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Single Sampling and Double Sampling Inspection Tables

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Introduction

A CONSIDERABLE amount of attention has been given to the application of statistical methods to problems of inspection with emphasis on means for securing certain definite advantages such as reduction in the cost of inspection, reduction in the cost of production by minimizing rejections, and the attainment of uniform quality of manufactured products.[1, 2, 3, 4] This paper presents four sets of sampling inspection tables that have contributed in a notable way to important reductions in such costs and to substantial improvements in control of quality for many characteristics of products used in the Bell System.

Whether sampling may be employed to advantage in place of 100% inspection usually depends, of course, on the purpose for which inspection is made. The sampling tables here presented provide definite procedures for conducting inspections that have certain immediate purposes which are described in some detail. Through their provision for instituting a "screening" inspection whenever quality falls below an acceptable level, the procedures have been found in practice to enforce a program of controlling quality in process as the alternative to high inspection costs.

General Field of Application

The sampling tables presented herewith have been developed for use in consumer or producer inspections of products composed of similar individual articles or pieces, where it is desired to have assurance of a definite degree of conformance to specification requirements with a minimum of expense.

The following paragraphs indicate the general conditions under which the tables are applicable, as well as some of the assumptions involved in their development.

Acceptance Inspection of Lots—The tables are intended for application in inspections whose immediate purpose is to determine the acceptability of individual lots of product.

By a lot will be meant a collection of individual pieces from a common source, possessing a common set of quality characteristics, and offered as a group for inspection and acceptance at one time. These pieces may be parts, partial assemblies or finished units of product. For purposes of inspection, it is desirable that a lot be composed of pieces all of which have been produced under what are judged to be the same essential conditions. To this end, an attempt should be made to avoid grouping together batches of product that are likely to differ from one another in quality, because of differences in the raw materials used, or differences in manufacturing methods or conditions. For inspections made in a manufacturing plant, particularly where production is continuous as with conveyor systems, the time element may often be the deciding factor in fixing the size of lot, and such items as convenience in handling, and stocking or shipping facilities may make it desirable to take an hour's, a half-day's, or a day's production as the quantity to be considered as a lot for inspection purposes.

Quantity Production—Maximum advantage in the use of the tables may be expected for products produced more or less continuously on a quantity basis as distinguished from those produced intermittently on a small scale.

Inspection by "Method of Attributes"—Inspection by the "method of attributes"[5] is assumed. That is, each piece inspected is examined, gauged, or tested to determine whether it does or does not conform to the requirements imposed by specification.

For some characteristics, the requirements may be expressed as numerical limits to be met by the piece, such as maximum and minimum tolerance limits for a dimension, or the minimum tolerance limit for the illumination of a lamp. For others, the requirements may be expressed in less precise terms, and inspection may consist in observing whether the piece does or does not conform to the finish, appearance, color, etc., of say a standard sample, or to the grade of workmanship commonly understood by the phrase "accepted standards of good workmanship."

Nondestructive Inspection—The tables are applicable primarily to quality characteristics that may be inspected by nondestructive means, so that at any time it is entirely practicable to inspect every piece in the lot.

This limitation is a consequence of the inspection procedure adopted in the development of the tables, wherein complete inspection of individual lots is prescribed under certain conditions.

Quality Measured by "Fraction Defective"—The yardstick of quality used in the tables is "fraction defective" (or fraction nonconforming), that is, the ratio of the number of pieces that fail to conform to a specified requirement to the total number of pieces under consideration.

A piece of product that fails to meet the requirement for a characteristic is classed as nonconforming with respect to that characteristic, and for convenience is referred to as defective. Thus, a deviation from a specified requirement or from accepted standards of good workmanship is termed a "defect." If, in the inspection of the "end illumination" of 1000 lamps, it were found that 10 of the lamps had illumination less than the minimum value specified, and the remaining 990 had illumination equal to or greater than the minimum value, we would say that 10 defects were observed, and the lot of 1000 was 1% defective (fraction defective, $p = 0.01$).

Sampling Inspection—The tables are applicable where, under normal conditions, it will be satisfactory to inspect only a portion of the pieces in the lot and to accept the lot if the inspection results for this sample of pieces meet certain criteria. This, in effect, imposes the condition that it is not the purpose of this inspection to make sure that each piece in the lot conforms to the requirements for the characteristic inspected.

Such a situation is common, for example, in the process inspection of component parts of product units, where it may be the purpose of inspection to make reasonably certain that the quality passing on to the next stage is such that no extraordinary effort will be expended on defective parts. This situation is also common for various characteristics of finished units of product, such as some adjustment and dimensional items, items of condition, finish and workmanship that can be covered by a "surface" inspection, as well as items for which 100% inspections or tests have been made previously during process or are to be made in subsequent operations before delivery to the ultimate consumer. Characteristics, whose conformance to specified requirements is of vital importance to the functional quality of the product, and for which 100% inspection is feasible, may not of course be candidates for sampling inspection.

Acceptance Based on Observed Number of Defects—The acceptance criterion used in the tables is a stated allowable number of defects in a sample of stated size.

If only one defect is allowed in a sample of n pieces selected from a lot, then the "Allowable Defect Number" is 1 (referred to as the "Acceptance Number" in an earlier paper[3]). The criterion for the acceptance of a lot is the finding of a number of defects equal to or less than the Allowable Defect Number.

Random Samples—The theory used in the development of the tables assumes that each sample drawn from a lot is a random sample.

A random sample is one selected by a random operation,[6] such as would obtain if a number of physically similar chips, numbered to correspond to the pieces of product under consideration, were thoroughly mixed in a mixing bowl, and a number of them, equal to the desired sample size, were withdrawn to identify which pieces of product should be included in the inspection sample. When, in practice, there are indications that individual lots may be stratified in quality, it is of course best to select a "representative" sample, one such that each stratum or subportion of the lot is proportionately represented by a subsample that is selected by a random operation.

Inspection Procedures

Two distinct methods of inspection are employed—single sampling and double sampling. In single sampling, only one sample is permitted before a decision is reached regarding the disposition of the lot, and the acceptance criterion is expressed as an allowable defect number, c. In double sampling, a second sample is permitted if the first fails, and two allowable defect numbers are used—the first, c_1, applying to the observed number of defects for the first sample alone, and the second, c_2, applying to the observed number of defects for the first and second samples combined. The specific procedures assumed in the development of the tables are as follows:

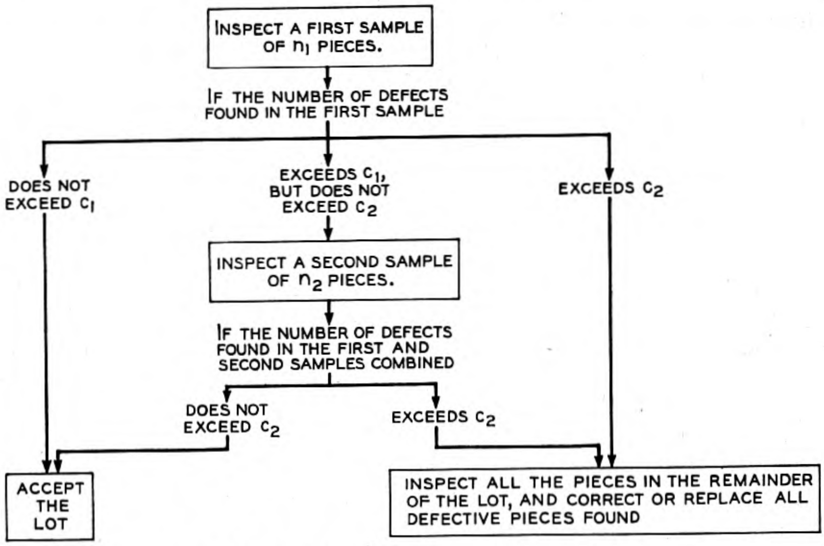

Fig. 1—Double sampling inspection procedure

Single Sampling Inspection Procedure

(a) Inspect a sample of n pieces.
(b) If the number of defects found in the sample does not exceed c, accept the lot.
(c) If the number of defects found in the sample exceeds c, inspect all the pieces in the remainder of the lot.
(d) Correct or replace all defective pieces found.

Double Sampling Inspection Procedure

(a) Inspect a first sample of n_1 pieces.
(b) If the number of defects found in the first sample does not exceed c_1, accept the lot.

(c) If the number of defects found in the first sample exceeds c_2, inspect all the pieces in the remainder of the lot.
(d) If the number of defects found in the first sample exceeds c_1 but does not exceed c_2, inspect a second sample of n_2 pieces.
(e) If the total number of defects found in the first and second samples combined does not exceed c_2, accept the lot.
(f) If the total number of defects found in the first and second samples combined exceeds c_2, inspect all the pieces in the remainder of the lot.
(g) Correct or replace all defective pieces found.

The double sampling procedure can, perhaps, be visualized more easily by reference to Fig. 1.

The theoretical development assumes that the inspection operation itself never overlooks a defect and that all defective pieces found, whether in samples or in the remainders of those lots that are inspected completely, will be corrected or replaced by conforming pieces.* Thus, lots that fail to be accepted by sample are assumed to be completely cleared of defects.

Protection and Economy Features

When a consumer† adopts sampling inspection in place of 100 per cent inspection, he forgoes the opportunity of assuring himself that each piece of product will conform to requirements, and must choose a sampling plan that will provide a degree of protection against defective material that is consistent with his needs. This choice may be narrowed down by choosing some value of allowable per cent defective, and by deciding whether this allowable value should apply to a limited quantity of product such as a lot, or to the general output comprising a more or less steady flow of lots.

Two Kinds of Consumer Protection

For both the single sampling and double sampling procedures outlined above, tables are developed for each of the following two kinds of consumer protection:

(*a*) *Lot Quality Protection*—in which there is prescribed (1) some chosen value of allowable per cent defective in a lot (Lot Tolerance Per Cent Defective), and also (2) some chosen value for the probability of accepting

* While the mathematical solution assumes correction or replacement of defective pieces, it may be expedient practically to reject defective pieces and not replace them. The effect of following this, rather than the assumed procedure, involves differences in results too small to be of any practical consequence for the small values of per cent defective covered by the tables.

† The term "consumer" is used in the general sense of the recipient of the product after the inspection has been completed. This may, of course, be the ultimate consumer or his agent. However, in a manufacturing unit, if one department produces parts for use by a subsequent assembly department, the first department may be considered as the producer and the second, the consumer.

a submitted lot that has a per cent defective equal to the Lot Tolerance Per Cent Defective. This probability is termed the Consumer's Risk.

(*b*) *Average Quality Protection*—in which there is prescribed some chosen value of *average* per cent defective in the product *after inspection* (Average Outgoing Quality Limit, *AOQL*), that shall not be exceeded no matter what may be the level of per cent defective in the product submitted to the inspector.

Single sampling plans employing the first of these two types of protection were developed in an earlier paper.[3] An extension of the underlying theory as applied to double sampling will be given here. Sampling plans employing the second type of protection will likewise be covered for both the single sampling and double sampling procedures.*

The development of the second concept (*AOQL*) in 1927 was the result of a practical need in certain types of manufacturing process inspections, following considerable experience in the application of inspection procedures based on the first concept (Lot Tolerance and Consumer's Risk) which had been developed in 1924. Both have since been used extensively.

Minimum Amount of Inspection

For all of the four inspection plans covered, certain general principles, given in the earlier paper,[3] are used.

For each plan two requirements are imposed—first, that the plan shall provide a specified degree of protection (as covered by (a) or (b) above), and second, that the amount of inspection shall be a minimum for product of *expected* quality, subject to the degree of protection imposed by the first requirement.

The first requirement can be satisfied by a large number of different combinations of sample sizes and allowable defect numbers. The second requirement dictates which one of these combinations shall be chosen, and requires a determination of the value of per cent defective to be normally expected in product submitted to the inspector. This expected value is referred to as the "process average" per cent defective.

For the inspection procedures here adopted, the amount of inspection that will be done *in the long run* is made up of two parts: (1) the number of pieces inspected in the samples and (2) the number of pieces inspected in the remainder of those lots that fail to be accepted by sample. We are

* An adaptation of these concepts to inspection by the method of variables, using the arithmetic mean as an acceptance criterion, is given in a doctorate thesis (Columbia University) by H. G. Romig, "Allowable Average in Sampling Inspection," March 1939, for the case of a normally distributed characteristic that is statistically controlled with respect to the standard deviation.

to find a solution that will minimize the amount of inspection for uniform product* of process average quality.

In single sampling, for each combination of sample size and allowable defect number, there will be a definite probability of exceeding the allowable defect number for a sample drawn from uniform product of process average quality. This probability is termed the Producer's Risk. It represents the chance of not accepting a lot on the basis of the sample findings under these postulated conditions, and for the adopted inspection procedure is thus the chance of inspecting the remainder of the pieces in the lot. The average (expected) amount of inspection per lot then equals the number inspected in the sampled portion plus the product of the Producer's Risk and the number of pieces in the remainder of the lot. This average value can be found for each combination, and the desired solution is obtained by choosing that combination of sample size and allowable defect number for which the average amount of inspection is smallest.

In double sampling, an entirely similar procedure is followed. Here, of course, we must consider the probability of taking a second sample when the first sample fails, and then the probability of failure for the second sample. The overall chance of failure constitutes the Producer's Risk for the complete double sampling plan.

No distinction is made here as to who actually inspects the remainders of those lots that fail to be accepted by sample. Whether the consumer does this inspection, or rejects such lots and thus in effect requires the producer to do it, will be considered immaterial. Interest will be centered only on the total amount of inspection done, recognizing that no matter which agency performs this service the cost will probably be reflected in the overall cost to the consumer.

It should be noted that, in the theoretical developments, the number of defects observed in a sample is not used to "estimate" the quality of the lot. Instead, it serves to indicate what action should be taken—whether the lot should be accepted, subjected to further sampling, or inspected completely—the entire process constituting a set of operations which when repeated over and over again produce a desired end result.

Single Sampling—Lot Quality Protection

The solution for this plan was given in the earlier paper,[3] but will be reviewed briefly since certain of the principles and terms employed will be extended to the other three inspection plans.

* By "uniform product" is meant one produced under statistically controlled conditions such that the probability of producing a defective piece remains constant at some definite value p. The solution thus provides for a minimum of inspection *if* quality is statistically controlled at a per cent defective level equal to the process average per cent defective.

Protection is defined by specifying values of,

(a) Lot Tolerance Per Cent Defective, the allowable per cent defective in a lot.

(b) Consumer's Risk, the probability of accepting a lot of tolerance quality.

If the allowable defect number is c, then the Consumer's Risk is the probability of finding c or less defects in a random sample of n pieces drawn from a lot of N pieces in which the per cent defective is equal to the lot tolerance per cent defective. The tables presented are based on a Consumer's Risk of 0.10, a value found most useful in practice. For this choice, the chances of accepting a lot of worse than tolerance quality are less than 1 in 10.

TABLE 1

SOLUTION FOR A PARTICULAR CASE—SINGLE SAMPLING, LOT QUALITY PROTECTION

n and c Combinations for Lot Size, 1000; Lot Tol. % Def., 3%; Cons. Risk, 0.10		Application to Product having Proc. Av. % Def. = 0.45%				
				Av. No. of Pieces Inspected per Lot		
Sample Size n	Allowable Defect Number, c	Prob. of Acceptance by Sample	Prob. of Inspecting Remainder of Lot (Producer's Risk)	In Sample	In Remainder of Lot	Total
75	0	.713	.287	75	265	340
125	1	.891	.109	125	95	220
*170	*2	.*958	*.042	*170	*35	*205
210	3	.984	.016	210	13	223
250	4	.994	.006	250	5	255
290	5	.998	.002	290	1	291
325	6	.999+	.000+	325	0	325

* Plan involving minimum amount of inspection.

For each value of c, such as 0, 1, 2, etc., there is a unique value of sample size n, such that the probability of finding c or less defects is 0.10. Any of these combinations of n and c will thus provide the desired consumer protection.

Now, for a given value of process average per cent defective, one of these combinations involves a smaller total amount of inspection than any of the others, as illustrated in Table 1. This combination of n and c, which provides the desired solution, gives the most efficient adjustment between the Consumer's Risk and Producer's Risk from the standpoint of minimizing inspection effort. Fig. 2 shows the relationship between these two risks for the conditions given in Table 1.

Curves providing a basis for solutions, such as that given in Table 1, have been published[3] for a Consumer's Risk of 0.10. The appended SL tables (Single Sampling Lot Quality Protection) provide for practical use a complete set of such solutions for lot tolerance values from 0.5% to 10%. Each table is based on a particular value of lot tolerance per cent defective, and each solution, comprising a sample size, n, and allowable defect number, c, covers a range of lot sizes and a range of process average values.* The value of n given in the tables is based on the largest lot size for each lot size range, and the value of c corresponds to the mean lot size in each lot size range and to the mean value of process average in each

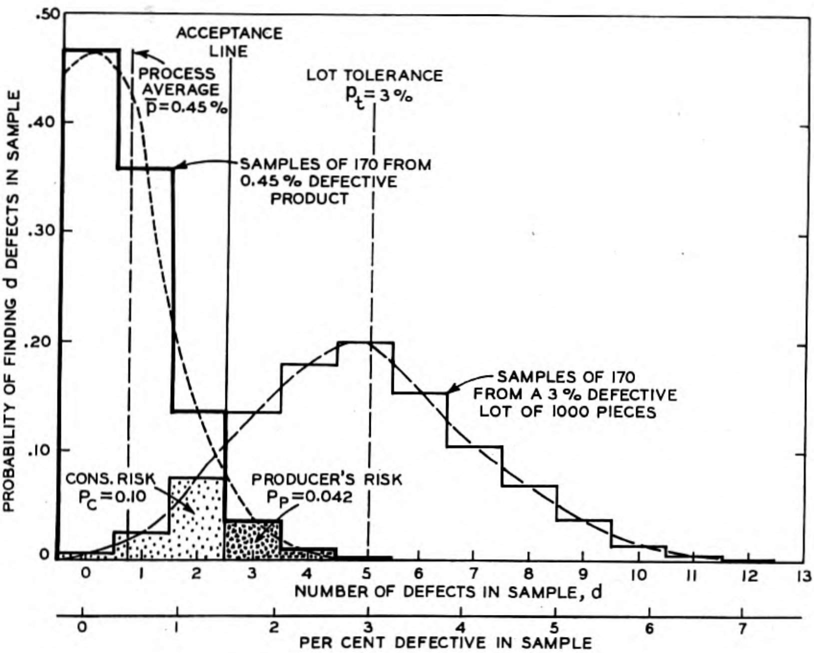

Fig. 2—Relation between consumer's risk and producer's risk

process average range, as indicated in Fig. 3. This procedure is followed for all of the sampling tables presented with this paper.

For the lot quality protection tables for both single and double sampling (SL and DL Tables), these choices are made to insure that, for the lot size range covered, the risk will not exceed the specified value (0.10) and to give *on the average*, for the process average range covered, the most economical plan. For reasons found advantageous in practice, sample sizes for samples of over 50 pieces are given to the nearest 5 units. For

* The extremely small process average range in the first column of each table has been specifically provided for those cases, increasingly common with long continued use of these inspection procedures, where the process average per cent defective is for all practical purposes zero.

extremely large samples, the size is given to the nearest 10. This basis of rounding sample sizes is followed for all of the sampling tables presented with this paper.

On each table are listed values of AOQL to indicate the upper bound to the long term average per cent defective in product after inspection that may be reached under the most adverse conditions.

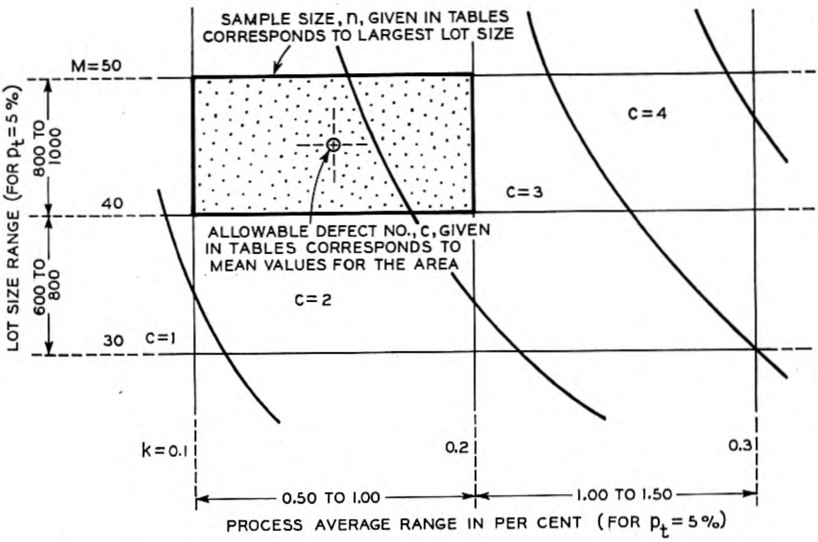

Fig. 3—Basis of choosing the n and c values given in the sampling tables

Double Sampling—Lot Quality Protection

The solution for this plan is carried out in substantially the same way as for single sampling. Protection is defined, as before, by specifying values of lot tolerance per cent defective and Consumer's Risk. As for the single sampling procedure, a Consumer's Risk value of 0.10 is adopted. In double sampling, a lot is given a second chance of acceptance if the first sample results are unfavorable, so that the Consumer's Risk is the sum of two parts: (a) the probability of accepting a lot of tolerance quality for the first sample, and (b) the probability of its acceptance for the second sample, if the first fails. For example, if the two allowable defect numbers, c_1 and c_2, are 1 and 7, respectively, the Consumer's Risk is the sum of the probabilities for all of the following possible ways in which these criteria may be met, as shown in Table 2.

As in the case of single sampling, for any given process average value there are a large number of acceptance criteria—pairs of c_1 and c_2 in this case—for each of which sample sizes may be selected so as to give the desired Consumer's Risk of 0.10, but we wish to choose the combinations of n_1, n_2, c_1 and c_2 that will involve a minimum amount of inspection for product of process average quality. Furthermore, there are an unlimited number of ways of apportioning the Consumer's Risk between the first and second samples for each process average value. This latter factor introduces one more variable factor than will permit of a ready solution by other than trial and error methods, and accordingly an empirical choice has been made on the basis of a complete investigation of the relative practical advantages of several possible choices. Specifically, the solutions are based on an apportionment such that the risk for the first sample is equal to the risk for an independent sample equal in size to the first and second samples

TABLE 2

COMPUTATION OF CONSUMER'S RISK—DOUBLE SAMPLING

No. of Defects: In 1st Sample	No. of Defects: In 2nd Sample	Probability for $n_1 = 88$, $n_2 = 154$ 5% Defective Lot of 1000 pieces	
0		.010	Accepted by 1st Sample
1		.048	
2	0, 1, 2, 3, 4 or 5	.018	Accepted by 2nd Sample
3	0, 1, 2, 3 or 4	.015	
4	0, 1, 2 or 3	.007	
5	0, 1 or 2	.002	
6	0 or 1	.000	
7	0	.000	
Total		.100	Consumer's Risk

combined. The use of an 0.06 risk in determining n_1 and $n_1 + n_2$ for given values of c_1 and c_2 provides a Consumer's Risk of almost exactly 0.10 over a considerable portion of the field covered by the tables, though in some areas a value as low as 0.056 is necessary. The "minimum" solutions for double sampling are, of course, conditioned by this choice.*

As shown in the Appendix, paired values of c_1 and c_2 that satisfy the condition of minimum inspection depend on (1) the tolerance number of defects for a lot, and (2) the ratio of the process average to the lot tolerance

* Study of the effect of different apportionments of the Consumer's Risk on the average amount of inspection for product of process average quality indicates that considerably more than half of the 0.10 risk should be taken for small process average values and that less than half should be taken for large process average values. The single choice that was made provides a solution that closely approximates the true minimum over a large portion of the tables, and was considered justified by the great saving in computation effort. With this choice, the average amount of inspection per lot does not in general exceed the true minimum by more than 3 to 5% although for extremely low process average values the excess may be as much as 15%.

per cent defective. These values have been determined by trial and error and form the basis of the c_1 c_2 zones given in Fig. 7 of the Appendix.

The appended DL tables (Double Sampling Lot Quality Protection) provide a complete set of solutions using paired values of c_1 and c_2 determined from Fig. 7. These tables are constructed on the same principles as the single sampling tables described above.

Single Sampling—Average Quality Protection

The solution for this plan considers the degree to which the entire inspection procedure screens out defects in the product submitted to the inspector. Lots accepted by sample undergo a partial screening through the elimination of defects found in samples. Lots that fail to be accepted

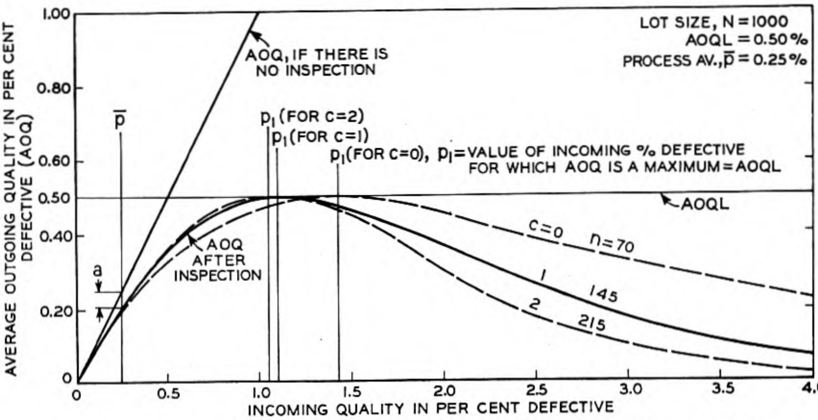

Fig. 4—Relationship between incoming quality, outgoing quality and *AOQL*

by sample are completely cleared of defects. The overall result is some average per cent defective in the product as it leaves the inspector, termed the "average outgoing quality," which depends on the level of per cent defective for incoming product and the proportion of total defects that are screened out.

The solid curve of Fig. 4 shows how the average outgoing quality varies for different values of incoming quality for a lot size of $N = 1000$, a sample size of $n = 145$ and an allowable defect number of $c = 1$. The curve is based on the concept of incoming product of uniform quality treated mathematically as an homogeneous universe. As the level of incoming per cent defective gets higher and higher, more and more lots are completely inspected. In turn, the average outgoing per cent defective increases, reaches a maximum value (0.50%, in Fig. 4), and then falls off as a result of rapid increase in the amount of screening. This maximum value is termed the average outgoing quality limit (AOQL).

For this plan, protection is defined by specifying a definite value of AOQL. For each possible value of c such as 0, 1, 2, etc. there is a unique value of sample size that will give the specified value of AOQL. This is illustrated in Fig. 4. Any of these combinations of n and c provide the desired protection, and as for the lot quality protection plans, we choose that combination of n and c that gives a minimum amount of inspection for uniform product of process average quality.

In the Appendix it is shown that the allowable defect number satisfying the condition of minimum inspection is dependent on two factors (1) the number of defects per lot for process average quality, and (2) the ratio of the process average per cent defective to the AOQL value. Fig. 9 of the Appendix defines zones of allowable defect numbers for which the average amount of inspection is a minimum.

The appended SA tables (Single Sampling Average Quality Protection) provide a complete set of minimum inspection solutions for AOQL values from 0.1% to 10%. The choice of n and c for each solution in the tables is based on the procedure of Fig. 3 (using c zones given by Fig. 9), to insure that the AOQL value over the area in question will not exceed the specified value and to give on the average for this area the most economical plan.

On each table are given values of lot tolerance per cent defective for a Consumer's Risk of 10%. These values are found useful in practice since it is often desirable to know the degree of protection afforded to individual lots.

Double Sampling—Average Quality Protection

The solution for double sampling differs from that for single sampling in that no simple relation has been found that gives directly the sample sizes that will result in a specified value of AOQL for a given lot size. This, together with the lack of simple relations for determining the choice of allowable defect numbers (c_1 and c_2) that provide a minimum solution, has necessitated an empirical choice, the consequence of which is much the same as for the similar action taken in the solution of the problem of double sampling for lot quality protection.* Specifically, the interrelationship between n_1, n_2, c_1 and c_2 used in the latter case for a 10% Consumer's Risk is used again here and the solutions given are consequently minima that are contingent on this choice. An extensive trial and error investigation, using the underlying theoretical relations, leads to the conclusion that the degree to which the solutions given in these tables approach the true minima, is of the same order of magnitude as for the double sampling tables for lot quality protection.

The method of solution is essentially that illustrated by example in the

* See footnote page 11.

Appendix. The pairs of values of c_1 and c_2 used in the solution are confined to those given in Fig. 7 of the Appendix. For each of these pairs of c_1 and c_2, sample sizes are determined, using the above mentioned relationship to a 10% Consumer's Risk, that will give the desired AOQL value. Of these several sets of c_1, c_2, n_1 and n_2, that one is selected which involves the least amount of inspection.

The appended DA tables (Double Sampling Average Quality Protection) provide a complete set of such minimum inspection solutions for AOQL values from 0.1% to 10%. The choice of n_1, n_2, c_1 and c_2 for each solution in the tables is based on the general procedure of Fig. 3 (using the zones given in Fig. 7) to insure that the AOQL value over the area in question will not exceed the specified value and to give on the average for this area the most economical plan.

As for the single sampling AOQL tables there are listed values of lot tolerance per cent defective for a Consumer's Risk of 10%. In this case, these values have entered directly into the solution as explained above.

Application of Sampling Tables

In the above description of the sampling tables, attention has been confined to the inspection of a single characteristic. The tables are, however, equally applicable to a group of characteristics considered collectively provided defects with respect to these characteristics are of essentially the same seriousness and may, therefore, be considered additive. When such application is made, the per cent defective values given in the tables embrace all such defects collectively, and since more than one defect may occur on a single piece of product, any allowable defect number listed in the tables should, by agreement, be considered either as a "number of defective pieces" or as a "number of defects."

The sampling tables based on lot quality protection (Tables SL and DL) are perhaps best adapted to conditions where interest centers on each lot separately—for example, where the individual lot tends to retain its identity either from a shipment or a service standpoint. They have been found particularly useful in inspections made by the ultimate consumer or his purchasing agent for lots or shipments purchased more or less intermittently.

The sampling tables based on average quality protection (Tables SA and DA) are especially adapted for use where interest centers on the *average* quality of product after inspection rather than on the quality of each individual lot and where inspection is, therefore, intended to serve, if necessary, as a partial screen for defective pieces. The latter point of view has been found particularly helpful, for example, in consumer inspections of continuing purchases of large quantities of a product, and in manufacturing process inspections of parts where the inspection lots tend to lose their identity by merger in a common storeroom from which quantities are withdrawn on order as needed.

Other things being equal the average amount of inspection for double sampling is less than for single sampling. Fig. 5* gives a direct comparison for the lot protection tables (SL and DL). The saving obtained by using double instead of single sampling is greatest for large lot sizes and low process averages. Over the area of the tables found most useful in practice (percentage inspection less than 25 or 30%), the saving generally exceeds 10% and may be as great as 50%. The saving that results from using the double sampling instead of the single sampling AOQL tables (SA and DA) is of the same order of magnitude and may be estimated roughly from Fig. 5 by using the associated lot tolerance values listed in the AOQL tables, for a chosen set of AOQL, lot size, and process average values. While the amount of inspection is a major cost item, other costs associated with double

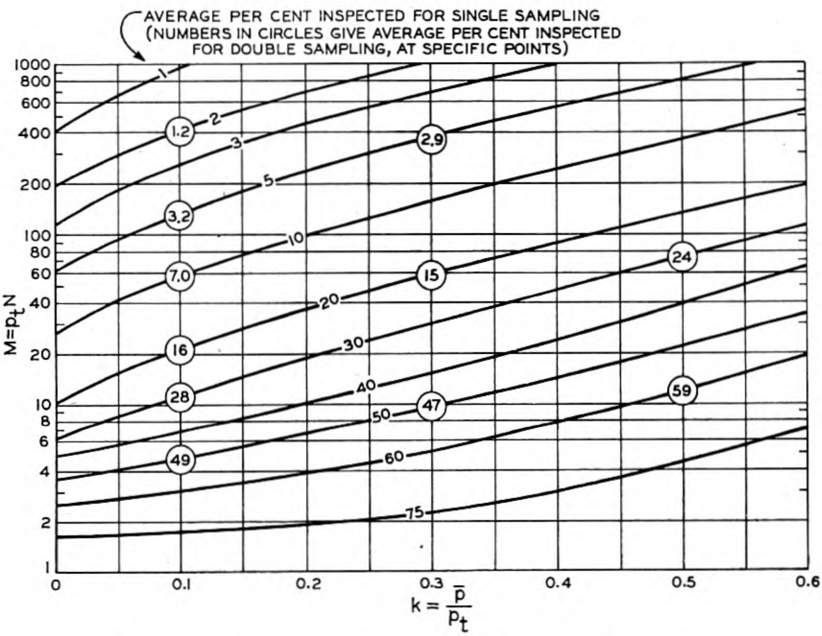

Fig. 5—Relative amount of inspection, double and single sampling

* The curves and figures on this chart should be regarded as approximate. The mathematical relations involved are such that there exist unique values to be plotted on the M–k plane when certain approximate probability equations, referred to in the appendix, are employed in the solution, but not when exact equations are employed.

sampling frequently throw the advantage to single sampling. Among the added costs are those associated with interruption of work, extra handling of product, etc. incidental to the selection of an independent second sample. Aside from these considerations, it is common to find a psychological preference for double sampling. This appears to be associated with the tendency to look with favor on any plan that permits a "second chance" to make good, particularly when an initial failure is of a marginal character.

Given a specific problem of replacing 100% screening inspection by a sampling inspection, the first step is to decide on the type of protection desired, to select the desired limit of per cent defective—lot tolerance or AOQL value—for that type of protection, and to choose between single and double sampling. This results in the selection of one of the appended tables. The second step is to determine whether the quality of product is good enough to warrant the introduction of sampling. The economies of sampling will be realized, of course, only insofar as the per cent defective in submitted product is such that the acceptance criteria of the selected sampling plan will be met. A statistical analysis of past inspection results should first be made, therefore, in order to determine existing levels and fluctuations in the per cent defective for the characteristic or the group of characteristics under consideration. This provides information with respect to the degree of control of quality as well as the usual level of per cent defective to be expected under existing conditions. From this and other information is to be determined a value for the "process average" per cent defective that should be used in applying the selected sampling table, if sampling is to be introduced.

The determination of the process average per cent defective is an engineering problem, essentially one of prediction, in which use is made of all available information—knowledge of manufacturing conditions past and anticipated, judgment as to what periods of the past, if any, may be taken as representative of the future, results of analyses showing uniformity and level of per cent defective for such past periods, etc. The application of "control chart" analysis[1,7] to past data is especially recommended.* If

* The following procedure has been used with general success. Tabulate the observed values of fraction defective, p, for at least 25 immediately preceding lots (or groups of lots, say by days or weeks, if p is very small), excluding lots that are nonrepresentative for known reasons, and apply the control chart test to the observed values of p. If the data show statistical control, and if there are grounds for believing that future manufacturing conditions will be essentially the same as those of the past, use the average of the observed values of p as the process average value, $\bar{p}$. If lack of statistical control is shown, replace values of p that are beyond $\pm 3\sigma$ control limits[1, 7] by values corresponding to $\pm 2\sigma$ control limits (where $\sigma = \sqrt{\bar{p}\,(1 - \bar{p})/n}$). Compute a corrected average value of p, in which the individually corrected values are used in place of the corresponding observed values. Unless other conflicting evidence predominates, use this corrected value as a tentative process average value, until such time as a revision appears warranted on the basis of new evidence.

the process average value thus determined is well within the range of process average values listed in the selected sampling table then sampling can advantageously be introduced. If it is beyond this range, it would be quite satisfactory from a protection standpoint to use the last process average column of the selected table but the sampling plan itself would force rejection or a screening inspection of such a large proportion of the lots that the introduction of sampling probably would not pay. If the process average value is but poorly estimated, the amount of inspection will be somewhat larger than need be but the specified degree of protection will still be realized. Where there is uncertainty it is better to overestimate than to underestimate the process average value since, for a given magnitude of error, a lesser amount of excess inspection will thereby be incurred.

It should be especially noted that the tables may be safely applied whether quality is well controlled or not. If, for example, the usual level of per cent defective is well within the range of process average values listed in the selected table but individual lots are frequently well outside this range, the sampling plan will usually permit acceptance by sampling while quality is good but force 100% inspection when it is bad.

Experience with the tables indicates that where the procedures are used by a manufacturer within his own organization or by a consumer who rejects lots that are not accepted by sample, the general plan forces corrective action whenever quality becomes poorer than normally expected. The attendant increase in overall inspection costs provides a compelling argument, in a language well understood by all, for determining the cause of trouble in the manufacturing process and for instituting measures for eliminating it as speedily as possible. Thus, while the inspection procedures have as their immediate purpose the provision of a curative technique whereby product already made is cleared of abnormal proportions of defects, they are found by experience to enforce the adoption of a preventive technique—one that exerts economic pressure to track down and remove causes of abnormal quality variations, thus enforcing control of quality in the process and assuring better health in the product of tomorrow. Because of these factors the long term average outgoing per cent defective may rarely be expected to exceed half the AOQL value associated with the inspection plan in use.

Quality control is achieved most efficiently, of course, not by the inspection operation itself but by getting at causes.[6] It may be expedited by carrying out regular statistical control analyses of the cumulative results of sampling inspection—preparing quality control charts[1,7] for "per cent defective" with subgrouping of results on a lot-by-lot, a day-by-day, or a week-by-week basis—and making the findings available to those directly responsible for manufacturing processes.

Where a steady supply of product is offered for acceptance on a lot-by-lot basis, the use of these sampling procedures and tables, together with continuing control chart analyses of the inspection results obtained therefrom, have been found to provide a balanced and economical inspection program.

Acknowledgment

Work underlying the development and application of these tables has been contributed by many individuals in the Bell Telephone Laboratories and the Western Electric Company. The authors here express their indebtedness to these associates, particularly to those in the Western Electric Company who cooperated in the early development of the technical features of the plans and worked out shop procedures for use in their application. The laborious work of computing and preparing the tables in their final form was carried out by Miss Mary N. Torrey and Miss Ruth A. Bender—we wish to express our appeciation to them for their efforts to make the tables as free from error as possible.

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MATHEMATICAL APPENDIX

Fundamental Probability Formulas

The mathematical probabilities used in the solutions are based on equations corresponding to one or the other of the following two sets of conditions:

(a) Sampling from a finite universe.

(b) Sampling from an infinite universe.

