Quality Control in Radio-Tube Manufacture*

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Summary—**Methods of quality control in the radio-tube manufacturing industry are surveyed. Typical mount-inspection service, use of statistical control charts, and sampling procedures are discussed.**

INTRODUCTION

IN THE PAST five years, quality control has firmly established itself in the radio-tube industry. Although the methods are relatively new, the rapid acceptance of quality control shows that it has proved a considerable aid to engineering, production, and inspection. However, statistical quality control in this industry is still only partially developed. With continued developments of statistical methods which are easily applied in the factory, the future of quality control is indeed promising.

SURVEY OF QUALITY CONTROL IN THE RADIO-TUBE INDUSTRY

The over-all view of quality control in this industry is a broad and progressive one, indicating that the proven tools of statistical quality control have been adapted to each manufacturer's requirements for inspection of finished tubes, and are now being extended to cover most phases of production.

The previous statements are based on the current status of quality control as revealed by an industry-wide survey which the author made recently. A quality-control questionnaire was sent to each radio-tube manufacturer listed in the RMA index. The response was encouraging and quite appreciated. Replies were received from about two-thirds of these companies, including the three top producers. A summary of the replies is given in the following statements.

1. All radio-tube manufacturers responding use statistical quality control.
2. These companies all have a quality-control department or section.
3. In general, the quality-control department is a separate group which reports directly to top management.
4. The emphasis is placed much more on manufacturing than on engineering operations. In manufacturing the emphasis is very strong on finished tubes, strong on incoming materials and parts processing, and low on assembly and exhaust. In engineering operations a fair amount of emphasis is placed on specifications and on design.
5. The types of quality-control techniques applied in order of usage are sampling-acceptance plans, control charts, and miscellaneous methods.
6. The extent of these techniques, according to their application, is as follows:

A. Among sampling plans, double sampling is heavily favored. Single sampling and sequential sampling follow in order.

B. Under control charts, the percentage defective is used considerably, while charts for defects per unit rank next, and charts for average and range, and for average and deviation, come last.

C. In the miscellaneous group, the leader is frequency distributions. The assorted techniques include some unique schemes among which are a quality control on testing equipment, a percentage rating for tube-life tests and a grand-lot continuous sampling for finished tubes.

7. The most successful applications have been in control of quality of finished tubes. This conclusion is right in line with the fact that the most emphasis has been placed on finished tubes in the manufacturing operations.

MANUFACTURING VARIATION

There are many applications of quality-control methods in radio-tube manufacture, but all have the same aim—the control of variation. Variation is inherent to the nature of all manufactured products. It is the main function of quality-control engineers to devise and apply methods to stabilize this variation within expected limits.

Immediately the following questions arise: How much variation is normally expected? When does it become excessive? How did it develop?

Statistical quality control supplies answers to the first two questions by indicating probability limits of variation and the trend of quality. Engineering investigation is required to uncover the cause, but statistical quality control can assist even in this direction. Analysis of the production at the point at which the trend started saves the production engineer a great deal of time in identifying the cause of abnormal variation. Also, the production man is spared the waste motion of trying to find a nonexistent cause of product variation when it is within expected limits. *It is evident that these so-called "control limits" are also economic limits.* Their application is made through the quality-control techniques, such as control charts, frequency distributions, or sampling inspections.

QUALITY CONTROL IN OWENSBORO TUBE WORKS

It is felt that a description of the methods used at the Receiving Tube Works of the General Electric Com-

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* Decimal classification: R330×R720. Original manuscript received by the Institute, December 29, 1947; revised manuscript received, October 1, 1948. Presented, 1947 Rochester Fall Meeting, Rochester, N. Y., November 18, 1947.

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pany will portray an adequate picture of how quality of radio tubes is controlled for the joint interest of manufacturer and consumer.

We have centered the body of controls on finished tubes, but also are now attempting to establish sound quality-control procedures throughout the manufacturing operations from purchased materials to shipped tubes—and finally to satisfied customers.

Fig. 1, showing an operations flow chart, will be helpful at this point. This diagram shows the general order of manufacturing operations, together with the main materials and processes from incoming materials to outgoing tubes. Our quality-control functions either have been or are now being developed in the following main divisions of manufacturing; incoming materials; parts and processing; grid making; mount assembly; exhaust; finished tubes; life testing; preshipment inspection; and rework. In addition to these connections with manufacturing our quality-control section has tie-ins with Specifications for setting or re-setting limits; with Design Engineering for analysis of pilot runs, tube development, and evaluation of tube quality in field application; and with Production Engineering for design and analysis of experiments.

