A UNIFIED METHOD OF INSPECTION AND QUALITY CONTROL

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ABSTRACT

It has been shown earlier that the mean and range charts used for S.Q.C. can be replaced by a single chart showing the largest and smallest values of samples taken from the machine at regular intervals. This chart designated as L-S chart has been found to be economical and efficient in many respects. The present paper shows that by modifying the sampling procedure, the S.Q.C. chart, besides providing information on the machine setting, tool wearing etc. for controlling the quality, gives information on the quality of the products collected during sampling intervals and thus enables us to dispense with 100 per cent stage inspection which is in practice in the ordnance factories. The modification consists in taking one or two jobs from the machine at regular intervals and another four jobs at random from the products manufactured during every interval. The samples so selected are plotted on a chart against the specification limits. The collections during the different intervals will be accepted if all the four jobs are within the specification limits; otherwise screening will be done. Condition of the machine is judged mainly from the jobs taken from it. The experimental investigations conducted at the Gun & Shell Factory, Cossipore show that this procedure works as effectively as the L-S chart and cent per cent inspection.

Introduction

A finished ordnance component is the result of a number of successive operations carried out either in a multi-spindle machine or in different machines. After the operations in a machine the jobs are usually inspected 100 per cent by the viewer. This inspection is called 'Stage inspection.' Before the final acceptance, all the jobs accepted at the last stage inspection are once again inspected for all the characters of the component. This is called the 'final inspection' or 'bond inspection'. The general production and inspection plan in the ordnance factories is shown below.

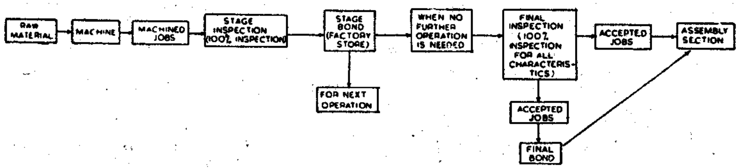


FIG 1—Production and Inspection Plan in the Ordnance Factory

It will be noted from the above plan that the jobs accepted for assembly have to undergo at least two inspections: once at the stage and again at the bond, the second inspection being the final one. Both the inspections are carried out by the T.D.E. personnel.

The stage inspection is done with a view to—

(1) Improving the quality of the product by preventing the production of scraps.

(2) Ascertaining the number of correct jobs produced for which wage is to be paid to the worker.

(3) Stopping further operations on defective jobs.

This inspection is done as follows—

After setting the machine in the morning the first few jobs manufactured are placed on the inspection table. If they are to the specifications for all the characteristics the machine is allowed to go ahead with production, otherwise the setting is altered. The jobs produced during the first hour or so are collected and placed on the stage inspection table and the viewer inspects them one by one. The result of the inspection is brought to the notice of the machine operator. But the complete inspection of all the jobs on his table takes a good deal of time and by the time it is finished an equal number of jobs are produced by the machine. The information available from the inspection of the previous batch of products is practically of no value to reduce the scraps during the succeeding period. Thus one of the purposes of stage inspection is not fully served by the present method.

The stage inspection is intended to be 100 per cent. But due to shortage of staff and human limitations it may not always prove to be as efficient as it is desired to be. Under these circumstances we feel that the stage inspection may be more efficiently and economically done by replacing cent per cent inspection by sampling inspection. It will be all the more economical if such sampling inspection and statistical quality control (S.Q.C.) are combined together.

At present S.Q.C. for measurable character is done by the aid of the X and R charts[1]. Recently, following Howell[2], it has been shown [3,4] that S.Q.C. work in factories can be simplified to a considerable extent by replacing the conventional $\bar{X}$ and R charts with the L-S chart, that is, the chart showing the largest and smallest values of the samples. The advantages of the L-S chart are—

(1) It is much simpler and hence less costly.

(2) It detects lack of control almost as efficiently as the X and R charts when there is change in the standard deviation without any appreciable shift in the mean. But when the mean changes its efficiency gets down appreciably.

(3) In L-S chart a simple comparison of the control limits to the tolerance limits ensures economic control, while in $\overline{X}$ and R chart such assurance requires further calculation and comparison.

(4) In some cases, quicker diagnosis of the assignable cause is possible in the L-S chart.