In relations involving the determination of the Consumer's Risk, the sample is considered as a sample from a lot of a finite number of pieces and probabilities are correspondingly based on (a). For all other relations in the solutions—involving the determination of the Producer's Risk, the determination of the average number of pieces inspected per lot, etc.— the sample is considered as a sample from the general output of product—a source of supply—and probabilities are correspondingly based on (b).

Finite Universe

The probability of finding m defects in a random sample of n units drawn from a finite universe (lot) of N pieces in which the number of defects is $M = pN$, is given exactly by

$$P_{m,n,N,M} = \frac{1}{C_n^N} C_{n-m}^{N-M} C_m^M. \tag{1}$$

When $p < 0.10$, a good approximation to (1) is given by the $m + 1$st term of the expansion of the binomial, $\left[\left(1 - \frac{n}{N}\right) + \frac{n}{N}\right]^M$,

$$P_{m,n,N,M} \approx P_{m,\frac{n}{N},M} = C_m^M \left(1 - \frac{n}{N}\right)^{M-m} \left(\frac{n}{N}\right)^m. \tag{1'}$$

When $p < 0.10$ and when $\frac{n}{N} < 0.10$, a good approximation to (1) is given by the $m + 1$st term of the Poisson exponential distribution,

$$P_{m,n,N,M} \approx P_{m,pn} = \frac{e^{-pn}(pn)^m}{m!}. \tag{1''}$$

These are general equations applicable for any fraction defective, p, but are used in this paper only for the specific case where $p = p_t$, the lot tolerance fraction defective, and where in turn $M = p_tN$.

The Consumer's Risk P_C, is the probability of meeting the acceptance criteria—c, for single sampling, and c_1 and c_2, for double sampling—in samples drawn from a lot of N pieces containing exactly the tolerance number of defects $M = p_tN$.

For single sampling,

$$P_C = \sum_{m=0}^{m=c} P_{m,n,N,M} \quad (\text{when } p = p_t). \tag{2}$$

For double sampling,

$$\begin{aligned} P_C = \sum_{m=0}^{m=c_1} P_{m,n_1,N,M} &+ P_{c_1+1,n_1,N,M} \sum_{m=0}^{m=c_2-c_1-1} P_{m,n_2,N-n_1,M-c_1-1} \\ &+ P_{c_1+2,n_1,N,M} \sum_{m=0}^{m=c_2-c_1-2} P_{m,n_2,N-n_1,M-c_1-2} + \cdots \\ &+ P_{c_2,n_1,N,M} P_{0,n_2,N-n_1,M-c_2} \quad (\text{when } p = p_t). \end{aligned} \tag{3}$$

Values of P_C in equations (2) and (3) are given approximately by substituting $P_{m,\frac{n}{N},M}$ or $P_{m,pn}$ for $P_{m,n,N,M}$ throughout, in accordance with equations (1′) and (1″), using $p = p_t$. The resulting equations will be referred to as (2′), (2″), (3′) and (3″), respectively. (2′) (2″) (3′) (3″)

Infinite Universe

The probability of finding m defects in a random sample of n pieces drawn from an infinite universe (general output of uniform product) in which the fraction defective is p, is given exactly by the $m + 1$st term of the expansion of the binomial, $[(1 - p) + p]^n$,

$$P_{m,n,p} = C_m^n(1 - p)^{n-m} p^m. \tag{4}$$

When $p < 0.10$, a good approximation to (4) is given by the $m + 1$st term of the Poisson exponential distribution,

$$P_{m,n,p} \approx P_{m,pn} = \frac{e^{-pn}(pn)^m}{m!}. \tag{4'}$$

The probability of meeting the acceptance criteria—c, for single sampling, and c_1 and c_2 for double sampling—in samples drawn from submitted product having a fraction defective of p, is termed the probability of acceptance, P_a. For single sampling,

$$P_a = \sum_{m=0}^{m=c} P_{m,n,p}. \tag{5}$$

For double sampling,

$$P_a = \sum_{m=0}^{m=c_1} P_{m,n_1,p} + P_{c_1+1,n_1,p} \sum_{m=0}^{m=c_2-c_1-1} P_{m,n_2,p} + P_{c_1+2,n_1,p} \sum_{m=0}^{m=c_2-c_1-2} P_{m,n_2,p} + \cdots + P_{c_2,n_1,p} P_{0,n_2,p}. \tag{6}$$

Values of P_a in equations (5) and (6) are given approximately by substituting Poisson exponential probabilities, $P_{m,pn}$, for $P_{m,n,p}$ throughout in accordance with equation (4′). The resulting equations will be referred to as equations (5′) and (6′), respectively. (5′) (6′)

The Poisson exponential approximation is used in subsequent paragraphs wherever probabilities in sampling from an infinite universe apply. Tables[8] and charts[9, 10] are available from which these probability values (single term values, or cumulative values for "c or less defects") may be read directly.* Figure 6 gives a cumulative probability chart for the Poisson exponential distribution, which is widely useful in the solutions involved.

The Producer's Risk, P_P, is the probability of failing to meet the acceptance criteria in samples drawn from product of process average ($\bar{p}$) quality. Using $p = \bar{p}$ in equations (5) and (6),

$$P_P = 1 - P_a \text{ (when } p = \bar{p}). \tag{7}$$

Lot Quality Protection

Single Sampling

Given: Lot Size (N), lot tolerance fraction defective (p_t), Consumer's Risk ($P_C = 0.10$), process average fraction defective ($\bar{p}$).

* In this work use was made of more complete tables, giving cumulative probabilities for pn values up to 100, prepared by Office of the Switching Theory Engineer, Bell Telephone Laboratories.

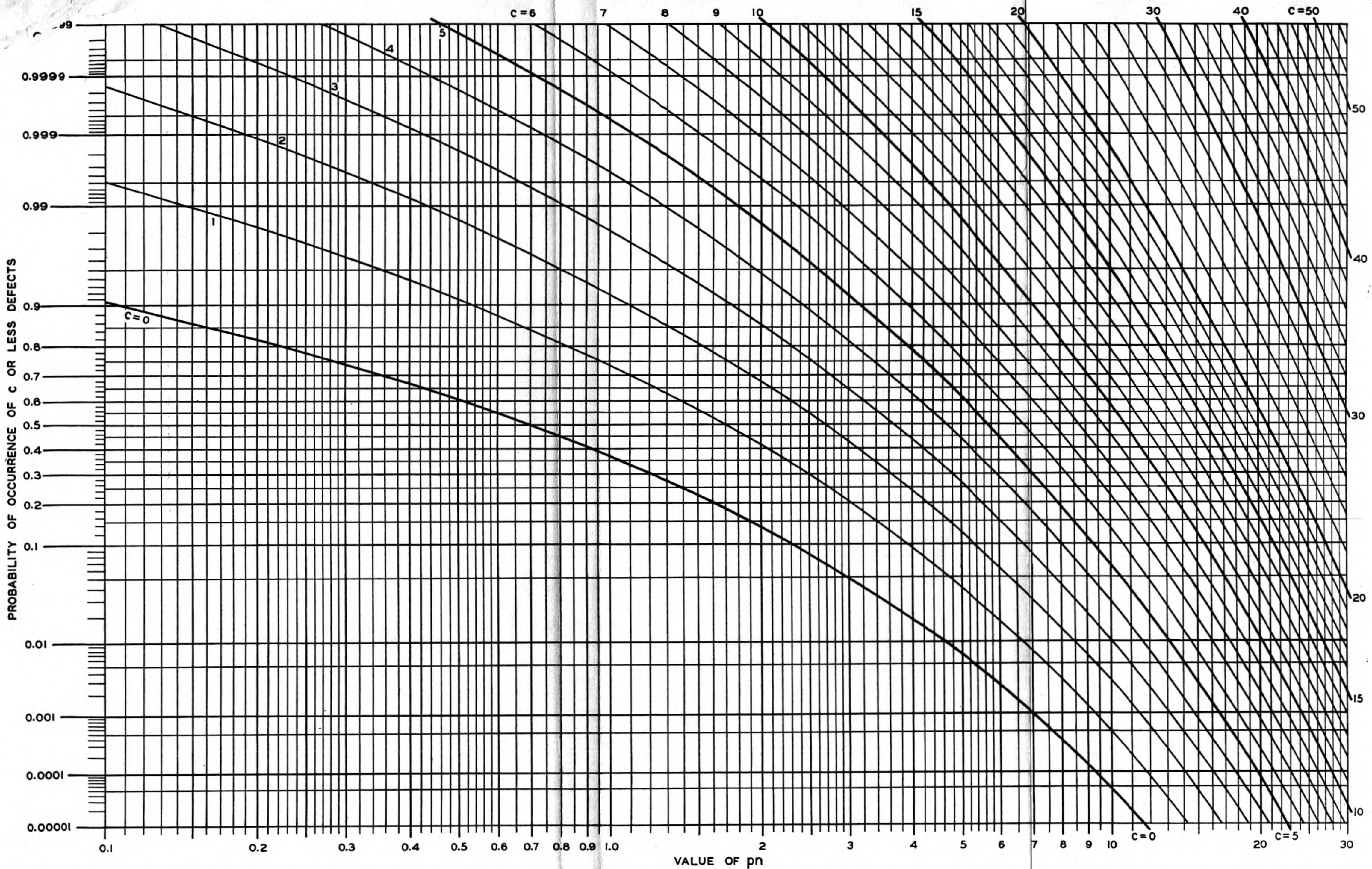

Fig. 6—Cumulative probability curves—Poisson exponential. For determining probability of occurrence of c or less defects in a sample of n pieces selected from an infinite universe in which the fraction defective is p (A modification of chart given by Miss F. Thorndike *B. S. T. J.*, October 1926).

To find: Values of n and c that will minimize $\bar{I}$, the average number of pieces inspected per lot for product of process average ($\bar{p}$) quality.

The average number of pieces inspected per lot (I) for product of p quality is given by

$$I = n + (N - n)(1 - P_a), \tag{8}$$

where P_a is given by equation (5). Substituting the approximation of equation (5′) gives

$$I = n + (N - n)\left(1 - \sum_{m=0}^{m=c} P_{m,pn}\right). \tag{8'}$$

$\bar{I}$ is a specific value of I and is obtained from equation (8′) by using $p = \bar{p}$. The value of c that makes $\bar{I}$ a minimum may be read from the chart of Fig. 2 of the previous paper,[3] which uses coordinates of $M = p_t N$ and $k = \dfrac{\bar{p}}{p_t}$ and is based on $P_C = 0.10$. The corresponding sample size n may be read from Fig. 3 of the previous paper[3] (based on equation (2′)), from Fig. 6 if appropriate, or by direct computation from equation (2), (2′), or (2″), using $P_C = 0.10$.

Double Sampling

Given: Lot size (N), lot tolerance fraction defective (p_t), Consumer's Risk ($P_C = 0.10$), process average fraction defective ($\bar{p}$).

To find: Values of n_1, n_2, c_1, c_2 that will minimize $\bar{I}$.

The average number of pieces inspected per lot (I) for product of p quality is given by

$$I = n_1 + n_2\left(1 - \sum_{m=0}^{m=c_1} P_{m,pn_1}\right) + (N - n_1 - n_2)(1 - P_a), \tag{9}$$

where P_a is determined from equation (6′).

$\bar{I}$ is a specific value of I and is obtained from equation (9) by using $p = \bar{p}$. As outlined on page 11, the pair of values of c_1 and c_2 that makes $\bar{I}$ a minimum is determined by trial and error, conditioned by the choice that the Consumer's Risk of 0.10 be divided between the first and second samples so that the "initial risk" for the first sample is 0.06. Figure 7 gives such pairs of c_1, c_2 values, corresponding to values $M = p_t N$ and $k = \dfrac{\bar{p}}{p_t}$.

For the selected apportionment of Consumer's Risk, the sample sizes n_1 and n_2 may be determined approximately from the following equations, which are based on equation (1′),

$$\left.\begin{aligned} 0.06 &= \sum_{m=0}^{m=c_1} C_m^M \left(1 - \frac{n_1}{N}\right)^{M-m} \left(\frac{n_1}{N}\right)^m, \\ 0.06 &= \sum_{m=0}^{m=c_2} C_m^M \left(1 - \frac{n_1 + n_2}{N}\right)^{M-m} \left(\frac{n_1 + n_2}{N}\right)^m. \end{aligned}\right\} \tag{10}$$

Figure 8 based on these equations gives $p_t n_1$ and $p_t(n_1 + n_2)$ values associated with c_1 and c_2 for a given value of $M = p_t N$, and thus provides the desired values of n_1 and n_2.

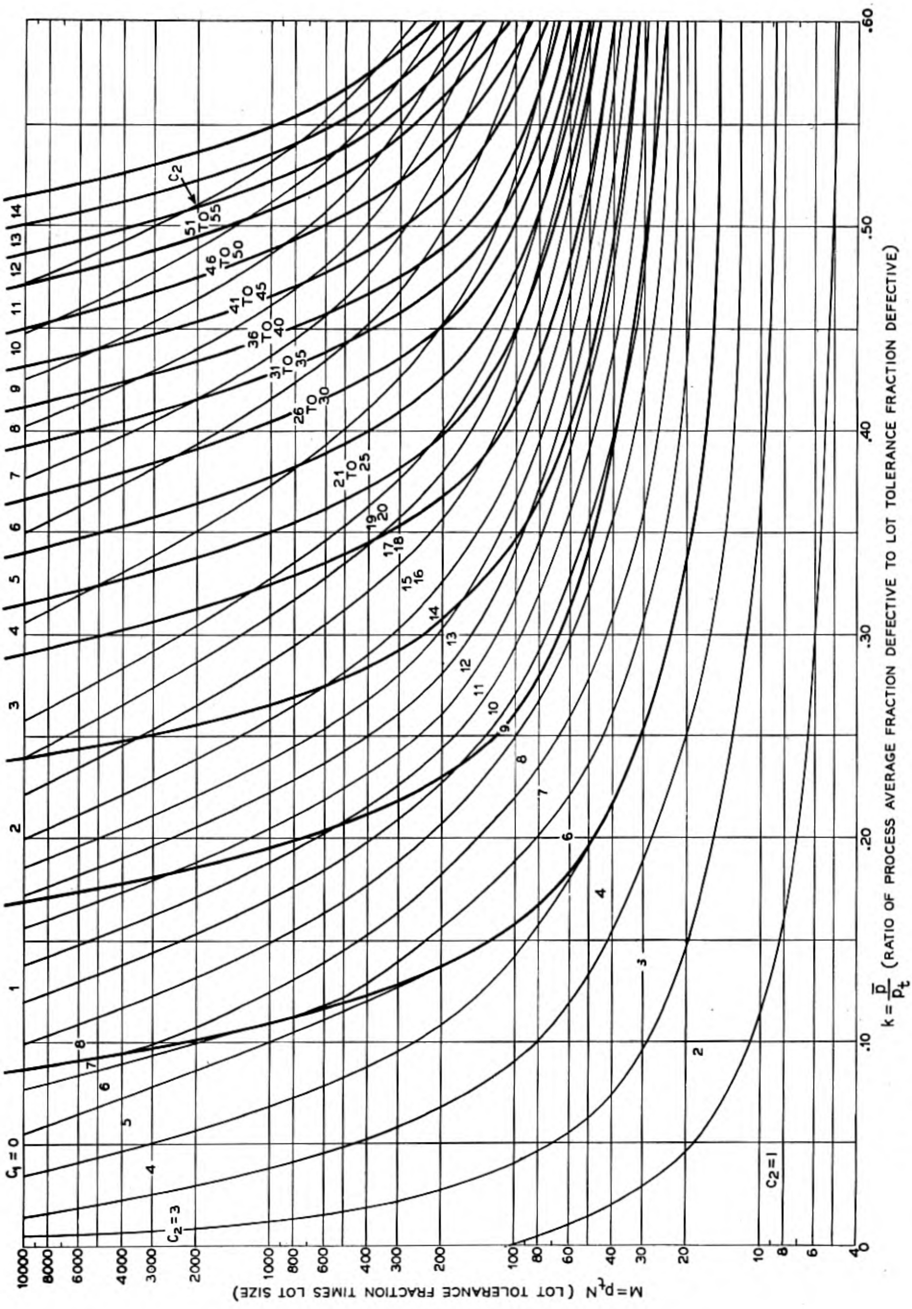

Fig. 7—Chart for determining allowable defect numbers, c_1 and c_2—lot tolerance protection, Consumer's Risk 0.10

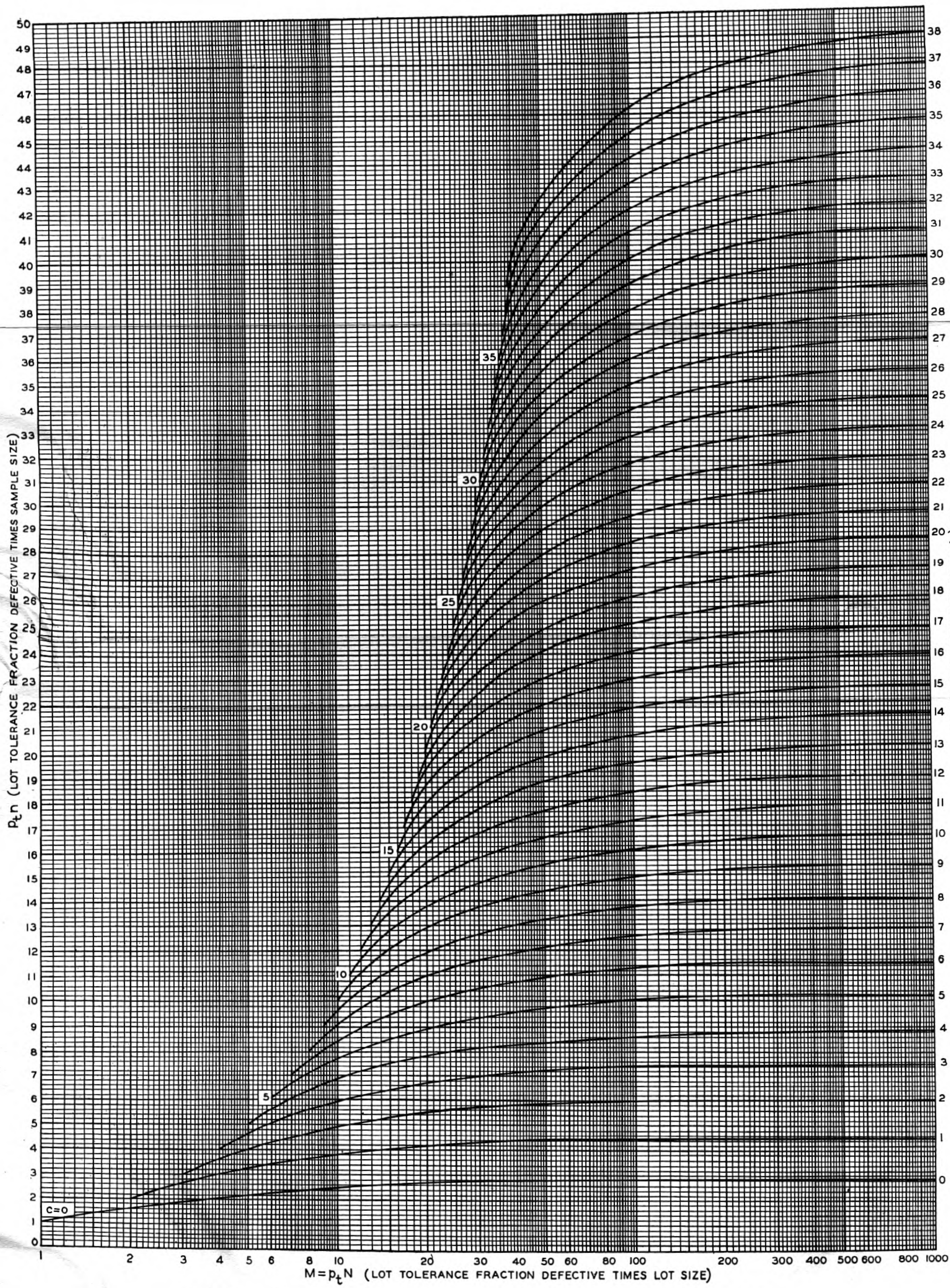

Fig. 8—Curves for determining sample sizes, n_1 and n_2—lot tolerance protection, Consumer's Risk, 0.10.

The use of $P = 0.06$ for determining $n_1 + n_2$ corresponding to c_2 as well as for determining n_1 corresponding to c_1 results in a Consumer's Risk of approximately 0.10, as may be checked by writing the Consumer's Risk equation (3) as follows:

$$P_C = \sum_{m=0}^{m=c_1} P_{m,n_1,N,M} + \sum_{m=0}^{m=c_2} P_{m,n_1+n_2,N,M} - \left(P_{0,n_1,N,M} \sum_{m=0}^{m=c_2} P_{m,n_2,N-n_1,M} \right.$$
$$+ P_{1,n_1,N,M} \sum_{m=0}^{m=c_2-1} P_{m,n_2,N-n_1,M-1} + \cdots$$
$$\left. + P_{c_1,n_1,N,M} \sum_{m=0}^{m=c_2-c_1} P_{m,n_2,N-n_1,M-c_1} \right). \tag{11}$$

The sum of the first two terms is 0.12 and the sum of the terms in parentheses is of the order of 0.02.

Average Quality Protection

General Relations

When the fraction defective in submitted product is p, the average quality after inspection (p_A) is given by

$$p_A = p \frac{N - I}{N} \tag{12}$$

when all defective pieces found are replaced. If defective pieces found are removed but not replaced,

$$p_A = p \frac{N - I}{N - pI}, \tag{12'}$$

the factor pI representing the average number of defective pieces removed. In deriving the tables, equation (12) has been used. The error in p_A resulting from the use of (12) rather than (12′) is $\frac{pI}{N}$, which is generally small.

The average outgoing quality limit (p_L) is the maximum value of p_A that will result under any sampling plan, considering all possible values of p in the submitted product. The value of p for which this maximum value of p_A occurs is designated as p_1, hence

$$p_L = p_1 \frac{N - I}{N}. \tag{13}$$

The value of p_1 for which $p_A = p_L$ may be determined by differentiating equation (12) with respect to p, equating to 0, and solving for p, that is

$$\frac{dp_A}{dp} = \frac{N - I}{N} - \frac{p}{N}\frac{dI}{dp} = 0. \tag{14}$$

Single Sampling

Given: Lot size (N), *AOQL* (p_L), process average fraction defective ($\bar{p}$).
To find: Values of n and c that will minimize $\bar{I}$.

The average quality after inspection (p_A), after substituting in equation (12) the value of I given in equation (8′), is obtained from the relation

$$p_A = p \frac{(N - n)}{N} \sum_{m=0}^{m=c} \frac{e^{-pn}(pn)^m}{m!}. \tag{15}$$

Differentiating with respect to p in accordance with equation (14) gives,

$$\frac{dp_A}{dp} = \frac{(N - n)}{N} \left[\sum_{m=0}^{m=c} \frac{e^{-pn}(pn)^m}{m!} - \frac{e^{-pn}(pn)^{c+1}}{c!} \right]. \tag{16}$$

Equating to zero and solving for p, gives the value of $p = p_1$ that makes p_A a maximum; i.e., $p_A = p_L$.

Let $p_1 n = x$; the particular case covered by equation (15) where $p = p_1$, and $p_A = p_L$ may then be expressed as

$$p_L = \frac{N - n}{Nn} x \sum_{m=0}^{m=c} \frac{e^{-x} x^m}{m!}, \tag{17}$$

or

$$p_L = y\left(\frac{1}{n} - \frac{1}{N}\right), \tag{18}$$

where

$$y = x \sum_{m=0}^{m=c} \frac{e^{-x} x^m}{m!}. \tag{19}$$

Similarly, equation (16) equated to zero becomes, after substituting $p_1 n = x$ and simplifying,

$$\sum_{m=0}^{m=c} \frac{e^{-x} x^m}{m!} - \frac{e^{-x} x^{c+1}}{c!} = 0. \tag{20}$$

Substituting in equation (19) the second term of equation (20) for the summation term gives

$$y = \frac{e^{-x} x^{c+2}}{c!}. \tag{21}$$

These relations* provide a basis for determining the values of x and y, corresponding to specific values of c, listed in Table A. The values of x for $c = 0$ to 30 were determined from equation (20) using Newton's Method of Approximation. The values of x for $c = 31$ to 40 were estimated on the basis of successive differences. The listed values of y are averages of the two values determined from equations (19) and (21), which differ slightly because values of x were determined to only two decimal places.

* Reduction of the mathematical relations to this simplified form and the determination of several x and y values, were contributed by Dr. Walter Bartky of the University of Chicago (when he was associated with the Western Electric Co.) shortly after the development of the *AOQL* concept and the preparation of preliminary *AOQL* double sampling tables. The methods and work of computing the values in Table A were contributed by Mr. George C. Campbell, formerly of the Bell Telephone Laboratories.

TABLE A

VALUES OF x AND y FOR GIVEN VALUES OF c

Used in equation (18) for determining p_L when N, n and c are given, or in equation (22) for determining n when N, c and p_L are given

c =	0	1	2	3	4	5	6	7	8	9	10
x =	1.00	1.62	2.27	2.95	3.64	4.35	5.07	5.80	6.55	7.30	8.06
y =	0.3679	0.8408	1.372	1.946	2.544	3.172	3.810	4.465	5.150	5.836	6.535
c =	11	12	13	14	15	16	17	18	19	20	
x =	8.82	9.59	10.37	11.15	11.93	12.72	13.52	14.32	15.12	15.92	
y =	7.234	7.948	8.677	9.404	10.12	10.87	11.63	12.38	13.14	13.88	
c =	21	22	23	24	25	26	27	28	29	30	
x =	16.73	17.54	18.35	19.17	19.98	20.81	21.63	22.46	23.29	24.13	
y =	14.66	15.42	16.18	16.97	17.73	18.54	19.30	20.11	20.91	21.75	
c =	31	32	33	34	35	36	37	38	39	40	
x =	24.96	25.81	26.65	27.50	28.35	29.21	30.06	30.93	31.79	32.66	
y =	22.54	23.40	24.22	25.08	25.94	26.83	27.68	28.62	29.50	30.44	

The value of c that minimizes $\bar{I}$ (equation (8′), using $p = \bar{p}$), is given directly by Fig. 9, which uses coordinates of $\bar{M} = \bar{p}N$ and $\bar{k} = \bar{p}/p_L$. The curves bounding the c zones on Fig. 9 were obtained directly from relations between equations (18) and (8′), using $p = \bar{p}$, that define values of $\bar{M}$ and $\bar{k}$ such that $\bar{I}$ is the same for c and $c + 1$.

The value of n, corresponding to the value of c given on Fig. 9, is determined from equation (18), expressed as

$$n = \frac{yN}{p_L N + y}. \tag{22}$$

Example: Given: $N = 750$, $p_L = 0.01$, $\bar{p} = 0.004$.

To Find: n and c.

Solution: $\bar{M} = \bar{p}N = (0.004)\,(750) = 3$; $\bar{k} = \dfrac{\bar{p}}{p_L} = \dfrac{0.004}{0.01} = 0.4.$

Consulting Fig. 9, for $\bar{M} = 3$ and $\bar{k} = 0.4$, read $c = 1$.

From Table A, for $c = 1$, read $y = 0.8408$.

From equation (22), $n = \dfrac{(0.8408)\,(750)}{(0.01)\,(750) + 0.8408} = 75.6.$

Sampling Plan: $n = 76$, $c = 1$.

Double Sampling

Given: Lot Size (N), *AOQL* (p_L), process average fraction defective ($\bar{p}$).

To find: Values of n_1, n_2, c_1 and c_2 that will minimize $\bar{I}$.

The average quality after inspection (p_A) is found by substituting in equation (12), the value of I given in equation (9).

$$p_A = \frac{p}{N}\left[(N - n_1)\sum_{m=0}^{m=c_1} P_{m,pn_1} + (N - n_1 - n_2)\left(P_{c_1+1,pn_1}\sum_{m=0}^{m=c_2-c_1-1} P_{m,pn_2} + \cdots + P_{c_2,pn_1}P_{0,pn_2}\right)\right]. \tag{23}$$

Differentiating equation (23) with respect to p and equating to 0, in accordance with equation (14), and solving for p, gives the value of $p = p_1$ that makes p_A a maximum; i.e., $p_A = p_L$. The resulting equation is not reproduced here since

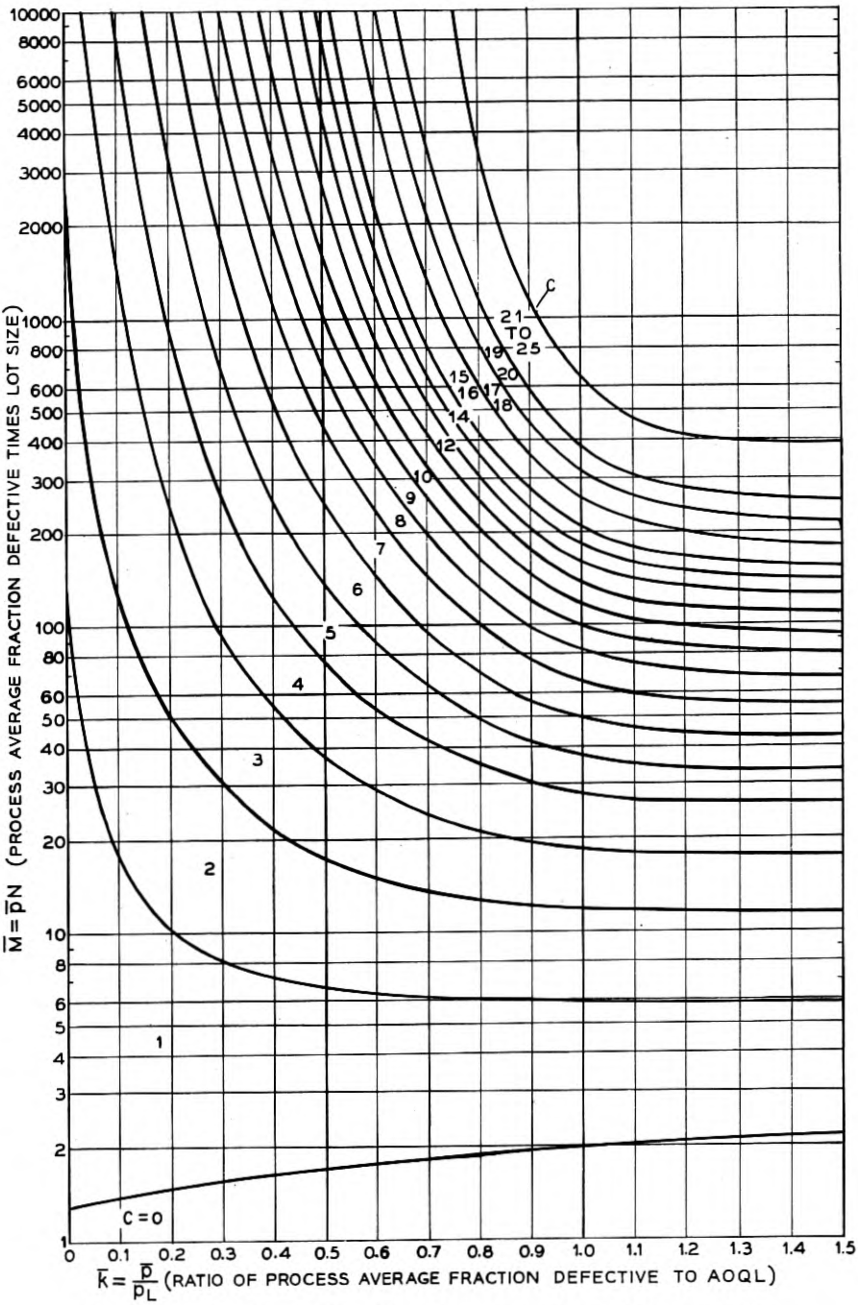

Fig. 9—Chart for determining allowable defect number—AOQL protection

it can be readily solved only for small values of c_1 and c_2. It is usually easier, particularly for the larger values of c_1 and c_2, to determine the maximum value of p_A (i.e., p_L) by trial and error, using work charts for estimating the region in which p_1 will be found.

The procedure used in preparing the tables and in finding the solution for a specific set of conditions is probably best illustrated by working out an actual example. In this procedure, use is made of known relationships between p_t and p_L values as given by the DL tables, where an initial risk of 0.06 and a Consumer's Risk of 0.10 are associated with p_t as outlined on page 11. For a given lot size, a work chart is prepared on which points corresponding to associated p_L and p_t values are plotted for each pair of c_1, c_2 values given in Fig. 7. A line drawn through all points for a single pair, such as $c_1 = 0$, $c_2 = 1$, indicates what p_t value should be associated with any p_L value specified. Fig. 10 indicates the nature of the work charts and the following example illustrates its use.

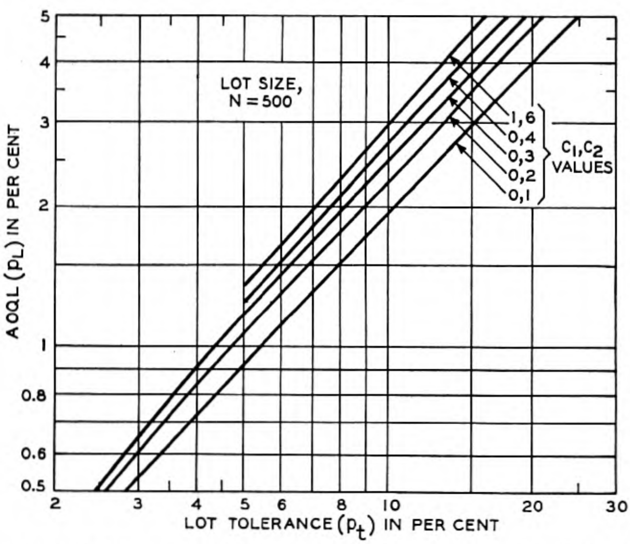

Fig. 10—Work chart giving p_t values corresponding to p_L values for given pairs of c_1, c_2 values—lot size, $N = 500$

Example: Given: $N = 500$, $p_L = .01$, $\bar{p} = .004$.

To find: n_1, n_2, c_1 and c_2 that will minimize average amount of inspection per lot. (Condition: For the associated lot tolerance value, p_t, the initial risk is 0.06 and the Consumer's Risk $P_C = 0.10$).

Solution: *Step 1*—Consult work chart, Fig. 10 for $N = 500$. Try $c_1 = 0$, $c_2 = 1$, and corresponding to $p_L = .01$, read $p_t = .054$.

Step 2—To determine if first choice of c_1, c_2 was the best.

$$M = p_t N = 0.054\ (500) = 27;\ k = \frac{\bar{p}}{p_t} = \frac{0.004}{0.054} = 0.074.$$

Consult Fig. 7, giving best c_1, c_2 values for given M and

k values. Corresponding to $M = 27$, $k = 0.074$, read $c_1 = 0$, $c_2 = 2$. Hence the first choice was not the best.

Step 3—Similar to Step 1. Consult work chart, Fig. 10. For $c_1 = 0$, $c_2 = 2$, corresponding to $p_L = 0.01$, read $p_t = .047$.

Step 4—Similar to Step 2. $M = p_t N = .047\ (500) = 23.5$; $k = \dfrac{\bar{p}}{p_t} = 0.085$. Consult Fig. 7 and corresponding to $M = 23.5$, $k = 0.085$, read $c_1 = 0, c_2 = 2$. This agrees with the choice in Step 3 and gives desired solution.

Step 5—To determine n_1 and n_2 for $c_1 = 0$, $c_2 = 2$. On Fig. 8, corresponding to $M = 23.5$, for $c_1 = 0$, read $p_t n_1 = 2.67$ and for $c_2 = 2$, read $p_t\,(n_1 + n_2) = 5.60$. Since per Step 3, $p_t = .047, n_1 = 57, n_1 + n_2 = 119$ and $n_2 = 62$.

Sampling Plan. $n_1 = 57, n_2 = 62, c_1 = 0, c_2 = 2$. (Rounding these values of n to the nearest 5 in accordance with the practice used in preparing the tables, gives $n_1 = 55$, $n_1 + n_2 = 120$, $n_2 = 65$, the values shown in Table DA-1 for $N = 401$–500, $\bar{p} = 0.21$–0.40%.)

Nature and Magnitude of Errors

Each sampling plan (combination of n and c values for single sampling, and of n_1, n_2, c_1 and c_2 values for double sampling) in the tables constitutes a solution for a range of process average values and a range of lot sizes. The following paragraphs give information regarding the magnitude of errors, associated with these solutions, that may be present because of the following two factors:

(1) Approximate equations and curves derived therefrom were used in place of exact equations over most areas of the tables, in order to minimize computative effort.

(2) The sample sizes, n_1 and $n_1 + n_2$, listed in the tables represent computed values rounded to the nearest unit for $n = 50$ or less, rounded to the nearest 5 for $50 < n < 1000$, and rounded to the nearest 10 for $n > 1000$.

Effect of Approximations—The percentage error in the Consumer's Risk value of 0.10, corresponding to lot tolerance values listed in the tables, attributable to the use of approximate equations and curves derived therefrom, is on the average about 3% and should not exceed 7%. The percentage error in the *AOQL* values, listed in the tables, attributable to the use of approximate relations involving the Poisson exponential rather than the binomial distribution, is on the average about 4% and should not exceed 12%. In a large number of exploratory checks for both single and double sampling, it was found in every instance that the Consumer's Risk and the *AOQL* values derived from approximate equations were larger than the corresponding exact values. The largest error observed in the Consumer's Risk for single sampling occurred when, instead of 0.10, the exact relation gave a value of 0.0937. Similarly the largest error in the *AOQL* occurred in single sampling when, instead of 0.0883, the exact relation gave a value of 0.0786. The observed errors in double sampling were of the same order of magnitude.

Effect of Rounding—The use of rounded values of n, n_1 and n_2 gives values of Consumer's Risk other than exactly 0.10. However each sampling plan lists sample sizes based on the largest lot size in the corresponding lot size range. As a result, the Consumer's Risk associated with the p_t value designated at the top of the Lot Tolerance tables does not exceed 0.10 except in a few isolated cases, where the risk may be as high as 0.12 for the largest lot size. Likewise, the *AOQL* value for any sampling plan in the *AOQL* tables does not exceed the value designated at the top of each table except in a few isolated cases, where the error due to rounding may be as much as 10% of the designated value for the largest lot size.

The Consumer's Risk value of 0.10 and the *AOQL* values listed in the tables, are therefore with few exceptions, upper bounds that will not be exceeded in the application of the tables.