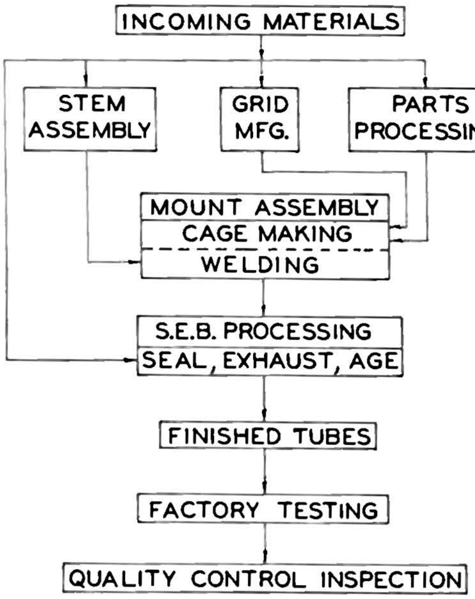

Fig. 1—Operations flow chart.

Our quality-control functions are administered by two groups: Process Quality Control, and Quality-Control Section. As the name implies, the function of the former group embraces all phases of production from incoming materials up to finished tubes. Operations of the latter group begin with finished tubes and extend through the shipped product.

It has been our experience that there is no best place to initiate a new control, since there is no such thing as an isolated quality-control operation. A control method started in one section of manufacturing always shows effects in several others. Although the first point considered for starting control methods is usually at inspection of finished tubes, it is not necessarily the most effective, and certainly not the most economic. The swing is toward maintaining a high quality level throughout production by control methods along the way at key spots. This concept is in direct opposition to the former idea of sorting the good from the bad tubes after manufacture by 100 per cent inspection. Quality cannot be inspected into a tube—quality must be built in.

Quality-Control Methods for Description

Generally, the usual statistical quality-control techniques of sampling-acceptance plans or control charts have been adapted to our local plant personnel. In addition, we have developed some modifications of the usual control methods which have proved quite successful. Two of these methods which will be explained are:

1. Assembly or mount inspection which uses a combination of sampling for attributes and a control chart for percentage defective.
2. Finished-tubes quality control effected by a median control chart and double sampling.

Assembly or Mount Inspection

Utility

Mount inspection is an extremely important operation which is used as a barometer for forecasting the amount of factory shrinkage or tube losses at final testing, and the quality level of finished tubes. Although no absolute relation exists between the results of mount inspection and over-all quality at final test, a sufficiently close correlation for all practical purposes has been established using a time lag of two to three days. A separate correlation is made by tube type, so that final inspection results can be estimated from mount-inspection records. To focus attention on the importance of completely rechecking trays of mounts that showed questionable or inferior quality at inspection, the device of Inspection Service was developed.

Fundamentals of Mount-Inspection Service

Briefly, Inspection Service means sampling inspection for attributes (either OK or defective mounts) without a decision on acceptance or rejection, but merely a visual record of results at inspection. The decision concerning the disposition of the lot is made the responsibility of the Mounting Section. This is probably better psychology than quality control, but in practice it has directed action at the right place and time, thereby disclosing the cause of excessive rejects. This method has also been instrumental in selling the idea that quality control is a guide, not a police force. We have found that the mounting operators are more critical of their own work and quality than inspectors ever have been. A control chart which records the inspection results is kept by the assistant foreman of Mounting for each mounting unit.

Procedure of Mount Inspection Service

All trays of mounts (50 per tray) are subject to mount inspection. A sample of ten mounts or 20 per cent of the number of mounts per tray is carefully inspected visually under a magnifying glass by Mount Inspection personnel. Inspected mounts are judged OK, questionable, or defective. Since the inspection is visual, distinct definitions of questionable and defective mounts have been made to minimize incorrect decisions by inspectors. Defective mounts are defined by tube type as those mounts which, in the opinion of Engineering and Mounting Supervision, are made inoperative by improper assembly. Each defective mount is tagged with a yellow ticket fastened to the exhaust tube, and is counted as a definite cause of mounting shrinkage. A questionable mount is tagged with a white ticket and is not recorded, being considered only a possible cause of mounting shrinkage.

Each tray of mounts, together with its Inspection Record, is turned over to the Mounting Section foremen who make the decision concerning the disposition of that tray of mounts. Disposition may be made in any one of the following ways:

1. Release tray to Exhaust after reworking the defective mounts tagged.
2. Release tray to Exhaust after defective mounts have been repaired and the remainder inspected by the mount unit responsible.
3. Request additional inspection by Mount Inspection after carefully checking over all mounts on the tray.

A daily summary for each mount unit is prepared by inspection personnel showing the number of mounts inspected, number defective, percentage defective, and type of defects. The percentage defective is plotted on a control chart for each mount unit. Analyses of out-of-control points are traced back to the operator responsible by means of the type of defect which shows whether cage-making or welding is the cause.

Use of Mount Inspection Records

Attention is first directed toward a tube type whose over-all control chart shows a point out of control. Next, the charts for all mount units making that type are reviewed to locate the unit or units responsible for excessive rejects. Finally, the summary sheet for type of defects is used to disclose the nature of main rejects. Armed with this specific information daily, the group leader can readily spot the operators whose work is inferior, and thereby correct the mounting problem at its source. However, the operator may not be at fault. The reason for defective mounts may be poor materials or a faulty welder. In any case, the welding machines and the parts are checked.

The inspection records provide a current check on quality. Engineering and Mounting use the records to dispose of the portion of production which is sampled and to reduce defects of a similar kind in future production.