(5) The L-S chart is readily explainable to the machine operator.

In view of the above advantages we may now examine how the sampling procedure of the L-S chart can be modified to give information regarding production between two instants of sampling and also about the condition of the machine setting and tool wearing etc. The L-S chart is based on samples of five consecutive jobs taken from the machine at regular intervals. The measurements of these jobs are noted and the L-S chart is plotted on this basis. No information is available on the intermittent products and as such their acceptability is decided by 100 per cent stage inspection mentioned earlier. If instead of taking five consecutive jobs we select at random four jobs from the products manufactured between two sampling instants and one or two jobs from the machine at the fixed interval, this will provide information on the condition of the machine and also on the acceptability of the intermittent products. The efficiency of this procedure has been compared in this paper with the result of the L-S chart and cent per cent stage inspection. This has been done by collecting data on two ordnance components manufactured at the Gun and Shell Factory, Cossipore. The details of the experiments are discussed in the next section.

Experimental Investigations

Selection of components

Two components were selected for study. One was the safety pin of fuze 162, mark 2/2 body, manufactured in a single spindle automatic machine and the other was the sleeve (also called inertia pellet) of fuze 119B mark 15 body. The latter was manufactured in a six spindle automatic machine. The rate of production of the former was 120 per hour while of the other it was approximately 100 per hour. These jobs were selected for the high rate of production and the expected continuity of manufacture during the experimental period. Multi-spindle automatic machine was specially selected for studying the efficacy of the proposed modified S.Q.C. for controlling simultaneously a group of spindles in place of the present group control chart.

Past inspection record

Previous stage inspection results for these two components, as collected from the T.D.E. stage inspection records are given in the Tables I & II. These do not include the repairable defectives. Thus the actual percentage of bad works done by the machines will be more than what has been shown in the T.D.E. record. It may also be noted that the above inspection results give the defectives for all the characteristics of the component, 3 for the safety pin and 10 for the sleeve.

TABLE I

Stage Inspection results

Fuze 162 Mk 2/2 body, Component—Safety pin.

Date	Number of jobs manufactured	No. of defective jobs
1-12-56	312	12
3-12-56	620	20
4-12-56	617	17
5-12-56	632	32
6-12-56	620	20
7-12-56	631	31
8-12-56	415	15
10-12-56	412	12
11-12-56	629	29
12-12-56	138	8
13-12-56	420	20
14-12-56	315	15
15-12-56	260	10
26-12-56	316	16
27-12-56	371	21
28-12-56	528	28
29-12-56	210	10
31-12-56	290	15
1-1-57	262	12
2-1-57	503	28
3-1-57	314	14
	8815	385

Percentage defectives = 4·4%

TABLE II

Stage Inspection results

Store —Fuze 119B Mk 15

Component—Sleeve

Date	Number of jobs manufactured	Defective jobs
2-1-57	466	16
3-1-57	212	12
7-1-57	627	27
8-1-57	629	29
9-1-57	731	31
10-1-57	625	25
11-1-57	526	26
14-1-57	618	18
15-1-57	627	27
16-1-57	624	24
17-1-57	618	18
18-1-57	616	16
19-1-57	363	13
21-1-57	721	21
22-1-57	619	19
24-1-57	622	22
25-1-57	620	20
28-1-57	614	14
29-1-57	615	15
30-1-57	620	20
	11713	413

Percentage defectives—3·5%

Characteristics studied

Data were collected on three characteristics, Flange diameter, Head diameter & Body diameter of the safety pin. Body diameter is a critical defect because if the safety device fails, the fuze may function prematurely there by causing harm to the user. For the sleeve there are ten characteristics out of which three, external diameter, overall length and the depth of recess were studied.

Collection of data

Data were collected for the safety pin for 9 days from 15-1-57 to 25-1-57 excluding two holidays. At regular intervals of half an hour four jobs were selected at random from the collections in the tray after thoroughly mixing them, and their measurements were recorded separately. Besides these, five consecutive jobs were also collected and measured at regular intervals of half an hour.

For the sleeve of fuze 119 B, mark 15, which was manufactured in a six-spindle automatic machine, sampling procedure was slightly different from that explained above. As in the case of safety pin, four jobs were taken at random from the tray. In addition, two consecutive jobs from each of the spindles were also collected at regular intervals of half an hour.