NOMENCLATURE

N Number of pieces in lot.
n Number of pieces in sample.
n_1 Number of pieces in first sample.
n_2 Number of pieces in second sample.
c Allowable defect number.
c_1 Allowable defect number for first sample, n_1.
c_2 Allowable defect number for first and second samples combined, $n_1 + n_2$.
p_t Lot tolerance fraction defective.
p Fraction defective; also used specifically to denote fraction defective in submitted product.
$\bar{p}$ Process average (expected) fraction defective in submitted product.
p_A Average fraction defective in product after inspection—Average Outgoing Quality (*AOQ*).
p_L Maximum value of average fraction defective in product after inspection—Average Outgoing Quality Limit (*AOQL*).
p_1 Specific value of p in submitted product, for which $p_A = p_L$.
P_C Consumer's Risk.
P_a Probability of acceptance.
P_P Producer's Risk.
I Average number of pieces inspected per lot for submitted product of p quality.
$\bar{I}$ Specific value of I when p in submitted product $= \bar{p}$.
$\bar{I}_{min}$ Minimum value of $\bar{I}$.
$M = p_t N$ Number of defects in lot of tolerance (p_t) quality.
$\bar{M} = \bar{p}N$ Number of defects in a lot of process average ($\bar{p}$) quality.
$k = \dfrac{\bar{p}}{p_t}$ Ratio of process average fraction defective to lot tolerance fraction defective.
$\bar{k} = \dfrac{\bar{p}}{p_L}$ Ratio of process average fraction defective to *AOQL*.
m Number of defects found in sample.
$C_n^N = \dfrac{N!}{(N-n)!\,n!}$ Number of combinations of N things taken n at a time.

TABLE I: SINGLE SAMPLING LOT INSPECTION TABLES—BASED ON STATED VALUES OF "LOT TOLERANCE PER CENT DEFECTIVE" AND CONSUMER'S RISK = 0.10

TABLE SL-0.5
LOT TOLERANCE PER CENT DEFECTIVE = 0.5%

Process Average %	0–.005			.006–.050			.051–.100			.101–.150			.151–.200			.201–.250		
Lot Size	n	c	AOQL %	n	c	AOQL %	n	c	AOQL %	n	c	AOQL %	n	c	AOQL %	n	c	AOQL %
1–180	All	0	0	All	0	0	All	0	0	All	0	0	All	0	0	All	0	0
181–210	180	0	.02	180	0	.02	180	0	.02	180	0	.02	180	0	.02	180	0	.02
211–250	210	0	.03	210	0	.03	210	0	.03	210	0	.03	210	0	.03	210	0	.03
251–300	240	0	.03	240	0	.03	240	0	.03	240	0	.03	240	0	.03	240	0	.03
301–400	275	0	.04	275	0	.04	275	0	.04	275	0	.04	275	0	.04	275	0	.04
401–500	300	0	.05	300	0	.05	300	0	.05	300	0	.05	300	0	.05	300	0	.05
501–600	320	0	.05	320	0	.05	320	0	.05	320	0	.05	320	0	.05	320	0	.05
601–800	350	0	.06	350	0	.06	350	0	.06	350	0	.06	350	0	.06	350	0	.06
801–1000	365	0	.06	365	0	.06	365	0	.06	365	0	.06	365	0	.06	365	0	.06
1001–2000	410	0	.07	410	0	.07	410	0	.07	670	1	.08	670	1	.08	670	1	.08
2001–3000	430	0	.07	430	0	.07	705	1	.09	705	1	.09	955	2	.10	955	2	.10
3001–4000	440	0	.07	440	0	.07	730	1	.09	985	2	.10	1230	3	.11	1230	3	.11
4001–5000	445	0	.08	740	1	.10	1000	2	.11	1000	2	.11	1250	3	.12	1480	4	.12
5001–7000	450	0	.08	750	1	.10	1020	2	.12	1280	3	.12	1510	4	.13	1760	5	.14
7001–10,000	455	0	.08	760	1	.10	1040	2	.12	1530	4	.14	1790	5	.14	2240	7	.16
10,001–20,000	460	0	.08	775	1	.10	1330	3	.14	1820	5	.16	2300	7	.17	2780	9	.18
20,001–50,000	775	1	.11	1050	2	.13	1600	4	.15	2080	6	.18	3060	10	.20	4200	15	.22
50,001–100,000	780	1	.11	1060	2	.13	1840	5	.17	2590	8	.19	3780	13	.22	5140	19	.24

TABLE SL-1
LOT TOLERANCE PER CENT DEFECTIVE = 1.0%

Process Average %	0–.010			.011–.10			.11–.20			.21–.30			.31–.40			.41–.50		
Lot Size	n	c	AOQL %	n	c	AOQL %	n	c	AOQL %	n	c	AOQL %	n	c	AOQL %	n	c	AOQL %
1–120	All	0	0	All	0	0	All	0	0	All	0	0	All	0	0	All	0	0
121–150	120	0	.06	120	0	.06	120	0	.06	120	0	.06	120	0	.06	120	0	.06
151–200	140	0	.08	140	0	.08	140	0	.08	140	0	.08	140	0	.08	140	0	.08
201–300	165	0	.10	165	0	.10	165	0	.10	165	0	.10	165	0	.10	165	0	.10
301–400	175	0	.12	175	0	.12	175	0	.12	175	0	.12	175	0	.12	175	0	.12
401–500	180	0	.13	180	0	.13	180	0	.13	180	0	.13	180	0	.13	180	0	.13
501–600	190	0	.13	190	0	.13	190	0	.13	190	0	.13	190	0	.13	305	1	.14
601–800	200	0	.14	200	0	.14	200	0	.14	330	1	.15	330	1	.15	330	1	.15
801–1000	205	0	.14	205	0	.14	205	0	.14	335	1	.17	335	1	.17	335	1	.17
1001–2000	220	0	.15	220	0	.15	360	1	.19	490	2	.21	490	2	.21	610	3	.22
2001–3000	220	0	.15	375	1	.20	505	2	.23	630	3	.24	745	4	.26	870	5	.26
3001–4000	225	0	.15	380	1	.20	510	2	.24	645	3	.25	880	5	.28	1000	6	.29
4001–5000	225	0	.16	380	1	.20	520	2	.24	770	4	.28	895	5	.29	1120	7	.31
5001–7000	230	0	.15	385	1	.21	655	3	.27	780	4	.29	1020	6	.32	1260	8	.34
7001–10,000	230	0	.16	520	2	.25	660	3	.28	910	5	.32	1150	7	.34	1500	10	.37
10,001–20,000	390	1	.21	525	2	.26	785	4	.31	1040	6	.35	1400	9	.39	1980	14	.43
20,001–50,000	390	1	.21	530	2	.26	920	5	.34	1300	8	.39	1890	13	.44	2570	19	.48
50,001–100,000	390	1	.21	670	3	.29	1040	6	.36	1420	9	.41	2120	15	.47	3150	23	.50

n = Size of Sample; entry of "All" indicates that each piece in lot is to be inspected.
c = Allowable Defect Number for Sample.
AOQL = Average Outgoing Quality Limit.

TABLE I CONT'D: SINGLE SAMPLING LOT INSPECTION TABLES—BASED ON STATED VALUES OF "LOT TOLERANCE PER CENT DEFECTIVE" AND CONSUMER'S RISK = 0.10

TABLE SL-2
Lot Tolerance Per Cent Defective = 2.0%

Process Average %	0–.02			.03–.20			.21–.40			.41–.60			.61–.80			.81–1.00		
Lot Size	n	c	AOQL %	n	c	AOQL %	n	c	AOQL %	n	c	AOQL %	n	c	AOQL %	n	c	AOQL %
1–75	All	0	0	All	0	0	All	0	0	All	0	0	All	0	0	All	0	0
76–100	70	0	.16	70	0	.16	70	0	.16	70	0	.16	70	0	.16	70	0	.16
101–200	85	0	.25	85	0	.25	85	0	.25	85	0	.25	85	0	.25	85	0	.25
201–300	95	0	.26	95	0	.26	95	0	.26	95	0	.26	95	0	.26	95	0	.26
301–400	100	0	.28	100	0	.28	100	0	.28	160	1	.32	160	1	.32	160	1	.32
401–500	105	0	.28	105	0	.28	105	0	.28	165	1	.34	165	1	.34	165	1	.34
501–600	105	0	.29	105	0	.29	175	1	.34	175	1	.34	175	1	.34	235	2	.36
601–800	110	0	.29	110	0	.29	180	1	.36	240	2	.40	240	2	.40	300	3	.41
801–1000	115	0	.28	115	0	.28	185	1	.37	245	2	.42	305	3	.44	305	3	.44
1001–2000	115	0	.30	190	1	.40	255	2	.47	325	3	.50	380	4	.54	440	5	.56
2001–3000	115	0	.31	190	1	.41	260	2	.48	385	4	.58	450	5	.60	565	7	.64
3001–4000	115	0	.31	195	1	.41	330	3	.54	450	5	.63	510	6	.65	690	9	.70
4001–5000	195	1	.41	260	2	.50	335	3	.54	455	5	.63	575	7	.69	750	10	.74
5001–7000	195	1	.42	265	2	.50	335	3	.55	515	6	.69	640	8	.73	870	12	.80
7001–10,000	195	1	.42	265	2	.50	395	4	.62	520	6	.69	760	10	.79	1050	15	.86
10,001–20,000	200	1	.42	265	2	.51	460	5	.67	650	8	.77	885	12	.86	1230	18	.94
20,001–50,000	200	1	.42	335	3	.58	520	6	.73	710	9	.81	1060	15	.93	1520	23	1.0
50,001–100,000	200	1	.42	335	3	.58	585	7	.76	770	10	.84	1180	17	.97	1690	26	1.1

TABLE SL-3
Lot Tolerance Per Cent Defective = 3.0%

Process Average %	0–.03			.04–.30			.31–.60			.61–.90			.91–1.20			1.21–1.50		
Lot Size	n	c	AOQL %	n	c	AOQL %	n	c	AOQL %	n	c	AOQL %	n	c	AOQL %	n	c	AOQL %
1–40	All	0	0	All	0	0	All	0	0	All	0	0	All	0	0	All	0	0
41–55	40	0	.18	40	0	.18	40	0	.18	40	0	.18	40	0	.18	40	0	.18
56–100	55	0	.30	55	0	.30	55	0	.30	55	0	.30	55	0	.30	55	0	.30
101–200	65	0	.38	65	0	.38	65	0	.38	65	0	.38	65	0	.38	65	0	.38
201–300	70	0	.40	70	0	.40	70	0	.40	110	1	.48	110	1	.48	110	1	.48
301–400	70	0	.43	70	0	.43	115	1	.52	115	1	.52	115	1	.52	155	2	.54
401–500	70	0	.45	70	0	.45	120	1	.53	120	1	.53	160	2	.58	160	2	.58
501–600	75	0	.43	75	0	.43	120	1	.56	160	2	.63	160	2	.63	200	3	.65
601–800	75	0	.44	125	1	.57	125	1	.57	165	2	.66	205	3	.71	240	4	.74
801–1000	75	0	.45	125	1	.59	170	2	.67	210	3	.73	250	4	.76	290	5	.78
1001–2000	75	0	.47	130	1	.60	175	2	.72	260	4	.85	300	5	.90	380	7	.95
2001–3000	75	0	.48	130	1	.62	220	3	.82	300	5	.95	385	7	1.0	460	9	1.1
3001–4000	130	1	.63	175	2	.75	220	3	.84	305	5	.96	425	8	1.1	540	11	1.2
4001–5000	130	1	.63	175	2	.76	260	4	.91	345	6	1.0	465	9	1.1	620	13	1.2
5001–7000	130	1	.63	175	2	.76	265	4	.92	390	7	1.1	505	10	1.2	700	15	1.3
7001–10,000	130	1	.64	175	2	.77	265	4	.93	390	7	1.1	550	11	1.2	775	17	1.4
10,001–20,000	130	1	.64	175	2	.78	305	5	1.0	430	8	1.2	630	13	1.3	900	20	1.5
20,001–50,000	130	1	.65	225	3	.86	350	6	1.1	520	10	1.2	750	16	1.4	1090	25	1.6
50,001–100,000	130	1	.65	265	4	.96	390	7	1.1	590	12	1.3	830	18	1.5	1215	28	1.6

n = Size of Sample; entry of "All" indicates that each piece in lot is to be inspected.
c = Allowable Defect Number for Sample.
AOQL = Average Outgoing Quality Limit.

TABLE I CONT'D: SINGLE SAMPLING LOT INSPECTION TABLES—BASED ON STATED VALUES OF "LOT TOLERANCE PER CENT DEFECTIVE" AND CONSUMER'S RISK = 0.10

TABLE SL-4
Lot Tolerance Per Cent Defective = 4.0%

Process Average %	0–.04			.05–.40			.41–.80			.81–1.20			1.21–1.60			1.61–2.00		
Lot Size	n	c	AOQL %	n	c	AOQL %	n	c	AOQL %	n	c	AOQL %	n	c	AOQL %	n	c	AOQL %
1–35	All	0	0	All	0	0	All	0	0	All	0	0	All	0	0	All	0	0
36–50	34	0	.35	34	0	.35	34	0	.35	34	0	.35	34	0	.35	34	0	.35
51–100	44	0	.47	44	0	.47	44	0	.47	44	0	.47	44	0	.47	44	0	.47
101–200	50	0	.55	50	0	.55	50	0	.55	50	0	.55	50	0	.55	50	0	.55
201–300	55	0	.57	55	0	.57	85	1	.71	85	1	.71	85	1	.71	85	1	.71
301–400	55	0	.58	55	0	.58	90	1	.72	120	2	.80	120	2	.80	145	3	.86
401–500	55	0	.60	55	0	.60	90	1	.77	120	2	.87	150	3	.91	150	3	.91
501–600	55	0	.61	95	1	.76	125	2	.87	125	2	.87	155	3	.93	185	4	.95
601–800	55	0	.62	95	1	.78	125	2	.93	160	3	.97	190	4	1.0	220	5	1.0
801–1000	55	0	.63	95	1	.80	130	2	.92	165	3	.98	220	5	1.1	255	6	1.1
1001–2000	55	0	.65	95	1	.84	165	3	1.1	195	4	1.2	255	6	1.3	315	8	1.4
2001–3000	95	1	.86	130	2	1.0	165	3	1.1	230	5	1.3	320	8	1.4	405	11	1.6
3001–4000	95	1	.86	130	2	1.0	195	4	1.2	260	6	1.4	350	9	1.5	465	13	1.6
4001–5000	95	1	.87	130	2	1.0	195	4	1.2	290	7	1.4	380	10	1.6	520	15	1.7
5001–7000	95	1	.87	130	2	1.0	200	4	1.2	290	7	1.5	410	11	1.7	575	17	1.9
7001–10,000	95	1	.88	130	2	1.1	230	5	1.4	325	8	1.5	440	12	1.7	645	19	1.9
10,001–20,000	95	1	.88	165	3	1.2	265	6	1.4	355	9	1.6	500	14	1.8	730	22	2.0
20,001–50,000	95	1	.88	165	3	1.2	295	7	1.5	380	10	1.7	590	17	2.0	870	26	2.1
50,001–100,000	95	1	.88	200	4	1.3	325	8	1.6	410	11	1.8	620	18	2.0	925	29	2.2

TABLE SL-5
Lot Tolerance Per Cent Defective = 5.0%

Process Average %	0–.05			.06–.50			.51–1.00			1.01–1.50			1.51–2.00			2.01–2.50		
Lot Size	n	c	AOQL %	n	c	AOQL %	n	c	AOQL %	n	c	AOQL %	n	c	AOQL %	n	c	AOQL %
1–30	All	0	0	All	0	0	All	0	0	All	0	0	All	0	0	All	0	0
31–50	30	0	.49	30	0	.49	30	0	.49	30	0	.49	30	0	.49	30	0	.49
51–100	37	0	.63	37	0	.63	37	0	.63	37	0	.63	37	0	.63	37	0	.63
101–200	40	0	.74	40	0	.74	40	0	.74	40	0	.74	40	0	.74	40	0	.74
201–300	43	0	.74	43	0	.74	70	1	.92	70	1	.92	95	2	.99	95	2	.99
301–400	44	0	.74	44	0	.74	70	1	.99	100	2	1.0	120	3	1.1	145	4	1.1
401–500	45	0	.75	75	1	.95	100	2	1.1	100	2	1.1	125	3	1.2	150	4	1.2
501–600	45	0	.76	75	1	.98	100	2	1.1	125	3	1.2	150	4	1.3	175	5	1.3
601–800	45	0	.77	75	1	1.0	100	2	1.2	130	3	1.2	175	5	1.4	200	6	1.4
801–1000	45	0	.78	75	1	1.0	105	2	1.2	155	4	1.4	180	5	1.4	225	7	1.5
1001–2000	45	0	.80	75	1	1.0	130	3	1.4	180	5	1.6	230	7	1.7	280	9	1.8
2001–3000	75	1	1.1	105	2	1.3	135	3	1.4	210	6	1.7	280	9	1.9	370	13	2.1
3001–4000	75	1	1.1	105	2	1.3	160	4	1.5	210	6	1.7	305	10	2.0	420	15	2.2
4001–5000	75	1	1.1	105	2	1.3	160	4	1.5	235	7	1.8	330	11	2.0	440	16	2.2
5001–7000	75	1	1.1	105	2	1.3	185	5	1.7	260	8	1.9	350	12	2.2	490	18	2.4
7001–10,000	75	1	1.1	105	2	1.3	185	5	1.7	260	8	1.9	380	13	2.2	535	20	2.5
10,001–20,000	75	1	1.1	135	3	1.4	210	6	1.8	285	9	2.0	425	15	2.3	610	23	2.6
20,001–50,000	75	1	1.1	135	3	1.4	235	7	1.9	305	10	2.1	470	17	2.4	700	27	2.7
50,001–100,000	75	1	1.1	160	4	1.6	235	7	1.9	355	12	2.2	515	19	2.5	770	30	2.8

n = Size of Sample; entry of "All" indicates that each piece in lot is to be inspected.
c = Allowable Defect Number for Sample.
AOQL = Average Outgoing Quality Limit.

TABLE I CONT'D: SINGLE SAMPLING LOT INSPECTION TABLES—BASED ON STATED VALUES OF "LOT TOLERANCE PER CENT DEFECTIVE" AND CONSUMER'S RISK = 0.10

TABLE SL-7

LOT TOLERANCE PER CENT DEFECTIVE = 7.0%

Process Average %	0–.07			.08–.70			.71–1.40			1.41–2.10			2.11–2.80			2.81–3.50		
Lot Size	n	c	AOQL %	n	c	AOQL %	n	c	AOQL %	n	c	AOQL %	n	c	AOQL %	n	c	AOQL %
1–25	All	0	0	All	0	0	All	0	0	All	0	0	All	0	0	All	0	0
26–50	24	0	.80	24	0	.80	24	0	.80	24	0	.80	24	0	.80	24	0	.80
51–100	28	0	.95	28	0	.95	28	0	.95	28	0	.95	28	0	.95	28	0	.95
101–200	30	0	1.0	30	0	1.0	49	1	1.3	49	1	1.3	49	1	1.3	65	2	1.4
201–300	31	0	1.1	31	0	1.1	50	1	1.4	70	2	1.5	85	3	1.6	85	3	1.6
301–400	32	0	1.1	55	1	1.4	70	2	1.6	90	3	1.7	105	4	1.8	125	5	1.8
401–500	32	0	1.1	55	1	1.4	75	2	1.6	90	3	1.8	110	4	1.9	140	6	2.0
501–600	32	0	1.1	55	1	1.4	75	2	1.7	95	3	1.8	125	5	2.0	145	6	2.1
601–800	32	0	1.1	55	1	1.4	75	2	1.7	110	4	2.0	130	5	2.1	160	7	2.2
801–1000	33	0	1.1	55	1	1.4	95	3	1.9	110	4	2.1	145	6	2.2	180	8	2.4
1001–2000	55	1	1.5	75	2	1.8	95	3	2.0	130	5	2.3	185	8	2.5	230	11	2.8
2001–3000	55	1	1.5	75	2	1.8	115	4	2.1	150	6	2.4	215	10	2.8	300	15	3.0
3001–4000	55	1	1.5	75	2	1.8	115	4	2.2	165	7	2.6	235	11	2.9	330	17	3.2
4001–5000	55	1	1.5	75	2	1.8	130	5	2.4	185	8	2.7	250	12	3.0	350	18	3.3
5001–7000	55	1	1.5	75	2	1.8	130	5	2.4	185	8	2.7	270	13	3.1	385	20	3.4
7001–10,000	55	1	1.5	95	3	2.0	150	6	2.5	200	9	2.9	285	14	3.2	415	22	3.6
10,001–20,000	55	1	1.5	95	3	2.0	150	6	2.5	220	10	2.9	320	16	3.3	470	25	3.7
20,001–50,000	55	1	1.5	115	4	2.2	170	7	2.6	235	11	3.1	355	18	3.5	530	29	3.9
50,001–100,000	55	1	1.5	115	4	2.2	185	8	2.7	270	13	3.1	370	19	3.5	530	29	3.9

TABLE SL-10

LOT TOLERANCE PER CENT DEFECTIVE = 10.0%

Process Average %	0–.10			.11–1.00			1.01–2.00			2.01–3.00			3.01–4.00			4.01–5.00		
Lot Size	n	c	AOQL %	n	c	AOQL %	n	c	AOQL %	n	c	AOQL %	n	c	AOQL %	n	c	AOQL %
1–20	All	0	0	All	0	0	All	0	0	All	0	0	All	0	0	All	0	0
21–50	17	0	1.3	17	0	1.3	17	0	1.3	17	0	1.3	17	0	1.3	17	0	1.3
51–100	20	0	1.5	20	0	1.5	20	0	1.5	33	1	1.7	33	1	1.7	33	1	1.7
101–200	22	0	1.5	22	0	1.5	35	1	2.0	48	2	2.2	48	2	2.2	60	3	2.4
201–300	23	0	1.5	38	1	1.9	50	2	2.3	65	3	2.4	75	4	2.6	85	5	2.7
301–400	23	0	1.5	38	1	2.0	50	2	2.4	65	3	2.5	90	5	2.7	100	6	2.9
401–500	23	0	1.5	38	1	2.0	50	2	2.5	75	4	2.8	90	5	2.9	110	7	3.2
501–600	23	0	1.5	38	1	2.1	65	3	2.7	80	4	3.0	100	6	3.2	125	8	3.3
601–800	23	0	1.6	38	1	2.1	65	3	2.8	90	5	3.1	100	6	3.3	140	9	3.4
801–1000	39	1	2.1	50	2	2.6	65	3	2.8	90	5	3.2	115	7	3.4	150	10	3.7
1001–2000	39	1	2.1	50	2	2.6	80	4	3.1	105	6	3.4	140	9	3.9	195	14	4.4
2001–3000	39	1	2.1	50	2	2.6	80	4	3.1	115	7	3.7	165	11	4.1	230	17	4.7
3001–4000	39	1	2.1	50	2	2.6	90	5	3.4	130	8	3.8	190	13	4.4	255	19	4.8
4001–5000	39	1	2.1	50	2	2.6	90	5	3.5	130	8	3.9	200	14	4.5	270	20	4.9
5001–7000	39	1	2.1	65	3	3.0	105	6	3.6	140	9	4.1	200	14	4.6	295	22	5.0
7001–10,000	39	1	2.2	65	3	3.0	105	6	3.6	150	10	4.2	210	15	4.7	315	24	5.2
10,001–20,000	39	1	2.2	65	3	3.0	120	7	3.7	150	10	4.3	240	17	4.8	340	26	5.4
20,001–50,000	39	1	2.2	80	4	3.2	120	7	3.7	165	11	4.4	260	19	5.0	380	30	5.7
50,001–100,000	39	1	2.2	95	5	3.3	130	8	4.0	180	12	4.4	270	20	5.1	380	30	5.7

n = Size of Sample; entry of "All" indicates that each piece in lot is to be inspected.
c = Allowable Defect Number for Sample.
AOQL = Average Outgoing Quality Limit.

TABLE II: DOUBLE SAMPLING LOT INSPECTION TABLES—BASED ON STATED VALUES OF "LOT TOLERANCE PER CENT DEFECTIVE" AND CONSUMER'S RISK = 0.10

TABLE DL-0.5

LOT TOLERANCE PER CENT DEFECTIVE = 0.5%

Process Average %	0–.005						.006–.050						.051–.100					
	Trial 1		Trial 2			AOQL in %	Trial 1		Trial 2			AOQL in %	Trial 1		Trial 2			AOQL in %
Lot Size	n_1	c_1	n_2	n_1+n_2	c_2		n_1	c_1	n_2	n_1+n_2	c_2		n_1	c_1	n_2	n_1+n_2	c_2	
1–180	All	0	–	–	–	0	All	0	–	–	–	0	All	0	–	–	–	0
181–210	180	0	–	–	–	.02	180	0	–	–	–	.02	180	0	–	–	–	.02
211–250	210	0	–	–	–	.03	210	0	–	–	–	.03	210	0	–	–	–	.03
251–300	240	0	–	–	–	.03	240	0	–	–	–	.03	240	0	–	–	–	.03
301–400	275	0	–	–	–	.04	275	0	–	–	–	.04	275	0	–	–	–	.04
401–450	290	0	–	–	–	.04	290	0	–	–	–	.04	290	0	–	–	–	.04
451–500	340	0	110	450	1	.04	340	0	110	450	1	.04	340	0	110	450	1	.04
501–550	350	0	130	480	1	.05	350	0	130	480	1	.05	350	0	130	480	1	.05
551–600	360	0	150	510	1	.05	360	0	150	510	1	.05	360	0	150	510	1	.05
601–800	400	0	185	585	1	.06	400	0	185	585	1	.06	400	0	185	585	1	.06
801–1000	430	0	200	630	1	.07	430	0	200	630	1	.07	430	0	200	630	1	.07
1001–2000	490	0	265	755	1	.08	490	0	265	755	1	.08	490	0	265	755	1	.08
2001–3000	520	0	290	810	1	.09	520	0	290	810	1	.09	520	0	530	1050	2	.10
3001–4000	530	0	310	840	1	.09	530	0	570	1100	2	.11	530	0	570	1100	2	.11
4001–5000	540	0	305	845	1	.09	540	0	580	1120	2	.11	540	0	830	1370	3	.12
5001–7000	545	0	315	860	1	.10	545	0	615	1160	2	.11	545	0	865	1410	3	.12
7001–10,000	550	0	330	880	1	.10	550	0	620	1170	2	.12	550	0	1130	1680	4	.14
10,001–20,000	555	0	345	900	1	.10	555	0	925	1480	3	.13	555	0	1185	1740	4	.15
20,001–50,000	560	0	650	1210	2	.12	560	0	940	1500	3	.14	900	1	1400	2300	6	.16
50,001–100,000	560	0	650	1210	2	.12	560	0	1210	1770	4	.15	905	1	1655	2560	7	.17

Process Average %	.101–.150						.151–.200						.201–.250					
	Trial 1		Trial 2			AOQL in %	Trial 1		Trial 2			AOQL in %	Trial 1		Trial 2			AOQL in %
Lot Size	n_1	c_1	n_2	n_1+n_2	c_2		n_1	c_1	n_2	n_1+n_2	c_2		n_1	c_1	n_2	n_1+n_2	c_2	
1–180	All	0	–	–	–	0	All	0	–	–	–	0	All	0	–	–	–	0
181–210	180	0	–	–	–	.02	180	0	–	–	–	.02	180	0	–	–	–	.02
211–250	210	0	–	–	–	.03	210	0	–	–	–	.03	210	0	–	–	–	.03
251–300	240	0	–	–	–	.03	240	0	–	–	–	.03	240	0	–	–	–	.03
301–400	275	0	–	–	–	.04	275	0	–	–	–	.04	275	0	–	–	–	.04
401–450	290	0	–	–	–	.04	290	0	–	–	–	.04	290	0	–	–	–	.04
451–500	340	0	110	450	1	.04	340	0	110	450	1	.04	340	0	110	450	1	.04
501–550	350	0	130	480	1	.05	350	0	130	480	1	.05	350	0	130	480	1	.05
551–600	360	0	150	510	1	.05	360	0	150	510	1	.05	360	0	150	510	1	.05
601–800	400	0	185	585	1	.06	400	0	185	585	1	.06	400	0	185	585	1	.06
801–1000	430	0	200	630	1	.07	430	0	200	630	1	.07	430	0	200	630	1	.07
1001–2000	490	0	500	990	2	.09	490	0	500	990	2	.09	490	0	500	990	2	.09
2001–3000	520	0	530	1050	2	.10	520	0	760	1280	3	.11	520	0	980	1500	4	.11
3001–4000	530	0	810	1340	3	.11	530	0	1030	1560	4	.12	840	1	1160	2000	6	.13
4001–5000	540	0	1060	1600	4	.13	845	1	1205	2050	6	.14	845	1	1425	2270	7	.14
5001–7000	545	0	1105	1650	4	.13	860	1	1490	2350	7	.15	860	1	1700	2560	8	.16
7001–10,000	880	1	1300	2180	6	.15	880	1	1770	2650	8	.16	1170	2	2160	3330	11	.17
10,001–20,000	900	1	1840	2740	8	.18	1200	2	2250	3450	11	.19	1740	4	2620	4360	15	.21
20,001–50,000	1210	2	2330	3540	11	.20	1500	3	2980	4480	15	.22	2300	6	4240	6540	24	.24
50,001–100,000	1210	2	2590	3800	12	.21	1770	4	3690	5460	19	.23	2560	7	5420	7980	30	.26

TABLE DL-1

LOT TOLERANCE PER CENT DEFECTIVE = 1.0%

Process Average %	0–.010						.011–.10					
	Trial 1		Trial 2			AOQL in %	Trial 1		Trial 2			AOQL in %
Lot Size	n_1	c_1	n_2	n_1+n_2	c_2		n_1	c_1	n_2	n_1+n_2	c_2	
1–120	All	0	–	–	–	0	All	0	–	–	–	0
121–150	120	0	–	–	–	.06	120	0	–	–	–	.06
151–200	140	0	–	–	–	.08	140	0	–	–	–	.08
201–260	165	0	–	–	–	.10	165	0	–	–	–	.10
261–300	180	0	75	255	1	.10	180	0	75	255	1	.10
301–400	200	0	90	290	1	.12	200	0	90	290	1	.12
401–500	215	0	100	315	1	.14	215	0	100	315	1	.14
501–600	225	0	115	340	1	.15	225	0	115	340	1	.15
601–800	235	0	125	360	1	.16	235	0	125	360	1	.16
801–1000	245	0	135	380	1	.17	245	0	135	380	1	.17
1001–2000	265	0	155	420	1	.18	265	0	155	420	1	.18
2001–3000	270	0	160	430	1	.19	270	0	300	570	2	.22
3001–4000	275	0	160	435	1	.19	275	0	305	580	2	.22
4001–5000	275	0	165	440	1	.19	275	0	310	585	2	.23
5001–7000	275	0	170	445	1	.20	275	0	315	590	2	.23
7001–10,000	280	0	320	600	2	.24	280	0	460	740	3	.26
10,001–20,000	280	0	325	605	2	.24	280	0	465	745	3	.27
20,001–50,000	280	0	325	605	2	.25	280	0	605	885	4	.30
50,001–100,000	280	0	325	605	2	.25	280	0	605	885	4	.30

Process Average %	.11–.20						.21–.30					
	Trial 1		Trial 2			AOQL in %	Trial 1		Trial 2			AOQL in %
Lot Size	n_1	c_1	n_2	n_1+n_2	c_2		n_1	c_1	n_2	n_1+n_2	c_2	
1–120	All	0	–	–	–	0	All	0	–	–	–	0
121–150	120	0	–	–	–	.06	120	0	–	–	–	.06
151–200	140	0	–	–	–	.08	140	0	–	–	–	.08
201–260	165	0	–	–	–	.10	165	0	–	–	–	.10
261–300	180	0	75	255	1	.10	180	0	75	255	1	.10
301–400	200	0	90	290	1	.12	200	0	90	290	1	.12
401–500	215	0	100	315	1	.14	215	0	100	315	1	.14
501–600	225	0	115	340	1	.15	225	0	115	340	1	.15
601–800	235	0	125	360	1	.16	235	0	230	465	2	.18
801–1000	245	0	250	495	2	.19	245	0	250	495	2	.19
1001–2000	265	0	285	550	2	.21	265	0	405	670	3	.23
2001–3000	270	0	420	690	3	.25	270	0	545	815	4	.26
3001–4000	275	0	435	710	3	.25	435	1	645	1080	6	.29
4001–5000	275	0	565	840	4	.28	440	1	660	1100	6	.30
5001–7000	275	0	580	855	4	.29	445	1	785	1230	7	.33
7001–10,000	280	0	590	870	4	.30	450	1	920	1370	8	.35
10,001–20,000	450	1	700	1150	6	.33	605	2	1035	1640	10	.39
20,001–50,000	450	1	830	1280	7	.36	605	2	1295	1900	12	.42
50,001–100,000	450	1	960	1410	8	.38	605	2	1545	2150	14	.44

Process Average %	.31–.40						.41–.50					
	Trial 1		Trial 2			AOQL in %	Trial 1		Trial 2			AOQL in %
Lot Size	n_1	c_1	n_2	n_1+n_2	c_2		n_1	c_1	n_2	n_1+n_2	c_2	
1–120	All	0	–	–	–	0	All	0	–	–	–	0
121–150	120	0	–	–	–	.06	120	0	–	–	–	.06
151–200	140	0	–	–	–	.08	140	0	–	–	–	.08
201–260	165	0	–	–	–	.10	165	0	–	–	–	.10
261–300	180	0	75	255	1	.10	180	0	75	255	1	.10
301–400	200	0	90	290	1	.12	200	0	90	290	1	.12
401–500	215	0	100	315	1	.14	215	0	100	315	1	.14
501–600	225	0	115	340	1	.15	225	0	205	430	2	.16
601–800	235	0	230	465	2	.18	235	0	230	465	2	.18
801–1000	245	0	250	495	2	.19	245	0	250	495	2	.19
1001–2000	265	0	515	780	4	.24	265	0	515	780	4	.24
2001–3000	430	1	620	1050	6	.28	430	1	830	1260	8	.30
3001–4000	435	1	865	1300	8	.30	580	2	940	1520	10	.33
4001–5000	440	1	1000	1440	9	.33	585	2	1075	1660	11	.35
5001–7000	590	2	990	1580	10	.36	730	3	1190	1920	13	.38
7001–10,000	600	2	1240	1840	12	.39	870	4	1540	2410	17	.41
10,001–20,000	745	3	1485	2230	15	.43	1150	6	1990	3140	23	.44
20,001–50,000	885	4	1845	2730	19	.47	1280	7	2600	3880	29	.52
50,001–100,000	885	4	2085	2970	21	.49	1410	8	3280	4690	36	.55

n_1 = Size of First Sample; n_2 = Size of Second Sample; entry of "All" indicates that each piece in lot is to be inspected.
c_1 = Allowable Defect Number for First Sample; c_2 = Allowable Defect Number for First and Second Samples Combined.
AOQL = Average Outgoing Quality Limit.