The control charts are the usual so-called "p-charts" using the percentage defective rather than the fraction defective. Fig. 2, showing a mount-assembly control chart of percentage defective, illustrates the nature of these charts. This is a typical control chart, although all figures used in it are hypothetical. A solid line labelled

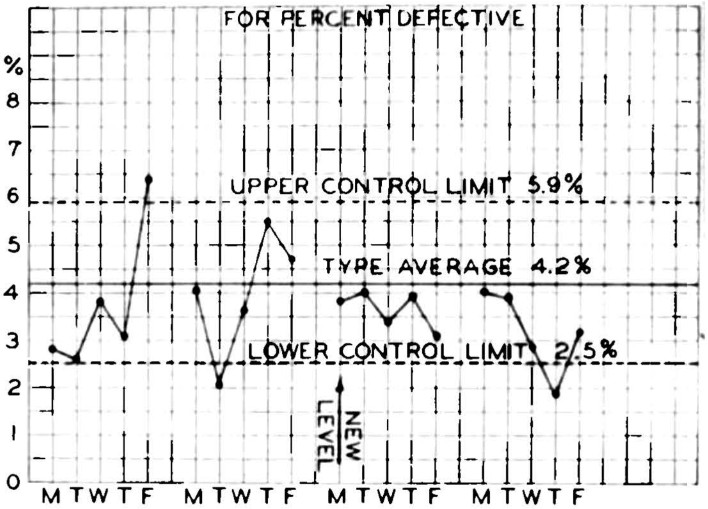

Fig. 2—Mount assembly control chart.

Type Average represents the average percentage of defective mounts for this type during the previous period of two to five weeks. This period depends on the production schedule as well as change in quality level, since the limits for expected variation are a function of the number inspected and a prescribed stability of the percentage defective. The control limits, upper and lower, are shown by dashed lines placed at 3 sigma units distance from the average. The sigma unit for the percentage chart is calculated from the formula $\sigma p = \sqrt{\bar{p}(1-\bar{p})/\bar{n}}$, where σp (the sigma unit) is the standard deviation of the average percentage of defects $\bar{p}$, and $\bar{n}$ is the average number of mounts inspected. For example, the limits for Fig. 2 are determined as follows: The type average $\bar{p} = 4.2$ per cent and the average number of mounts inspected daily $\bar{n} = 1{,}200$ are determined from previous records. Then $\sigma p = \sqrt{0.042 \times 0.958/1{,}200} = 0.0057$ or 0.57 per cent; $3\ \sigma p = 1.7$ per cent. Hence, the control limits are 4.2 per cent ± 1.7 per cent, or 2.5 per cent for the lower control limit (LCL) and 5.9 per cent for the upper control limit (UCL). The spread between limits represents the maximum variation expected from units producing mounts at the average level. Any daily percentage point above the UCL is circled in red to call attention to too many rejects. Likewise, any point below the LCL is circled in green to show better than average work. The 0 per cent points are starred in green as indicative of superior work.

Any noteworthy items that might aid or hinder mounting, thereby causing a decrease or an increase in the percentage of rejects, are marked on the chart at the proper date. Every out-of-control point is definitely explained and a continuous record is built up showing the difficulties encountered and the improvements made. Hence, a close check is kept on each operator, welding machine, and parts. As an illustration, it was noted that on one tube type open heater welds suddenly developed. The group leader traced the defects to a particular operator after it had been determined that the welder and heaters were all right. As a follow-up, a 100 per cent continuity check for heaters was made for a while. As a result of the careful instruction and follow-up by the group leader, this run of defects was practically eliminated as evidenced by subsequent points on the chart "in control."

Out-of-control points that lie near the control limits must be interpreted carefully because constant limits are used for convenience, although these limits are not exactly constant due to two major factors. First, a marked change in the number of mounts inspected will modify the control limits inversely with the square root of the number, as the formula shows. Second, we have noted a weekly cycle established over a year's use of the charts. This weekly cycle is roughly U-shaped, with the lowest percentage of mount rejects on Wednesday and the highest on Monday. The daily index, which represents the percentage ratio of rejects per average Monday, Tuesday, etc., to the weekly average, is: Monday, 106; Tuesday, 102; Wednesday, 93; Thursday, 98; Friday, 101. Since this cycle of rejects correlates inversely with the work-efficiency curves determined by time-study engineers, we feel that the day of the work week is also an important factor, and we modify our interpretation of the quality-control charts accordingly.

The chart also illustrates how a new level of quality is detected by the technique of runs. Beginning at the point indicated by the arrow as "new level" there are ten successive points under the Type Average, although only one falls below the LCL. The hypothesis that these figures are representative of the average level of 4.2 per cent rejects is untenable, since the chance of ten successive sample averages falling on the same side of center is $1/2^{10}$, or roughly 1 in 1,000. Thus, the assumption is made that a new quality level has been established about 3.4 per cent. The newly determined Type Average is 3.4 per cent and its 3-sigma deviation is approximately 1.6 per cent. Hence, the following control chart will have control limts of 3.4 per cent ± 1.6 per cent or LCL 1.8 per cent and UCL 5.0 per cent.