Plotting of control charts and their interpretations

The collected data have been represented graphically in figures 2 (A, B, C, D, E, F) and 3 (A, B, C, D, E, F). Figures 2 (A, C, E) represent the proposed chart for the flange diameter, head diameter and body diameter of the safety pin, while figures 2 (B, D, F) represent the corresponding L-S charts. Similarly, figures 3 (A, C, E) show the proposed group control charts for the external diameter, overall length and the depth of the recess of the sleeve. The corresponding conventional group control charts are represented in figures 3 (B, D, F). It will be observed from the explanations given in the figures that in the modified S.Q.C. chart, besides plotting the measurements of the four jobs collected from the intermittent product accumulated in the tray, the measurement of the first job belonging to the consecutive observations made on the machine has also been distinguishably plotted. This point has been plotted with a view to obtain information on the machine setting etc. When this point falls outside the tolerance limits, steps should be taken to bring the machine within control. If the first four points are within the specification limits, the jobs accumulated in the tray should be accepted without further inspection. On the other hand, if at least one of these points falls outside the limits, the jobs should be accepted only after 100 percent screening. The results of replacing the stage inspection by such a sampling inspection will be discussed by calculating the overall out-going quality in a later section.

In order to make a comparative study, the L-S charts have been plotted for the five consecutive jobs side by side with the modified S.Q.C. figures. In figure 2, the modified S.Q.C. chart has been plotted for the first four jobs along with the maximum and minimum of the first job from the spindles. The L-S chart for the six-spindle automatic machine corresponds to the conventional group control chart giving the maximum and minimum of the means of the two consecutive components from the spindles. As in the previous case, we shall accept the job collected at the tray between the sampling intervals if all the four jobs taken at random lie within the specification limits. Otherwise 100 per cent inspection will be done.

The results of 100 per cent inspection of the jobs manufactured during each day of the experimental period are also shown in the charts.

It will be noted from figures 2 (A) and 2(B) that on two occasions the proposed S.Q.C. chart detected lack of control while the L-S chart failed to do so.

In all the charts there was no occasion when the L-S chart could reveal out of control points while the proposed chart failed. This indicates that the efficiency of the proposed chart for the purpose of quality control may be more than the L-S chart though originally we have proposed such charts for replacing the stage inspection.