TABLE II CONT'D: DOUBLE SAMPLING LOT INSPECTION TABLES—BASED ON STATED VALUES OF "LOT TOLERANCE PER CENT DEFECTIVE" AND CONSUMER'S RISK = 0.10

TABLE DL-2

LOT TOLERANCE PER CENT DEFECTIVE = 2.0%

Process Average %	0–.02						.03–.20						.21–.40					
Lot Size	Trial 1		Trial 2			AOQL in %	Trial 1		Trial 2			AOQL in %	Trial 1		Trial 2			AOQL in %
	n_1	c_1	n_2	n_1+n_2	c_2		n_1	c_1	n_2	n_1+n_2	c_2		n_1	c_1	n_2	n_1+n_2	c_2	
1–75	All	0	–	–	–	0	All	0	–	–	–	0	All	0	–	–	–	0
76–100	70	0	–	–	–	.16	70	0	–	–	–	.16	70	0	–	–	–	.16
101–200	85	0	–	–	–	.25	85	0	–	–	–	.25	85	0	–	–	–	.25
201–300	115	0	50	165	1	.29	115	0	50	165	1	.29	115	0	50	165	1	.29
301–400	120	0	60	180	1	.32	120	0	60	180	1	.32	120	0	60	180	1	.32
401–500	125	0	65	190	1	.33	125	0	65	190	1	.33	125	0	120	245	2	.37
501–600	125	0	70	195	1	.34	125	0	70	195	1	.34	125	0	130	255	2	.39
601–800	130	0	75	205	1	.35	130	0	75	205	1	.35	130	0	135	265	2	.41
801–1000	135	0	75	210	1	.36	135	0	140	275	2	.42	135	0	140	275	2	.42
1001–2000	135	0	85	220	1	.38	135	0	155	290	2	.45	135	0	220	355	3	.50
2001–3000	140	0	85	225	1	.39	140	0	155	295	2	.46	140	0	285	425	4	.56
3001–4000	140	0	85	225	1	.40	140	0	225	365	3	.52	140	0	290	430	4	.57
4001–5000	140	0	160	300	2	.47	140	0	230	370	3	.53	140	0	360	500	5	.61
5001–7000	140	0	160	300	2	.48	140	0	230	370	3	.54	140	0	365	505	5	.62
7001–10,000	140	0	160	300	2	.48	140	0	235	375	3	.54	225	1	350	575	6	.66
10,001–20,000	140	0	165	305	2	.49	140	0	235	375	3	.54	225	1	415	640	7	.71
20,001–50,000	140	0	165	305	2	.49	140	0	305	445	4	.59	225	1	480	705	8	.75
50,001–100,000	140	0	165	305	2	.49	140	0	305	445	4	.60	225	1	545	770	9	.78

Process Average %	.41–.60						.61–.80						.81–1.00					
Lot Size	Trial 1		Trial 2			AOQL in %	Trial 1		Trial 2			AOQL in %	Trial 1		Trial 2			AOQL in %
	n_1	c_1	n_2	n_1+n_2	c_2		n_1	c_1	n_2	n_1+n_2	c_2		n_1	c_1	n_2	n_1+n_2	c_2	
1–75	All	0	–	–	–	0	All	0	–	–	–	0	All	0	–	–	–	0
76–100	70	0	–	–	–	.16	70	0	–	–	–	.16	70	0	–	–	–	.16
101–200	85	0	–	–	–	.25	85	0	–	–	–	.25	85	0	–	–	–	.25
201–300	115	0	50	165	1	.29	115	0	50	165	1	.29	115	0	50	165	1	.29
301–400	120	0	115	235	2	.34	120	0	115	235	2	.34	120	0	115	235	2	.34
401–500	125	0	120	245	2	.37	125	0	120	245	2	.37	125	0	120	245	2	.37
501–600	125	0	130	255	2	.39	125	0	185	310	3	.41	125	0	185	310	3	.41
601–800	130	0	195	325	3	.44	130	0	250	380	4	.45	130	0	250	380	4	.45
801–1000	135	0	200	335	3	.46	135	0	255	390	4	.48	210	1	290	500	6	.54
1001–2000	135	0	285	420	4	.54	220	1	375	595	7	.62	220	1	485	705	9	.65
2001–3000	225	1	385	610	7	.65	295	2	435	730	9	.69	360	3	535	895	12	.72
3001–4000	225	1	455	680	8	.69	295	2	555	850	11	.74	365	3	715	1080	15	.77
4001–5000	225	1	460	685	8	.70	300	2	620	920	12	.77	435	4	775	1210	17	.81
5001–7000	300	2	450	750	9	.74	370	3	680	1050	14	.82	505	5	935	1440	21	.89
7001–10,000	300	2	520	820	10	.77	375	3	735	1110	15	.85	575	6	1055	1630	24	.95
10,001–20,000	305	2	645	950	12	.83	375	3	935	1310	18	.92	640	7	1240	1880	28	1.0
20,001–50,000	305	2	715	1020	13	.86	445	4	1045	1490	21	.98	705	8	1635	2340	36	1.1
50,001–100,000	305	2	830	1135	15	.90	510	5	1150	1660	24	1.0	770	9	1850	2620	41	1.2

TABLE DL-3

LOT TOLERANCE PER CENT DEFECTIVE = 3.0%

Process Average %	0–.03						.04–.30					
	Trial 1		Trial 2				Trial 1		Trial 2			
Lot Size	n_1	c_1	n_2	n_1+n_2	c_2	AOQL in %	n_1	c_1	n_2	n_1+n_2	c_2	AOQL in %
1–40	All	0	–	–	–	0	All	0	–	–	–	0
41–55	40	0	–	–	–	.18	40	0	–	–	–	.18
56–100	55	0	–	–	–	.30	55	0	–	–	–	.30
101–150	70	0	30	100	1	.37	70	0	30	100	1	.37
151–200	75	0	40	115	1	.45	75	0	40	115	1	.45
201–300	75	0	40	115	1	.50	75	0	40	115	1	.50
301–400	80	0	45	125	1	.52	80	0	45	125	1	.52
401–500	85	0	50	135	1	.53	85	0	50	135	1	.53
501–600	85	0	50	135	1	.54	85	0	50	135	1	.54
601–800	90	0	50	140	1	.55	90	0	95	185	2	.64
801–1000	90	0	55	145	1	.56	90	0	100	190	2	.66
1001–2000	90	0	60	150	1	.58	90	0	105	195	2	.70
2001–3000	90	0	60	150	1	.59	90	0	155	245	3	.80
3001–4000	95	0	105	200	2	.72	95	0	150	245	3	.80
4001–5000	95	0	105	200	2	.73	95	0	155	250	3	.81
5001–7000	95	0	105	200	2	.73	95	0	155	250	3	.81
7001–10,000	95	0	105	200	2	.73	95	0	155	250	3	.81
10,001–20,000	95	0	105	200	2	.74	95	0	200	295	4	.92
20,001–50,000	95	0	105	200	2	.74	95	0	200	295	4	.93
50,001–100,000	95	0	105	200	2	.75	95	0	245	340	5	1.0

Process Average %	.31–.60						.61–.90					
	Trial 1		Trial 2				Trial 1		Trial 2			
Lot Size	n_1	c_1	n_2	n_1+n_2	c_2	AOQL in %	n_1	c_1	n_2	n_1+n_2	c_2	AOQL in %
1–40	All	0	–	–	–	0	All	0	–	–	–	0
41–55	40	0	–	–	–	.18	40	0	–	–	–	.18
56–100	55	0	–	–	–	.30	55	0	–	–	–	.30
101–150	70	0	30	100	1	.37	70	0	30	100	1	.37
151–200	75	0	40	115	1	.45	75	0	40	115	1	.45
201–300	75	0	40	115	1	.50	75	0	80	155	2	.54
301–400	80	0	85	165	2	.57	80	0	85	165	2	.57
401–500	85	0	90	175	2	.60	85	0	125	210	3	.64
501–600	85	0	95	180	2	.62	85	0	130	215	3	.67
601–800	90	0	135	225	3	.70	90	0	170	260	4	.74
801–1000	90	0	140	230	3	.72	90	0	180	270	4	.77
1001–2000	90	0	190	280	4	.84	150	1	210	360	6	.90
2001–3000	90	0	200	290	4	.86	150	1	300	450	8	1.0
3001–4000	95	0	235	330	5	.92	150	1	350	500	9	1.1
4001–5000	150	1	230	380	6	.98	200	2	340	540	10	1.2
5001–7000	150	1	230	380	6	1.0	200	2	385	585	11	1.2
7001–10,000	150	1	275	425	7	1.0	200	2	425	625	12	1.2
10,001–20,000	150	1	320	470	8	1.1	200	2	475	675	13	1.3
20,001–50,000	150	1	365	515	9	1.2	200	2	515	715	14	1.3
50,001–100,000	150	1	405	555	10	1.2	200	2	555	755	15	1.3

Process Average %	.91–1.20						1.21–1.50					
	Trial 1		Trial 2				Trial 1		Trial 2			
Lot Size	n_1	c_1	n_2	n_1+n_2	c_2	AOQL in %	n_1	c_1	n_2	n_1+n_2	c_2	AOQL in %
1–40	All	0	–	–	–	0	All	0	–	–	–	0
41–55	40	0	–	–	–	.18	40	0	–	–	–	.18
56–100	55	0	–	–	–	.30	55	0	–	–	–	.30
101–150	70	0	30	100	1	.37	70	0	30	100	1	.37
151–200	75	0	65	140	2	.47	75	0	65	140	2	.47
201–300	75	0	80	155	2	.54	75	0	80	155	2	.54
301–400	80	0	120	200	3	.62	80	0	120	200	3	.62
401–500	85	0	125	210	3	.64	85	0	160	245	4	.69
501–600	85	0	170	255	4	.72	135	1	185	320	6	.76
601–800	140	1	195	335	6	.79	140	1	210	350	7	.81
801–1000	145	1	235	380	7	.85	145	1	270	415	8	.86
1001–2000	150	1	325	475	9	1.0	195	2	350	545	11	1.1
2001–3000	200	2	365	565	11	1.1	290	4	470	760	16	1.2
3001–4000	245	3	405	650	13	1.2	330	5	545	875	19	1.2
4001–5000	250	3	445	695	14	1.2	380	6	620	1000	22	1.3
5001–7000	250	3	530	780	16	1.3	380	6	700	1080	24	1.4
7001–10,000	250	3	575	825	17	1.3	425	7	785	1210	27	1.5
10,001–20,000	295	4	655	950	20	1.4	470	8	900	1370	31	1.6
20,001–50,000	295	4	755	1050	23	1.5	515	9	1165	1680	39	1.7
50,001–100,000	340	5	840	1180	26	1.6	515	9	1315	1830	43	1.8

n_1 = Size of First Sample; n_2 = Size of Second Sample; entry of "All" indicates that each piece in lot is to be inspected.
c_1 = Allowable Defect Number for First Sample; c_2 = Allowable Defect Number for First and Second Samples Combined.
AOQL = Average Outgoing Quality Limit.

TABLE II CONT'D: DOUBLE SAMPLING LOT INSPECTION TABLES—BASED ON STATED VALUES OF "LOT TOLERANCE PER CENT DEFECTIVE" AND CONSUMER'S RISK = 0.10

TABLE DL-4

Lot Tolerance Per Cent Defective = 4.0%

Process Average %	0–.04						.05–.40					
	Trial 1		Trial 2				Trial 1		Trial 2			
Lot Size	n_1	c_1	n_2	n_1+n_2	c_2	AOQL in %	n_1	c_1	n_2	n_1+n_2	c_2	AOQL in %
1–35	All	0	–	–	–	0	All	0	–	–	–	0
36–50	34	0	–	–	–	.35	34	0	–	–	–	.35
51–75	40	0	–	–	–	.43	40	0	–	–	–	.43
76–100	50	0	25	75	1	.46	50	0	25	75	1	.46
101–150	55	0	30	85	1	.55	55	0	30	85	1	.55
151–200	60	0	30	90	1	.64	60	0	30	90	1	.64
201–300	60	0	35	95	1	.70	60	0	35	95	1	.70
301–400	65	0	35	100	1	.71	65	0	35	100	1	.71
401–500	65	0	40	105	1	.73	65	0	70	135	2	.83
501–600	65	0	40	105	1	.74	65	0	75	140	2	.85
601–800	65	0	40	105	1	.75	65	0	75	140	2	.87
801–1000	70	0	40	110	1	.76	70	0	75	145	2	.90
1001–2000	70	0	40	110	1	.78	70	0	80	150	2	.94
2001–3000	70	0	80	150	2	.95	70	0	115	185	3	1.1
3001–4000	70	0	80	150	2	.96	70	0	115	185	3	1.1
4001–5000	70	0	80	150	2	.97	70	0	115	185	3	1.1
5001–7000	70	0	80	150	2	.98	70	0	115	185	3	1.1
7001–10,000	70	0	80	150	2	.98	70	0	150	220	4	1.2
10,001–20,000	70	0	80	150	2	.98	70	0	150	220	4	1.2
20,001–50,000	70	0	80	150	2	.99	70	0	150	220	4	1.2
50,001–100,000	70	0	80	150	2	.99	70	0	185	255	5	1.3

Process Average %	.41–.80						.81–1.20					
	Trial 1		Trial 2				Trial 1		Trial 2			
Lot Size	n_1	c_1	n_2	n_1+n_2	c_2	AOQL in %	n_1	c_1	n_2	n_1+n_2	c_2	AOQL in %
1–35	All	0	–	–	–	0	All	0	–	–	–	0
36–50	34	0	–	–	–	.35	34	0	–	–	–	.35
51–75	40	0	–	–	–	.43	40	0	–	–	–	.43
76–100	50	0	25	75	1	.46	50	0	25	75	1	.46
101–150	55	0	30	85	1	.55	55	0	30	85	1	.55
151–200	60	0	30	90	1	.64	60	0	55	115	2	.68
201–300	60	0	65	125	2	.75	60	0	65	125	2	.75
301–400	65	0	65	130	2	.80	65	0	95	160	3	.86
401–500	65	0	70	135	2	.83	65	0	100	165	3	.92
501–600	65	0	100	165	3	.93	65	0	135	200	4	1.0
601–800	65	0	110	175	3	.97	65	0	140	205	4	1.0
801–1000	70	0	105	175	3	.98	110	1	155	265	6	1.2
1001–2000	70	0	145	215	4	1.1	110	1	195	305	7	1.3
2001–3000	70	0	180	250	5	1.2	110	1	260	370	9	1.4
3001–4000	110	1	175	285	6	1.3	150	2	255	405	10	1.5
4001–5000	115	1	170	285	6	1.3	150	2	285	435	11	1.6
5001–7000	115	1	205	320	7	1.4	150	2	320	470	12	1.6
7001–10,000	115	1	205	320	7	1.4	150	2	325	475	12	1.7
10,001–20,000	115	1	235	350	8	1.5	150	2	355	505	13	1.7
20,001–50,000	115	1	270	385	9	1.6	150	2	420	570	15	1.7
50,001–100,000	115	1	300	415	10	1.7	150	2	450	600	16	1.8

Process Average %	1.21–1.60						1.61–2.00					
	Trial 1		Trial 2				Trial 1		Trial 2			
Lot Size	n_1	c_1	n_2	n_1+n_2	c_2	AOQL in %	n_1	c_1	n_2	n_1+n_2	c_2	AOQL in %
1–35	All	0	–	–	–	0	All	0	–	–	–	0
36–50	34	0	–	–	–	.35	34	0	–	–	–	.35
51–75	40	0	–	–	–	.43	40	0	–	–	–	.43
76–100	50	0	25	75	1	.46	50	0	25	75	1	.46
101–150	55	0	30	85	1	.55	55	0	30	85	1	.55
151–200	60	0	55	115	2	.68	60	0	55	115	2	.68
201–300	60	0	90	150	3	.84	60	0	90	150	3	.84
301–400	65	0	95	160	3	.86	65	0	120	185	4	.92
401–500	65	0	130	195	4	.96	105	1	140	245	6	1.0
501–600	105	1	145	250	6	1.1	105	1	175	280	7	1.1
601–800	105	1	185	290	7	1.2	105	1	210	315	8	1.2
801–1000	110	1	210	320	8	1.2	145	2	230	375	10	1.3
1001–2000	150	2	240	390	10	1.5	180	3	295	475	13	1.6
2001–3000	185	3	305	490	13	1.6	220	4	410	630	18	1.7
3001–4000	185	3	340	525	14	1.6	285	6	465	750	22	1.8
4001–5000	185	3	395	580	16	1.7	285	6	520	805	24	1.9
5001–7000	185	3	435	620	17	1.7	320	7	585	905	27	2.0
7001–10,000	220	4	460	680	19	1.9	320	7	645	965	29	2.1
10,001–20,000	220	4	495	715	20	1.9	350	8	790	1140	35	2.2
20,001–50,000	255	5	575	830	24	2.0	385	9	895	1280	40	2.3
50,001–100,000	255	5	665	920	27	2.1	415	10	985	1400	44	2.4

TABLE DL-5

Lot Tolerance Per Cent Defective = 5.0%

Process Average %	0–.05						.06–.50					
	Trial 1		Trial 2				Trial 1		Trial 2			
Lot Size	n_1	c_1	n_2	n_1+n_2	c_2	AOQL in %	n_1	c_1	n_2	n_1+n_2	c_2	AOQL in %
1–30	All	0	–	–	–	0	All	0	–	–	–	0
31–50	30	0	–	–	–	.49	30	0	–	–	–	.49
51–75	38	0	–	–	–	.59	38	0	–	–	–	.59
76–100	44	0	21	65	1	.64	44	0	21	65	1	.64
101–200	49	0	26	75	1	.84	49	0	26	75	1	.84
201–300	50	0	30	80	1	.91	50	0	30	80	1	.91
301–400	55	0	30	85	1	.92	55	0	55	110	2	1.1
401–500	55	0	30	85	1	.93	55	0	55	110	2	1.1
501–600	55	0	30	85	1	.94	55	0	60	115	2	1.1
601–800	55	0	35	90	1	.95	55	0	65	120	2	1.1
801–1000	55	0	35	90	1	.96	55	0	65	120	2	1.1
1001–2000	55	0	35	90	1	.98	55	0	95	150	3	1.3
2001–3000	55	0	65	120	2	1.2	55	0	95	150	3	1.3
3001–4000	55	0	65	120	2	1.2	55	0	95	150	3	1.3
4001–5000	55	0	65	120	2	1.2	55	0	95	150	3	1.4
5001–7000	55	0	65	120	2	1.2	55	0	95	150	3	1.4
7001–10,000	55	0	65	120	2	1.2	55	0	120	175	4	1.5
10,001–20,000	55	0	65	120	2	1.2	55	0	120	175	4	1.5
20,001–50,000	55	0	65	120	2	1.2	55	0	150	205	5	1.7
50,001–100,000	55	0	65	120	2	1.2	55	0	150	205	5	1.7

Process Average %	.51–1.00						1.01–1.50					
	Trial 1		Trial 2				Trial 1		Trial 2			
Lot Size	n_1	c_1	n_2	n_1+n_2	c_2	AOQL in %	n_1	c_1	n_2	n_1+n_2	c_2	AOQL in %
1–30	All	0	–	–	–	0	All	0	–	–	–	0
31–50	30	0	–	–	–	.49	30	0	–	–	–	.49
51–75	38	0	–	–	–	.59	38	0	–	–	–	.59
76–100	44	0	21	65	1	.64	44	0	21	65	1	.64
101–200	49	0	26	75	1	.84	49	0	51	100	2	.91
201–300	50	0	55	105	2	1.0	50	0	55	105	2	1.0
301–400	55	0	55	110	2	1.1	55	0	80	135	3	1.1
401–500	55	0	80	135	3	1.2	55	0	105	160	4	1.3
501–600	55	0	85	140	3	1.2	55	0	110	165	4	1.3
601–800	55	0	85	140	3	1.3	90	1	125	215	6	1.5
801–1000	55	0	115	170	4	1.4	90	1	150	240	7	1.5
1001–2000	55	0	120	175	4	1.4	90	1	185	275	8	1.7
2001–3000	55	0	150	205	5	1.5	120	2	180	300	9	1.9
3001–4000	90	1	140	230	6	1.6	120	2	210	330	10	2.0
4001–5000	90	1	165	255	7	1.8	120	2	255	375	12	2.1
5001–7000	90	1	165	255	7	1.8	120	2	260	380	12	2.1
7001–10,000	90	1	190	280	8	1.9	120	2	285	405	13	2.1
10,001–20,000	90	1	190	280	8	1.9	120	2	310	430	14	2.2
20,001–50,000	90	1	215	305	9	2.0	120	2	335	455	15	2.2
50,001–100,000	90	1	240	330	10	2.1	120	2	360	480	16	2.3

Process Average %	1.51–2.00						2.01–2.50					
	Trial 1		Trial 2				Trial 1		Trial 2			
Lot Size	n_1	c_1	n_2	n_1+n_2	c_2	AOQL in %	n_1	c_1	n_2	n_1+n_2	c_2	AOQL in %
1–30	All	0	–	–	–	0	All	0	–	–	–	0
31–50	30	0	–	–	–	.49	30	0	–	–	–	.49
51–75	38	0	–	–	–	.59	38	0	–	–	–	.59
76–100	44	0	21	65	1	.64	44	0	21	65	1	.64
101–200	49	0	51	100	2	.91	49	0	51	100	2	.91
201–300	50	0	80	130	3	1.1	50	0	100	150	4	1.1
301–400	55	0	100	155	4	1.2	85	1	105	190	6	1.3
401–500	85	1	120	205	6	1.4	85	1	140	225	7	1.4
501–600	85	1	145	230	7	1.4	85	1	165	250	8	1.5
601–800	90	1	170	260	8	1.5	120	2	185	305	10	1.6
801–1000	90	1	200	290	9	1.6	120	2	210	330	11	1.7
1001–2000	120	2	225	345	11	1.9	175	4	260	435	15	2.0
2001–3000	150	3	270	420	14	2.1	205	5	375	580	21	2.3
3001–4000	150	3	295	445	15	2.3	230	6	420	650	24	2.4
4001–5000	150	3	345	495	17	2.3	255	7	445	700	26	2.5
5001–7000	150	3	370	520	18	2.3	255	7	495	750	28	2.6
7001–10,000	175	4	370	545	19	2.4	280	8	540	820	31	2.7
10,001–20,000	175	4	420	595	21	2.4	280	8	660	940	36	2.8
20,001–50,000	205	5	485	690	25	2.5	305	9	745	1050	41	2.9
50,001–100,000	205	5	555	760	28	2.6	330	10	810	1140	45	3.0

n_1 = Size of First Sample; n_2 = Size of Second Sample; entry of "All" indicates that each piece in lot is to be inspected.
c_1 = Allowable Defect Number for First Sample; c_2 = Allowable Defect Number for First and Second Samples Combined.
AOQL = Average Outgoing Quality Limit.

TABLE II CONT'D: DOUBLE SAMPLING LOT INSPECTION TABLES—BASED ON STATED VALUES OF "LOT TOLERANCE PER CENT DEFECTIVE" AND CONSUMER'S RISK = 0.10

TABLE DL-7

Lot Tolerance Per Cent Defective = 7.0%

Process Average %	0–07						.08–.70						.71–1.40					
	Trial 1		Trial 2				Trial 1		Trial 2				Trial 1		Trial 2			
Lot Size	n_1	c_1	n_2	n_1+n_2	c_2	AOQL in %	n_1	c_1	n_2	n_1+n_2	c_2	AOQL in %	n_1	c_1	n_2	n_1+n_2	c_2	AOQL in %
1–25	All	0	–	–	–	0	All	0	–	–	–	0	All	0	–	–	–	0
26–50	24	0	–	–	–	.80	24	0	–	–	–	.80	24	0	–	–	–	.80
51–75	31	0	15	46	1	.90	31	0	15	46	1	.90	31	0	15	46	1	.90
76–110	34	0	16	50	1	1.1	34	0	16	50	1	1.1	34	0	16	50	1	1.1
111–200	36	0	19	55	1	1.2	36	0	19	55	1	1.2	36	0	39	75	2	1.4
201–300	37	0	23	60	1	1.3	37	0	23	60	1	1.3	37	0	38	75	2	1.5
301–400	38	0	22	60	1	1.3	38	0	42	80	2	1.5	38	0	57	95	3	1.7
401–500	39	0	21	60	1	1.3	39	0	41	80	2	1.5	39	0	61	100	3	1.7
501–600	39	0	26	65	1	1.3	39	0	46	85	2	1.6	39	0	61	100	3	1.7
601–800	39	0	26	65	1	1.4	39	0	46	85	2	1.6	39	0	81	120	4	1.9
801–1000	39	0	26	65	1	1.4	39	0	46	85	2	1.6	39	0	86	125	4	2.0
1001–2000	40	0	45	85	2	1.7	40	0	65	105	3	1.9	40	0	105	145	5	2.2
2001–3000	40	0	45	85	2	1.7	40	0	65	105	3	1.9	65	1	100	165	6	2.3
3001–4000	40	0	45	85	2	1.7	40	0	65	105	3	1.9	65	1	115	180	7	2.4
4001–5000	40	0	45	85	2	1.7	40	0	85	125	4	2.1	65	1	115	180	7	2.5
5001–7000	40	0	45	85	2	1.7	40	0	85	125	4	2.1	65	1	135	200	8	2.5
7001–10,000	40	0	45	85	2	1.7	40	0	85	125	4	2.1	65	1	135	200	8	2.6
10,001–20,000	40	0	45	85	2	1.7	40	0	85	125	4	2.1	65	1	155	220	9	2.7
20,001–50,000	40	0	45	85	2	1.7	40	0	105	145	5	2.3	65	1	170	235	10	2.8
50,001–100,000	40	0	45	85	2	1.7	40	0	105	145	5	2.3	65	1	170	235	10	2.9

Process Average %	1.41–2.10						2.11–2.80						2.81–3.50					
	Trial 1		Trial 2				Trial 1		Trial 2				Trial 1		Trial 2			
Lot Size	n_1	c_1	n_2	n_1+n_2	c_2	AOQL in %	n_1	c_1	n_2	n_1+n_2	c_2	AOQL in %	n_1	c_1	n_2	n_1+n_2	c_2	AOQL in %
1–25	All	0	–	–	–	0	All	0	–	–	–	0	All	0	–	–	–	0
26–50	24	0	–	–	–	.80	24	0	–	–	–	.80	24	0	–	–	–	.80
51–75	31	0	15	46	1	.90	31	0	15	46	1	.90	31	0	15	46	1	.90
76–110	34	0	31	65	2	1.2	34	0	31	65	2	1.2	34	0	31	65	2	1.2
111–200	36	0	54	90	3	1.5	36	0	54	90	3	1.5	36	0	69	105	4	1.5
201–300	37	0	58	95	3	1.6	37	0	73	110	4	1.7	60	1	80	140	6	1.9
301–400	38	0	77	115	4	1.8	60	1	85	145	6	1.9	60	1	100	160	7	2.0
401–500	39	0	76	115	4	1.8	60	1	105	165	7	2.1	60	1	135	195	9	2.2
501–600	65	1	90	155	6	2.1	65	1	120	185	8	2.2	85	2	130	215	10	2.3
601–800	65	1	105	170	7	2.2	65	1	140	205	9	2.3	85	2	165	250	12	2.5
801–1000	65	1	110	175	7	2.2	85	2	140	225	10	2.5	105	3	180	285	14	2.7
1001–2000	65	1	150	215	9	2.5	105	3	175	280	13	2.8	145	5	230	375	19	3.1
2001–3000	85	2	165	250	11	2.7	105	3	210	315	15	3.0	165	6	300	465	24	3.3
3001–4000	85	2	185	270	12	2.8	105	3	250	355	17	3.1	180	7	335	515	27	3.4
4001–5000	85	2	185	270	12	2.9	125	4	245	370	18	3.2	180	7	370	550	29	3.6
5001–7000	85	2	205	290	13	3.0	125	4	265	390	19	3.3	200	8	385	585	31	3.8
7001–10,000	85	2	205	290	13	3.1	125	4	300	425	21	3.4	200	8	450	650	35	3.9
10,001–20,000	85	2	220	305	14	3.2	125	4	335	460	23	3.5	220	9	485	705	38	4.0
20,001–50,000	85	2	240	325	15	3.3	145	5	360	505	26	3.5	220	9	565	785	43	4.1
50,001–100,000	105	3	270	375	18	3.4	165	6	390	555	29	3.7	235	10	610	845	47	4.2

TABLE DL-10

LOT TOLERANCE PER CENT DEFECTIVE = 10.0%

Process Average %	0–.10						.11–1.00					
	Trial 1		Trial 2				Trial 1		Trial 2			
Lot Size	n_1	c_1	n_2	n_1+n_2	c_2	AOQL in %	n_1	c_1	n_2	n_1+n_2	c_2	AOQL in %
1–20	All	0	–	–	–	0	All	0	–	–	–	0
21–50	17	0	–	–	–	1.3	17	0	–	–	–	1.3
51–100	25	0	13	38	1	1.6	25	0	13	38	1	1.6
101–200	27	0	15	42	1	1.8	27	0	15	42	1	1.8
201–300	27	0	16	43	1	1.9	27	0	30	57	2	2.2
301–400	27	0	17	44	1	1.9	27	0	33	60	2	2.2
401–500	28	0	16	44	1	1.9	28	0	32	60	2	2.3
501–600	28	0	17	45	1	1.9	28	0	32	60	2	2.3
601–800	28	0	17	45	1	2.0	28	0	47	75	3	2.6
801–1000	28	0	32	60	2	2.3	28	0	47	75	3	2.6
1001–2000	28	0	32	60	2	2.4	28	0	47	75	3	2.7
2001–3000	28	0	32	60	2	2.4	28	0	47	75	3	2.7
3001–4000	28	0	32	60	2	2.4	28	0	62	90	4	2.9
4001–5000	28	0	32	60	2	2.4	28	0	62	90	4	3.0
5001–7000	28	0	32	60	2	2.4	28	0	62	90	4	3.0
7001–10,000	28	0	32	60	2	2.5	28	0	62	90	4	3.0
10,001–20,000	28	0	32	60	2	2.5	28	0	62	90	4	3.0
20,001–50,000	28	0	32	60	2	2.5	28	0	72	100	5	3.3
50,001–100,000	28	0	32	60	2	2.5	28	0	72	100	5	3.3

Process Average %	1.01–2.00						2.01–3.00					
	Trial 1		Trial 2				Trial 1		Trial 2			
Lot Size	n_1	c_1	n_2	n_1+n_2	c_2	AOQL in %	n_1	c_1	n_2	n_1+n_2	c_2	AOQL in %
1–20	All	0	–	–	–	0	All	0	–	–	–	0
21–50	17	0	–	–	–	1.3	17	0	–	–	–	1.3
51–100	25	0	13	38	1	1.6	25	0	24	49	2	1.8
101–200	27	0	28	55	2	2.1	27	0	38	65	3	2.3
201–300	27	0	43	70	3	2.4	27	0	53	80	4	2.7
301–400	27	0	43	70	3	2.5	44	1	66	110	6	2.9
401–500	28	0	57	85	4	2.7	44	1	76	120	7	3.1
501–600	28	0	57	85	4	2.8	45	1	75	120	7	3.3
601–800	28	0	57	85	4	2.9	45	1	90	135	8	3.5
801–1000	28	0	72	100	5	3.0	45	1	90	135	8	3.5
1001–2000	45	1	70	115	6	3.3	60	2	105	165	10	3.9
2001–3000	45	1	85	130	7	3.5	60	2	130	190	12	4.1
3001–4000	45	1	85	130	7	3.5	60	2	130	190	12	4.2
4001–5000	45	1	95	140	8	3.7	60	2	140	200	13	4.3
5001–7000	45	1	95	140	8	3.8	60	2	140	200	13	4.4
7001–10,000	45	1	95	140	8	3.8	60	2	155	215	14	4.4
10,001–20,000	45	1	110	155	9	3.9	60	2	165	225	15	4.4
20,001–50,000	45	1	120	165	10	3.9	75	3	165	240	16	4.5
50,001–100,000	45	1	135	180	11	4.2	75	3	200	275	19	4.8

Process Average %	3.01–4.00						4.01–5.00					
	Trial 1		Trial 2				Trial 1		Trial 2			
Lot Size	n_1	c_1	n_2	n_1+n_2	c_2	AOQL in %	n_1	c_1	n_2	n_1+n_2	c_2	AOQL in %
1–20	All	0	–	–	–	0	All	0	–	–	–	0
21–50	17	0	–	–	–	1.3	17	0	–	–	–	1.3
51–100	25	0	24	49	2	1.8	25	0	24	49	2	1.8
101–200	27	0	53	80	4	2.4	27	0	53	80	4	2.4
201–300	43	1	62	105	6	2.8	43	1	82	125	8	3.0
301–400	44	1	86	130	8	3.1	60	2	90	150	10	3.2
401–500	44	1	101	145	9	3.3	60	2	105	165	11	3.4
501–600	60	2	100	160	10	3.4	75	3	115	190	13	3.6
601–800	60	2	110	170	11	3.7	75	3	140	215	15	3.9
801–1000	60	2	125	185	12	3.9	90	4	150	240	17	4.1
1001–2000	75	3	150	225	15	4.3	115	6	200	315	23	4.8
2001–3000	75	3	175	250	17	4.4	130	7	235	365	27	5.0
3001–4000	90	4	170	260	18	4.6	130	7	255	385	29	5.1
4001–5000	90	4	180	270	19	4.7	140	8	270	410	31	5.2
5001–7000	90	4	205	295	21	4.9	140	8	315	455	35	5.3
7001–10,000	90	4	220	310	22	5.0	140	8	340	480	37	5.4
10,001–20,000	100	5	230	330	24	5.1	155	9	370	525	41	5.6
20,001–50,000	100	5	280	380	28	5.2	165	10	405	570	45	5.7
50,001–100,000	115	6	285	400	30	5.3	165	10	440	605	48	6.2

n_1 = Size of First Sample; n_2 = Size of Second Sample; entry of "All" indicates that each piece in lot is to be inspected
c_1 = Allowable Defect Number for First Sample; c_2 = Allowable Defect Number for First and Second Samples Combined.
AOQL = Average Outgoing Quality Limit.

TABLE III: SINGLE SAMPLING LOT INSPECTION TABLES—BASED ON STATED VALUES OF "AVERAGE OUTGOING QUALITY LIMIT"

TABLE SA-0.1
Average Outgoing Quality Limit = 0.1%

Process Average %	0-.002			.003-.020			.021-.040			.041-.060			.061-.080			.081-.100		
Lot Size	n	c	p_t%	n	c	p_t%	n	c	p_t%	n	c	p_t%	n	c	p_t%	n	c	p_t%
1-75	All	0	-	All	0	-	All	0	-	All	0	-	All	0	-	All	0	-
76-95	75	0	1.5	75	0	1.5	75	0	1.5	75	0	1.5	75	0	1.5	75	0	1.5
96-130	95	0	1.4	95	0	1.4	95	0	1.4	95	0	1.4	95	0	1.4	95	0	1.4
131-200	130	0	1.2	130	0	1.2	130	0	1.2	130	0	1.2	130	0	1.2	130	0	1.2
201-300	165	0	1.1	165	0	1.1	165	0	1.1	165	0	1.1	165	0	1.1	165	0	1.1
301-400	190	0	.96	190	0	.96	190	0	.96	190	0	.96	190	0	.96	190	0	.96
401-500	210	0	.91	210	0	.91	210	0	.91	210	0	.91	210	0	.91	210	0	.91
501-600	230	0	.86	230	0	.86	230	0	.86	230	0	.86	230	0	.86	230	0	.86
601-800	250	0	.81	250	0	.81	250	0	.81	250	0	.81	250	0	.81	250	0	.81
801-1000	270	0	.76	270	0	.76	270	0	.76	270	0	.76	270	0	.76	270	0	.76
1001-2000	310	0	.71	310	0	.71	310	0	.71	310	0	.71	310	0	.71	310	0	.71
2001-3000	330	0	.67	330	0	.67	330	0	.67	330	0	.67	330	0	.67	655	1	.64
3001-4000	340	0	.64	340	0	.64	340	0	.64	695	1	.59	695	1	.59	695	1	.59
4001-5000	345	0	.62	345	0	.62	345	0	.62	720	1	.54	720	1	.54	720	1	.54
5001-7000	350	0	.61	350	0	.61	750	1	.51	750	1	.51	750	1	.51	750	1	.51
7001-10,000	355	0	.60	355	0	.60	775	1	.49	775	1	.49	775	1	.49	1210	2	.44
10,001-20,000	360	0	.59	810	1	.48	810	1	.48	1280	2	.42	1280	2	.42	1770	3	.38
20,001-50,000	365	0	.58	830	1	.47	1330	2	.41	1870	3	.37	2420	4	.34	2980	5	.33
50,001-100,000	365	0	.58	835	1	.46	1350	2	.40	2480	4	.33	3070	5	.32	4270	7	.30

TABLE SA-0.25
Average Outgoing Quality Limit = 0.25%

Process Average %	0-.005			.006-.050			.051-.100			.101-.150			.151-.200			.201-.250		
Lot Size	n	c	p_t%	n	c	p_t%	n	c	p_t%	n	c	p_t%	n	c	p_t%	n	c	p_t%
1-60	All	0	-	All	0	-	All	0	-	All	0	-	All	0	-	All	0	-
61-100	60	0	2.5	60	0	2.5	60	0	2.5	60	0	2.5	60	0	2.5	60	0	2.5
101-200	85	0	2.1	85	0	2.1	85	0	2.1	85	0	2.1	85	0	2.1	85	0	2.1
201-300	100	0	1.9	100	0	1.9	100	0	1.9	100	0	1.9	100	0	1.9	100	0	1.9
301-400	110	0	1.8	110	0	1.8	110	0	1.8	110	0	1.8	110	0	1.8	110	0	1.8
401-500	115	0	1.8	115	0	1.8	115	0	1.8	115	0	1.8	115	0	1.8	115	0	1.8
501-600	120	0	1.7	120	0	1.7	120	0	1.7	120	0	1.7	120	0	1.7	120	0	1.7
601-800	125	0	1.7	125	0	1.7	125	0	1.7	125	0	1.7	125	0	1.7	125	0	1.7
801-1000	130	0	1.7	130	0	1.7	130	0	1.7	130	0	1.7	130	0	1.7	250	1	1.4
1001-2000	135	0	1.6	135	0	1.6	135	0	1.6	290	1	1.3	290	1	1.3	290	1	1.3
2001-3000	140	0	1.6	140	0	1.6	300	1	1.3	300	1	1.3	300	1	1.3	300	1	1.3
3001-4000	140	0	1.6	140	0	1.6	310	1	1.3	310	1	1.3	310	1	1.3	485	2	1.1
4001-5000	145	0	1.6	145	0	1.6	315	1	1.2	315	1	1.2	495	2	1.1	495	2	1.1
5001-7000	145	0	1.6	320	1	1.2	320	1	1.2	510	2	1.0	510	2	1.0	700	3	.94
7001-10,000	145	0	1.6	325	1	1.2	325	1	1.2	520	2	1.0	720	3	.91	720	3	.91
10,001-20,000	145	0	1.6	330	1	1.2	535	2	1.0	750	3	.89	970	4	.81	1190	5	.75
20,001-50,000	145	0	1.6	335	1	1.2	545	2	1.0	995	4	.80	1240	5	.74	1980	8	.66
50,001-100,000	335	1	1.2	545	2	1.0	775	3	.87	1250	5	.73	1750	7	.67	2810	11	.62

n = Size of Sample; entry of "All" indicates that each piece in lot is to be inspected.
c = Allowable Defect Number for Sample.
p_t = Lot Tolerance Per Cent Defective corresponding to a Consumer's Risk (P_C) = 0.10.