Efficiency of Mount Inspection

An excellent check on the efficiency of Mount Inspection is provided by the 100 per cent factory test made on finished tubes to eliminate inoperatives. Inoperatives consist mostly of two types of defects, shorted elements or open elements. It is recognized that a 20 per cent mount inspection will not disclose all of these defects, but neither will 100 per cent mount inspection eliminate 100 per cent of the defects. During a month's trial of 100 per cent mount inspection on a specific type, analysis of the shorts and opens found at both Mount Inspection and Factory Test showed that 100 per cent inspection of mounts was effective in removing 70 per cent of the shorts, 91 per cent of the opens, and 77 per cent of the inoperatives over-all.

These efficiency figures are very good for a visual inspection of the mounts in question. Further, they are in keeping with actual experience at mount inspection. Obviously, an open element can be observed more easily than a short, due to the very nature of mount structure which often prevents a complete visual examination of a cathode or grid enclosed within a plate.

Results From Mount Inspection

Over an eight months' period the relative percentage of defective mounts has dropped 31 per cent, almost one-third. *This is a real benefit, since the initial figure was not high by any means.* Further, a corresponding improvement of 29 per cent was noted at the exhaust-machine port check. These figures are well reflected in a 28.5 per cent reduction in mounting shrinkage for finished tubes over this period. Aside from the considerable tube savings, the intangible results of improved quality are extremely important. Reduced variation in production from mounting requires fewer changes at the exhaust machine and aging rack. Hence, better uniformity of tubes is obtained, assuring the factory of more production with less spoilage and the customer of high-quality tubes.

QUALITY CONTROL OF FINISHED TUBES

Test Classifications

Finished tubes naturally occupy the center of attention as the end-point of manufacturing operations. Packed production of excellent quality is desirable both from a manufacturing viewpoint and in keeping with the company policy to produce more goods for more people for less.

Three objectives of the quality-control program for finished tubes are dictated by practical requirements. The tubes must be unquestionably operative, must be interchangeable by type, and must evidence good workmanship. Translation of these requirements into characteristics for inspection gives a natural classification of test items. Generally, items for tube operation comprise the inoperatives and the major functional characteristic of the tube such as power output, or transconductance, etc. Tube interchangeability is effected by controlling the electrical test items for center and spread. Good workmanship is maintained by inspection for mechanical test items such as appearance of etch, solder, etc.

We use several quality-control techniques to control these different groups of test items. The "go—no-go" items of operation and the mechanical test items are controlled by sampling inspection by attributes; i.e., either it is or it is not conforming. From this type of test we obtain information about the per cent defective on operation and workmanship. The electrical characteristics are controlled by sampling inspection by variables which shows the central tendency and the spread of each electrical test item, as well as the per cent defective.

Attributes-Acceptance Test

Our sampling inspection by attributes follows standard quality-control practice for double sampling. In double-sampling procedure the results of the first sample indicate whether to accept or to reject the lot at this point, or to test a second sample. If a second sample is required, a decision for acceptance or rejection of the lot is made on the results of the combined samples. Example: An inspection of a production lot per tube type for a certain lot size is performed on a first sample of 150 tubes with acceptance number 3 (maximum of three allowable defectives) and a second sample, if necessary, of 300 tubes with acceptance number 9 for the combined samples. This is the so-called "normal" acceptance which will usually pass lots with less than 1 per cent defectives. This plan has an "average outgoing quality limit" (AOQL) of about 1.6 per cent which means that, with 100 per cent inspection of rejected lots, the average per cent of defectives in the outgoing product will not exceed 1.6 per cent approximately. If the average per cent defective exceeds 1.6 per cent for the last 1,000 tubes in cumulated first samples, the tube type represented is immediately put on "stricter" acceptance which has an AOQL of slightly less than 1 per cent. The stricter-acceptance plan uses the same sample sizes, but smaller acceptance numbers. Thus, for the same lot size as indicated in the previous example of normal acceptance, the stricter acceptance plan is: first sample, 150 tubes with acceptance number 2, and second sample, if necessary, of 300 tubes with acceptance number 4 for the combined samples. This type must remain on stricter acceptance until accumulated first samples totaling 2,000 tubes indicate a process average of 1 per cent or less.

By this method of normal-or-stricter acceptance, we get a twofold protection:

1. The manufacturing section is guarded against rejection of lots of better-than-average quality by a freak sample as long as the production level of quality is high.
2. The customer is protected against the acceptance of lots of worse-than-average quality by the operation of stricter acceptance as soon as production shows questionable quality. Continuation of the stricter plan further assures the customer of excellent quality while the product variation is being corrected.