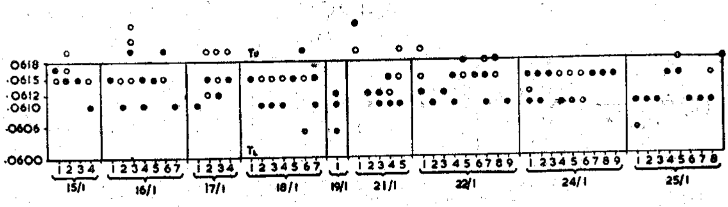
STATISTICAL QUALITY CONTROL CHART

STORE FUSE 162 MK 2/2 BODY: COMPONENT-SAFETY PIN

Characteristic—Flange Diameter

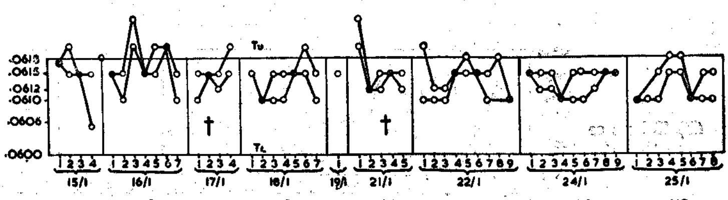
MODIFIED S.Q.C. CHART

(A) Tolerance ·0018″



L–S CHART

(B) Tolerance ·0018″

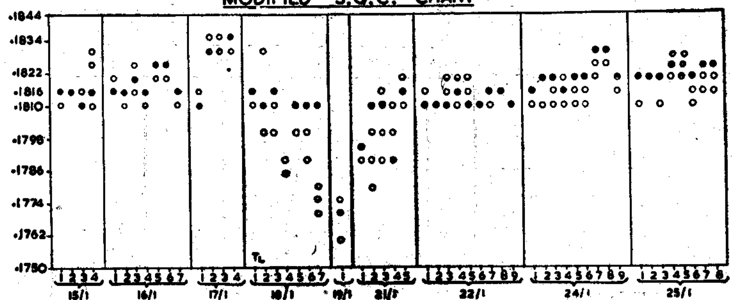


	15/1	16/1	17/1	18/1	19/1	21/1	22/1	24/1	25/1
JOBS	220	435	418	225		250	250	400	410
HIGH	20	35	23	9		16	9	0	10
LOW	0	0	0	0		0	0	0	0
REJECTION%	9.09	8.04	5.50	4.00		6.04	3.60	0	2.44

CHARACTERISTIC—HEAD DIAMETER

MODIFIED S.Q.C. CHART

(C) Tolerance ·0094″



(*i*) In modified SQC method a sample consists of five jobs; four being taken at random from the total production of the sampling interval and one, as it is parted off from the machine at a particular time. The last one is represented by a solid point ⊙ in the chart.

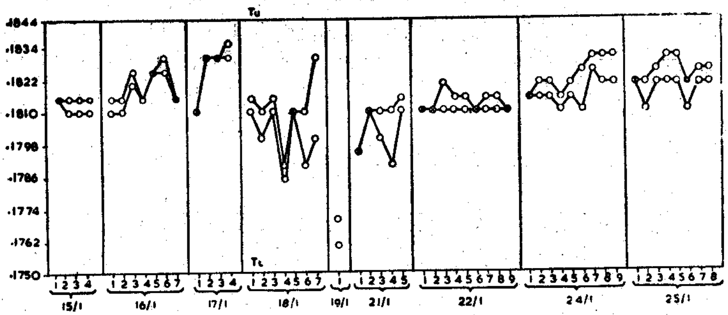
(*ii*) In modified S.Q.C. chart all the individual observations of the sample have been plotted. The number of points for some samples is less because of coincidence of observations.

(*iii*) The coincidence of maximum & minimum of the sample is indicated by point (*) in the L-S chart.

(*iv*) † L-S chart failed to detect lack of control while the modified S.Q.C. method indicated presence of defective jobs.