TABLE III CONT'D: SINGLE SAMPLING LOT INSPECTION TABLES—BASED ON STATED VALUES OF "AVERAGE OUTGOING QUALITY LIMIT"

TABLE SA-0.5
Average Outgoing Quality Limit = 0.5%

Process Average %	0–.010			.011–.10			.11–.20			.21–.30			.31–.40			41.–.50		
Lot Size	n	c	p_t%	n	c	p_t%	n	c	p_t%	n	c	p_t%	n	c	p_t%	n	c	p_t%
1–30	All	0	–	All	0	–	All	0	–	All	0	–	All	0	–	All	0	–
31–50	30	0	5.0	30	0	5.0	30	0	5.0	30	0	5.0	30	0	5.0	30	0	5.0
51–100	42	0	4.2	42	0	4.2	42	0	4.2	42	0	4.2	42	0	4.2	42	0	4.2
101–200	55	0	3.6	55	0	3.6	55	0	3.6	55	0	3.6	55	0	3.6	55	0	3.6
201–300	60	0	3.4	60	0	3.4	60	0	3.4	60	0	3.4	60	0	3.4	60	0	3.4
301–400	60	0	3.5	60	0	3.5	60	0	3.5	60	0	3.5	60	0	3.5	60	0	3.5
401–500	65	0	3.3	65	0	3.3	65	0	3.3	65	0	3.3	65	0	3.3	125	1	2.9
501–600	65	0	3.3	65	0	3.3	65	0	3.3	65	0	3.3	130	1	2.7	130	1	2.7
601–800	65	0	3.4	65	0	3.4	65	0	3.4	140	1	2.6	140	1	2.6	140	1	2.6
801–1000	70	0	3.2	70	0	3.2	70	0	3.2	145	1	2.6	145	1	2.6	145	1	2.6
1001–2000	70	0	3.2	70	0	3.2	155	1	2.5	155	1	2.5	155	1	2.5	240	2	2.2
2001–3000	70	0	3.3	70	0	3.3	160	1	2.4	160	1	2.4	250	2	2.1	250	2	2.1
3001–4000	70	0	3.3	160	1	2.4	160	1	2.4	255	2	2.1	255	2	2.1	355	3	1.9
4001–5000	75	0	3.0	165	1	2.4	165	1	2.4	260	2	2.0	360	3	1.9	460	4	1.7
5001–7000	75	0	3.0	165	1	2.4	265	2	2.0	265	2	2.0	370	3	1.8	475	4	1.7
7001–10,000	75	0	3.1	165	1	2.4	265	2	2.0	375	3	1.8	485	4	1.7	595	5	1.6
10,001–20,000	75	0	3.1	165	1	2.4	270	2	1.9	380	3	1.7	615	5	1.5	855	7	1.4
20,001–50,000	170	1	2.3	275	2	1.9	390	3	1.7	625	5	1.5	875	7	1.3	1410	11	1.2
50,001–100,000	170	1	2.3	275	2	1.9	510	4	1.6	755	6	1.4	1290	10	1.2	2130	16	1.1

TABLE SA-0.75
Average Outgoing Quality Limit = 0.75%

Process Average %	0–.015			.016–.15			.16–.30			.31–.45			.46–.60			.61–.75		
Lot Size	n	c	p_t%	n	c	p_t%	n	c	p_t%	n	c	p_t%	n	c	p_t%	n	c	p_t%
1–25	All	0	–	All	0	–	All	0	–	All	0	–	All	0	–	All	0	–
26–50	25	0	6.4	25	0	6.4	25	0	6.4	25	0	6.4	25	0	6.4	25	0	6.4
51–100	33	0	5.6	33	0	5.6	33	0	5.6	33	0	5.6	33	0	5.6	33	0	5.6
101–200	39	0	5.2	39	0	5.2	39	0	5.2	39	0	5.2	39	0	5.2	39	0	5.2
201–300	42	0	5.0	42	0	5.0	42	0	5.0	42	0	5.0	42	0	5.0	42	0	5.0
301–400	44	0	4.9	44	0	4.9	44	0	4.9	44	0	4.9	90	1	4.0	90	1	4.0
401–500	45	0	4.8	45	0	4.8	45	0	4.8	90	1	4.1	90	1	4.1	90	1	4.1
501–600	45	0	4.9	45	0	4.9	45	0	4.9	95	1	3.9	95	1	3.9	95	1	3.9
601–800	46	0	4.9	46	0	4.9	100	1	3.8	100	1	3.8	100	1	3.8	100	1	3.8
801–1000	47	0	4.8	47	0	4.8	100	1	3.8	100	1	3.8	100	1	3.8	155	2	3.2
1001–2000	48	0	4.7	48	0	4.7	105	1	3.7	105	1	3.7	170	2	3.1	170	2	3.1
2001–3000	48	0	4.7	110	1	3.5	110	1	3.5	170	2	3.1	170	2	3.1	240	3	2.8
3001–4000	48	0	4.7	110	1	3.5	110	1	3.5	175	2	3.1	245	3	2.7	315	4	2.5
4001–5000	49	0	4.6	110	1	3.6	175	2	3.1	175	2	3.1	245	3	2.7	320	4	2.5
5001–7000	49	0	4.6	110	1	3.6	180	2	3.0	250	3	2.7	325	4	2.5	400	5	2.3
7001–10,000	49	0	4.6	110	1	3.7	180	2	3.0	255	3	2.6	405	5	2.3	560	7	2.1
10,001–20,000	49	0	4.6	110	1	3.7	255	3	2.6	335	4	2.4	495	6	2.1	750	9	1.9
20,001–50,000	110	1	3.7	180	2	3.0	260	3	2.6	420	5	2.2	675	8	1.9	1130	13	1.6
50,001–100,000	110	1	3.7	185	2	2.9	335	4	2.4	590	7	2.0	955	11	1.7	1720	19	1.5

n = Size of Sample; entry of "All" indicates that each piece in lot is to be inspected.
c = Allowable Defect Number for Sample.
p_t = Lot Tolerance Per Cent Defective corresponding to a Consumer's Risk (P_C) = 0.10.

TABLE III CONT'D: SINGLE SAMPLING LOT INSPECTION TABLES—BASED ON STATED VALUES OF "AVERAGE OUTGOING QUALITY LIMIT"

TABLE SA-1.0

Average Outgoing Quality Limit = 1.0%

Process Average %	0–.02			.03–.20			.21–.40			.41–.60			.61–.80			.81–1.00		
Lot Size	n	c	p_t%	n	c	p_t%	n	c	p_t%	n	c	p_t%	n	c	p_t%	n	c	p_t%
1–25	All	0	–	All	0	–	All	0	–	All	0	–	All	0	–	All	0	–
26–50	22	0	7.7	22	0	7.7	22	0	7.7	22	0	7.7	22	0	7.7	22	0	7.7
51–100	27	0	7.1	27	0	7.1	27	0	7.1	27	0	7.1	27	0	7.1	27	0	7.1
101–200	32	0	6.4	32	0	6.4	32	0	6.4	32	0	6.4	32	0	6.4	32	0	6.4
201–300	33	0	6.3	33	0	6.3	33	0	6.3	33	0	6.3	33	0	6.3	65	1	5.0
301–400	34	0	6.1	34	0	6.1	34	0	6.1	70	1	4.6	70	1	4.6	70	1	4.6
401–500	35	0	6.1	35	0	6.1	35	0	6.1	70	1	4.7	70	1	4.7	70	1	4.7
501–600	35	0	6.1	35	0	6.1	75	1	4.4	75	1	4.4	75	1	4.4	75	1	4.4
601–800	35	0	6.2	35	0	6.2	75	1	4.4	75	1	4.4	75	1	4.4	120	2	4.2
801–1000	35	0	6.3	35	0	6.3	80	1	4.4	80	1	4.4	120	2	4.3	120	2	4.3
1001–2000	36	0	6.2	80	1	4.5	80	1	4.5	130	2	4.0	130	2	4.0	180	3	3.7
2001–3000	36	0	6.2	80	1	4.6	80	1	4.6	130	2	4.0	185	3	3.6	235	4	3.3
3001–4000	36	0	6.2	80	1	4.7	135	2	3.9	135	2	3.9	185	3	3.6	295	5	3.1
4001–5000	36	0	6.2	85	1	4.6	135	2	3.9	190	3	3.5	245	4	3.2	300	5	3.1
5001–7000	37	0	6.1	85	1	4.6	135	2	3.9	190	3	3.5	305	5	3.0	420	7	2.8
7001–10,000	37	0	6.2	85	1	4.6	135	2	3.9	245	4	3.2	310	5	3.0	430	7	2.7
10,001–20,000	85	1	4.6	135	2	3.9	195	3	3.4	250	4	3.2	435	7	2.7	635	10	2.4
20,001–50,000	85	1	4.6	135	2	3.9	255	4	3.1	380	6	2.8	575	9	2.5	990	15	2.1
50,001–100,000	85	1	4.6	135	2	3.9	255	4	3.1	445	7	2.6	790	12	2.3	1520	22	1.9

TABLE SA-1.5

Average Outgoing Quality Limit = 1.5%

Process Average %	0–.03			.04–.30			.31–.60			.61–.90			.91–1.20			1.21–1.50		
Lot Size	n	c	p_t%	n	c	p_t%	n	c	p_t%	n	c	p_t%	n	c	p_t%	n	c	p_t%
1–15	All	0	–	All	0	–	All	0	–	All	0	–	All	0	–	All	0	–
16–50	16	0	11.6	16	0	11.6	16	0	11.6	16	0	11.6	16	0	11.6	16	0	11.6
51–100	20	0	9.8	20	0	9.8	20	0	9.8	20	0	9.8	20	0	9.8	20	0	9.8
101–200	22	0	9.5	22	0	9.5	22	0	9.5	22	0	9.5	22	0	9.5	44	1	8.2
201–300	23	0	9.2	23	0	9.2	23	0	9.2	47	1	7.9	47	1	7.9	47	1	7.9
301–400	23	0	9.3	23	0	9.3	49	1	7.8	49	1	7.8	49	1	7.8	49	1	7.8
401–500	23	0	9.4	23	0	9.4	50	1	7.7	50	1	7.7	50	1	7.7	50	1	7.7
501–600	24	0	9.0	24	0	9.0	50	1	7.7	50	1	7.7	50	1	7.7	50	1	7.7
601–800	24	0	9.1	24	0	9.1	50	1	7.8	50	1	7.8	80	2	6.4	80	2	6.4
801–1000	24	0	9.1	55	1	7.0	55	1	7.0	85	2	6.2	85	2	6.2	85	2	6.2
1001–2000	24	0	9.1	55	1	7.0	55	1	7.0	85	2	6.2	120	3	5.4	155	4	5.0
2001–3000	24	0	9.2	55	1	7.1	90	2	5.9	125	3	5.3	160	4	4.9	200	5	4.6
3001–4000	24	0	9.2	55	1	7.1	90	2	5.9	125	3	5.3	165	4	4.8	240	6	4.4
4001–5000	24	0	9.2	55	1	7.1	90	2	5.9	125	3	5.3	205	5	4.6	280	7	4.2
5001–7000	24	0	9.2	55	1	7.1	90	2	5.9	165	4	4.8	205	5	4.6	325	8	4.0
7001–10,000	24	0	9.2	55	1	7.1	130	3	5.2	165	4	4.8	250	6	4.2	375	9	3.8
10,001–20,000	55	1	7.1	90	2	5.9	130	3	5.2	210	5	4.4	340	8	3.8	515	12	3.4
20,001–50,000	55	1	7.1	90	2	5.9	170	4	4.7	295	7	4.0	480	11	3.5	860	19	3.0
50,001–100,000	55	1	7.1	130	3	5.2	210	5	4.4	340	8	3.8	625	14	3.3	1120	24	2.8

n = Size of Sample; entry of "All" indicates that each piece in lot is to be inspected.
c = Allowable Defect Number for Sample.
p_t = Lot Tolerance Per Cent Defective corresponding to a Consumer's Risk (P_C) = 0.10.

TABLE III CONT'D: SINGLE SAMPLING LOT INSPECTION TABLES—BASED ON STATED VALUES OF "AVERAGE OUTGOING QUALITY LIMIT"

TABLE SA-2.0

AVERAGE OUTGOING QUALITY LIMIT = 2.0%

Process Average %	0-.04			.05-.40			.41-.80			.81-1.20			1.21-1.60			1.61-2.00		
Lot Size	n	c	pt%	n	c	pt%	n	c	pt%	n	c	pt%	n	c	pt%	n	c	pt%
1-15	All	0	-	All	0	-	All	0	-	All	0	-	All	0	-	All	0	-
16-50	14	0	13.6	14	0	13.6	14	0	13.6	14	0	13.6	14	0	13.6	14	0	13.6
51-100	16	0	12.4	16	0	12.4	16	0	12.4	16	0	12.4	16	0	12.4	16	0	12.4
101-200	17	0	12.2	17	0	12.2	17	0	12.2	17	0	12.2	35	1	10.5	35	1	10.5
201-300	17	0	12.3	17	0	12.3	17	0	12.3	37	1	10.2	37	1	10.2	37	1	10.2
301-400	18	0	11.8	18	0	11.8	38	1	10.0	38	1	10.0	38	1	10.0	60	2	8.5
401-500	18	0	11.9	18	0	11.9	39	1	9.8	39	1	9.8	60	2	8.6	60	2	8.6
501-600	18	0	11.9	18	0	11.9	39	1	9.8	39	1	9.8	60	2	8.6	60	2	8.6
601-800	18	0	11.9	40	1	9.6	40	1	9.6	65	2	8.0	65	2	8.0	85	3	7.5
801-1000	18	0	12.0	40	1	9.6	40	1	9.6	65	2	8.1	65	2	8.1	90	3	7.4
1001-2000	18	0	12.0	41	1	9.4	65	2	8.2	65	2	8.2	95	3	7.0	120	4	6.5
2001-3000	18	0	12.0	41	1	9.4	65	2	8.2	95	3	7.0	120	4	6.5	180	6	5.8
3001-4000	18	0	12.0	42	1	9.3	65	2	8.2	95	3	7.0	155	5	6.0	210	7	5.5
4001-5000	18	0	12.0	42	1	9.3	70	2	7.5	125	4	6.4	155	5	6.0	245	8	5.3
5001-7000	18	0	12.0	42	1	9.3	95	3	7.0	125	4	6.4	185	6	5.6	280	9	5.1
7001-10,000	42	1	9.3	70	2	7.5	95	3	7.0	155	5	6.0	220	7	5.4	350	11	4.8
10,001-20,000	42	1	9.3	70	2	7.6	95	3	7.0	190	6	5.6	290	9	4.9	460	14	4.4
20,001-50,000	42	1	9.3	70	2	7.6	125	4	6.4	220	7	5.4	395	12	4.5	720	21	3.9
50,001-100,000	42	1	9.3	95	3	7.0	160	5	5.9	290	9	4.9	505	15	4.2	955	27	3.7

TABLE SA-2.5

AVERAGE OUTGOING QUALITY LIMIT = 2.5%

Process Average %	0-.05			.06-.50			.51-1.00			1.01-1.50			1.51-2.00			2.01-2.50		
Lot Size	n	c	pt%	n	c	pt%	n	c	pt%	n	c	pt%	n	c	pt%	n	c	pt%
1-10	All	0	-	All	0	-	All	0	-	All	0	-	All	0	-	All	0	-
11-50	11	0	17.6	11	0	17.6	11	0	17.6	11	0	17.6	11	0	17.6	11	0	17.6
51-100	13	0	15.3	13	0	15.3	13	0	15.3	13	0	15.3	13	0	15.3	13	0	15.3
101-200	14	0	14.7	14	0	14.7	14	0	14.7	29	1	12.9	29	1	12.9	29	1	12.9
201-300	14	0	14.9	14	0	14.9	30	1	12.7	30	1	12.7	30	1	12.7	30	1	12.7
301-400	14	0	15.0	14	0	15.0	31	1	12.3	31	1	12.3	31	1	12.3	48	2	10.7
401-500	14	0	15.0	14	0	15.0	32	1	12.0	32	1	12.0	49	2	10.6	49	2	10.6
501-600	14	0	15.1	32	1	12.0	32	1	12.0	50	2	10.4	50	2	10.4	70	3	9.3
601-800	14	0	15.1	32	1	12.0	32	1	12.0	50	2	10.5	50	2	10.5	70	3	9.4
801-1000	15	0	14.2	33	1	11.7	33	1	11.7	50	2	10.6	70	3	9.4	90	4	8.5
1001-2000	15	0	14.2	33	1	11.7	55	2	9.3	75	3	8.8	95	4	8.0	120	5	7.6
2001-3000	15	0	14.2	33	1	11.8	55	2	9.4	75	3	8.8	120	5	7.6	145	6	7.2
3001-4000	15	0	14.3	33	1	11.8	55	2	9.5	100	4	7.9	125	5	7.4	195	8	6.6
4001-5000	15	0	14.3	33	1	11.8	75	3	8.9	100	4	7.9	150	6	7.0	225	9	6.3
5001-7000	33	1	11.8	55	2	9.7	75	3	8.9	125	5	7.4	175	7	6.7	250	10	6.1
7001-10,000	34	1	11.4	55	2	9.7	75	3	8.9	125	5	7.4	200	8	6.4	310	12	5.8
10,001-20,000	34	1	11.4	55	2	9.7	100	4	8.0	150	6	7.0	260	10	6.0	425	16	5.3
20,001-50,000	34	1	11.4	55	2	9.7	100	4	8.0	180	7	6.7	345	13	5.5	640	23	4.8
50,001-100,000	34	1	11.4	80	3	8.4	125	5	7.4	235	9	6.1	435	16	5.2	800	28	4.5

n = Size of Sample; entry of "All" indicates that each piece in lot is to be inspected.
c = Allowable Defect Number for Sample.
p_t = Lot Tolerance Per Cent Defective corresponding to a Consumer's Risk (P_C) = 0.10.

TABLE III CONT'D: SINGLE SAMPLING LOT INSPECTION TABLES—BASED ON STATED VALUES OF "AVERAGE OUTGOING QUALITY LIMIT"

TABLE SA-3.0
Average Outgoing Quality Limit = 3.0%

Process Average %	0–.06			.07–.60			.61–1.20			1.21–1.80			1.81–2.40			2.41–3.00		
Lot Size	n	c	p_t%	n	c	p_t%	n	c	p_t%	n	c	p_t%	n	c	p_t%	n	c	p_t%
1–10	All	0	–	All	0	–	All	0	–	All	0	–	All	0	–	All	0	–
11–50	10	0	19.0	10	0	19.0	10	0	19.0	10	0	19.0	10	0	19.0	10	0	19.0
51–100	11	0	18.0	11	0	18.0	11	0	18.0	11	0	18.0	11	0	18.0	22	1	16.4
101–200	12	0	17.0	12	0	17.0	12	0	17.0	25	1	15.1	25	1	15.1	25	1	15.1
201–300	12	0	17.0	12	0	17.0	26	1	14.6	26	1	14.6	26	1	14.6	40	2	12.8
301–400	12	0	17.1	12	0	17.1	26	1	14.7	26	1	14.7	41	2	12.7	41	2	12.7
401–500	12	0	17.2	27	1	14.1	27	1	14.1	42	2	12.4	42	2	12.4	42	2	12.4
501–600	12	0	17.3	27	1	14.2	27	1	14.2	42	2	12.4	42	2	12.4	60	3	10.8
601–800	12	0	17.3	27	1	14.2	27	1	14.2	43	2	12.1	60	3	10.9	60	3	10.9
801–1000	12	0	17.4	27	1	14.2	44	2	11.8	44	2	11.8	60	3	11.0	80	4	9.8
1001–2000	12	0	17.5	28	1	13.8	45	2	11.7	65	3	10.2	80	4	9.8	100	5	9.1
2001–3000	12	0	17.5	28	1	13.8	45	2	11.7	65	3	10.2	100	5	9.1	140	7	8.2
3001–4000	12	0	17.5	28	1	13.8	65	3	10.3	85	4	9.5	125	6	8.4	165	8	7.8
4001–5000	28	1	13.8	28	1	13.8	65	3	10.3	85	4	9.5	125	6	8.4	210	10	7.4
5001–7000	28	1	13.8	45	2	11.8	65	3	10.3	105	5	8.8	145	7	8.1	235	11	7.1
7001–10,000	28	1	13.9	46	2	11.6	65	3	10.3	105	5	8.8	170	8	7.6	280	13	6.8
10,001–20,000	28	1	13.9	46	2	11.7	85	4	9.5	125	6	8.4	215	10	7.2	380	17	6.2
20,001–50,000	28	1	13.9	65	3	10.3	105	5	8.8	170	8	7.6	310	14	6.5	560	24	5.7
50,001–100,000	28	1	13.9	65	3	10.3	125	6	8.4	215	10	7.2	385	17	6.2	690	29	5.4

TABLE SA-4.0
Average Outgoing Quality Limit = 4.0%

Process Average %	0–.08			.09–.80			.81–1.60			1.61–2.40			2.41–3.20			3.21–4.00		
Lot Size	n	c	p_t%	n	c	p_t%	n	c	p_t%	n	c	p_t%	n	c	p_t%	n	c	p_t%
1–10	All	0	–	All	0	–	All	0	–	All	0	–	All	0	–	All	0	–
11–50	8	0	23.0	8	0	23.0	8	0	23.0	8	0	23.0	8	0	23.0	8	0	23.0
51–100	8	0	24.0	8	0	24.0	8	0	24.0	8	0	24.0	17	1	21.5	17	1	21.5
101–200	9	0	22.0	9	0	22.0	19	1	20.0	19	1	20.0	19	1	20.0	19	1	20.0
201–300	9	0	22.5	9	0	22.5	20	1	19.0	20	1	19.0	31	2	16.8	31	2	16.8
301–400	9	0	22.5	20	1	19.1	20	1	19.1	32	2	16.2	32	2	16.2	43	3	15.2
401–500	9	0	22.5	20	1	19.1	20	1	19.1	32	2	16.3	32	2	16.3	44	3	14.9
501–600	9	0	22.5	20	1	19.2	20	1	19.2	32	2	16.3	45	3	14.6	60	4	12.9
601–800	9	0	22.5	20	1	19.2	33	2	15.9	33	2	15.9	46	3	14.3	60	4	13.0
801–1000	9	0	22.5	21	1	18.3	33	2	16.0	46	3	14.3	60	4	13.0	75	5	12.2
1001–2000	9	0	22.5	21	1	18.4	34	2	15.6	47	3	14.1	75	5	12.2	105	7	11.0
2001–3000	9	0	22.5	21	1	18.4	34	2	15.6	60	4	13.2	90	6	11.3	125	8	10.4
3001–4000	21	1	18.4	21	1	18.4	48	3	13.8	65	4	12.2	110	7	10.7	155	10	9.8
4001–5000	21	1	18.5	34	2	15.7	48	3	13.9	80	5	11.6	110	7	10.8	175	11	9.5
5001–7000	21	1	18.5	34	2	15.7	48	3	13.9	80	5	11.6	125	8	10.4	210	13	9.0
7001–10,000	21	1	18.5	34	2	15.7	65	4	12.3	95	6	11.1	145	9	9.8	245	15	8.6
10,001–20,000	21	1	18.5	34	2	15.7	65	4	12.3	110	7	10.8	195	12	9.0	340	20	7.9
20,001–50,000	21	1	18.5	49	3	13.6	80	5	11.6	145	9	9.8	250	15	8.5	460	26	7.4
50,001–100,000	21	1	18.5	49	3	13.6	95	6	11.1	165	10	9.6	310	18	8.0	540	30	7.1

n = Size of Sample; entry of "All" indicates that each piece in lot is to be inspected.
c = Allowable Defect Number for Sample.
p_t = Lot Tolerance Per Cent Defective corresponding to a Consumer's Risk (P_C) = 0.10.

TABLE III CONT'D: SINGLE SAMPLING LOT INSPECTION TABLES—BASED ON STATED VALUES OF "AVERAGE OUTGOING QUALITY LIMIT"

TABLE SA-5.0

AVERAGE OUTGOING QUALITY LIMIT = 5.0%

Process Average %	0–.10			.11–1.00			1.01–2.00			2.01–3.00			3.01–4.00			4.01–5.00		
Lot Size	n	c	p_t%	n	c	p_t%	n	c	p_t%	n	c	p_t%	n	c	p_t%	n	c	p_t%
1–5	All	0	–	All	0	–	All	0	–	All	0	–	All	0	–	All	0	–
6–50	6	0	30.5	6	0	30.5	6	0	30.5	6	0	30.5	6	0	30.5	6	0	30.5
51–100	7	0	27.0	7	0	27.0	7	0	27.0	14	1	26.5	14	1	26.5	14	1	26.5
101–200	7	0	27.5	7	0	27.5	16	1	24.0	16	1	24.0	16	1	24.0	24	2	21.5
201–300	7	0	27.5	16	1	24.0	16	1	24.0	16	1	24.0	25	2	21.0	25	2	21.0
301–400	7	0	27.5	16	1	24.0	16	1	24.0	26	2	20.0	26	2	20.0	35	3	18.8
401–500	7	0	27.5	16	1	24.0	16	1	24.0	26	2	20.0	36	3	18.3	46	4	17.0
501–600	7	0	28.0	16	1	24.0	26	2	20.0	26	2	20.0	37	3	17.9	47	4	16.6
601–800	7	0	28.0	16	1	24.0	27	2	19.4	37	3	17.9	48	4	16.3	60	5	15.2
801–1000	7	0	28.0	17	1	22.5	27	2	19.5	37	3	17.9	48	4	16.3	70	6	14.3
1001–2000	7	0	28.0	17	1	23.0	27	2	19.6	38	3	17.6	60	5	15.3	85	7	13.7
2001–3000	7	0	28.0	17	1	23.0	38	3	17.6	50	4	15.8	75	6	13.9	125	10	12.3
3001–4000	17	1	23.0	27	2	19.6	39	3	17.0	60	5	15.4	85	7	13.8	140	11	11.8
4001–5000	17	1	23.0	27	2	19.6	39	3	17.0	65	5	14.2	100	8	12.9	155	12	11.6
5001–7000	17	1	23.0	27	2	19.7	39	3	17.1	75	6	13.9	115	9	12.3	185	14	11.0
7001–10,000	17	1	23.0	27	2	19.7	50	4	15.9	75	6	14.0	130	10	12.0	225	17	10.4
10,001–20,000	17	1	23.0	27	2	19.7	50	4	15.9	90	7	13.1	170	13	11.0	305	22	9.6
20,001–50,000	17	1	23.0	39	3	17.1	65	5	14.3	115	9	12.3	215	16	10.4	400	28	9.0
50,001–100,000	17	1	23.0	39	3	17.1	75	6	14.0	145	11	11.6	275	20	9.8	450	31	8.8

TABLE SA-7.0

AVERAGE OUTGOING QUALITY LIMIT = 7.0%

Process Average %	0–.14			.15–1.40			1.41–2.80			2.81–4.20			4.21–5.60			5.61–7.00		
Lot Size	n	c	p_t%	n	c	p_t%	n	c	p_t%	n	c	p_t%	n	c	p_t%	n	c	p_t%
1–5	All	0	–	All	0	–	All	0	–	All	0	–	All	0	–	All	0	–
6–50	5	0	35.5	5	0	35.5	5	0	35.5	5	0	35.5	5	0	35.5	5	0	35.5
51–100	5	0	36.0	5	0	36.0	5	0	36.0	11	1	28.5	11	1	28.5	11	1	28.5
101–200	5	0	36.5	5	0	36.5	11	1	30.5	11	1	30.5	18	2	26.5	18	2	26.5
201–300	5	0	36.5	12	1	28.5	12	1	28.5	18	2	26.5	18	2	26.5	25	3	26.0
301–400	5	0	37.0	12	1	28.5	12	1	28.5	19	2	25.5	26	3	25.0	33	4	23.5
401–500	5	0	37.0	12	1	28.5	19	2	25.5	19	2	25.5	26	3	25.0	34	4	23.0
501–600	5	0	37.0	12	1	28.5	19	2	25.5	27	3	24.5	34	4	23.0	42	5	21.5
601–800	5	0	37.0	12	1	29.0	19	2	25.5	27	3	24.5	35	4	22.5	50	6	20.5
801–1000	5	0	37.0	12	1	29.0	19	2	25.5	27	3	24.5	43	5	21.5	60	7	19.3
1001–2000	5	0	37.0	12	1	29.0	27	3	24.5	36	4	22.0	50	6	21.0	70	8	17.7
2001–3000	12	1	29.0	19	2	25.5	28	3	23.5	45	5	20.5	60	7	19.6	100	11	16.5
3001–4000	12	1	29.0	20	2	24.5	28	3	24.0	45	5	20.5	70	8	18.1	120	13	15.8
4001–5000	12	1	29.0	20	2	24.5	36	4	22.0	55	6	19.0	80	9	17.3	140	15	15.1
5001–7000	12	1	29.0	20	2	24.5	36	4	22.0	55	6	19.1	90	10	16.8	160	17	14.6
7001–10,000	12	1	29.0	20	2	24.5	36	4	22.0	65	7	18.4	110	12	15.9	195	20	13.9
10,001–20,000	12	1	29.0	28	3	24.0	45	5	20.5	75	8	17.8	135	14	15.2	240	24	13.2
20,001–50,000	12	1	29.0	28	3	24.0	55	6	19.2	95	10	16.6	175	18	14.1	310	30	12.4
50,001–100,000	12	1	29.0	28	3	24.0	55	6	19.2	115	12	15.8	210	21	13.4	355	34	12.1

n = Size of Sample; entry of "All" indicates that each piece in lot is to be inspected.
c = Allowable Defect Number for Sample.
p_t = Lot Tolerance Per Cent Defective corresponding to a Consumer's Risk (P_C) = 0.10.

TABLE III CONT'D: SINGLE SAMPLING LOT INSPECTION TABLES—BASED ON STATED VALUES OF "AVERAGE OUTGOING QUALITY LIMIT"

TABLE SA-10.0

Average Outgoing Quality Limit = 10.0%

Process Average %	0–.20			.21–2.00			2.01–4.00			4.01–6.00			6.01–8.00			8.01–10.00		
Lot Size	n	c	p_t%	n	c	p_t%	n	c	p_t%	n	c	p_t%	n	c	p_t%	n	c	p_t%
1–3	All	0	–	All	0	–	All	0	–	All	0	–	All	0	–	All	0	–
4–50	3	0	52.5	3	0	52.5	3	0	52.5	3	0	52.5	3	0	52.5	7	1	43.5
51–100	4	0	43.0	4	0	43.0	8	1	40.0	8	1	40.0	8	1	40.0	12	2	37.5
101–200	4	0	43.5	8	1	40.0	8	1	40.0	13	2	35.5	13	2	35.5	18	3	33.0
201–300	4	0	43.5	8	1	40.5	8	1	40.5	13	2	35.5	18	3	33.0	23	4	32.0
301–400	4	0	43.5	8	1	40.5	13	2	35.5	13	2	35.5	24	4	30.0	29	5	30.0
401–500	4	0	43.5	8	1	40.5	13	2	36.0	19	3	31.5	24	4	30.0	30	5	29.5
501–600	4	0	43.5	8	1	40.5	13	2	36.0	19	3	31.5	24	4	30.5	36	6	28.5
601–800	4	0	43.5	8	1	40.5	13	2	36.0	19	3	31.5	31	5	29.5	42	7	27.5
801–1000	4	0	44.0	8	1	40.5	14	2	33.5	25	4	30.0	37	6	28.0	49	8	26.5
1001–2000	8	1	40.5	14	2	33.5	19	3	32.0	31	5	30.0	44	7	26.5	65	10	23.5
2001–3000	8	1	40.5	14	2	33.5	19	3	32.0	31	5	30.0	50	8	26.0	85	13	22.5
3001–4000	8	1	40.5	14	2	33.5	25	4	30.0	38	6	27.5	65	10	24.0	100	15	21.5
4001–5000	8	1	40.5	14	2	33.5	25	4	30.0	38	6	27.5	65	10	24.0	120	18	20.5
5001–7000	8	1	40.5	14	2	33.5	25	4	30.0	44	7	27.0	80	12	22.5	135	20	19.8
7001–10,000	8	1	40.5	14	2	33.5	32	5	29.0	50	8	26.0	85	13	22.5	160	23	19.2
10,001–20,000	8	1	40.5	19	3	32.0	32	5	29.0	60	9	24.5	110	16	21.0	190	27	18.3
20,001–50,000	8	1	40.5	19	3	32.0	38	6	27.5	70	11	23.0	130	19	19.7	225	31	17.5
50,001–100,000	14	2	33.5	19	3	32.0	44	7	27.0	80	12	22.5	155	22	19.0	260	35	16.9

n = Size of Sample; entry of "All" indicates that each piece in lot is to be inspected.
c = Allowable Defect Number for Sample.
p_t = Lot Tolerance Per Cent Defective corresponding to a Consumer's Risk (P_C) = 0.10.

TABLE IV: DOUBLE SAMPLING LOT INSPECTION TABLES—BASED ON STATED VALUES OF "AVERAGE OUTGOING QUALITY LIMIT"

TABLE DA-0.1

AVERAGE OUTGOING QUALITY LIMIT = 0.1%

Process Average %	0–.002						.003–.020					
Lot Size	Trial 1		Trial 2			p_t %	Trial 1		Trial 2			p_t %
	n_1	c_1	n_2	n_1+n_2	c_2		n_1	c_1	n_2	n_1+n_2	c_2	
1–75	All	0	–	–	–	–	All	0	–	–	–	–
76–95	75	0	–	–	–	1.5	75	0	–	–	–	1.5
96–130	95	0	–	–	–	1.4	95	0	–	–	–	1.4
131–200	130	0	–	–	–	1.2	130	0	–	–	–	1.2
201–300	165	0	–	–	–	1.1	165	0	–	–	–	1.1
301–350	190	0	–	–	–	.96	190	0	–	–	–	.96
351–400	225	0	95	320	1	.86	225	0	95	320	1	.86
401–500	250	0	120	370	1	.80	250	0	120	370	1	.80
501–600	275	0	130	405	1	.77	275	0	130	405	1	.77
601–800	310	0	155	465	1	.71	310	0	155	465	1	.71
801–1000	350	0	185	535	1	.66	350	0	185	535	1	.66
1001–2000	430	0	240	670	1	.58	430	0	240	670	1	.58
2001–3000	465	0	265	730	1	.56	465	0	265	730	1	.56
3001–4000	495	0	285	780	1	.54	495	0	285	780	1	.54
4001–5000	505	0	295	800	1	.53	505	0	295	800	1	.53
5001–7000	520	0	320	840	1	.52	520	0	320	840	1	.52
7001–10,000	540	0	335	875	1	.51	625	0	715	1340	2	.44
10,001–20,000	555	0	345	900	1	.50	650	0	750	1400	2	.43
20,001–50,000	660	0	760	1420	2	.42	660	0	760	1420	2	.42
50,001–100,000	670	0	770	1440	2	.42	740	0	1230	1970	3	.38

Process Average %	.021–.040						.041–.060					
Lot Size	Trial 1		Trial 2			p_t %	Trial 1		Trial 2			p_t %
	n_1	c_1	n_2	n_1+n_2	c_2		n_1	c_1	n_2	n_1+n_2	c_2	
1–75	All	0	–	–	–	–	All	0	–	–	–	–
76–95	75	0	–	–	–	1.5	75	0	–	–	–	1.5
96–130	95	0	–	–	–	1.4	95	0	–	–	–	1.4
131–200	130	0	–	–	–	1.2	130	0	–	–	–	1.2
201–300	165	0	–	–	–	1.1	165	0	–	–	–	1.1
301–350	190	0	–	–	–	.96	190	0	–	–	–	.96
351–400	225	0	95	320	1	.86	225	0	95	320	1	.86
401–500	250	0	120	370	1	.80	250	0	120	370	1	.80
501–600	275	0	130	405	1	.77	275	0	130	405	1	.77
601–800	310	0	155	465	1	.71	310	0	155	465	1	.71
801–1000	350	0	185	535	1	.66	350	0	185	535	1	.66
1001–2000	430	0	240	670	1	.58	430	0	240	670	1	.58
2001–3000	465	0	265	730	1	.56	520	0	530	1050	2	.50
3001–4000	540	0	570	1110	2	.49	540	0	570	1110	2	.49
4001–5000	555	0	615	1170	2	.48	555	0	615	1170	2	.48
5001–7000	590	0	660	1250	2	.46	655	0	1045	1700	3	.41
7001–10,000	625	0	715	1340	2	.44	700	0	1120	1820	3	.39
10,001–20,000	720	0	1150	1870	3	.38	740	0	1530	2270	4	.37
20,001–50,000	770	0	1700	2470	4	.36	1400	1	2170	3570	6	.32
50,001–100,000	805	0	1725	2530	4	.35	1460	1	3060	4520	8	.31

Process Average %	.061–.080						.081–.100					
Lot Size	Trial 1		Trial 2			p_t %	Trial 1		Trial 2			p_t %
	n_1	c_1	n_2	n_1+n_2	c_2		n_1	c_1	n_2	n_1+n_2	c_2	
1–75	All	0	–	–	–	–	All	0	–	–	–	–
76–95	75	0	–	–	–	1.5	75	0	–	–	–	1.5
96–130	95	0	–	–	–	1.4	95	0	–	–	–	1.4
131–200	130	0	–	–	–	1.2	130	0	–	–	–	1.2
201–300	165	0	–	–	–	1.1	165	0	–	–	–	1.1
301–350	190	0	–	–	–	.96	190	0	–	–	–	.96
351–400	225	0	95	320	1	.86	225	0	95	320	1	.86
401–500	250	0	120	370	1	.80	250	0	120	370	1	.80
501–600	275	0	130	405	1	.77	275	0	130	405	1	.77
601–800	310	0	155	465	1	.71	310	0	155	465	1	.71
801–1000	350	0	185	535	1	.66	350	0	185	535	1	.66
1001–2000	430	0	240	670	1	.58	475	0	450	925	2	.54
2001–3000	520	0	530	1050	2	.50	520	0	530	1050	2	.50
3001–4000	540	0	570	1110	2	.49	585	0	885	1470	3	.45
4001–5000	605	0	935	1540	3	.44	605	0	935	1540	3	.44
5001–7000	655	0	1045	1700	3	.41	680	0	1360	2040	4	.40
7001–10,000	700	0	1120	1820	3	.39	1250	1	1780	3030	6	.35
10,001–20,000	1350	1	2020	3370	6	.33	1400	1	2420	3820	7	.32
20,001–50,000	1450	1	3030	4480	8	.31	2230	2	4650	6880	12	.27
50,001–100,000	2330	2	4910	7240	12	.26	3690	4	7580	11270	19	.24

n_1 = Size of First Sample; n_2 = Size of Second Sample; entry of "All" indicates that each piece in lot is to be inspected.
c_1 = Allowable Defect Number for First Sample; c_2 = Allowable Defect Number for First and Second Samples Combined.
p_t = Lot Tolerance Per Cent Defective corresponding to a Consumer's Risk (P_C) = 0.10.