AOQL Versus Process Average

Let us give some consideration to what the previous 1 per cent and 1.6 per cent AOQL values mean practically. The AOQL is the maximum value which the average quality after inspection can reach regardless of the percentage defective incoming, under a procedure which calls for 100 per cent inspection of rejected lots and elimination of all defects found. This maximum value occurs because more frequent rejections and consequent screening of low-quality lots force the over-all outgoing percentage defective down. Evidently, the production average of rejects must be maintained at a level much lower than the AOQL, in order to minimize rejections which disrupt manufacturing schedules. The process average is usually not more than one-third to one-half of the AOQL for efficient operation in the factory. This means that our tubes must run under $\frac{1}{2}$ per cent to $\frac{3}{4}$ per cent rejects under normal acceptance, and about $\frac{1}{3}$ per cent to $\frac{1}{2}$ per cent rejects under stricter acceptance. The $\frac{1}{2}$ per cent average reject figure is very low and practically can be considered as perfect quality, since even with the sensitive test sets and meters the trained technicians cannot test radio tubes continually with better than $99\frac{1}{2}$ per cent accuracy. Since this acceptance test by attributes holds the production average of defects to approximately the limit of test accuracy, we feel that our acceptance-test control method assures our customers of receiving tubes of very high quality.

Inspection by Variables

However, controlling the percentage of rejects, or tubes out of limits, is only part of the objective of our quality-control program. Tube interchangeability is equally important from the customer's viewpoint. This requires a control of the center and spread of every tube characteristic. Obviously, this is a big job, since some tube types—such as converters and duplex tubes—have over twenty electrical test items. For this purpose we have developed a method of control by variables applied to each characteristic. Much credit for the impetus and direction of this method is due to Walter Kirk, designing engineer, and to James Campbell, quality-control supervisor.

Quality tests for characteristics that are read as continuous variables give a much better picture of how production is going than corresponding tests on a "go—no-go" basis do. At the low level of percentage rejects found in quality-acceptance tests of our tubes, under 1 per cent, a single sample of about 100 tubes is required to test by attributes. However, at the same quality level, testing by variables will give the same required accuracy with less than one-fourth the number of tubes in the sample. The variables method makes use of a twenty-tube sample.

The variables control is a composite of the standard quality-control techniques of control chart and frequency distribution with the extra feature of graphic presentation for comparison of test items. Admittedly, this is a definite hybrid which escapes classification. For the purpose of reference, it will be called the "median-control method."

Stripped to its absolute essentials, the median-control nethod is a daily chart on which the distributions of eadings on the twenty tubes for all test characteristics ire plotted. The center value, or median, of each test n the sample is marked on the distribution. Control imits for the median of each test are predetermined ind marked on the chart. Each median will fall within ts control limits, providing the production is centered iear bogie, the published value of the characteristic. This chart gives a clear picture which is readily interpreted in the light of day-to-day variation, and also hows the tendency for any distribution to wander off bogie seriously or to have excessive spread.

What It Is

An example of the median-control chart is given by Fig. 3. A special form is prepared for each tube type so that all test items are included and their scales along the abscissa are designated. The desired center values (bogies) for all tests are located along the long dashed line, one under another. The short dashed lines mark the control limits for the median of twenty measurements. Solid lines show the tolerance limits for individual tube measurements. Scale values are chosen as a compromise between meaningful intervals and sufficient spread to include tolerance limits. Unequal class intervals are used frequently to include the tolerance limits, and yet make the control interval sensitive. The precision of measurement is considered in selecting the class intervals.

The distribution is obtained by marking an x for each tube reading in the appropriate column. The resulting tabulation of twenty crosses for each test takes the form of a discontinuous frequency distribution for which the number of crosses in each column show the frequency of occurrence of the readings. Thus, the central tendency and spread of each test item are easy to read and to compare with bogie and with other test items.

Since this graphic tally automatically arranges the readings in order of magnitude. it becomes a simple matter to count to the middle x in the array. This middle value, between the tenth and eleventh marks, is the median of the twenty readings. The position of the median is shown by a large red dot placed between the tenth and eleventh crosses. Its approximate value can