L-S CHART

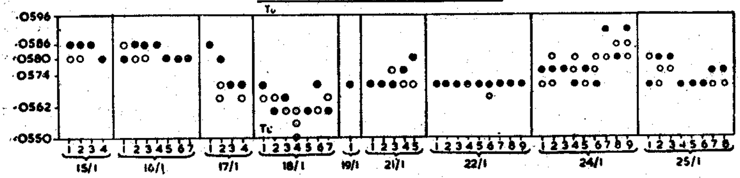
(D) Tolerance ·0094″



CHARACTERISTIC — BODY DIAMETER

MODIFIED S.Q.C. CHART

(E) Tolerance ·0046″



L-S CHART

(F) Tolerance ·0046″

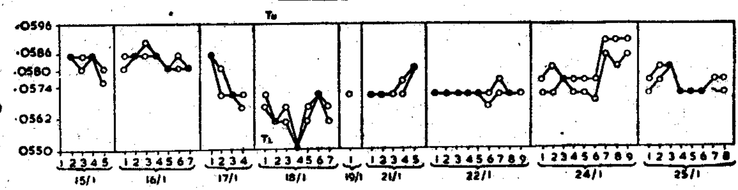


FIG 2

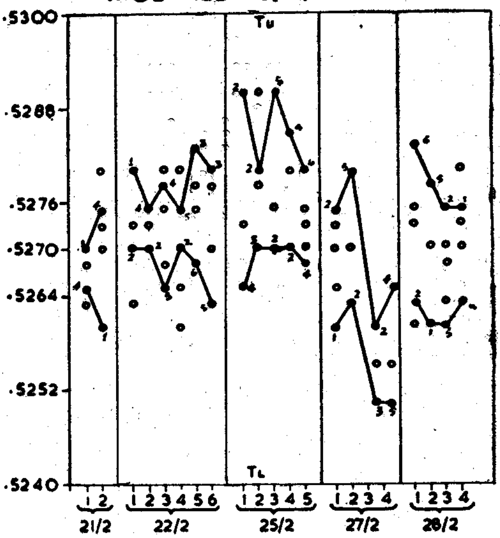
STATISTICAL QUALITY CONROL CHART: STORE FUSE 119B MK 15

BODY: COMPONENT—SLEEVE

CHARACTERISTIC—EXTERNAL DIAMETER

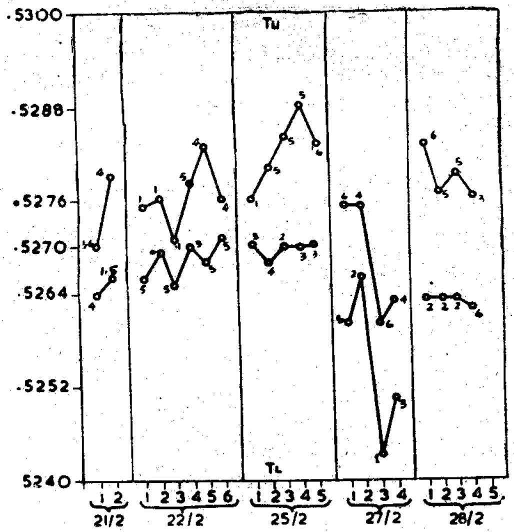
MODIFIED S.Q.C. CHART

(A) Tolerance ·0050″



L-S CHART FOR THE MEANS OF TWO OBSERVATION PER SPINDLE

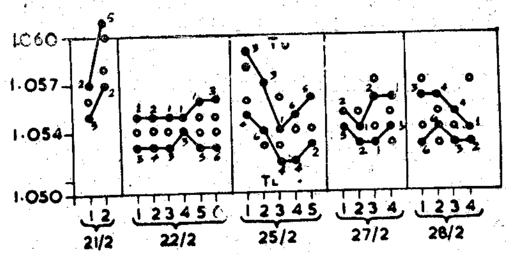
(B) Tolerance ·0060″



CHARACTERISTIC : OVERALL LENGTH

MODIFIED S.Q.C. CHART

(C) Tolerance ·010″



L-S CHART FOR THE MEANS OF TWO OBSERVATIONS PER SPINDLE.

(D) Tolerance ·010″

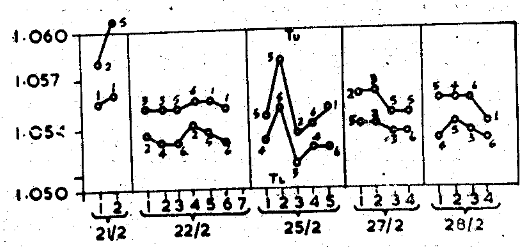
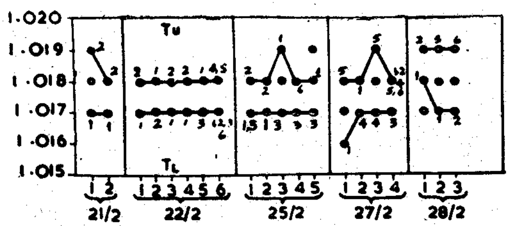


Fig 3

CHARACTERISTIC: DEPTH OF RECESS

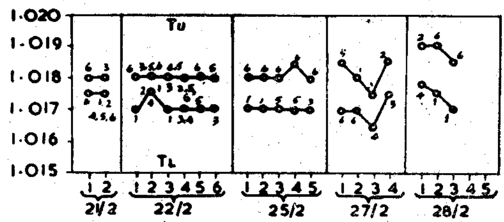
MODIFIED S.Q.C. CHART

(E) Tolerance ·005"



L-S CHART FOR THE MEANS OF TWO OBSERVATIONS PER SPINDLE.

(F) Tolerance ·005"



The sampling procedure followed in the investigation consisted in taking four components at random from the tray and consecutive two components from each of the spindles, the modified S.Q.C. chart shows the first four observations and the maximum and minimum of the first set of observations from the spindles. In the L. S. chart the maximum and the minimum of the means of consecutive observations from spindles are plotted.