TABLE IV CONT'D: DOUBLE SAMPLING LOT INSPECTION TABLES—BASED ON STATED VALUES OF "AVERAGE OUTGOING QUALITY LIMIT"

TABLE DA-0.25

AVERAGE OUTGOING QUALITY LIMIT = 0.25%

Process Average %	0–.005						.006–.050					
Lot Size	Trial 1		Trial 2			Pt %	Trial 1		Trial 2			Pt %
	n_1	c_1	n_2	n_1+n_2	c_2		n_1	c_1	n_2	n_1+n_2	c_2	
1–60	All	0	–	–	–	–	All	0	–	–	–	–
61–100	60	0	–	–	–	2.5	60	0	–	–	–	2.5
101–200	85	0	–	–	–	2.1	85	0	–	–	–	2.1
201–300	120	0	65	185	1	1.8	120	0	65	185	1	1.8
301–400	135	0	70	205	1	1.7	135	0	70	205	1	1.7
401–500	145	0	80	225	1	1.6	145	0	80	225	1	1.6
501–600	160	0	90	250	1	1.5	160	0	90	250	1	1.5
601–800	165	0	95	260	1	1.5	165	0	95	260	1	1.5
801–1000	180	0	105	285	1	1.4	180	0	105	285	1	1.4
1001–2000	205	0	120	325	1	1.3	205	0	120	325	1	1.3
2001–3000	210	0	125	335	1	1.3	210	0	125	335	1	1.3
3001–4000	210	0	130	340	1	1.3	210	0	130	340	1	1.3
4001–5000	215	0	130	345	1	1.3	245	0	280	525	2	1.1
5001–7000	215	0	135	350	1	1.3	250	0	285	535	2	1.1
7001–10,000	255	0	290	545	2	1.1	255	0	290	545	2	1.1
10,001–20,000	260	0	295	555	2	1.1	260	0	295	555	2	1.1
20,001–50,000	265	0	300	565	2	1.0	305	0	505	810	3	.91
50,001–100,000	270	0	305	575	2	1.0	310	0	510	820	3	.91

Process Average %	.051–.100						.101–.150					
Lot Size	Trial 1		Trial 2			Pt %	Trial 1		Trial 2			Pt %
	n_1	c_1	n_2	n_1+n_2	c_2		n_1	c_1	n_2	n_1+n_2	c_2	
1–60	All	0	–	–	–	–	All	0	–	–	–	–
61–100	60	0	–	–	–	2.5	60	0	–	–	–	2.5
101–200	85	0	–	–	–	2.1	85	0	–	–	–	2.1
201–300	120	0	65	185	1	1.8	120	0	65	185	1	1.8
301–400	135	0	70	205	1	1.7	135	0	70	205	1	1.7
401–500	145	0	80	225	1	1.6	145	0	80	225	1	1.6
501–600	160	0	90	250	1	1.5	160	0	90	250	1	1.5
601–800	165	0	95	260	1	1.5	165	0	95	260	1	1.5
801–1000	180	0	105	285	1	1.4	200	0	195	395	2	1.3
1001–2000	220	0	245	465	2	1.2	220	0	245	465	2	1.2
2001–3000	235	0	275	510	2	1.1	260	0	435	695	3	1.0
3001–4000	240	0	280	520	2	1.1	270	0	440	710	3	1.0
4001–5000	275	0	445	720	3	1.0	275	0	445	720	3	1.0
5001–7000	290	0	475	765	3	.95	315	0	660	975	4	.88
7001–10,000	295	0	490	785	3	.94	325	0	705	1030	4	.84
10,001–20,000	330	0	730	1060	4	.83	590	1	910	1500	6	.76
20,001–50,000	335	0	735	1070	4	.83	645	1	1355	2000	8	.70
50,001–100,000	350	0	930	1280	5	.80	665	1	1615	2280	9	.68

Process Average %	.151–.200						.201–.250					
Lot Size	Trial 1		Trial 2			Pt %	Trial 1		Trial 2			Pt %
	n_1	c_1	n_2	n_1+n_2	c_2		n_1	c_1	n_2	n_1+n_2	c_2	
1–60	All	0	–	–	–	–	All	0	–	–	–	–
61–100	60	0	–	–	–	2.5	60	0	–	–	–	2.5
101–200	85	0	–	–	–	2.1	85	0	–	–	–	2.1
201–300	120	0	65	185	1	1.8	120	0	65	185	1	1.8
301–400	135	0	70	205	1	1.7	135	0	70	205	1	1.7
401–500	145	0	80	225	1	1.6	145	0	80	225	1	1.6
501–600	160	0	90	250	1	1.5	175	0	160	335	2	1.4
601–800	195	0	185	380	2	1.3	195	0	185	380	2	1.3
801–1000	200	0	195	395	2	1.3	200	0	195	395	2	1.3
1001–2000	220	0	245	465	2	1.2	240	0	375	615	3	1.1
2001–3000	260	0	435	695	3	1.0	280	0	570	850	4	.96
3001–4000	290	0	600	890	4	.94	290	0	600	890	4	.94
4001–5000	300	0	615	915	4	.92	520	1	750	1270	6	.85
5001–7000	545	1	795	1340	6	.82	555	1	965	1520	7	.80
7001–10,000	585	1	1045	1630	7	.76	620	1	1420	2040	9	.72
10,001–20,000	660	1	1530	2190	9	.68	1220	3	2000	3220	13	.61
20,001–50,000	990	2	2340	3330	13	.61	1850	5	3500	5350	21	.55
50,001–100,000	1340	3	2910	4250	16	.56	2930	8	6090	9020	33	.48

TABLE DA-0.5

AVERAGE OUTGOING QUALITY LIMIT = 0.5%

Process Average %	0–.010						.011–.10						.11–.20					
	Trial 1		Trial 2				Trial 1		Trial 2				Trial 1		Trial 2			
Lot Size	n_1	c_1	n_2	n_1+n_2	c_2	p_t %	n_1	c_1	n_2	n_1+n_2	c_2	p_t %	n_1	c_1	n_2	n_1+n_2	c_2	p_t %
1–30	All	0	–	–	–	–	All	0	–	–	–	–	All	0	–	–	–	–
31–50	30	0	–	–	–	5.0	30	0	–	–	–	5.0	30	0	–	–	–	5.0
51–75	40	0	–	–	–	4.6	40	0	–	–	–	4.6	40	0	–	–	–	4.6
76–100	47	0	23	70	1	4.4	47	0	23	70	1	4.4	47	0	23	70	1	4.4
101–150	60	0	30	90	1	3.8	60	0	30	90	1	3.8	60	0	30	90	1	3.8
151–200	70	0	35	105	1	3.3	70	0	35	105	1	3.3	70	0	35	105	1	3.3
201–300	80	0	45	125	1	3.0	80	0	45	125	1	3.0	80	0	45	125	1	3.0
301–400	85	0	50	135	1	2.9	85	0	50	135	1	2.9	85	0	50	135	1	2.9
401–500	90	0	55	145	1	2.8	90	0	55	145	1	2.8	90	0	55	145	1	2.8
501–600	95	0	55	150	1	2.8	95	0	55	150	1	2.8	95	0	55	150	1	2.8
601–800	100	0	55	155	1	2.7	100	0	55	155	1	2.7	110	0	115	225	2	2.4
801–1000	100	0	60	160	1	2.7	100	0	60	160	1	2.7	115	0	125	240	2	2.3
1001–2000	105	0	60	165	1	2.6	125	0	135	260	2	2.2	125	0	135	260	2	2.2
2001–3000	110	0	60	170	1	2.6	130	0	145	275	2	2.1	145	0	235	380	3	1.9
3001–4000	110	0	65	175	1	2.5	130	0	155	285	2	2.1	145	0	240	385	3	1.9
4001–5000	135	0	150	285	2	2.1	135	0	150	285	2	2.1	150	0	240	390	3	1.9
5001–7000	135	0	155	290	2	2.1	135	0	155	290	2	2.1	155	0	245	400	3	1.8
7001–10,000	135	0	160	295	2	2.1	135	0	160	295	2	2.1	175	0	375	550	4	1.6
10,001–20,000	140	0	160	300	2	2.0	155	0	250	405	3	1.8	185	0	500	685	5	1.5
20,001–50,000	140	0	165	305	2	2.0	155	0	255	410	3	1.8	185	0	505	690	5	1.5
50,001–100,000	140	0	170	310	2	2.0	155	0	260	415	3	1.8	325	1	495	820	6	1.4

Process Average %	.21–.30						.31–.40						.41–.50					
	Trial 1		Trial 2				Trial 1		Trial 2				Trial 1		Trial 2			
Lot Size	n_1	c_1	n_2	n_1+n_2	c_2	p_t %	n_1	c_1	n_2	n_1+n_2	c_2	p_t %	n_1	c_1	n_2	n_1+n_2	c_2	p_t %
1–30	All	0	–	–	–	–	All	0	–	–	–	–	All	0	–	–	–	–
31–50	30	0	–	–	–	5.0	30	0	–	–	–	5.0	30	0	–	–	–	5.0
51–75	40	0	–	–	–	4.6	40	0	–	–	–	4.6	40	0	–	–	–	4.6
76–100	47	0	23	70	1	4.4	47	0	23	70	1	4.4	47	0	23	70	1	4.4
101–150	60	0	30	90	1	3.8	60	0	30	90	1	3.8	60	0	30	90	1	3.8
151–200	70	0	35	105	1	3.3	70	0	35	105	1	3.3	70	0	35	105	1	3.3
201–300	80	0	45	125	1	3.0	80	0	45	125	1	3.0	80	0	45	125	1	3.0
301–400	85	0	50	135	1	2.9	95	0	90	185	2	2.7	95	0	90	185	2	2.7
401–500	100	0	100	200	2	2.6	100	0	100	200	2	2.6	100	0	100	200	2	2.6
501–600	105	0	105	210	2	2.5	105	0	105	210	2	2.5	105	0	105	210	2	2.5
601–800	110	0	115	225	2	2.4	110	0	115	225	2	2.4	120	0	180	300	3	2.2
801–1000	115	0	125	240	2	2.3	125	0	185	310	3	2.2	125	0	185	310	3	2.2
1001–2000	135	0	220	355	3	2.0	135	0	220	355	3	2.0	145	0	295	440	4	1.9
2001–3000	145	0	235	380	3	1.9	150	0	320	470	4	1.8	275	1	475	750	7	1.6
3001–4000	155	0	325	480	4	1.8	280	1	415	695	6	1.6	295	1	600	895	8	1.5
4001–5000	165	0	345	510	4	1.7	300	1	525	825	7	1.5	430	2	700	1130	10	1.4
5001–7000	175	0	455	630	5	1.6	310	1	670	980	8	1.4	460	2	860	1320	11	1.3
7001–10,000	300	1	460	760	6	1.5	465	2	785	1250	10	1.3	620	3	1120	1740	14	1.2
10,001–20,000	320	1	680	1000	8	1.4	495	2	1175	1670	13	1.2	740	4	1420	2160	18	1.2
20,001–50,000	350	1	930	1280	10	1.3	680	3	1490	2170	16	1.1	925	5	2085	3010	24	1.1
50,001–100,000	505	2	1075	1580	12	1.2	680	3	1810	2490	19	1.1	1550	9	3410	4960	38	.99

n_1 = Size of First Sample; n_2 = Size of Second Sample; entry of "All" indicates that each piece in lot is to be inspected.
c_1 = Allowable Defect Number for First Sample; c_2 = Allowable Defect Number for First and Second Samples Combined.
p_t = Lot Tolerance Per Cent Defective corresponding to a Consumer's Risk (P_C) = 0.10

TABLE IV CONT'D: DOUBLE SAMPLING LOT INSPECTION TABLES—BASED ON STATED VALUES OF "AVERAGE OUTGOING QUALITY LIMIT"

TABLE DA-0.75

AVERAGE OUTGOING QUALITY LIMIT = 0.75%

Process Average %	0–.015						.016–.15					
	Trial 1		Trial 2				Trial 1		Trial 2			
Lot Size	n_1	c_1	n_2	n_1+n_2	c_2	p_t %	n_1	c_1	n_2	n_1+n_2	c_2	p_t %
1–25	All	0	–	–	–	–	All	0	–	–	–	–
26–50	25	0	–	–	–	6.4	25	0	–	–	–	6.4
51–75	35	0	15	50	1	6.0	35	0	15	50	1	6.0
76–100	39	0	21	60	1	5.6	39	0	21	60	1	5.6
101–200	55	0	30	85	1	4.5	55	0	30	85	1	4.5
201–300	60	0	30	90	1	4.3	60	0	30	90	1	4.3
301–400	60	0	35	95	1	4.2	60	0	35	95	1	4.2
401–500	65	0	35	100	1	4.1	65	0	35	100	1	4.1
501–600	65	0	40	105	1	4.0	65	0	40	105	1	4.0
601–800	70	0	40	110	1	3.9	70	0	40	110	1	3.9
801–1000	70	0	40	110	1	3.9	70	0	40	110	1	3.9
1001–2000	75	0	40	115	1	3.8	85	0	90	175	2	3.3
2001–3000	75	0	40	115	1	3.8	85	0	100	185	2	3.2
3001–4000	90	0	105	195	2	3.1	90	0	105	195	2	3.1
4001–5000	90	0	105	195	2	3.1	90	0	105	195	2	3.1
5001–7000	90	0	105	195	2	3.1	90	0	105	195	2	3.1
7001–10,000	90	0	110	200	2	3.0	100	0	165	265	3	2.8
10,001–20,000	90	0	110	200	2	3.0	100	0	165	265	3	2.8
20,001–50,000	90	0	110	200	2	3.0	105	0	165	270	3	2.7
50,001–100,000	95	0	110	205	2	3.0	110	0	250	360	4	2.5

Process Average %	.16–.30						.31–.45					
	Trial 1		Trial 2				Trial 1		Trial 2			
Lot Size	n_1	c_1	n_2	n_1+n_2	c_2	p_t %	n_1	c_1	n_2	n_1+n_2	c_2	p_t %
1–25	All	0	–	–	–	–	All	0	–	–	–	–
26–50	25	0	–	–	–	6.4	25	0	–	–	–	6.4
51–75	35	0	15	50	1	6.0	35	0	15	50	1	6.0
76–100	39	0	21	60	1	5.6	39	0	21	60	1	5.6
101–200	55	0	30	85	1	4.5	55	0	30	85	1	4.5
201–300	60	0	30	90	1	4.3	60	0	30	90	1	4.3
301–400	60	0	35	95	1	4.2	70	0	70	140	2	3.8
401–500	70	0	75	145	2	3.7	70	0	75	145	2	3.7
501–600	75	0	80	155	2	3.6	75	0	80	155	2	3.6
601–800	75	0	85	160	2	3.5	75	0	85	160	2	3.5
801–1000	80	0	90	170	2	3.4	85	0	140	225	3	3.1
1001–2000	95	0	155	250	3	2.9	95	0	155	250	3	2.9
2001–3000	100	0	160	260	3	2.8	105	0	230	335	4	2.6
3001–4000	100	0	160	260	3	2.8	110	0	290	400	5	2.5
4001–5000	105	0	235	340	4	2.6	195	1	300	495	6	2.3
5001–7000	110	0	245	355	4	2.5	200	1	375	575	7	2.2
7001–10,000	110	0	245	355	4	2.5	205	1	375	580	7	2.2
10,001–20,000	120	0	325	445	5	2.3	215	1	455	670	8	2.1
20,001–50,000	130	0	335	465	5	2.2	225	1	605	830	10	2.0
50,001–100,000	215	1	395	610	7	2.1	335	2	725	1060	12	1.8

Process Average %	.46–.60						.61–.75					
	Trial 1		Trial 2				Trial 1		Trial 2			
Lot Size	n_1	c_1	n_2	n_1+n_2	c_2	p_t %	n_1	c_1	n_2	n_1+n_2	c_2	p_t %
1–25	All	0	–	–	–	–	All	0	–	–	–	–
26–50	25	0	–	–	–	6.4	25	0	–	–	–	6.4
51–75	35	0	15	50	1	6.0	35	0	15	50	1	6.0
76–100	39	0	21	60	1	5.6	39	0	21	60	1	5.6
101–200	55	0	30	85	1	4.5	55	0	30	85	1	4.5
201–300	60	0	30	90	1	4.3	60	0	30	90	1	4.3
301–400	70	0	70	140	2	3.8	70	0	70	140	2	3.8
401–500	70	0	75	145	2	3.7	70	0	75	145	2	3.7
501–600	75	0	80	155	2	3.6	80	0	120	200	3	3.3
601–800	85	0	130	215	3	3.2	85	0	130	215	3	3.2
801–1000	85	0	140	225	3	3.1	95	0	185	280	4	2.9
1001–2000	100	0	215	315	4	2.7	175	1	265	440	6	2.5
2001–3000	185	1	280	465	6	2.4	205	1	405	610	8	2.2
3001–4000	195	1	345	540	7	2.3	285	2	475	760	10	2.1
4001–5000	210	1	415	625	8	2.2	300	2	560	860	11	2.0
5001–7000	300	2	510	810	10	2.0	390	3	710	1100	14	1.9
7001–10,000	320	2	665	985	12	1.9	415	3	955	1370	17	1.8
10,001–20,000	335	2	855	1190	14	1.8	600	5	1200	1800	22	1.7
20,001–50,000	440	3	1030	1470	17	1.7	800	7	1640	2440	29	1.6
50,001–100,000	555	4	1305	1860	21	1.6	1025	9	2405	3430	40	1.5

TABLE DA-1

Average Outgoing Quality Limit = 1.0%

Process Average %	0–.02						.03–.20					
	Trial 1		Trial 2				Trial 1		Trial 2			
Lot Size	n_1	c_1	n_2	n_1+n_2	c_2	p_t %	n_1	c_1	n_2	n_1+n_2	c_2	p_t %
1–25	All	0	–	–	–	–	All	0	–	–	–	–
26–50	22	0	–	–	–	7.7	22	0	–	–	–	7.7
51–100	33	0	17	50	1	6.9	33	0	17	50	1	6.9
101–200	43	0	22	65	1	5.8	43	0	22	65	1	5.8
201–300	47	0	28	75	1	5.5	47	0	28	75	1	5.5
301–400	49	0	31	80	1	5.4	49	0	31	80	1	5.4
401–500	50	0	30	80	1	5.4	50	0	30	80	1	5.4
501–600	50	0	30	80	1	5.4	50	0	30	80	1	5.4
601–800	50	0	35	85	1	5.3	60	0	70	130	2	4.5
801–1000	55	0	30	85	1	5.2	60	0	75	135	2	4.4
1001–2000	55	0	35	90	1	5.1	65	0	75	140	2	4.3
2001–3000	65	0	80	145	2	4.2	65	0	80	145	2	4.2
3001–4000	70	0	80	150	2	4.1	70	0	80	150	2	4.1
4001–5000	70	0	80	150	2	4.1	70	0	80	150	2	4.1
5001–7000	70	0	80	150	2	4.1	75	0	125	200	3	3.7
7001–10,000	70	0	80	150	2	4.1	80	0	125	205	3	3.6
10,001–20,000	70	0	80	150	2	4.1	80	0	130	210	3	3.6
20,001–50,000	75	0	80	155	2	4.0	80	0	135	215	3	3.6
50,001–100,000	75	0	80	155	2	4.0	85	0	180	265	4	3.3

Process Average %	.21–.40						.41–.60					
	Trial 1		Trial 2				Trial 1		Trial 2			
Lot Size	n_1	c_1	n_2	n_1+n_2	c_2	p_t %	n_1	c_1	n_2	n_1+n_2	c_2	p_t %
1–25	All	0	–	–	–	–	All	0	–	–	–	–
26–50	22	0	–	–	–	7.7	22	0	–	–	–	7.7
51–100	33	0	17	50	1	6.9	33	0	17	50	1	6.9
101–200	43	0	22	65	1	5.8	43	0	22	65	1	5.8
201–300	47	0	28	75	1	5.5	55	0	50	105	2	4.9
301–400	55	0	60	115	2	4.8	55	0	60	115	2	4.8
401–500	55	0	65	120	2	4.7	55	0	65	120	2	4.7
501–600	60	0	65	125	2	4.6	60	0	65	125	2	4.6
601–800	60	0	70	130	2	4.5	65	0	105	170	3	4.1
801–1000	60	0	75	135	2	4.4	65	0	110	175	3	4.0
1001–2000	75	0	120	195	3	3.8	80	0	165	245	4	3.7
2001–3000	75	0	125	200	3	3.7	80	0	170	250	4	3.6
3001–4000	80	0	175	255	4	3.5	85	0	220	305	5	3.3
4001–5000	80	0	180	260	4	3.4	145	1	225	370	6	3.1
5001–7000	80	0	180	260	4	3.4	155	1	285	440	7	2.9
7001–10,000	85	0	180	265	4	3.3	165	1	355	520	8	2.7
10,001–20,000	90	0	230	320	5	3.2	175	1	415	590	9	2.6
20,001–50,000	95	0	300	395	6	2.9	250	2	490	740	11	2.4
50,001–100,000	170	1	380	550	8	2.6	275	2	700	975	14	2.2

Process Average %	.61–.80						.81–1.00					
	Trial 1		Trial 2				Trial 1		Trial 2			
Lot Size	n_1	c_1	n_2	n_1+n_2	c_2	p_t %	n_1	c_1	n_2	n_1+n_2	c_2	p_t %
1–25	All	0	–	–	–	–	All	0	–	–	–	–
26–50	22	0	–	–	–	7.7	22	0	–	–	–	7.7
51–100	33	0	17	50	1	6.9	33	0	17	50	1	6.9
101–200	43	0	22	65	1	5.8	47	0	43	90	2	5.4
201–300	55	0	50	105	2	4.9	55	0	50	105	2	4.9
301–400	55	0	60	115	2	4.8	60	0	80	140	3	4.5
401–500	60	0	95	155	3	4.3	60	0	95	155	3	4.3
501–600	65	0	100	165	3	4.2	65	0	100	165	3	4.2
601–800	65	0	105	170	3	4.1	70	0	140	210	4	3.9
801–1000	70	0	150	220	4	3.8	125	1	180	305	6	3.5
1001–2000	135	1	200	335	6	3.3	140	1	245	385	7	3.2
2001–3000	150	1	265	415	7	3.0	215	2	355	570	10	2.8
3001–4000	160	1	330	490	8	2.8	225	2	455	680	12	2.7
4001–5000	225	2	375	600	10	2.7	240	2	595	835	14	2.5
5001–7000	235	2	440	675	11	2.6	310	3	665	975	16	2.4
7001–10,000	250	2	585	835	13	2.4	385	4	785	1170	19	2.3
10,001–20,000	325	3	655	980	15	2.3	520	6	980	1500	24	2.2
20,001–50,000	340	3	910	1250	19	2.2	610	7	1410	2020	32	2.1
50,001–100,000	420	4	1050	1470	22	2.1	770	9	1850	2620	41	2.0

n_1 = Size of First Sample; n_2 = Size of Second Sample; entry of "All" indicates that each piece in lot is to be inspected.
c_1 = Allowable Defect Number for First Sample; c_2 = Allowable Defect Number for First and Second Samples Combined.
p_t = Lot Tolerance Per Cent Defective corresponding to a Consumer's Risk (P_C) = 0.10.

TABLE IV CONT'D: DOUBLE SAMPLING LOT INSPECTION TABLES—BASED ON STATED VALUES OF "AVERAGE OUTGOING QUALITY LIMIT"

TABLE DA-1.5

AVERAGE OUTGOING QUALITY LIMIT = 1.5%

Process Average %	0–.03						.04–.30						.31–.60					
	Trial 1		Trial 2				Trial 1		Trial 2				Trial 1		Trial 2			
Lot Size	n_1	c_1	n_2	n_1+n_2	c_2	p_t %	n_1	c_1	n_2	n_1+n_2	c_2	p_t %	n_1	c_1	n_2	n_1+n_2	c_2	p_t %
1–15	All	0	–	–	–	–	All	0	–	–	–	–	All	0	–	–	–	–
16–50	16	0	–	–	–	11.6	16	0	–	–	–	11.6	16	0	–	–	–	11.6
51–75	23	0	11	34	1	10.5	23	0	11	34	1	10.5	23	0	11	34	1	10.5
76–100	26	0	14	40	1	9.4	26	0	14	40	1	9.4	26	0	14	40	1	9.4
101–200	31	0	18	49	1	8.4	31	0	18	49	1	8.4	31	0	18	49	1	8.4
201–300	33	0	22	55	1	8.0	33	0	22	55	1	8.0	38	0	37	75	2	7.0
301–400	34	0	21	55	1	7.9	34	0	21	55	1	7.9	39	0	41	80	2	6.9
401–500	35	0	20	55	1	7.8	35	0	20	55	1	7.8	39	0	46	85	2	6.9
501–600	35	0	20	55	1	7.8	40	0	45	85	2	6.8	40	0	45	85	2	6.8
601–800	35	0	20	55	1	7.8	41	0	49	90	2	6.7	46	0	74	120	3	6.0
801–1000	36	0	19	55	1	7.8	42	0	48	90	2	6.5	47	0	78	125	3	5.9
1001–2000	44	0	51	95	2	6.3	44	0	51	95	2	6.3	49	0	81	130	3	5.7
2001–3000	45	0	50	95	2	6.2	45	0	50	95	2	6.2	55	0	110	165	4	5.3
3001–4000	45	0	50	95	2	6.2	50	0	85	135	3	5.5	55	0	115	170	4	5.2
4001–5000	45	0	50	95	2	6.2	50	0	85	135	3	5.5	55	0	120	175	4	5.1
5001–7000	46	0	54	100	2	6.1	50	0	90	140	3	5.4	60	0	155	215	5	4.7
7001–10,000	46	0	54	100	2	6.1	50	0	90	140	3	5.4	60	0	160	220	5	4.6
10,001–20,000	46	0	54	100	2	6.1	50	0	90	140	3	5.4	60	0	165	225	5	4.5
20,001–50,000	47	0	53	100	2	6.1	55	0	125	180	4	5.0	65	0	195	260	6	4.4
50,001–100,000	47	0	53	100	2	6.1	55	0	130	185	4	4.9	115	1	235	350	8	4.0

Process Average %	.61–.90						.91–1.20						1.21–1.50					
	Trial 1		Trial 2				Trial 1		Trial 2				Trial 1		Trial 2			
Lot Size	n_1	c_1	n_2	n_1+n_2	c_2	p_t %	n_1	c_1	n_2	n_1+n_2	c_2	p_t %	n_1	c_1	n_2	n_1+n_2	c_2	p_t %
1–15	All	0	–	–	–	–	All	0	–	–	–	–	All	0	–	–	–	–
16–50	16	0	–	–	–	11.6	16	0	–	–	–	11.6	16	0	–	–	–	11.6
51–75	23	0	11	34	1	10.5	23	0	11	34	1	10.5	23	0	11	34	1	10.5
76–100	26	0	14	40	1	9.4	26	0	14	40	1	9.4	26	0	14	40	1	9.4
101–200	35	0	35	70	2	7.5	35	0	35	70	2	7.5	35	0	35	70	2	7.5
201–300	38	0	37	75	2	7.0	38	0	37	75	2	7.0	40	0	60	100	3	6.6
301–400	39	0	41	80	2	6.9	42	0	63	105	3	6.3	42	0	63	105	3	6.3
401–500	44	0	71	115	3	6.1	44	0	71	115	3	6.1	46	0	94	140	4	5.8
501–600	44	0	71	115	3	6.1	44	0	71	115	3	6.1	47	0	98	145	4	5.7
601–800	46	0	74	120	3	6.0	49	0	101	150	4	5.6	85	1	125	210	6	5.0
801–1000	47	0	78	125	3	5.9	50	0	105	155	4	5.5	90	1	125	215	6	4.9
1001–2000	55	0	105	160	4	5.4	95	1	175	270	7	4.6	100	1	230	330	9	4.4
2001–3000	100	1	145	245	6	4.6	110	1	255	365	9	4.1	155	2	345	500	13	3.9
3001–4000	105	1	190	295	7	4.3	160	2	300	460	11	3.8	205	3	405	610	15	3.6
4001–5000	105	1	190	295	7	4.3	165	2	340	505	12	3.7	250	4	480	730	18	3.5
5001–7000	110	1	225	335	8	4.2	165	2	375	540	13	3.7	310	5	610	920	22	3.3
7001–10,000	115	1	280	395	9	3.9	170	2	420	590	14	3.6	360	6	660	1020	24	3.2
10,001–20,000	120	1	315	435	10	3.8	210	3	420	630	15	3.6	415	7	835	1250	29	3.1
20,001–50,000	165	2	350	515	12	3.7	225	3	640	865	20	3.3	510	9	1130	1640	38	3.0
50,001–100,000	175	2	440	615	14	3.5	275	4	725	1000	23	3.2	570	10	1400	1970	45	2.9

TABLE DA-2

AVERAGE OUTGOING QUALITY LIMIT = 2.0%

Process Average %	0–.04						.05–.40					
	Trial 1		Trial 2			p_t %	Trial 1		Trial 2			p_t %
Lot Size	n_1	c_1	n_2	n_1+n_2	c_2		n_1	c_1	n_2	n_1+n_2	c_2	
1–15	All	0	–	–	–	–	All	0	–	–	–	–
16–50	14	0	–	–	–	13.6	14	0	–	–	–	13.6
51–100	21	0	12	33	1	11.7	21	0	12	33	1	11.7
101–200	24	0	13	37	1	11.0	24	0	13	37	1	11.0
201–300	26	0	15	41	1	10.4	26	0	15	41	1	10.4
301–400	26	0	16	42	1	10.3	26	0	16	42	1	10.3
401–500	27	0	16	43	1	10.3	30	0	35	65	2	9.0
501–600	27	0	16	43	1	10.3	31	0	34	65	2	8.9
601–800	27	0	17	44	1	10.2	31	0	39	70	2	8.8
801–1000	27	0	17	44	1	10.2	32	0	38	70	2	8.7
1001–2000	33	0	37	70	2	8.5	33	0	37	70	2	8.5
2001–3000	34	0	41	75	2	8.2	34	0	41	75	2	8.2
3001–4000	34	0	41	75	2	8.2	38	0	62	100	3	7.3
4001–5000	34	0	41	75	2	8.2	38	0	62	100	3	7.3
5001–7000	35	0	40	75	2	8.1	38	0	62	100	3	7.3
7001–10,000	35	0	40	75	2	8.1	38	0	62	100	3	7.3
10,001–20,000	35	0	40	75	2	8.1	39	0	66	105	3	7.2
20,001–50,000	35	0	40	75	2	8.1	43	0	92	135	4	6.6
50,001–100,000	35	0	45	80	2	8.0	43	0	92	135	4	6.6

Process Average %	.41–.80						.81–1.20					
	Trial 1		Trial 2			p_t %	Trial 1		Trial 2			p_t %
Lot Size	n_1	c_1	n_2	n_1+n_2	c_2		n_1	c_1	n_2	n_1+n_2	c_2	
1–15	All	0	–	–	–	–	All	0	–	–	–	–
16–50	14	0	–	–	–	13.6	14	0	–	–	–	13.6
51–100	21	0	12	33	1	11.7	21	0	12	33	1	11.7
101–200	24	0	13	37	1	11.0	27	0	28	55	2	9.6
201–300	29	0	31	60	2	9.1	29	0	31	60	2	9.1
301–400	30	0	35	65	2	9.0	33	0	52	85	3	8.2
401–500	30	0	35	65	2	9.0	34	0	56	90	3	7.9
501–600	35	0	55	90	3	7.9	35	0	55	90	3	7.9
601–800	35	0	60	95	3	7.7	38	0	82	120	4	7.3
801–1000	36	0	59	95	3	7.6	38	0	87	125	4	7.2
1001–2000	37	0	63	100	3	7.5	43	0	112	155	5	6.5
2001–3000	41	0	84	125	4	7.0	75	1	115	190	6	6.1
3001–4000	41	0	89	130	4	6.9	80	1	140	220	7	5.8
4001–5000	42	0	88	130	4	6.9	80	1	175	255	8	5.5
5001–7000	44	0	116	160	5	6.4	85	1	205	290	9	5.3
7001–10,000	45	0	115	160	5	6.3	85	1	210	295	9	5.2
10,001–20,000	45	0	115	160	5	6.3	90	1	260	350	11	5.1
20,001–50,000	47	0	148	195	6	6.0	130	2	300	430	13	4.7
50,001–100,000	85	1	185	270	8	5.2	135	2	345	480	14	4.5

Process Average %	1.21–1.60						1.61–2.00					
	Trial 1		Trial 2			p_t %	Trial 1		Trial 2			p_t %
Lot Size	n_1	c_1	n_2	n_1+n_2	c_2		n_1	c_1	n_2	n_1+n_2	c_2	
1–15	All	0	–	–	–	–	All	0	–	–	–	–
16–50	14	0	–	–	–	13.6	14	0	–	–	–	13.6
51–100	21	0	12	33	1	11.7	23	0	23	46	2	10.9
101–200	27	0	28	55	2	9.6	27	0	28	55	2	9.6
201–300	32	0	48	80	3	8.4	32	0	48	80	3	8.4
301–400	33	0	52	85	3	8.2	36	0	69	105	4	7.6
401–500	36	0	74	110	4	7.5	60	1	90	150	6	7.0
501–600	37	0	78	115	4	7.4	65	1	95	160	6	6.8
601–800	38	0	82	120	4	7.3	70	1	120	190	7	6.4
801–1000	70	1	100	170	6	6.5	70	1	145	215	8	6.2
1001–2000	80	1	160	240	8	5.8	110	2	205	315	11	5.5
2001–3000	115	2	195	310	10	5.3	160	3	310	470	15	4.7
3001–4000	120	2	255	375	12	5.0	235	5	415	650	20	4.3
4001–5000	125	2	285	410	13	4.9	275	6	475	750	23	4.2
5001–7000	125	2	320	445	14	4.8	280	6	575	855	26	4.1
7001–10,000	165	3	335	500	15	4.5	320	7	645	965	29	4.0
10,001–20,000	170	3	425	595	18	4.4	395	9	835	1230	37	3.9
20,001–50,000	205	4	515	720	22	4.3	480	11	1090	1570	46	3.7
50,001–100,000	250	5	615	865	26	4.1	580	13	1460	2040	58	3.5

n_1 = Size of First Sample; n_2 = Size of Second Sample; entry of "All" indicates that each piece in lot is to be inspected.
c_1 = Allowable Defect Number for First Sample; c_2 = Allowable Defect Number for First and Second Samples Combined.
p_t = Lot Tolerance Per Cent Defective corresponding to a Consumer's Risk (P_C) = 0.10.

TABLE IV CONT'D: DOUBLE SAMPLING LOT INSPECTION TABLES—BASED ON STATED VALUES OF "AVERAGE OUTGOING QUALITY LIMIT"

TABLE DA-2.5

AVERAGE OUTGOING QUALITY LIMIT = 2.5%

Process Average %	0–.05						.06–.50					
	Trial 1		Trial 2			Pt %	Trial 1		Trial 2			Pt %
Lot Size	n_1	c_1	n_2	n_1+n_2	c_2		n_1	c_1	n_2	n_1+n_2	c_2	
1–10	All	0	–	–	–	–	All	0	–	–	–	–
11–50	11	0	–	–	–	17.6	11	0	–	–	–	17.6
51–100	18	0	10	28	1	14.1	18	0	10	28	1	14.1
101–200	20	0	11	31	1	13.7	20	0	11	31	1	13.7
201–300	21	0	13	34	1	13.0	21	0	13	34	1	13.0
301–400	21	0	14	35	1	12.8	24	0	26	50	2	11.3
401–500	22	0	13	35	1	12.7	25	0	25	50	2	11.1
501–600	22	0	14	36	1	12.5	25	0	30	55	2	10.9
601–800	22	0	14	36	1	12.5	26	0	29	55	2	10.8
801–1000	26	0	29	55	2	10.8	26	0	29	55	2	10.8
1001–2000	27	0	33	60	2	10.5	27	0	33	60	2	10.5
2001–3000	27	0	33	60	2	10.5	30	0	50	80	3	9.3
3001–4000	27	0	33	60	2	10.5	31	0	49	80	3	9.1
4001–5000	27	0	33	60	2	10.5	31	0	49	80	3	9.1
5001–7000	28	0	32	60	2	10.3	31	0	49	80	3	9.1
7001–10,000	28	0	32	60	2	10.3	31	0	49	80	3	9.2
10,001–20,000	28	0	32	60	2	10.3	31	0	49	80	3	9.2
20,001–50,000	28	0	32	60	2	10.3	33	0	87	120	4	7.7
50,001–100,000	28	0	37	65	2	10.2	33	0	92	125	4	7.6

Process Average %	.51–1.00						1.01–1.50					
	Trial 1		Trial 2			Pt %	Trial 1		Trial 2			Pt %
Lot Size	n_1	c_1	n_2	n_1+n_2	c_2		n_1	c_1	n_2	n_1+n_2	c_2	
1–10	All	0	–	–	–	–	All	0	–	–	–	–
11–50	11	0	–	–	–	17.6	11	0	–	–	–	17.6
51–100	18	0	10	28	1	14.1	18	0	10	28	1	14.1
101–200	23	0	25	48	2	11.7	23	0	25	48	2	11.7
201–300	24	0	25	49	2	11.4	26	0	44	70	3	10.3
301–400	24	0	26	50	2	11.3	27	0	43	70	3	9.9
401–500	28	0	47	75	3	9.8	28	0	47	75	3	9.8
501–600	28	0	47	75	3	9.8	30	0	65	95	4	9.1
601–800	28	0	47	75	3	9.8	31	0	69	100	4	8.8
801–1000	29	0	46	75	3	9.6	32	0	68	100	4	8.7
1001–2000	33	0	72	105	4	8.3	60	1	90	150	6	7.6
2001–3000	33	0	72	105	4	8.3	65	1	115	180	7	7.2
3001–4000	33	0	77	110	4	8.2	65	1	140	205	8	6.8
4001–5000	36	0	94	130	5	7.6	70	1	160	230	9	6.5
5001–7000	36	0	94	130	5	7.7	75	1	190	265	10	6.2
7001–10,000	36	0	94	130	5	7.7	100	2	195	295	11	6.0
10,001–20,000	36	0	94	130	5	7.8	105	2	215	320	12	5.9
20,001–50,000	70	1	145	215	8	6.6	105	2	245	350	13	5.8
50,001–100,000	70	1	170	240	9	6.4	110	2	295	405	15	5.6

Process Average %	1.51–2.00						2.01–2.50					
	Trial 1		Trial 2			Pt %	Trial 1		Trial 2			Pt %
Lot Size	n_1	c_1	n_2	n_1+n_2	c_2		n_1	c_1	n_2	n_1+n_2	c_2	
1–10	All	0	–	–	–	–	All	0	–	–	–	–
11–50	11	0	–	–	–	17.6	11	0	–	–	–	17.6
51–100	20	0	20	40	2	13.0	20	0	20	40	2	13.0
101–200	23	0	25	48	2	11.7	25	0	35	60	3	10.8
201–300	26	0	44	70	3	10.3	28	0	57	85	4	9.5
301–400	29	0	61	90	4	9.3	49	1	71	120	6	8.8
401–500	30	0	60	90	4	9.2	50	1	80	130	6	8.4
501–600	30	0	65	95	4	9.1	55	1	95	150	7	8.0
601–800	55	1	85	140	6	8.0	60	1	115	175	8	7.6
801–1000	60	1	100	160	7	7.8	85	2	120	205	9	7.2
1001–2000	65	1	150	215	9	7.0	95	2	210	305	13	6.5
2001–3000	90	2	170	260	11	6.8	125	3	265	390	16	6.0
3001–4000	95	2	205	300	12	6.4	185	5	350	535	21	5.5
4001–5000	100	2	255	355	14	6.0	220	6	410	630	24	5.2
5001–7000	130	3	265	395	15	5.7	255	7	495	750	28	5.0
7001–10,000	140	3	355	495	18	5.3	325	9	665	990	36	4.7
10,001–20,000	170	4	380	550	20	5.2	360	10	830	1190	43	4.6
20,001–50,000	205	5	485	690	25	5.0	415	11	1145	1560	54	4.3
50,001–100,000	245	6	610	855	30	4.7	510	14	1370	1880	65	4.2

TABLE DA-3

Average Outgoing Quality Limit = 3.0%

Process Average %	0–.06						.07–.60					
	Trial 1		Trial 2				Trial 1		Trial 2			
Lot Size	n_1	c_1	n_2	n_1+n_2	c_2	p_t %	n_1	c_1	n_2	n_1+n_2	c_2	p_t %
1–10	All	0	–	–	–	–	All	0	–	–	–	–
11–50	10	0	–	–	–	19.0	10	0	–	–	–	19.0
51–100	16	0	9	25	1	16.4	16	0	9	25	1	16.4
101–200	17	0	9	26	1	16.0	17	0	9	26	1	16.0
201–300	18	0	10	28	1	15.5	18	0	10	28	1	15.5
301–400	18	0	11	29	1	15.2	21	0	24	45	2	13.2
401–500	18	0	11	29	1	15.2	21	0	25	46	2	13.0
501–600	18	0	12	30	1	15.0	21	0	25	46	2	13.0
601–800	21	0	25	46	2	13.0	21	0	25	46	2	13.0
801–1000	21	0	26	47	2	12.8	21	0	26	47	2	12.8
1001–2000	22	0	26	48	2	12.6	22	0	26	48	2	12.6
2001–3000	22	0	26	48	2	12.6	25	0	40	65	3	11.4
3001–4000	23	0	26	49	2	12.4	25	0	45	70	3	11.0
4001–5000	23	0	26	49	2	12.4	26	0	44	70	3	11.0
5001–7000	23	0	27	50	2	12.2	26	0	44	70	3	11.0
7001–10,000	23	0	27	50	2	12.2	27	0	43	70	3	11.0
10,001–20,000	23	0	27	50	2	12.2	27	0	43	70	3	11.0
20,001–50,000	23	0	27	50	2	12.2	28	0	67	95	4	9.7
50,001–100,000	23	0	27	50	2	12.2	31	0	84	115	5	9.0

Process Average %	.61–1.20						1.21–1.80					
	Trial 1		Trial 2				Trial 1		Trial 2			
Lot Size	n_1	c_1	n_2	n_1+n_2	c_2	p_t %	n_1	c_1	n_2	n_1+n_2	c_2	p_t %
1–10	All	0	–	–	–	–	All	0	–	–	–	–
11–50	10	0	–	–	–	19.0	10	0	–	–	–	19.0
51–100	16	0	9	25	1	16.4	17	0	17	34	2	15.8
101–200	17	0	9	26	1	16.0	20	0	21	41	2	13.7
201–300	21	0	23	44	2	13.3	23	0	37	60	3	12.0
301–400	23	0	37	60	3	12.0	23	0	37	60	3	12.0
401–500	24	0	36	60	3	11.7	24	0	36	60	3	11.7
501–600	24	0	41	65	3	11.5	26	0	54	80	4	10.7
601–800	24	0	41	65	3	11.5	26	0	54	80	4	10.7
801–1000	25	0	40	65	3	11.4	27	0	58	85	4	10.3
1001–2000	27	0	58	85	4	10.3	49	1	76	125	6	9.1
2001–3000	28	0	62	90	4	10.0	50	1	95	145	7	8.7
3001–4000	29	0	76	105	5	9.6	55	1	110	165	8	8.5
4001–5000	30	0	75	105	5	9.5	60	1	135	195	9	7.8
5001–7000	30	0	80	110	5	9.4	60	1	165	225	10	7.3
7001–10,000	30	0	80	110	5	9.4	85	2	160	245	11	7.2
10,001–20,000	31	0	94	125	6	9.2	85	2	180	265	12	7.2
20,001–50,000	55	1	120	175	8	8.0	85	2	205	290	13	7.0
50,001–100,000	60	1	140	200	9	7.6	90	2	245	335	15	6.8

Process Average %	1.81–2.40						2.41–3.00					
	Trial 1		Trial 2				Trial 1		Trial 2			
Lot Size	n_1	c_1	n_2	n_1+n_2	c_2	p_t %	n_1	c_1	n_2	n_1+n_2	c_2	p_t %
1–10	All	0	–	–	–	–	All	0	–	–	–	–
11–50	10	0	–	–	–	19.0	10	0	–	–	–	19.0
51–100	17	0	17	34	2	15.8	17	0	17	34	2	15.8
101–200	22	0	33	55	3	12.4	22	0	33	55	3	12.4
201–300	23	0	37	60	3	12.0	24	0	51	75	4	11.1
301–400	25	0	55	80	4	10.8	42	1	63	105	6	10.4
401–500	25	0	55	80	4	10.8	46	1	79	125	7	9.7
501–600	46	1	69	115	6	9.7	48	1	97	145	8	9.2
601–800	49	1	81	130	7	9.4	50	1	115	165	9	8.9
801–1000	49	1	86	135	7	9.2	70	2	120	190	10	8.4
1001–2000	50	1	150	200	10	8.0	100	3	180	280	14	7.5
2001–3000	80	2	165	245	12	7.6	130	4	260	390	19	6.9
3001–4000	105	3	200	305	14	7.0	155	5	330	485	23	6.5
4001–5000	110	3	225	335	15	6.7	215	7	390	605	27	6.0
5001–7000	110	3	250	360	16	6.6	270	9	505	775	34	5.7
7001–10,000	115	3	290	405	18	6.5	285	9	680	965	41	5.4
10,001–20,000	140	4	315	455	20	6.3	315	10	805	1120	47	5.3
20,001–50,000	170	5	420	590	26	6.0	390	13	940	1330	56	5.2
50,001–100,000	200	6	505	705	30	5.7	445	15	1105	1550	65	5.1

n_1 = Size of First Sample; n_2 = Size of Second Sample; entry of "All" indicates that each piece in lot is to be inspected.
c_1 = Allowable Defect Number for First Sample; c_2 = Allowable Defect Number for First and Second Samples Combined.
p_t = Lot Tolerance Per Cent Defective corresponding to a Consumer's Risk (P_C) = 0.10.