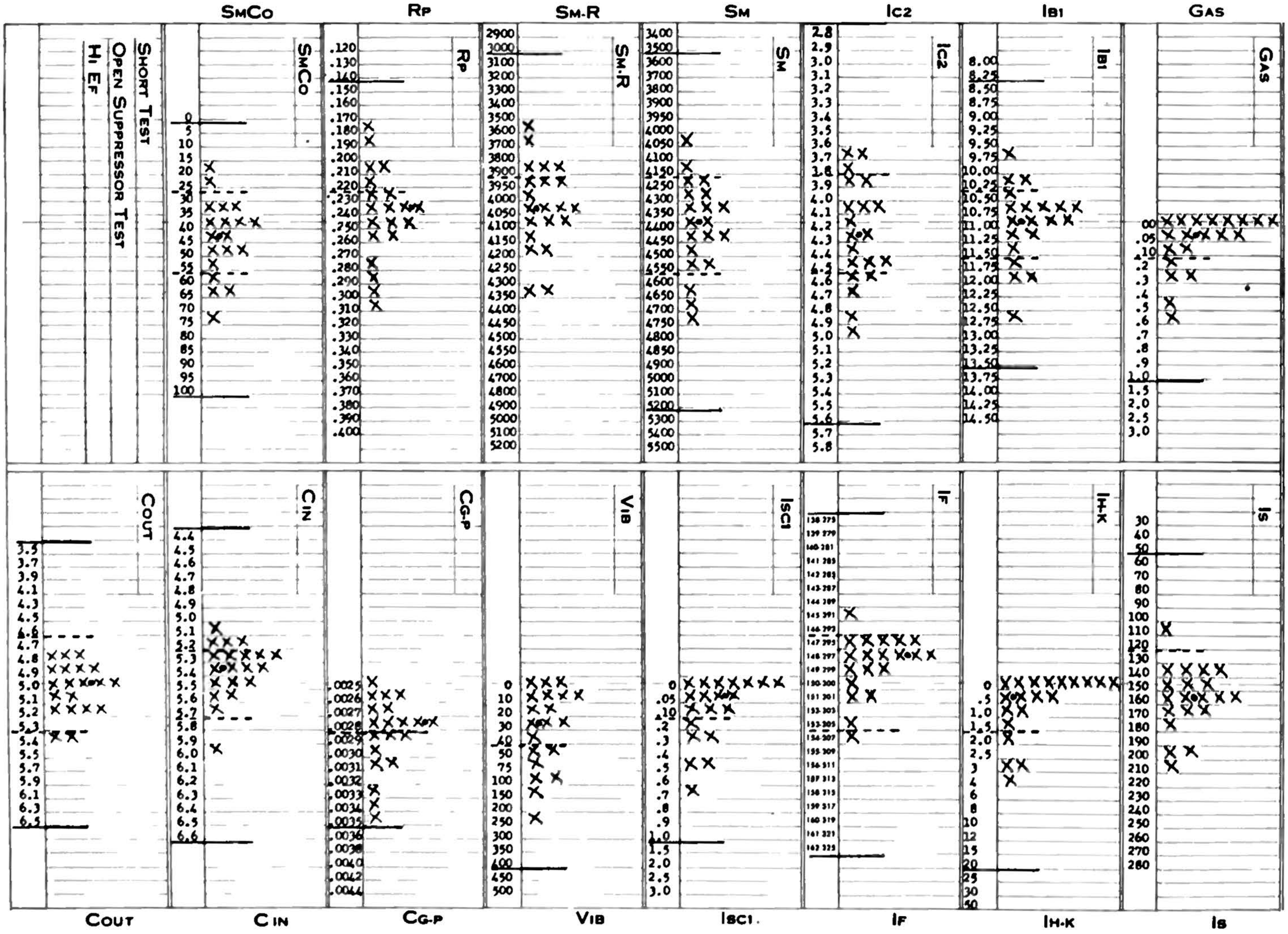

Fig. 3—Median control form.

be observed from the figure at the foot of the column in which it occurs. A more precise value of the median may be obtained by interpolation. The counting procedure locates the median very quickly and without any calculations. A median which falls outside the control limits is an excellent indicator that the production is not well centered. In this case, one of two courses of action is possible:

1. The distribution should be recentered for that characteristic.
2. The limits are not real, meaningful figures, and should be investigated for the purpose of changing.

Use of the median of the distribution is merely a test for stability of the process center, for efficient tube interchangeability.

Why Use The Median?

Analysis of considerable test data indicated that the median represents the center of production effectively for all electrical test items. The reasons for selecting the median rather than the average or the modal value as the indicator are:

The median is practically as good an estimate of central tendency as the average when the distribution is near-normal or approximately symmetric. It is easier for operators to determine, being located by counting rather than by computation. Since it is an "average of position" rather than a mathematical average, the median is not affected by extremely high or low readings which occur as mavericks. Finally, the median is more representative of the production center when the distribution is quite skewed or J-shaped.

Wherever the median of the sample occurs, we know that about 50 per cent of the production readings lie on either side of it, regardless of the shape of the distribution. The only disadvantage of the median is that theoretically it is not so sensitive an indicator as the average, since the median has a sampling variation about 21 per cent greater than that of the average, for samples of twenty.

Control Limits

Control limits which we use are boundaries for permissible variation of the median due jointly to sampling and slight product variations. Theoretically, the entire interval between control limits is due solely to sampling variation, which depends on the product variation, the number of tubes included in the sample, and the degree of assurance desired for control. The control limits we use include an interval which is 5 to 10 per cent wider than the theoretical one. This additional spread permits a small shift in the production center. These modified control limits are obtained by rounding-off upwards the actual standard deviation of each characteristic as much as 10 per cent, or by using an approximation equation for computing control limits.

The theoretical control limits are determined from the relation:

$$\text{Control Limits for Median (CLM)} = \text{Bogie} \pm 3(1.214)\sigma_x/\sqrt{20}, \quad (1)$$

where

Bogie is the desired (published) process center
3 is the number of sigma units
1.214 is the factor which accounts for the extra variation introduced by the median
20 is the sample size
σ_x is the standard deviation of the characteristic.