Expected percentage defectives by the two methods

The extent to which these two metods detect lack of control has already been discussed on the basis of the respective control charts. We shall now examine the efficacy of the two methods by comparing the expected percentage of defectives that will be in the products manufactured on different days. The underlying assumption made for such comparison is that the appearance of the defectives is random and that there is no stage inspection and the proposed method is only for quality control purposes. If the expected percentage of defectives (E.P.D.) by the two methods is the same, we may reasonably conclude that the extent of control achieved by both the methods is for all practical purposes the same. In view of the fact that modified S.Q.C. includes inspection also, it is obvious that the modified S.Q.C. is preferable to L-S or the $\bar{X}$ & R charts. If, on the other hand, the (E.P.D.) is different for the two methods it shows that production is not going on satisfactorily. But it is very unlikely that there will be difference in the E.P.D.s for the two methods when the machines are running to our satisfaction. The table below gives the means, S.D. & E.P.D., based on the data collected for different days.

TABLE III

Expected Percentage Defectives (E.P.D.) by two methods

Store: Fuze 162 Mk 2/2 Body

Component: Safety Pin

Date	Proposed S.Q.C. method			L-S method		
	mean(m)	Standard deviation(s)	E.P.D.	mean(m)	Standard deviation(s)	E.P.D.
			Characteristic—Flange diameter			
15-1-57	·06157	·00013	3·53	·06148	·00036	18·33
16-1-57	·06149	·00034	17·79	·06162	·00036	30·56
17-1-57	·06142	·00033	10·27	·06144	·00029	10·72
18-1-57	·06127	·00031	4·40	·06135	·00028	5·44
19-1-57	·06120	·00045	9·12	·06150	..	..
21-1-57	·06145	·00050	24·07	·06147	·00037	18·48
22-1-57	·06135	·00028	5·52	·06138	·00029	7·38
24-1-57	·06134	·00023	2·32	·06138	·00021	2·10
25-1-57	·06110	·00030	·98	·06120	·00030	2·28
			Characteristic—Head diameter			
15-1-57	·18155	·00061	nil	·18133	·00025	nil
16-1-57	·18179	·00052	,,	·18180	·00066	,,
17-1-57	·18267	·00096	,,	·18257	·00096	,,
18-1-57	·18004	·00152	,,	·18043	·00114	,,
19-1-57	·17690	·00055	,,	·17650	·00035	,,
21-1-57	·18004	·00110	,,	·18056	·00068	,,
22-1-57	·18121	·00031	,,	·18118	·00026	,,
24-1-57	·18178	·00061	,,	·18189	·00051	,,
25-1-57	·18195	·00049	,,	·18213	·00047	,,
			Characteristic—Body diameter			
15-1-57	·05830	·00025	nil	·05833	·00029	nil
16-1-57	·05819	·00025	,,	·05830	·00028	,,
17-1-57	·05738	·00072	,,	·05743	·00069	,,
18-1-57	·05614	·00049	,,	·05621	·00065	,,
21-1-57	·05720	·00038	,,	·05726	·00041	,,
22-1-57	·05701	·00007	,,	·05701	·00041	,,
24-1-57	·05770	·00062	,,	·05774	·00068	,,
25-1-57	·05735	·00041	,,	·05734	·00038	,,

TABLE IV

Expected Percentage Defectives (E.P.D.) by two methods

Store: Fuze 119 B Mk 15; Component: Sleeve

Date	Proposed method			L-S method		
	mean (m)	Standard deviation(s)	E.P.D.	mean (m)	Standard deviation(s)	E.P.D.
			Characteristic—Depth of recess			
21-2-57	1·0176	·0006	nil	1·0177	·0006	nil
22-2-57	1·0176	·0005	nil	1·0176	·0005	,,
25-2-57	1·0176	·0006	nil	1·0176	·0006	,,
27-2-57	1·0176	·0006	nil	1·0176	·0006	,,
28-2-57	1·0179	·0007	·240	1·0181	·0007	·317
			Characteristic—Overall length			
21-2-57	1·0575	·0019	9·18	1·0579	·0020	14·917
22-2-57	1·0542	·0008	nil	1·0544	·0010	nil
25-2-57	1·0542	·0020	2·04	1·0539	·0019	1·618
27-2-57	1·0546	·0010	nil	1·0544	·0010	nil
28-2-57	1·0540	·0011	nil	1·0542	·0010	nil
			Characteristic—External Diameter			
21-2-57	·5269	·0004	nil	·5269	·0005	nil
22-2-57	·5272	·0006	,,	·5272	·0006	,,
25-2-57	·5277	·0008	·149	·5276	·0007	,,
27-2-57	·5262	·0009	1·160	·5263	·0010	1·101
28-2-57	·5269	·0007	nil	·5269	·0007	nil

From the above two tables we note that the expected percentage defectives (E.P.D.) by both the methods are practically same.