TABLE IV CONT'D: DOUBLE SAMPLING LOT INSPECTION TABLES—BASED ON STATED VALUES OF "AVERAGE OUTGOING QUALITY LIMIT"

TABLE DA-4

AVERAGE OUTGOING QUALITY LIMIT = 4.0%

Process Average %	0–.08						.09–.80					
	Trial 1		Trial 2				Trial 1		Trial 2			
Lot Size	n_1	c_1	n_2	n_1+n_2	c_2	p_t %	n_1	c_1	n_2	n_1+n_2	c_2	p_t %
1–10	All	0	–	–	–	–	All	0	–	–	–	–
11–50	8	0	–	–	–	23.0	8	0	–	–	–	23.0
51–100	12	0	7	19	1	22.0	12	0	7	19	1	22.0
101–200	13	0	8	21	1	21.0	13	0	8	21	1	21.0
201–300	13	0	9	22	1	20.5	16	0	18	34	2	17.4
301–400	14	0	8	22	1	20.0	16	0	19	35	2	17.0
401–500	14	0	8	22	1	20.0	16	0	19	35	2	17.0
501–600	16	0	19	35	2	17.0	16	0	19	35	2	17.0
601–800	16	0	20	36	2	16.7	16	0	20	36	2	16.7
801–1000	16	0	20	36	2	16.7	16	0	20	36	2	16.7
1001–2000	17	0	19	36	2	16.6	19	0	31	50	3	14.8
2001–3000	17	0	19	36	2	16.6	19	0	31	50	3	14.8
3001–4000	17	0	20	37	2	16.5	19	0	31	50	3	14.8
4001–5000	17	0	20	37	2	16.5	19	0	31	50	3	14.8
5001–7000	17	0	20	37	2	16.5	19	0	31	50	3	14.8
7001–10,000	17	0	20	37	2	16.5	19	0	36	55	3	14.6
10,001–20,000	17	0	20	37	2	16.5	21	0	44	65	4	13.6
20,001–50,000	17	0	20	37	2	16.5	21	0	44	65	4	13.6
50,001–100,000	17	0	20	37	2	16.5	23	0	62	85	5	12.5

Process Average %	.81–1.60						1.61–2.40					
	Trial 1		Trial 2				Trial 1		Trial 2			
Lot Size	n_1	c_1	n_2	n_1+n_2	c_2	p_t %	n_1	c_1	n_2	n_1+n_2	c_2	p_t %
1–10	All	0	–	–	–	–	All	0	–	–	–	–
11–50	8	0	–	–	–	23.0	8	0	–	–	–	23.0
51–100	12	0	7	19	1	22.0	13	0	14	27	2	20.5
101–200	15	0	17	32	2	18.0	16	0	26	42	3	16.5
201–300	16	0	18	34	2	17.4	17	0	28	45	3	16.0
301–400	18	0	28	46	3	15.5	19	0	41	60	4	14.3
401–500	19	0	28	47	3	15.3	20	0	40	60	4	14.0
501–600	19	0	29	48	3	15.1	20	0	45	65	4	13.8
601–800	19	0	30	49	3	14.9	22	0	58	80	5	13.0
801–1000	20	0	45	65	4	13.8	37	1	58	95	6	12.2
1001–2000	21	0	44	65	4	13.6	39	1	71	110	7	11.5
2001–3000	21	0	44	65	4	13.6	41	1	89	130	8	11.0
3001–4000	22	0	58	80	5	13.0	43	1	102	145	9	10.5
4001–5000	22	0	58	80	5	13.0	45	1	120	165	10	10.0
5001–7000	22	0	58	80	5	13.0	65	2	120	185	11	9.6
7001–10,000	23	0	57	80	5	12.7	65	2	140	205	12	9.3
10,001–20,000	23	0	72	95	6	12.0	65	2	160	225	13	9.0
20,001–50,000	43	1	92	135	8	10.6	70	2	175	245	14	8.8
50,001–100,000	44	1	106	150	9	10.3	70	2	205	275	16	8.7

Process Average %	2.41–3.20						3.21–4.00					
	Trial 1		Trial 2				Trial 1		Trial 2			
Lot Size	n_1	c_1	n_2	n_1+n_2	c_2	p_t %	n_1	c_1	n_2	n_1+n_2	c_2	p_t %
1–10	All	0	–	–	–	–	All	0	–	–	–	–
11–50	8	0	–	–	–	23.0	8	0	–	–	–	23.0
51–100	13	0	14	27	2	20.5	13	0	14	27	2	20.5
101–200	16	0	26	42	3	16.5	16	0	26	42	3	16.5
201–300	18	0	37	55	4	15.0	33	1	47	80	6	13.2
301–400	19	0	41	60	4	14.3	35	1	60	95	7	12.8
401–500	34	1	51	85	6	13.0	36	1	74	110	8	12.2
501–600	37	1	63	100	7	12.2	50	2	75	125	9	11.6
601–800	39	1	81	120	8	11.6	55	2	105	160	11	10.8
801–1000	41	1	94	135	9	11.1	55	2	120	175	12	10.5
1001–2000	55	2	110	165	11	10.6	80	3	165	245	16	9.5
2001–3000	60	2	145	205	13	9.8	95	4	210	305	20	9.2
3001–4000	80	3	160	240	15	9.4	115	5	250	365	23	8.8
4001–5000	85	3	180	265	16	8.9	160	7	305	465	28	8.1
5001–7000	85	3	200	285	17	8.7	210	9	450	660	38	7.4
7001–10,000	90	3	230	320	19	8.5	235	10	550	785	44	7.1
10,001–20,000	105	4	265	370	22	8.3	270	12	625	895	50	7.0
20,001–50,000	125	5	315	440	26	8.1	295	13	725	1020	57	6.9
50,001–100,000	150	6	385	535	31	7.7	335	15	845	1180	66	6.8

TABLE DA-5

AVERAGE OUTGOING QUALITY LIMIT = 5.0%

Process Average %	0–.10						.11–1.00					
	Trial 1		Trial 2				Trial 1		Trial 2			
Lot Size	n_1	c_1	n_2	n_1+n_2	c_2	p_t %	n_1	c_1	n_2	n_1+n_2	c_2	p_t %
1–5	All	0	–	–	–	–	All	0	–	–	–	–
6–50	6	0	–	–	–	30.5	6	0	–	–	–	30.5
51–100	10	0	6	16	1	26.5	10	0	6	16	1	26.5
101–200	11	0	6	17	1	26.0	12	0	15	27	2	22.0
201–300	11	0	7	18	1	25.0	13	0	15	28	2	21.0
301–400	11	0	8	19	1	25.0	13	0	15	28	2	21.0
401–500	13	0	15	28	2	21.0	13	0	15	28	2	21.0
501–600	13	0	15	28	2	21.0	13	0	15	28	2	21.0
601–800	13	0	16	29	2	20.5	13	0	16	29	2	20.5
801–1000	13	0	16	29	2	20.5	13	0	16	29	2	20.5
1001–2000	13	0	16	29	2	20.5	15	0	25	40	3	18.7
2001–3000	13	0	16	29	2	21.0	15	0	26	41	3	18.4
3001–4000	14	0	15	29	2	21.0	15	0	26	41	3	18.4
4001–5000	14	0	16	30	2	20.5	16	0	25	41	3	18.0
5001–7000	14	0	16	30	2	20.5	16	0	26	42	3	18.0
7001–10,000	14	0	16	30	2	20.5	16	0	26	42	3	18.0
10,001–20,000	14	0	17	31	2	20.5	17	0	38	55	4	16.4
20,001–50,000	14	0	17	31	2	20.5	17	0	38	55	4	16.4
50,001–100,000	14	0	18	32	2	20.5	18	0	47	65	5	15.6

Process Average %	1.01–2.00						2.01–3.00					
	Trial 1		Trial 2				Trial 1		Trial 2			
Lot Size	n_1	c_1	n_2	n_1+n_2	c_2	p_t %	n_1	c_1	n_2	n_1+n_2	c_2	p_t %
1–5	All	0	–	–	–	–	All	0	–	–	–	–
6–50	6	0	–	–	–	30.5	6	0	–	–	–	30.5
51–100	11	0	11	22	2	25.0	11	0	11	22	2	25.0
101–200	12	0	15	27	2	22.0	14	0	22	36	3	19.8
201–300	14	0	24	38	3	19.3	14	0	24	38	3	19.3
301–400	15	0	24	39	3	19.0	16	0	33	49	4	17.5
401–500	15	0	24	39	3	19.0	16	0	34	50	4	17.1
501–600	15	0	25	40	3	18.7	16	0	34	50	4	17.1
601–800	16	0	34	50	4	17.1	17	0	33	60	5	16.2
801–1000	16	0	34	50	4	17.1	30	1	45	75	6	15.0
1001–2000	17	0	33	50	4	17.1	31	1	59	90	7	14.5
2001–3000	17	0	48	65	5	15.5	32	1	68	100	8	14.0
3001–4000	18	0	47	65	5	15.5	34	1	81	115	9	13.5
4001–5000	18	0	47	65	5	15.5	35	1	95	130	10	13.0
5001–7000	18	0	47	65	5	15.5	50	2	90	140	11	12.5
7001–10,000	19	0	56	75	6	15.0	50	2	105	155	12	12.1
10,001–20,000	19	0	56	75	6	15.0	50	2	125	175	13	11.7
20,001–50,000	33	1	72	105	8	13.5	50	2	135	185	14	11.3
50,001–100,000	34	1	86	120	9	13.1	55	2	160	215	16	11.0

Process Average %	3.01–4.00						4.01–5.00					
	Trial 1		Trial 2				Trial 1		Trial 2			
Lot Size	n_1	c_1	n_2	n_1+n_2	c_2	p_t %	n_1	c_1	n_2	n_1+n_2	c_2	p_t %
1–5	All	0	–	–	–	–	All	0	–	–	–	–
6–50	6	0	–	–	–	30.5	6	0	–	–	–	30.5
51–100	11	0	11	22	2	25.0	12	0	18	30	3	23.0
101–200	14	0	22	36	3	19.8	14	0	30	44	4	19.0
201–300	15	0	32	47	4	18.0	27	1	48	75	7	16.3
301–400	27	1	38	65	6	16.6	29	1	56	85	8	15.5
401–500	29	1	51	80	7	15.5	30	1	70	100	9	14.9
501–600	31	1	64	95	8	14.3	43	2	72	115	10	13.9
601–800	32	1	78	110	9	13.9	45	2	90	135	12	13.5
801–1000	45	2	75	120	10	13.3	60	3	110	170	14	12.4
1001–2000	50	2	100	150	12	12.7	75	4	160	235	19	11.5
2001–3000	50	2	130	180	14	12.0	95	5	185	280	22	11.0
3001–4000	65	3	135	200	15	11.3	95	5	255	350	27	10.5
4001–5000	70	3	155	225	17	11.0	130	7	260	390	29	10.0
5001–7000	70	3	185	255	19	10.7	160	9	355	515	38	9.5
7001–10,000	85	4	200	285	21	10.4	180	10	430	610	44	9.2
10,001–20,000	100	5	220	320	23	10.0	215	12	490	705	50	8.9
20,001–50,000	120	6	290	410	29	9.5	230	13	605	835	59	8.7
50,001–100,000	140	7	315	455	32	9.3	265	15	705	970	68	8.5

n_1 = Size of First Sample; n_2 = Size of Second Sample; entry of "All" indicates that each piece in lot is to be inspected.
c_1 = Allowable Defect Number for First Sample; c_2 = Allowable Defect Number for First and Second Samples Combined.
p_t = Lot Tolerance Per Cent Defective corresponding to a Consumer's Risk (P c) = 0.10.

TABLE IV CONT'D: DOUBLE SAMPLING LOT INSPECTION TABLES—BASED ON STATED VALUES OF "AVERAGE OUTGOING QUALITY LIMIT"

TABLE DA-7

Average Outgoing Quality Limit = 7.0%

Process Average %	0–.14						.15–1.40					
	Trial 1		Trial 2				Trial 1		Trial 2			
Lot Size	n_1	c_1	n_2	n_1+n_2	c_2	p_t %	n_1	c_1	n_2	n_1+n_2	c_2	p_t %
1–5	All	0	–	–	–	–	All	0	–	–	–	–
6–25	5	0	–	–	–	35.5	5	0	–	–	–	35.5
26–50	7	0	4	11	1	38.5	7	0	4	11	1	38.5
51–100	7	0	5	12	1	36.5	7	0	5	12	1	36.5
101–200	8	0	5	13	1	36.0	9	0	10	19	2	30.5
201–300	8	0	6	14	1	35.5	9	0	11	20	2	30.0
301–400	9	0	11	20	2	30.0	9	0	11	20	2	30.0
401–500	9	0	11	20	2	30.0	9	0	11	20	2	30.0
501–600	9	0	12	21	2	29.5	9	0	12	21	2	29.5
601–800	9	0	12	21	2	29.5	9	0	12	21	2	29.5
801–1000	9	0	12	21	2	29.5	11	0	18	29	3	25.5
1001–2000	10	0	11	21	2	29.0	11	0	18	29	3	25.5
2001–3000	10	0	11	21	2	29.0	11	0	19	30	3	25.5
3001–4000	10	0	11	21	2	29.0	11	0	19	30	3	25.5
4001–5000	10	0	11	21	2	29.0	11	0	19	30	3	25.5
5001–7000	10	0	12	22	2	28.5	11	0	19	30	3	26.0
7001–10,000	10	0	12	22	2	28.5	12	0	26	38	4	23.5
10,001–20,000	10	0	12	22	2	28.5	12	0	27	39	4	23.0
20,001–50,000	10	0	12	22	2	28.5	13	0	36	49	5	21.0
50,001–100,000	10	0	12	22	2	28.5	13	0	36	49	5	21.0

Process Average %	1.41–2.80						2.81–4.20					
	Trial 1		Trial 2				Trial 1		Trial 2			
Lot Size	n_1	c_1	n_2	n_1+n_2	c_2	p_t %	n_1	c_1	n_2	n_1+n_2	c_2	p_t %
1–5	All	0	–	–	–	–	All	0	–	–	–	–
6–25	5	0	–	–	–	35.5	5	0	–	–	–	35.5
26–50	7	0	4	11	1	38.5	7	0	4	11	1	38.5
51–100	9	0	9	18	2	31.5	9	0	9	18	2	31.5
101–200	10	0	15	25	3	27.5	10	0	15	25	3	27.5
201–300	10	0	17	27	3	27.0	11	0	24	35	4	25.0
301–400	11	0	17	28	3	26.0	11	0	25	36	4	24.5
401–500	11	0	17	28	3	26.0	12	0	32	44	5	23.0
501–600	12	0	25	37	4	24.0	21	1	34	55	6	21.0
601–800	12	0	25	37	4	24.0	22	1	43	65	7	20.0
801–1000	12	0	25	37	4	24.0	23	1	42	65	7	19.8
1001–2000	12	0	25	37	4	24.0	23	1	47	70	8	19.2
2001–3000	13	0	34	47	5	21.5	24	1	56	80	9	18.7
3001–4000	13	0	34	47	5	21.5	24	1	66	90	10	18.2
4001–5000	13	0	35	48	5	21.5	26	1	74	100	11	17.7
5001–7000	14	0	46	60	6	20.0	37	2	78	115	12	16.5
7001–10,000	25	1	50	75	8	18.5	38	2	87	125	13	16.2
10,001–20,000	25	1	55	80	8	18.0	38	2	97	135	14	16.0
20,001–50,000	25	1	60	85	9	17.8	38	2	107	145	15	15.8
50,001–100,000	26	1	69	95	10	17.5	39	2	111	150	16	15.7

Process Average %	4.21–5.60						5.61–7.00					
	Trial 1		Trial 2				Trial 1		Trial 2			
Lot Size	n_1	c_1	n_2	n_1+n_2	c_2	p_t %	n_1	c_1	n_2	n_1+n_2	c_2	p_t %
1–5	All	0	–	–	–	–	All	0	–	–	–	–
6–25	5	0	–	–	–	35.5	5	0	–	–	–	35.5
26–50	8	0	8	16	2	34.0	8	0	8	16	2	34.0
51–100	10	0	14	24	3	28.5	10	0	14	24	3	28.5
101–200	11	0	22	33	4	25.5	18	1	28	46	6	24.0
201–300	19	1	28	47	6	23.5	20	1	40	60	8	22.0
301–400	20	1	35	55	7	22.0	29	2	41	70	9	21.0
401–500	22	1	43	65	8	20.5	31	2	59	90	11	19.5
501–600	23	1	52	75	9	19.5	32	2	63	95	12	19.0
601–800	32	2	53	85	10	19.0	41	3	74	115	14	18.3
801–1000	33	2	62	95	11	18.4	43	3	82	125	15	17.5
1001–2000	34	2	81	115	13	17.8	55	4	115	170	20	16.5
2001–3000	44	3	91	135	15	17.0	65	5	135	200	23	16.0
3001–4000	47	3	103	150	16	16.0	75	6	175	250	28	15.0
4001–5000	50	3	135	185	19	15.0	100	8	225	325	35	14.0
5001–7000	65	4	155	220	22	14.0	115	9	265	380	40	13.5
7001–10,000	75	5	180	255	25	13.6	130	10	310	440	45	13.0
10,001–20,000	85	6	210	295	29	13.2	150	12	370	520	52	12.5
20,001–50,000	100	7	235	335	33	12.9	180	14	460	640	63	12.0
50,001–100,000	110	8	300	410	40	12.6	205	16	555	760	75	11.7

TABLE DA-10

AVERAGE OUTGOING QUALITY LIMIT = 10.0%

Process Average %	0–.20						.21–2.00					
	Trial 1		Trial 2			p_t %	Trial 1		Trial 2			p_t %
Lot Size	n_1	c_1	n_2	n_1+n_2	c_2		n_1	c_1	n_2	n_1+n_2	c_2	
1–3	All	0	–	–	–	–	All	0	–	–	–	–
4–15	3	0	–	–	–	50.0	3	0	–	–	–	50.0
16–50	5	0	3	8	1	53.5	5	0	3	8	1	53.5
51–100	5	0	3	8	1	55.0	6	0	8	14	2	43.0
101–200	5	0	4	9	1	52.0	7	0	7	14	2	42.0
201–300	7	0	7	14	2	42.5	7	0	7	14	2	42.5
301–400	7	0	7	14	2	42.5	7	0	7	14	2	42.5
401–500	7	0	8	15	2	40.0	7	0	8	15	2	40.0
501–600	7	0	8	15	2	40.0	8	0	13	21	3	35.0
601–800	7	0	8	15	2	40.5	8	0	13	21	3	35.0
801–1000	7	0	8	15	2	40.5	8	0	13	21	3	35.0
1001–2000	7	0	8	15	2	40.5	8	0	14	22	3	34.0
2001–3000	7	0	8	15	2	41.0	8	0	14	22	3	34.0
3001–4000	7	0	8	15	2	41.0	8	0	14	22	3	34.5
4001–5000	7	0	8	15	2	41.0	8	0	14	22	3	35.0
5001–7000	7	0	8	15	2	41.0	9	0	18	27	4	32.5
7001–10,000	7	0	8	15	2	41.0	9	0	18	27	4	32.5
10,001–20,000	7	0	8	15	2	41.0	9	0	18	27	4	32.5
20,001–50,000	7	0	8	15	2	41.0	9	0	18	27	4	32.5
50,001–100,000	8	0	14	22	3	33.5	9	0	25	34	5	30.0

Process Average %	2.01–4.00						4.01–6.00					
	Trial 1		Trial 2			p_t %	Trial 1		Trial 2			p_t %
Lot Size	n_1	c_1	n_2	n_1+n_2	c_2		n_1	c_1	n_2	n_1+n_2	c_2	
1–3	All	0	–	–	–	–	All	0	–	–	–	–
4–15	3	0	–	–	–	50.0	3	0	–	–	–	50.0
16–50	5	0	3	8	1	53.5	6	0	6	12	2	48.0
51–100	6	0	8	14	2	43.0	7	0	11	18	3	38.5
101–200	7	0	12	19	3	38.0	8	0	16	24	4	35.5
201–300	7	0	13	20	3	37.0	8	0	17	25	4	35.0
301–400	8	0	17	25	4	35.0	8	0	22	30	5	34.0
401–500	8	0	18	26	4	34.0	15	1	23	38	6	30.5
501–600	8	0	18	26	4	34.0	16	1	28	44	7	28.5
601–800	8	0	18	26	4	34.5	16	1	28	44	7	29.0
801–1000	9	0	18	27	4	33.0	16	1	34	50	8	28.0
1001–2000	9	0	23	32	5	31.0	17	1	38	55	9	27.5
2001–3000	9	0	24	33	5	30.0	17	1	48	65	10	26.0
3001–4000	9	0	24	33	5	30.5	24	2	46	70	11	25.0
4001–5000	10	0	29	39	6	29.5	26	2	54	80	12	23.5
5001–7000	16	1	29	45	7	28.5	27	2	63	90	13	22.5
7001–10,000	17	1	38	55	8	26.0	27	2	68	95	14	22.0
10,001–20,000	17	1	38	55	8	26.0	28	2	77	105	15	22.0
20,001–50,000	18	1	42	60	9	25.5	28	2	87	115	17	21.5
50,001–100,000	18	1	52	70	10	24.5	36	3	99	135	20	21.0

Process Average %	6.01–8.00						8.01–10.00					
	Trial 1		Trial 2			p_t %	Trial 1		Trial 2			p_t %
Lot Size	n_1	c_1	n_2	n_1+n_2	c_2		n_1	c_1	n_2	n_1+n_2	c_2	
1–3	All	0	–	–	–	–	All	0	–	–	–	–
4–15	3	0	–	–	–	50.0	3	0	–	–	–	50.0
16–50	6	0	6	12	2	48.0	6	0	6	12	2	48.0
51–100	7	0	11	18	3	38.5	7	0	16	23	4	36.5
101–200	13	1	20	33	6	33.5	14	1	24	38	7	32.0
201–300	14	1	26	40	7	31.5	19	2	29	48	9	31.0
301–400	15	1	30	45	8	31.0	21	2	44	65	12	29.0
401–500	16	1	39	55	9	28.5	22	2	53	75	13	27.0
501–600	22	2	38	60	10	27.5	28	3	52	80	14	26.5
601–800	22	2	43	65	11	27.0	29	3	56	85	15	26.0
801–1000	24	2	56	80	13	25.5	36	4	69	105	18	24.5
1001–2000	24	2	61	85	14	25.0	45	5	95	140	23	23.0
2001–3000	33	3	72	105	16	23.0	50	6	115	165	27	22.0
3001–4000	41	4	99	140	21	21.5	70	8	150	220	34	20.5
4001–5000	44	4	111	155	22	20.0	80	9	195	275	41	19.0
5001–7000	50	5	120	170	24	19.5	90	10	240	330	47	18.0
7001–10,000	60	6	145	205	28	18.5	110	12	265	375	53	17.5
10,001–20,000	70	7	165	235	32	18.0	125	14	320	445	62	17.0
20,001–50,000	80	8	205	285	39	17.5	140	16	355	495	69	16.8
50,001–100,000	85	8	245	330	44	17.0	150	17	390	540	77	16.6

n_1 = Size of First Sample; n_2 = Size of Second Sample; entry of "All" indicates that each piece in lot is to be inspected.
c_1 = Allowable Defect Number for First Sample; c_2 = Allowable Defect Number for First and Second Samples Combined.
p_t = Lot Tolerance Per Cent Defective corresponding to a Consumer's Risk (P_C) = 0.10.

Television Transmission Over Wire Lines*

By M. E. STRIEBY and J. F. WENTZ

Intercity networks appear vital to the success of television broadcasting. Experiments with wire lines for this purpose and for local transmission of present-day television signals are reported herein. The design and construction of the equipment used are described and its performance characteristics given.

The intercity lines discussed involve carrier transmission over coaxial cable with repeaters which pass a net band of about 2¾ megacycles. For local intracity connections video transmission of about a 4 mc band is obtained over existing telephone plant or by means of special low attenuation cable. Various circuit arrangements including the facilities used in bringing scenes from the Republican Convention in Philadelphia to the N.B.C. in New York are shown together with their overall television transmission characteristics.

Introduction

IF THE development of television broadcasting follows in the footsteps of its predecessor in the sound broadcasting field, networks for interconnecting television stations will be very important. In fact many students[1] of the problem believe that such networks are a virtual necessity because of the expected high cost of programs.

Considerable progress in the development of a wire line technique for this purpose has been made in connection with the Bell System's study of coaxial conductor systems for use in wide band telephony. Data previously published[2, 3, 4] have been supplemented recently by certain tests and experiments in the transmission of 441-line television images, the results of which are presented in this paper. This will cover the transmission characteristics of facilities both for intercity and local distribution, including the wire lines which were used during the television broadcast in New York of the proceedings of the Republican Convention in Philadelphia during the last week of June, 1940. This broadcast was undertaken jointly by the National Broadcasting Company and Bell System Companies as an experiment in the furtherance of the television art. A large part of the experimental facilities used were manufactured by the Western Electric Company.

Long Haul Coaxial Systems

For long-distance broad-band transmission, coaxial systems have certain natural advantages which have been previously pointed out. In common

* Presented before the A.I.E.E., January 30, 1940.

with all long-distance systems for multiplex telephony, the carrier method of transmission is essential and has been found to be relatively straightforward. For long-distance television transmission, the carrier method is necessary with the present coaxial lines and coaxial repeaters, due to the fact that satisfactory long-distance transmission cannot be obtained at the very low frequencies involved in a video television signal. Hence for

Fig. 1—Photograph of coaxial cable

television the entire signal must be raised bodily to a higher frequency. The modulating means developed for this purpose will be described in detail later. In this section we will confine discussion to the transmission of a broad band of frequencies independently of how this band is used.

Cable

The transmission characteristics of ideal coaxial cables have long been known. The properties of practical structures so far built including matters of cross-talk

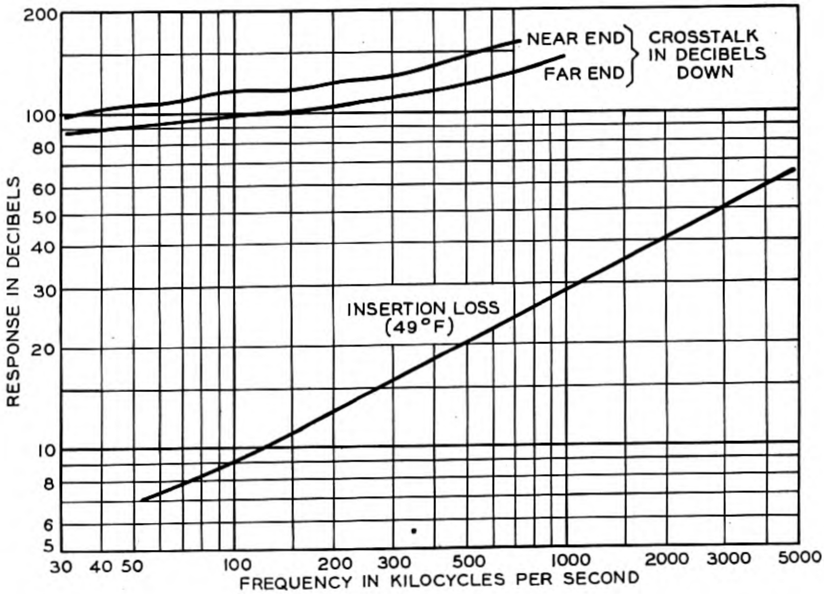

Fig. 2—Attenuation, crosstalk

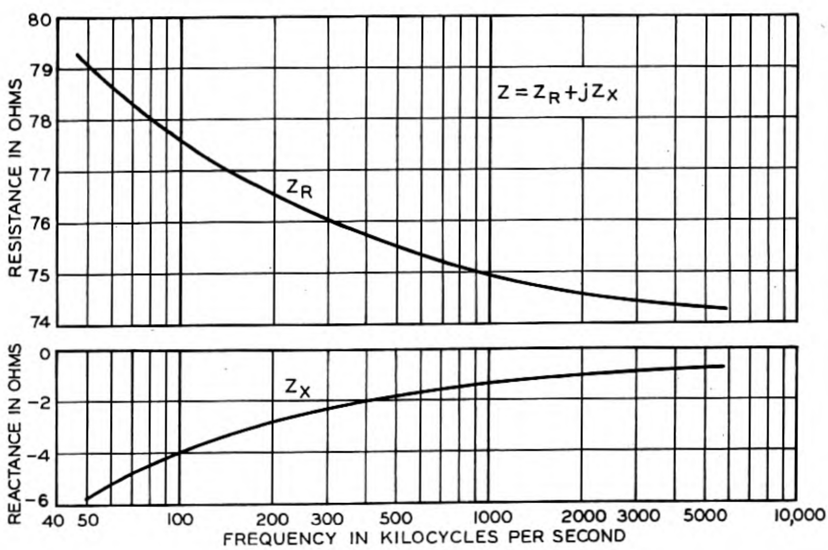

Fig. 3—Impedance of 5 miles

or shielding are also now well understood[5,6]. Certain mechanical improvements in construction have been made recently[7] and may be illustrated by a photograph,

Fig. 1, of the recently installed Baltimore-Washington coaxial cable. A similar construction was used in a cable completed last summer between Stevens Point, Wisconsin and Minneapolis, Minnesota.

These cables each contain 4 coaxial units. Two of these are used to provide a normal broad-band system having one pipe for each direction of transmission. The other two provide spare facilities for each direction. The construction of the coaxial unit itself can be seen from the photograph to use a single longitudinal copper tape for the outer conductor. This is formed into a tube which is held to a fixed diameter by the width of the tape and is prevented from collapsing by the interlocking of its saw-toothed edges. Two layers of steel tape provide the needed support against buckling and also give additional shielding. This construc-

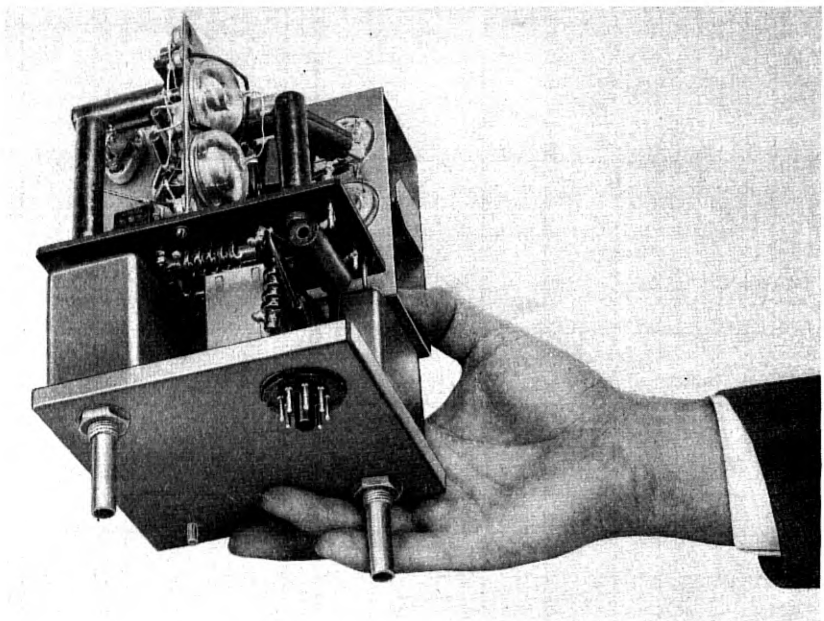

Fig. 4—3-Megacycle amplifier in hand

tion results in somewhat improved transmission characteristics and lower manufacturing costs as compared with other types of construction with which we have experimented. Improvements in transmission include lower attenuation, due to a reduction in the effective resistance of the outer conductor, and a smoother impedance frequency characteristic due to greater mechanical uniformity. In spite of the thinner outer conductor satisfactory crosstalk characteristics are obtained.[8] Typical attenuation, crosstalk and impedance characteristics of this cable as a function of frequency are shown in Figs. 2 and 3 for a 5-mile length of installed cable.

Repeaters

The band width of a coaxial system, at least over regions which we have studied, is limited only by the amplifiers with which it is provided. The amplifiers which have been built most recently for use in these systems are known as "3-megacycle amplifiers" and were intended to provide about a 2-megacycle band of suitable characteristics for telephone purposes or about a $2\frac{3}{4}$ megacycle band suitable for television transmission.

