can be used with advantage. Here below are introduced briefly some tests of significance.

(i) **GOODNESS OF FIT OR X^2 - TEST :** Suppose the packed reams are expected to certain on average one defective sheet, but when the reams are actually inspected they are found to contain defective sheets in varying number. To ascertain whether the observed results are representative of the expected number of defective sheets (i.e. one), X^2 - test can be used. The formula is–

$$X^2 = \frac{(\text{Observed}-\text{Expected})^2}{\text{Expected}}.$$

This Test can also be used to ascertain if the results from two tests are same or they have significant difference.

(ii) **COMPARISON OF TWO VARIANCES, F-TEST:** Suppose two sets of samples are drawn from two different lots and it is required to ascertain that the two lots have no significant diffrence in respect of the characteristic under consideration. F-test can be used in such cases. The procedure is to calculate variances of the two sets of samples separately and then ratio of the two variances. This ratio is then compared against the tabular values to find out if this is significant. If the ratio is significant then the two sets of samples are said to have been drawn from lots different in characteristic under study.

(iii) **t- TEST :** It is used in the following cases (a) when the average (μ) and standard deviation (σ) of the lot are unknown and it is desired to ascertain whether the sample with average $\bar{X}$ was drawn from this lot.

$$t = \frac{\bar{x}-\mu}{\sigma/\sqrt{n}}$$

This value of t is compared against tabular values to arrive at the above conclusion.

(b) when the same test is carried out by two persons, and it is required to verify whether difference between the results of the two is only due to chance causes or it is significant. Also when two sets of samples drawn from the same lot it is required to verify whether both can be taken to be drawn from the same lot or they have significant difference.

$$t = (\bar{x}_1 - \bar{x}_2) / \sigma \sqrt{\frac{1}{n_1} + \frac{1}{n_2}}$$

(iv) **TEST OF CONFIDENCE:** The prevailing practice in the paper industry is to estimate the average substance of a lot from the deckle samples drawn from pope-reel at the time of roll change. To verify whether this average is proper estimate of the actual average of the lot when actual lot average is known. When actual lot average is not known then confidence limits, within which the average of deckle samples can be expected to represent the actual average, can be specified by this technique :

$$\text{Confidence limits} = \mu \pm t. \frac{\sigma}{\sqrt{n}}$$

RELIABILITY ANALYSIS

Though developed only in early 1950's, it has become a highly specialized technique and a subject by itself known as RELIABILITY ENGINEERING. The reliability (of a system and device etc.) is the probability that it will give satisfactory performance for a specified period of time under specified operating conditions. The simple assumption as a basis of this technique is that throughout the period of life test of the system or device the probability of its failure is constant.

In reliability analysis the mean life of a system and its failure rate play an important role.

EVOLUTIONARY OPERATION (EVOP)

This is a method of process operation which has a built in procedure to increase productivity. It uses some simple statistical ideas and is run during normal routine production by plant personnel themselves. It is based on the maximum that "a process should be run so as to generate product plus information on how to improve the product". Being a highly specialised technique, developed into a subject by itself, explanation is beyond the scope of this paper.

EXPECTED BENEFITS

A successful SQC programme is expected to yield the following results : —

(i) Improvement in quality.
(ii) Reduction in broke and rejections.
(iii) Efficient use of men and machines.
(iv) Economic use of materials.
(v) Removing production bottlenecks.
(vi) Decreased inspection costs.
(vii) Reduction in manufacturing cost per unit.
(viii) Scientific evaluation of tolerances.
(ix) Scientific evaluation of quality and production.
(x) Quality consciousness at all levels.
(xi) Reduction in customer complaints.

CONCLUSION

It is important that quality is, quite often, sacrificed for short-run gains of production, or sales or profits; which in the long run is counter-productive and hence a change in the outlook of all concerned is imperative since simply the introduction of SQC methods cannot, by themselves produce any miracles in controlling the quality of product or process. The success or failure of these techniques depends, largely, on the ability of the SQC technologists, degree of coordination between the SQC and the production personnel and, above all, the uninstincted support of the Management to the programme.

APPENDIX—I

Product	—	Paper
Variety	—	X Y 2
Charactersitic	—	Substance (gsm)

Sample No.	Results across the deckle. 1	2	3	4	5	6	7	8	9
1.	77.0	79.4	80.9	79.3	80.0	80.5	83.4	80.8	81.4
2.	79.9	81.4	77.6	79.4	79.0	76.1	79.7	78.8	79.5
3.	80.4	80.2	80.0	78.8	81.2	81.0	81.0	80.4	79.9
4.	79.6	78.3	83.0	79.5	80.7	78.7	80.2	79.8	80.1
5.	79.2	81.2	82.0	80.9	81.4	81.2	80.4	80.1	80.5
6.	82.2	80.7	82.2	79.7	79.9	78.5	79.9	80.3	78.3
7.	77.7	80.0	81.3	81.4	79.9	80.8	76.7	76.9	80.5
8.	81.6	81.6	80.4	81.5	78.7	79.0	80.0	79.9	82.3
9.	79.3	82.1	78.6	79.3	80.3	80.4	79.7	80.2	80.5
10.	78.5	82.0	84.0	78.8	78.6	79.1	80.6	78.6	78.2

SUMMARISING DATA

(1) Frequency Distribution and Calculations of Average ($\overline{X}$) and standard Deviation (σ).