Effect of replacing the cent per cent stage inspection by the proposed modified S.Q.C.

The proposed modified S.Q.C. method is intended to replace the cent per cent stage inspection by sampling inspection besides controlling the production by giving the latest information regarding the machine setting, tool wearing etc. The productions, collected in the tray during the sampling intervals, will be accepted without further inspection if the corresponding sampled individuals are to the specifications. Otherwise these products will be screened. Since the acceptance is based on the results of sampling, some percentage of defectives is expected in the accepted lots due to chance. The percentage defectives in the accepted lots, *i.e.* the outgoing quality, will depend on the lot size, the sample size and the percentage defectives produced by the machine. A table giving the values of expected or average out-going quality

(A.O.Q.) is given in Table V and are represented graphically in Figs. 4, 5, 6. The method of calculation is explained below.

A.O.Q. FOR DIFFERENT SAMPLE SIZES (n) AND PERCENTAGE DEFECTIVE (100xp) FOR N=100 AND c=0.

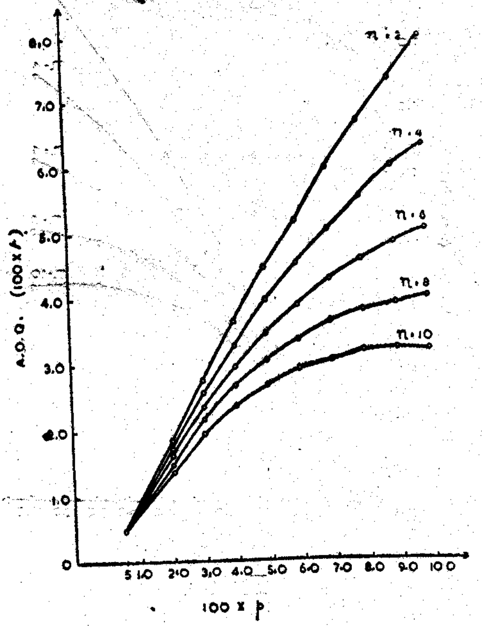


FIG 4

A.O.Q. FOR DIFFERENT SAMPLE SIZES (n) AND PERCENTAGE DEFECTIVE (100xp) FOR N=150 AND c=0.

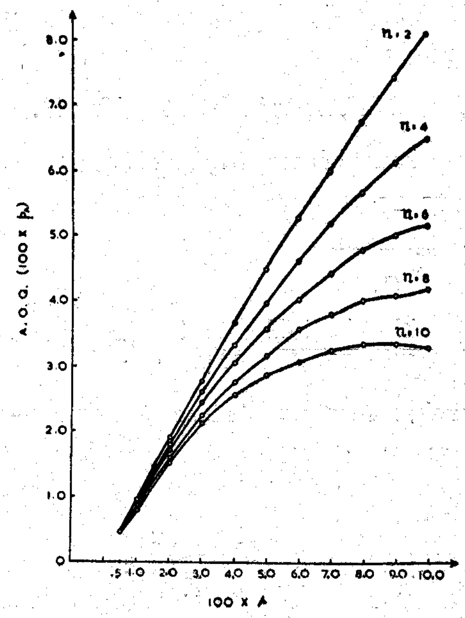


FIG 5

A.O.Q. FOR DIFFERENT SAMPLE SIZES (n) AND PERCENTAGE DEFECTIVE (100xp) FOR N=200 AND c=0.