This relation reduces to

$$\text{CLM} = \text{Bogie} \pm 0.814\sigma_x. \quad (1a)$$

Modified control limits are computed from the approximation equation:

$$\text{CLM (adj.)} = \text{Bogie} \pm 0.1(\text{Maximum} - \text{Minimum}), \text{ where Maximum and Minimum refer to specified tube limits.} \quad (2)$$

This approximation (2) is possible in our control program simply because a definite relation exists between the product standard deviation and the maximum and minimum test limits for individual tubes for most tests, excluding those giving J-shaped distributions. In general, the standard deviation is slightly less than $\frac{1}{8}$ of the spread between these limits. Actually, $8.6\sigma_x = \text{Max-Min}$ is the average relation found for various characteristics investigated. By using this relation in (1a), we obtain the exact equation, $\text{CLM} = \text{Bogie} \pm 0.0947\ (\text{Max-Min})$, which is given an adjustment of 5.6 per cent in spread to yield the approximation (2). This approximation equation is quite handy to use since it permits setting modified control limits directly from the published center and the tube limits. If a single-ended tube limit is specified, twice the half-spread is used in the approximation formula, giving control limits as follows:

$$\begin{aligned} \text{UCLM} &= \text{Bogie} + 0.2\ (\text{Max-Bogie}), \text{ and} \\ \text{LCLM} &= \text{Bogie} - 0.2\ (\text{Bogie-Min}) \end{aligned} \quad (2a)$$

As an example of the calculation of modified Median Control Limits for a normally distributed item, the plate current (Ib_1) test for type 6BA6 is illustrated by Fig. 4, showing distributions and control limits. Our published bogie is 11.0 ma and the JAN limits are 13.5 ma maximum and 8.5 ma minimum. The spread of tube limits is $13.5 - 8.5 = 5.0$. Hence, the variation allowed the median is $\pm 0.1 \times 5.0 = \pm 0.50$. Then the control limits are 11.0 ± 0.5, or 11.5 upper (UCLM) and 10.5 lower (LCLM). These control limits allow the median a variation of ±4.5 per cent from bogie.

For comparison, the exact control limits are given here. The actual standard deviation σ_x was determined from actual readings to be 0.56 ma. Thus, from (1a), the control limits are 11.0 ± 0.46 ma. It is evident that the modified control limits give about 9 per cent more spread than exact control limits in this case.

The test for grid emission (Isc_1) results in a J-shaped distribution as shown on Fig. 4. The upper control limit was determined from readings taken on 400 tubes. These readings gave a median of 0.005 and a deviation

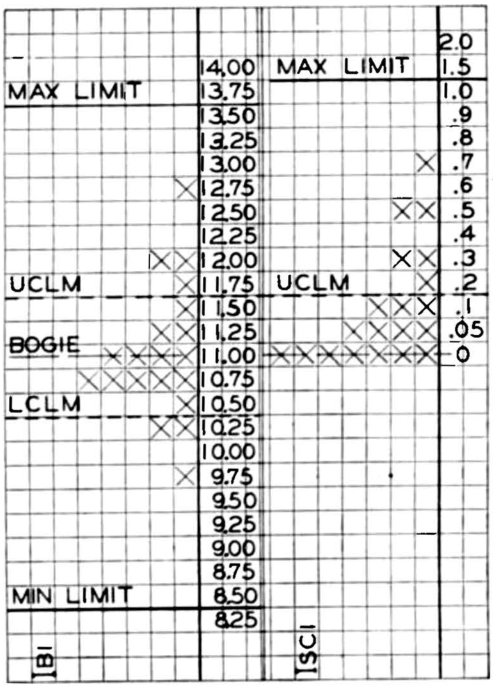

Fig. 4—Distributions and control limits.

of 0.109. Since bogie is 0, (1a) gives the control limit, $ULCM = 0+0.814\ (0.109) = 0.089$, which is used as 0.1 on the chart. The actual limits for the median are $0.005+0.089$, or 0 to 0.094, so the rounding off to 0.1 increases the actual interval about 6 per cent.

Distributions and Tolerances Related to Control Limits

All calculated control limits must be adjusted to fit the design of the chart. Adjustments are a practical necessity, since the continuous variables are plotted as discrete units. Note the unequal intervals used for plotting Isc_1 readings on Fig. 4.

The use of (1a), (2), or (2a) for calculating control limits is determined by the type of distribution for each test characteristic and the type of tolerance limits. Distributions usually are nearly normal, quite skewed, on J-shaped. Tolerance limits may be minimum only, maximum only, or both. Lower, upper, or both control limits are used, in keeping with the tolerance limits.

All test items having J-shaped distributions, such as the characteristics gas, $Ih-k$, Isc_1, and Vib on Fig. 3, have a maximum tolerance limit only since the desired center is zero. The "upper control limits for these items are determined from (1a).

All characteristics that have approximately normal distributions, such as Ib, $Ic2$, Sm, and If on Fig. 3, have both tolerance limits and bogie specified. For these tests the control limits are obtained by using (2).

The other characteristics on Fig. 3 have distributions that are skewed variously in combination with all three types of tolerance limits. Hence, control limits are computed for these tests by using either (1a), (2), or (2a) as experience indicates.