Variable value		Tally	Frequency f	Calculations for $\overline{X}$ and σ			
Class	Mid point x			f x	$(x-\overline{x})$	$(x-\overline{x})^2$	$f.(x-\overline{x})^2$
75.5–76.5	76.0	/	1	76	—4.0	16.0	16.0
76.5–77.5	77.0	///	3	231	—3.0	9.0	27.0
77.5–78.5	78.0	𝍸 ///	8	604	—2.0	4.0	32.0
78.5–79.5	79.0	𝍸 𝍸 𝍸 ////	19	1511	—1.0	1.0	19.0
79.5–80.5	80.0	𝍸 𝍸 𝍸 𝍸 𝍸 𝍸	30	2400	0	0	0
80.5–81.5	81.0	𝍸 𝍸 𝍸 ///	18	1458	+1.0	1.0	18.0
81.5–82.5	82.0	𝍸 //	7	574	+2.0	4.0	28.0
82.5–83.5	83.0	///	3	249	+3.0	9.0	27.0
83.5–84.5	84.0	/	1	84	+4.0	16.0	16.0
Total			90	7187			183.0

Note : All boundary values included in upper class boundary only.

(ii) Calculations of Average and Standard Deviation :

$$\text{Average } (\bar{X}) = \frac{\Sigma f.x}{\Sigma f} = \frac{7187}{90}$$

$$= 79.96$$

$$= 80 \text{ gsm.}$$

$$\text{S.D. } (\sigma) = \sqrt{\frac{\Sigma f.(x-\bar{x})^2}{\Sigma f.}} = \sqrt{\frac{183}{90}}$$

$$= 1.43 \text{ gsm.}$$

(iii) Pictorial Representation : (Diagram-I)

DIAGRAM-I. HISTOGRAM AND FREQUENCY POLYGON

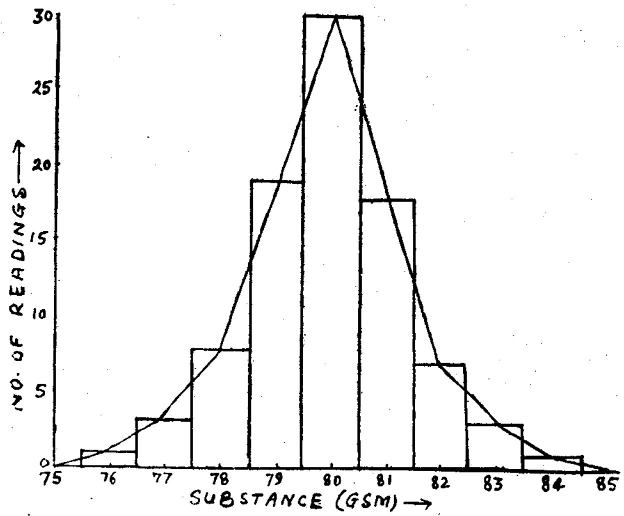
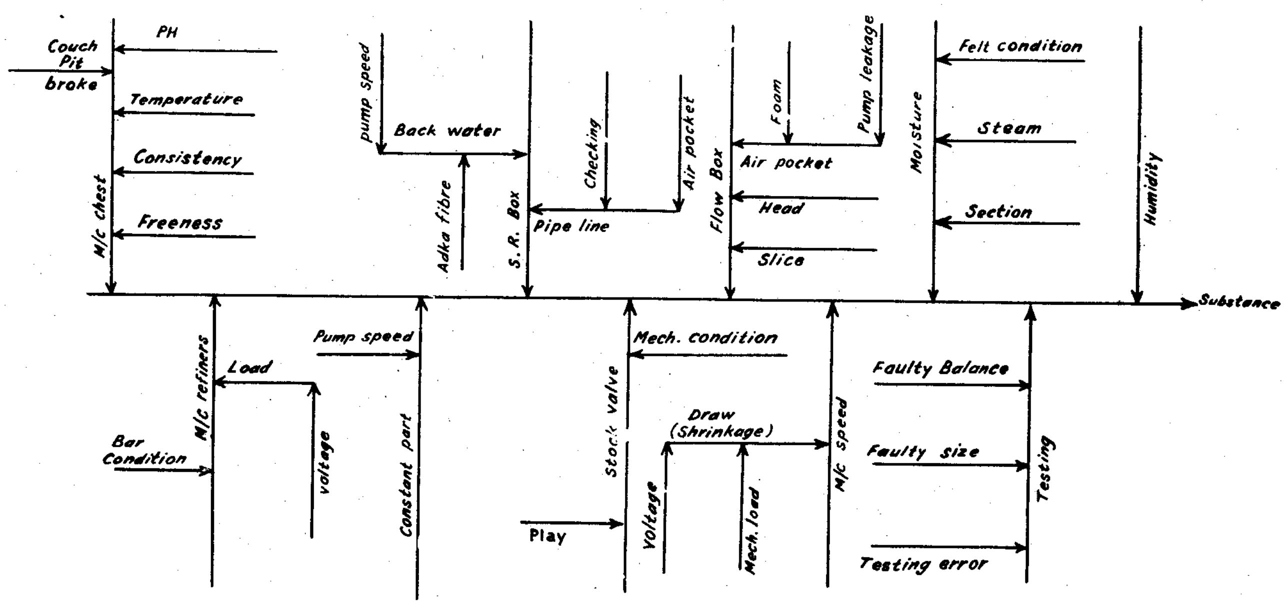


DIAGRAM-II. CAUSE AND EFFECT DIAGRAM FOR SUBSTANCE OF PAPER



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