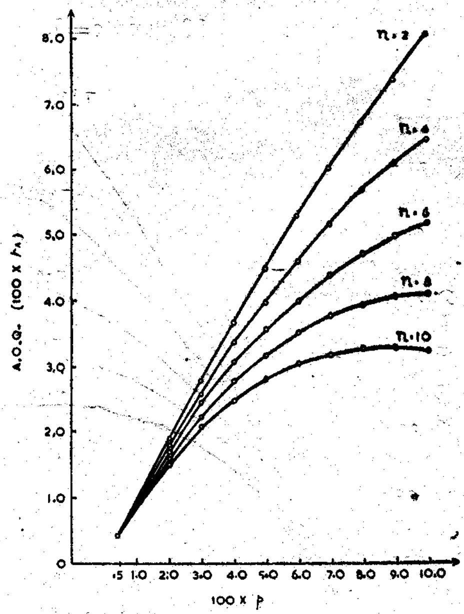


FIG 6

Lot size=N

Sample Size=n

Percentage defectives produced by the machine = 100 p

Allowable number of defects in the sample = c

Expected number of defectives in the lot = Np=M.

If c=O, then the chance of accepting a lot is

$$P_a = \frac{{}^{(N-M)}C_n}{{}^{N}C_n}$$

$$= \frac{(N-M)!\,(N-n)!}{(N-M-n)!\,N!} \sim (1-p)^n$$

I=Expected number of components inspected per lot—

$$= n + (N-n)\quad(1-P_a\ )$$

Average out-going quality

$$P_A = p\ \frac{N-I}{N} = p\ \frac{(N-n)\ P_a}{N}$$

TABLE V

Average Out-going Quality for different lot size (N) and Sample size (n) for varying values of percentage defectives (100 × p)

n / 100×p	N=100					N = 150					N = 200				
	2	4	6	8	10	2	4	6	8	10	2	4	6	8	10
·5	·49	·47	·46	·44	·43	·49	·48	·47	·46	·45	·49	·48	·47	·46	·45
1	·96	·92	·89	·85	·81	·97	·94	·91	·88	·85	·97	·94	·91	·89	·86
2	1·88	1·77	1·67	1·57	1·47	1·90	1·80	1·71	1·62	1·53	1·90	1·81	1·72	1·63	1·55
3	2·77	2·55	2·35	2·16	1·99	2·80	2·60	2·41	2·24	2·08	2·79	2·60	2·42	2·26	2·10
4	3·61	3·26	2·94	2·65	2·39	3·66	3·32	3·02	2·75	2·49	3·65	3·33	3·04	2·77	2·53
5	4·42	3·91	3·46	3·05	2·69	4·47	3·98	3·55	3·16	2·81	4·47	3·99	3·57	3·18	2·84
6	5·20	4·50	3·89	3·37	2·91	5·26	4·58	3·99	3·48	3·03	5·25	4·59	4·02	3·51	3·07
7	5·93	5·03	4·26	3·60	3·05	6·00	5·12	4·37	3·73	3·18	5·99	5·13	4·39	3·76	3·22
8	6·64	5·50	4·56	3·78	3·13	6·71	5·61	4·68	3·91	3·26	6·70	5·62	4·71	3·94	3·30
9	7·30	5·93	4·80	3·89	3·16	7·39	6·04	4·93	4·03	3·29	7·38	6·05	4·96	4·06	3·33
10	7·94	6·30	5·00	3·96	3·14	8·03	6·42	5·13	4·10	3·27	8·02	6·43	5·15	4·13	3·31

Discussions

The object of S.Q.C. is to reduce wastage in all forms by obtaining information periodically on machine setting, tool wearing etc. and thereby controlling the machine to produce components to the given specifications. This is at present done by making observations on five consecutive jobs at regular intervals. Obviously there is a certain amount of uncertainty regarding the number of defectives produced during the intermittent periods. In view of this uncertainty, the products are at present accepted after only cent per cent inspection. Acceptance by such a method involves two separate operations. The cent per cent inspection may not prove to be as efficient as it should be on account of human limitations. Therefore these two operations may be combined into one operation involving S.Q.C.-cum-sampling inspection to reduce the cost of production.

The results of the investigations presented in this paper show that by modifying the sampling procedure of the conventional method so as to include a random sample of four jobs from the intermittent products and one at regular intervals from the machine it is possible to detect lack of control, as efficiently, if not more, than the conventional method. The modified procedure provides information on the quality of the intermittent products also. Therefore by adopting the above method cent per cent stage inspection can be dispensed with.

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