It should be remarked that (1a) can be used to compute control limits for test items having any type of distribution and tolerance limits. The approximation formulas are mentioned only to illustrate a short-cut in setting control limits based on a previous knowledge of the distributions in relation to tolerance limits. Although the exact formula for computation (1a) is completely general, the approximation method may not apply to a similar procedure by another manufacturer, unless his tolerance limits are known to be some fixed multiple of sigma units. We have found that it is better to use the exact expression for control limits on new installations of the method, and developed the short-cuts from subsequent experience with the procedure.

Control of Out-of-Limit Tubes

Centering all electrical characteristics by keeping the median within control limits holds the amount of scrapped production to a minimum, regardless of the type of distribution for any characteristic.

As previously stated, the specification tolerance is about ±4.3 sigma units except for the zero-center test items. For test items which follow the normal distribution, the spread of ±4.3 sigma units includes over 99.9 per cent of the product. For those characteristics which give asymmetric distributions the conditions are met for applying the Camp-Meidell inequality,[1] which shows that at least 97.6 per cent of the product will be within the ±4.3 sigma units.

Those test items which have zero bogies give rise to the J-shaped distributions characterized by "die-away" curves. This type of distribution can be approximated closely by the probability curve $f(x)=1/\sigma e^{-x/\sigma}$. For this distribution, 98.6 per cent of the product is included between 0 and 4.3 sigma units.

It is evident that conformance of the median to the control limits in our procedure controls the out-of-limit tubes to not more than 2 per cent approximately, no matter what the nature of the distribution is.

Use

The information obtained from the median control chart is used correctively and preventatively to re-center an out-of-line test item, rather than to restrict the product on the basis of percentage of defects. Questionable lots are definitely indicated, and the next inspection station is advised in this case. Then decision concerning acceptance or rejection of the questionable lot is based on results of the attributes test made on a much larger sample. A questionable lot is used here as one whose sample shows the median out-of-control limits, but no tubes out of maximum or minimum limits.

As in regular control charts, trends of off-centeredness are indicated by runs of median points on successive charts above or below the center line. Interpretation of the charts by the technique of runs is most useful, since off-centeredness can be shown even when consecutive median points for any one test item fall within control

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[1] $P(\pm t\sigma) > 1-(1/2.25t^2)$.

limits. Two rule-of-thumb criteria used in connection with runs are:

1. Seven successive points on the same side of center give a strong warning that the characteristic is not centered.
2. Two successive points at the control limit on the same side of center give a very strong warning of an off-centered characteristic.

Since the chance of either one of these results happening if the product is well centered is small, the warning signs are quite forceful. Observance of their indications enables the engineers to anticipate and correct a shift in process centers before out-of-control points actually occur.

The main uses of the chart may be summed up as follows:

1. To provide an excellent visual record of how production is running for engineering and management information.
2. To point out uneconomic and unreal specification limits.
3. To indicate further action required on production represented by the sample.
4. To direct action to be taken for centering future production.

The feature of the median control chart in showing visually in advance *what* the coming change is, *which* way it is headed, and *when* it is expected to become serious makes this control method indispensable to management, engineering, quality, and inspection. Further, the results of finished-tubes inspection take on a double significance, being useful not only as a record of how quality has been previously, but also as a barometer to forecast future quality.

KEYNOTE FOR ESTABLISHING GOOD QUALITY-CONTROL METHODS

In each one of the control methods established we have provided for assurance of quality by representative samples and clear-cut inspection methods, as well as for action through definite allocation of duties and responsibilities. Taking a cue from advertising men, who sum up their objective by the letters A, I, D, A, our objective for sound quality-control procedure might be designated by S, I, D, A. The letters have the following significance:

S for Sampling, which must be random and representative of the product;

I for Inspection, which must be so designed and defined that it will consistently indicate good, mediocre, and inferior quality, not merely sort good from very bad;

D for Disposition of the production represented by the sample, thereby providing an excellent spot for cost reduction in shrinkage, reprocessing, and reinspection; and

A for Action to be taken with regard to the quality of future production as indicated by the quality barometer.

By following this compelling directive, we expect continually to provide our customers with a high-quality product.

A Field Survey of Television Channel 5 Propagation of New York Metropolitan Area*

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Summary—**A comprehensive study of the performance characteristics of Du Mont television station WABD, New York, N. Y., embracing a new measuring technique, is discussed. A comparison of theoretical and experimental data is illustrated by photographs and charts indicating receiving conditions within the service area. Pertinent information concerning various interference problems is also considered.**

INTRODUCTION

THIS PAPER covers field measurements made during the period of May through July, 1947, to determine the performance characteristics of television station WABD.

It was felt that a large quantity of spot measurements at an antenna height of 30 feet, when plotted on a true profile of the terrain between receiver and transmitter, would add much general information regarding television transmitting and receiving. It was also decided that

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* Decimal classification: R583.16. Original manuscript received by the Institute, February 6, 1948; revised manuscript received, February 2, 1949. Presented, 1948 IRE National Convention, March 24, 1948, New York, N. Y.

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