Figure 4 shows one of these amplifiers. It is a three-stage feedback device using two small pentodes in parallel in each stage. The mathematical design of the circuit is beyond the scope of this paper and has been treated elsewhere.[9] This type of pentode has an initial transconductance of from 2000 to 2500 mi-

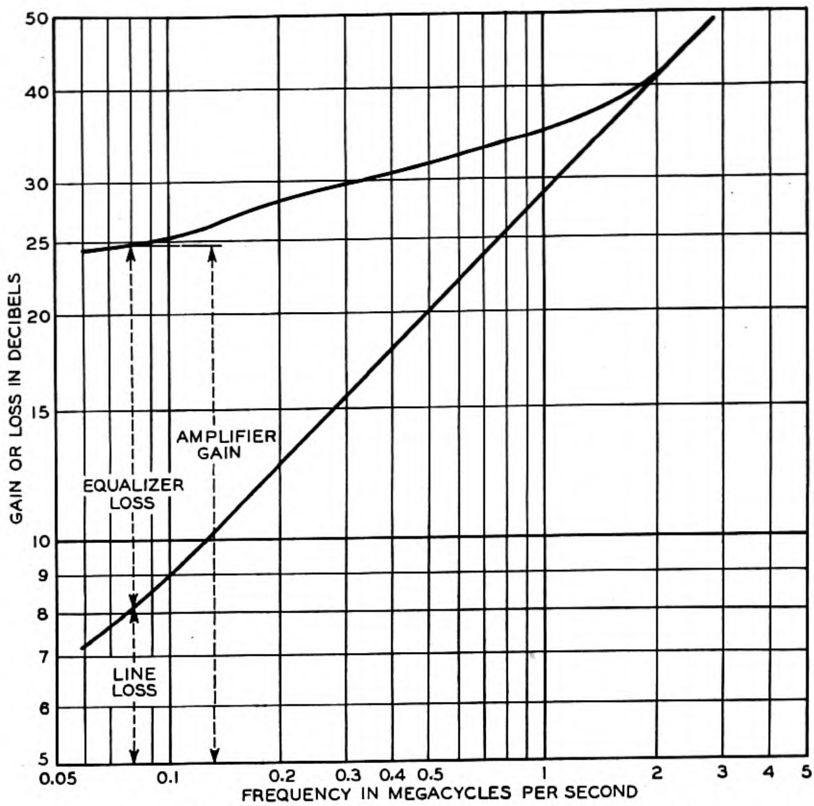

Fig. 5—Repeater gain line loss and equalization characteristics

cromhos and an output power of .1 to .2 watt at 130 volts as used in this system. These tubes are in parallel only to give added reliability. The gain of this amplifier is very roughly the complement of the line loss as a function of frequency. With this amplifier and the cable described above, these repeater sections are about $5\frac{1}{4}$ miles in length. As illustrated in Fig. 5, the difference between the gain and line loss is made up by a line equalizer so that to a first approximation, zero loss in transmission is obtained at all frequencies within the band over each repeater section. About 30 db of feedback is effective over the telephone frequency band (i.e. up to 2000 kc) around the entire amplifier with about 10 db additional around the final stage. From 2 mc up to 3 mc the feedback gradually falls off about 10 db. This arrangement gives the high degree of transmission stability and linearity required for long telephone systems with hundreds of amplifiers in tandem, and satisfactorily meets present requirments. Limited experience with television transmission so far indicates satisfactory performance. The linearity is illustrated in Fig. 6 which shows measurements of 2nd and 3rd order modulation products of a 1000-kc signal in a typical amplifier at various signal levels. As in previous coaxial systems, power for operating the amplifiers is transmitted at 60 cycles over the coaxial cable itself from main stations located at about 50-mile intervals.

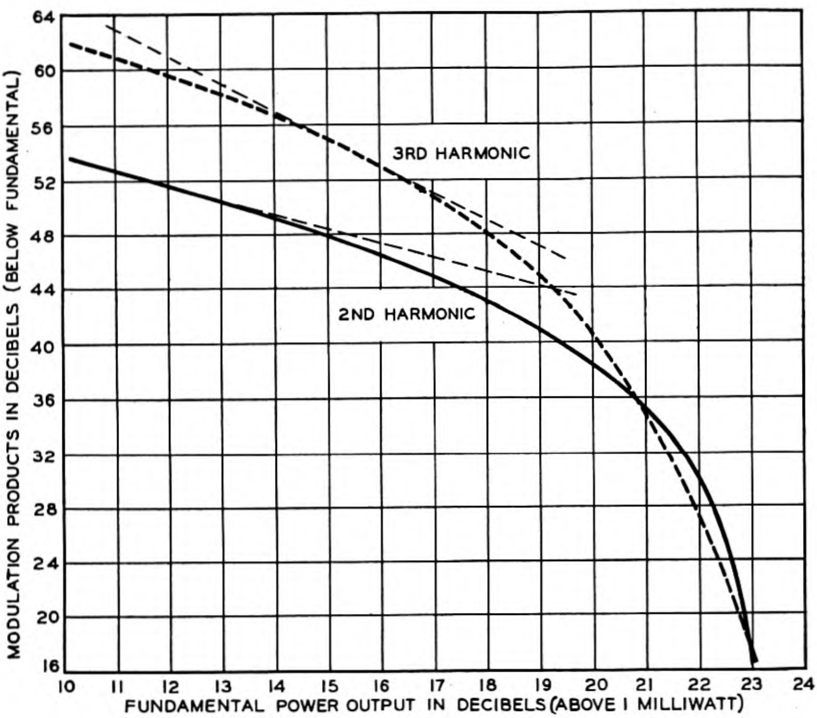

Fig. 6—Amplifier linearity

Regulation

In order to compensate for changes in attenuation due to temperature change of the copper conductors, the gain of the amplifier is regulated automatically by a device located at each amplifier point which is operated from a pilot channel. In this system a pilot frequency of 2064 kc is transmitted along the line with the signal. At the output of each amplifier, a high-impedance highly selective crystal filter is bridged on the circuit to select the pilot frequency. This is then amplified, rectified, and used to control the output of an oscillator. The oscillator output in turn is used to control the resistance of one element in the feedback circuit of the amplifier. This variable element is a very tiny thermistor[10] made up of certain oxides which have a very large negative temperature coefficient of resistance. The regulator is "back-acting" and maintains a substantially constant output voltage at the pilot frequency over a range of about 9 db in input voltage. The feedback circuit of the amplifier is so designed that the changes in the resistance of the thermistor produce changes in gain over the entire frequency band in such a way as to compensate for the changes in loss in the coaxial conductors, as illustrated in Fig. 7. Changes there shown are for ±70° F., which is about the maximum which is expected in a repeater section, even though the cable is of the aerial type.

In a long system, it has not been feasible to make the accuracy of equalization and regulation in each 5-mile section sufficient to give the desired overall uniformity of transmission. Hence, certain supplementary adjustment is required. Devices for such adjustment have been installed at 50-mile points on the Stevens Point-Minneapolis system with satisfactory results. Also, two additional pilot

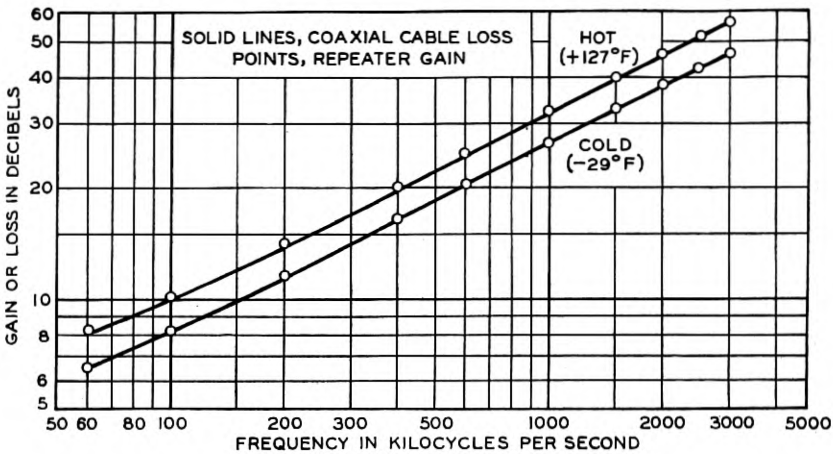

Fig. 7—Regulation hot and cold vs. frequency

channels have been provided, one at 64 kc and one at 3096 kc. These serve to indicate the circuit performance and the need for manual adjustment. These pilots could be used to actuate automatic regulators if desired. For longer systems, it is expected that additional, and necessarily more complicated, supplementary devices will be required at intervals of perhaps 200 to 500 miles.

Performance

A complete repeater containing amplifiers for each direction of transmission, automatic regulators, equalizers, power supply and various automatic alarm features is mounted in a box about 2 x 2 x 1 ft. as shown in a photograph (Fig. 8). Measurements on the overall performance of systems with many such repeaters in tandem indicate a high degree of transmission stability and freedom from noise. In the neighborhood of the pilot frequency the transmission variations are in the order of .1 db. At other frequencies there are slow drifts due to aging of tubes which, when they reach a few db, will require readjustment. These changes are now effected manually at the attended stations.

Interference from all sources, both external and internal, is very low in this system. The largest contributions of such interference are from tube noise and from thermal agitation in the conductors and circuit elements. The effect of interference from external sources so far encountered is lower than the above, although the presence of radio broadcasting stations can be detected. Intermodula-

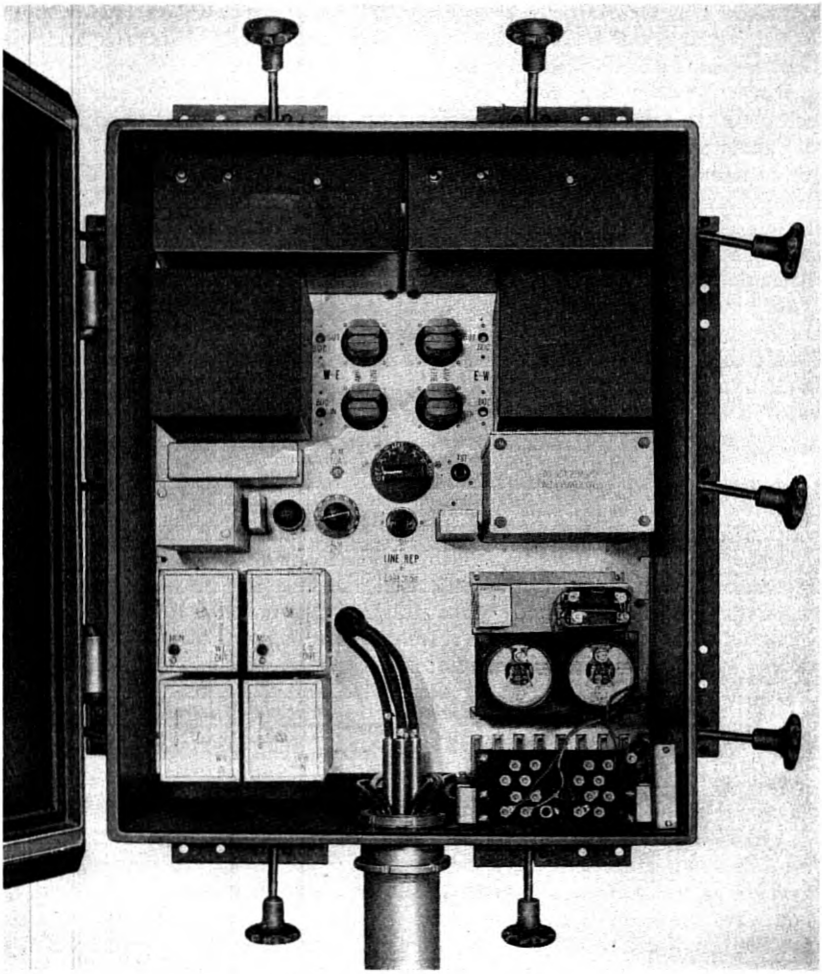

Fig. 8—Complete repeater

tion of signals traversing the system simultaneously has been very carefully measured because of its importance for multichannel telephony and television. In telephony, because of the large number of modulation products, principally 2nd and 3rd order, these appear as random interference.

The method of measurement of interference from all sources was to transmit over the system a wide-band signal having a continuous spectrum such as thermal noise. At the sending end a narrow-band elimination filter was inserted. At the far end the noise was measured within that same band.

The total noise so measured depends upon the signal energy levels at the input and the output of the repeaters, the former controlling the effect of line and resistance noise and the latter controlling the effect of modulation. These levels in turn are a function of repeater spacing. The tests that have been made indicate that it is practicable to keep this type of interference within desirable limits on long telephone or television circuits.

Due to the 60-cycle power supply used on the system, power frequency modulation products require special attention. Sixty-cycle sidebands are produced on all signals transmitted due to the traces of nonlinearity in the system. As these are very small in magnitude and result mostly in a 120-cycle component they are unimportant for telephony. However, in the television transmission system used, this component is larger because of the presence of a strong carrier and one or more pilot channels. Also, 120-cycle sidebands produce a very disturbing type of horizontal bar pattern across the picture. This type of interference will increase as the circuit length is increased, and may become more visible as receiving tubes are improved. On systems so far available for test, however, it has been possible to hold this type of interference within acceptable limits, on present day television broadcast images.

Distortion in Television Images

Departures from ideal transmission in the line, equipment or in a radio path produce distortion in the form of negative or positive fringes or "ghosts." These occur when there is a lack of proportionality between phase shift and frequency through the system. This trouble in television images is perhaps more easily understood if one thinks of it as an actual difference in time of transmission of various parts of the signal. In discussing this matter in this paper, we will use the term "delay" to mean the time of transmission of the envelope of a modulated wave. This quantity is often more accurately referred to as "envelope delay".[11] If this quantity varies too widely there is an actual difference in the time of transmission of various parts of the signal, producing distortion in the form of fringes or "ghosts" which are exhibited by many television images today.

Band Width

A band width of about 3 mc is required to give equal resolution in the vertical and horizontal directions in a 441-line, 30-frame interlaced image. Recent experiments[12] with out-of-focus moving pictures have shown not only that the eye is quite insensitive in its requirement for equal detail in the two directions but also that the loss of detail due to a narrowing of the frequency band from 4 mc to $2\frac{3}{4}$ mc will pass unnoticed by many careful observers at normal viewing distance.

Television on Coaxial Systems

As mentioned above, no practical method has been found for transmitting television over long-haul coaxial circuits in the video frequency range. By the carrier method, however, the video frequency band may be raised to a region suitable for transmission. To conserve frequency space, single-sideband transmission, of course, is desirable. The actual method chosen involves also a modest vestigial band since it appears impracticable to select a single sideband involving video frequencies as low as 45 cycles in any other way. The present coaxial amplifiers pass a band from about 64 kc to about 3100 kc. The region useful for television, however, appeared to be somewhat less than three megacycles on account of the difficulty of equalizing the delay distortion near the lower edge of this band. About 100 kc was allotted to obtain proper shaping of the vestigial sideband. The carrier was therefore placed at about 300 kc and a net television band of about $2\frac{3}{4}$ mc was obtained. If we attempt to move a 3 mc video band up 300 kc in a single step of modulation, the result is an overlapping of the sidebands which hopelessly distorts the signal. Two steps of modulation are therefore resorted to as shown in Fig. 9.

The energy of a television system is concentrated in the lower frequencies or, in a carrier system, near the carrier. To take most advantage of the coaxial system, the carrier should be at the low end where the full feedback in the amplifiers is available. The four lines in Fig. 9 illustrate the four stages of modulation, two at the transmitting terminal and two at the receiving terminal. As can be seen the signal is first modulated with a carrier of about 8 megacycles and the lower sideband, part of the carrier, and a portion of the upper sideband, are selected by a band filter. This signal is then modulated again with a carrier of about 8.3 megacycles and the lower sideband again selected. In this position of the signal, which is the position at which it will be transmitted over the coaxial line, the frequency which corresponds to d.c. in the video signal is at 311 kc, the main sideband extends from 311 to 3111 kc and the vestigial sideband from 311 kc down to 200 kc.

The receiving terminal is in general the inverse of the transmitting terminal and will not be discussed in detail. The sideband shaping[4] is accomplished by the four filters, two at the transmitting terminal and two similar ones at the receiving terminal, acting in conjunction. The result is that at the final stage of demodulation the contribution from the vestigial sideband when added to the contribution from the shaped portion of the main sideband gives back very nearly an undistorted video signal. This last stage of demodulation is accomplished in a linear detector. The carrier amplitude at the input terminals of this detector is about six db greater than the amplitude of the video envelope of the modulated signal, the amount of carrier which was mixed with the sidebands at the output of the first modulator having been adjusted to achieve this result. The reason for using this amount of transmitted carrier is the relatively narrow vestigial sideband—111 kc vs. a main sideband of about $2\frac{3}{4}$ mc. With such a narrow vestigial sideband the quadrature component of the carrier en-

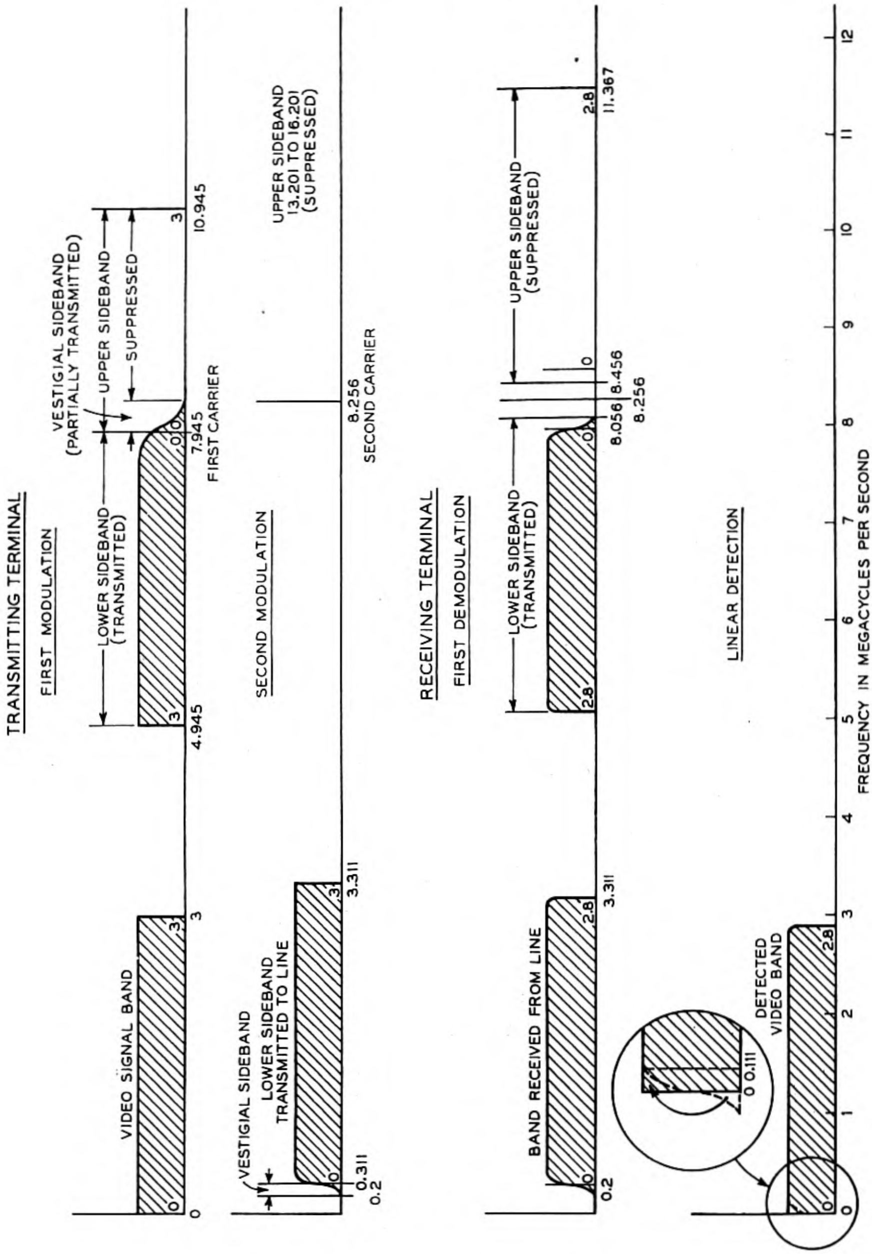

Fig. 9—Modulation steps diagram

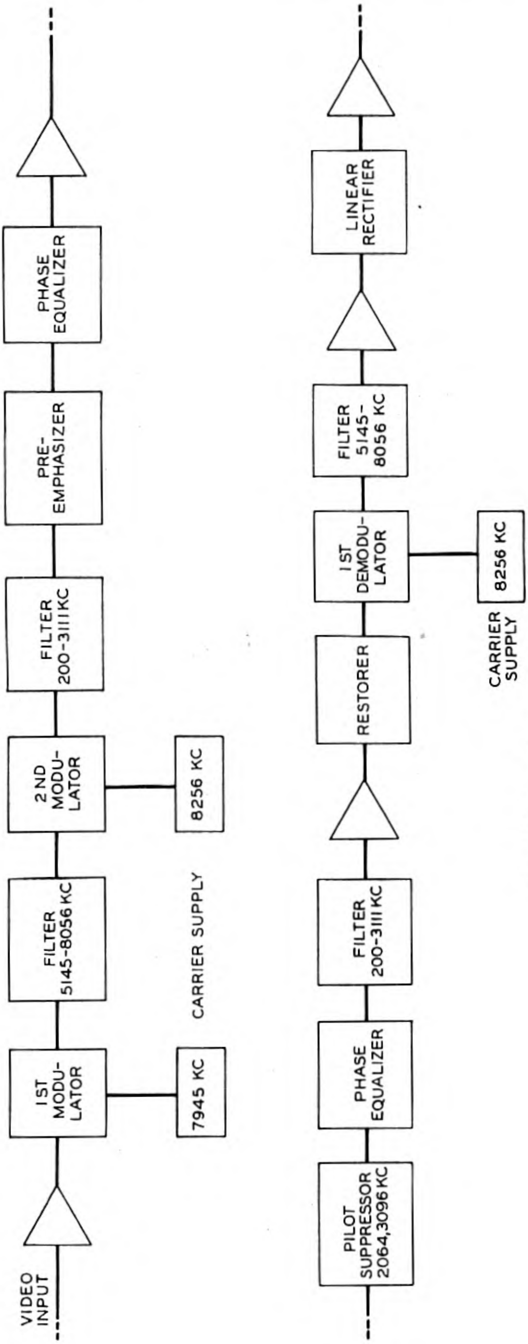

Fig. 10—Box diagram of carrier terminals

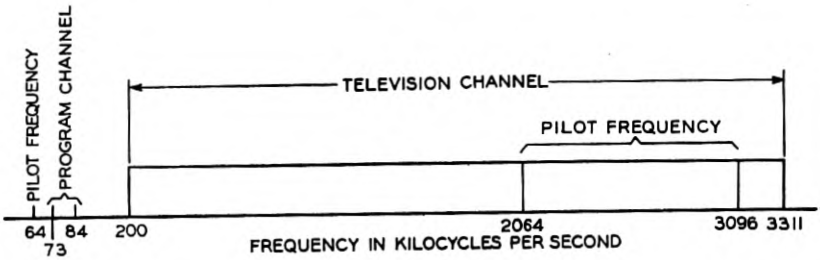

Fig. 11—Frequency allocation on line

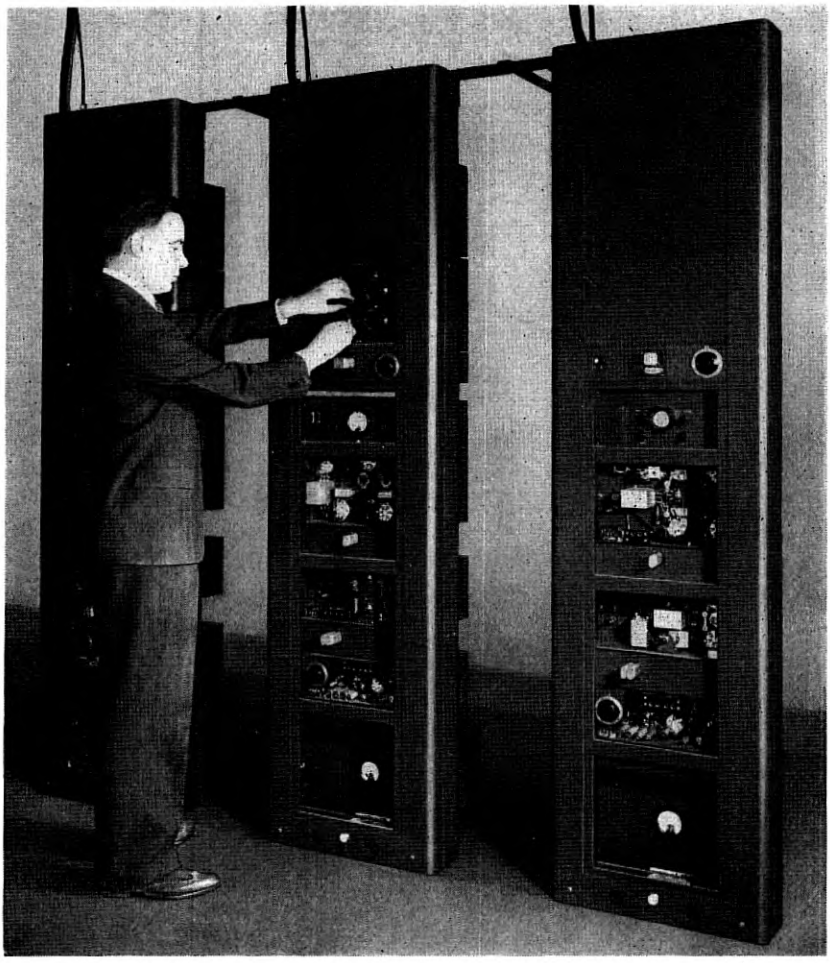

Fig. 12—Carrier terminals

velope is relatively large, resulting in objectionable distortion at sharp changes in the picture signal if the greater ratio of carrier to sideband is not employed.[13]

Figure 10 shows a box diagram of the terminal arrangements. In addition to ordinary video amplifiers and modulators and filters mentioned above, a "pre-emphasizer" and a "restorer" are shown. These networks partially equalize the energy in the various components of the signal, and thus help to override the noise and spurious modulation products introduced by the line and amplifiers. A phase equalizer is also shown which, in conjunction with a similar equalizer at the receiving end, is designed to correct for the phase distortion in both the transmitting and the receiving terminals. Before transmission over the coaxial, pilot frequencies of 64 kc, 2064 kc and 3096 kc are added, as well as a program channel from 73–84 kc. Figure 11 shows the frequency allocation of the television signal and its associated channels on the coaxial line.

At the receiving end the pilot frequencies and the program channel must be removed. The 64-kc pilot and the program channel are eliminated by the 200-3111 kc filter which precedes the first demodulator. The 2064-kc and 3096-kc pilots, however, are within the transmitted television band. The frequency allocation was so chosen as to place them approximately in the center of the "empty energy regions"[14] of the television spectrum where they can be eliminated by sharp selective networks without appreciably distorting adjacent television signal components.

Three carrier television terminals are shown in the photograph, Fig. 12. The one on the right is a transmitting terminal, the two on the left receiving terminals. Each terminal occupies one six-foot relay rack bay and is complete with power supply and means for adjustment.

Short Haul Lines for Television

For the pickup or transmission of television within cities or metropolitan areas, it appears to be more economical, as would be expected, not to use the carrier method described above but to transmit "video" frequency signals over cable circuits. For this purpose existing telephone cables may be used or special cables may be provided. In either case amplifiers and special equalizers are required which will overcome the attenuation and delay distortion of the cable circuits. Because of high-frequency crosstalk usually only a small fraction of the circuits in any existing telephone cable can be used simultaneously.

Video Amplifiers and Equalizers

Television pickup and broadcasting equipment is quite naturally designed on an unbalanced (i.e. one side grounded) basis. Unbalanced amplifiers for the video band have been available for some time.[15] New amplifier designs have been worked out for use with balanced lines. In general, the problem is to provide approximately zero loss and constant delay between unbalanced terminals a mile or more apart. Thus, an unbalanced to balanced amplifier is required at the sending end, the converse at the receiving end. If the circuit is long, balanced amplifiers are most convenient for use at intermediate points. The equalization problem has been successfully met even if ordinary telephone cables are used. A series of variable equalizers have been experimented with which have several degrees of flexibility. A variety of circuits ranging in length up to 9 miles have

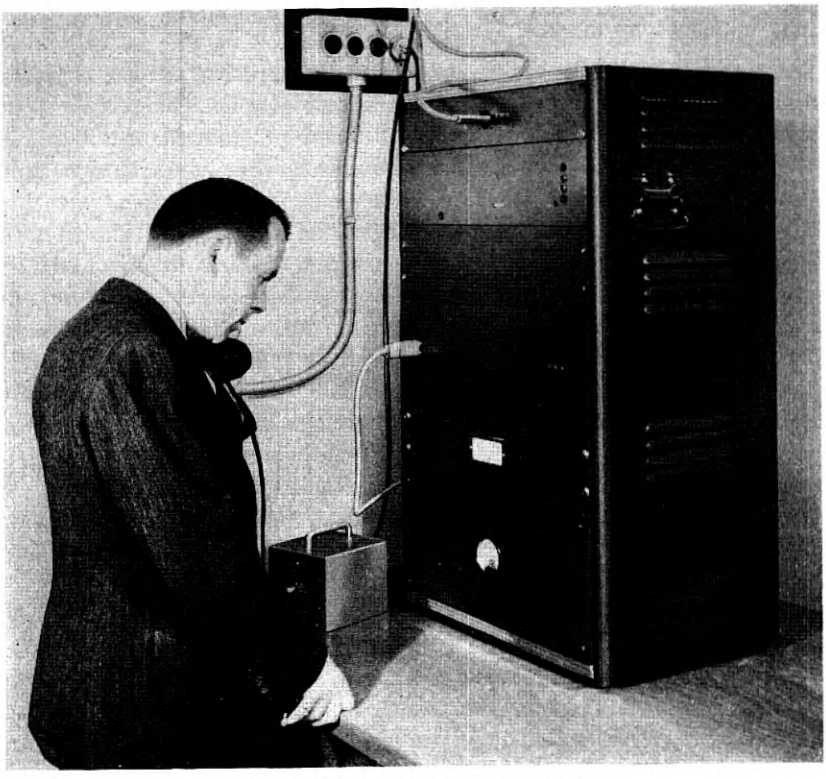

Fig. 13—Photograph of Video amplifier

been equalized with this arrangement with considerable success. A typical amplifier, equalizer, and power supply are shown in the photograph, Fig. 13.

Telephone Cables

Ordinary fine wire paper insulated cables have very high attenuation at the frequencies required. Typical values for loss and net loss after amplification and equalization are shown in Fig. 14. Experience has shown that the noise levels in such cables even at the higher video frequencies are rather high so that amplifiers are required at intervals of a mile or even less. Local telephone cables are usually laid out with many branches. At high frequencies these branches introduce irregularities similar to those produced by obstacles along a radio path which cause delay distortion. Plant changes are frequently required to obtain a clean circuit free from such bridged taps. When amplifiers and proper equalizers are added, however, substantially flat transmission is obtained as shown in the figure.

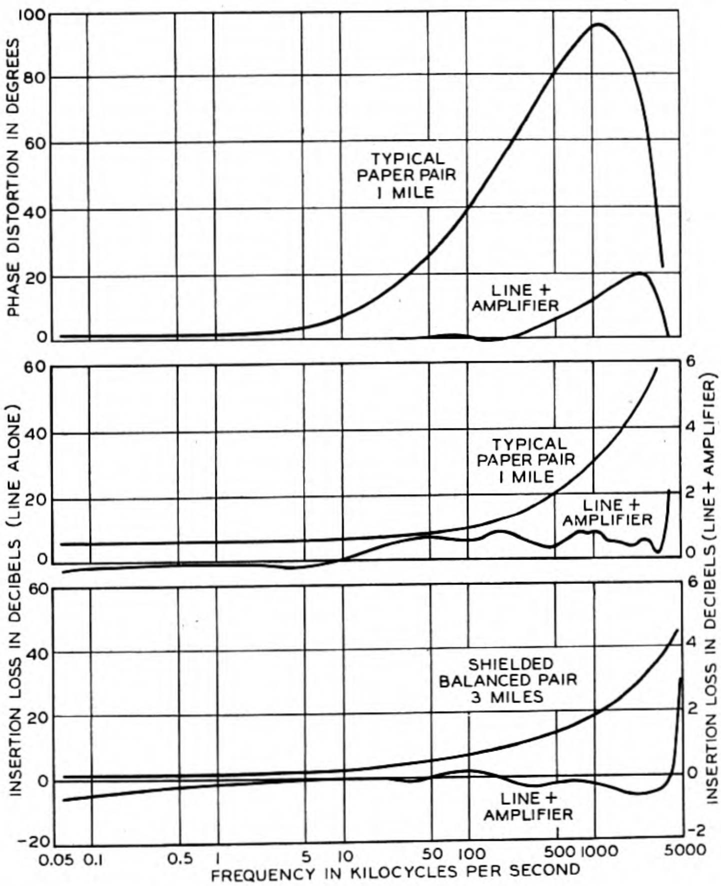

Fig. 14—Transmission characteristics of cables

Phase distortion characteristics of a typical cable circuit are also shown in Fig. 14. After the amplifiers and equalizers are added, the phase distortion is made substantially negligible.

Coaxial Cables

Coaxial cables may be used for video transmission for short distances but power or other low-frequency interference may introduce serious problems.

Coaxial units of the size discussed above have been used in a few cases a mile or so in length. Even for such distances, however, it has been found desirable to reduce the power interference by balancing it out. One method which we have used is shown in Fig. 15. This has given an improvement at power frequencies of the order of 50 db in certain cases.

Balanced Shielded Cables

The ideal type of transmission line for video signals combines the balance feature with low attenuation and a high-frequency shield. The distance over which such cables could be used appears to depend upon the perfection of balanced video amplifiers and the equalization, although power interference may also present difficulties. Such cables have been built using a pair of wires and a disc type of insulation analogous to the coaxial structure described above. Attenuation measurements on a 3-mile test length installed in New York City are shown in Fig. 14. This figure also shows the net result after amplifiers and equalizers were

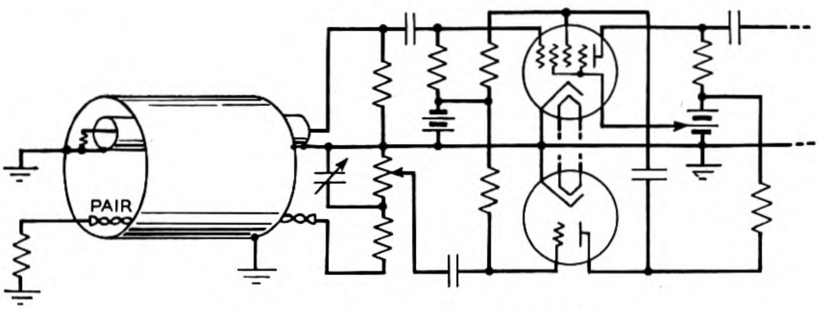

Fig. 15—60-Cycle balance on coaxial line

added. The attenuation of this special type of cable is such that amplifiers would be required at only about 5-mile intervals. The useful range of such a cable for video transmission has not been determined but in any case it should be considerably greater than that of the paper-insulated telephone cable circuit.

Experiment in Network Broadcasting

During the last week of June 1940, the proceedings of the Republican Convention in Philadelphia were broadcast in New York by television. The facilities used included the 3-megacycle coaxial system plus certain video connections at each end as shown in Fig. 16.

Because of the interest in this circuit and its good performance in transmitting 441-line television, the overall attenuation and delay characteristics are given on Fig. 17. It will be noticed that a net band of about $2\frac{3}{4}$ megacycles was transmitted and that over most of that band the delay distortion did not exceed ± 0.2 microsecond. The random noise, modulation and other distortions introduced by the wire line network appeared to be unimportant when viewed on a commercial television receiver.

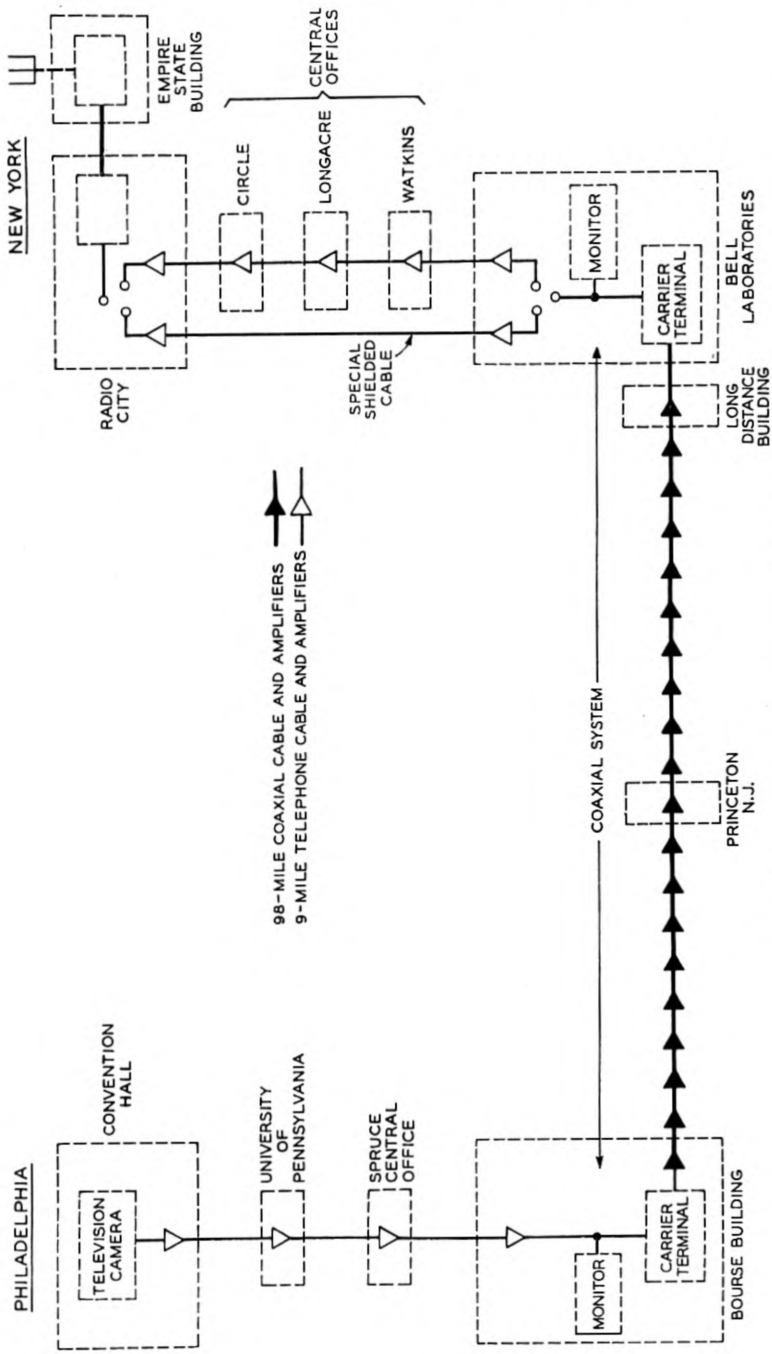

Fig. 16—Map of New York-Philadelphia network

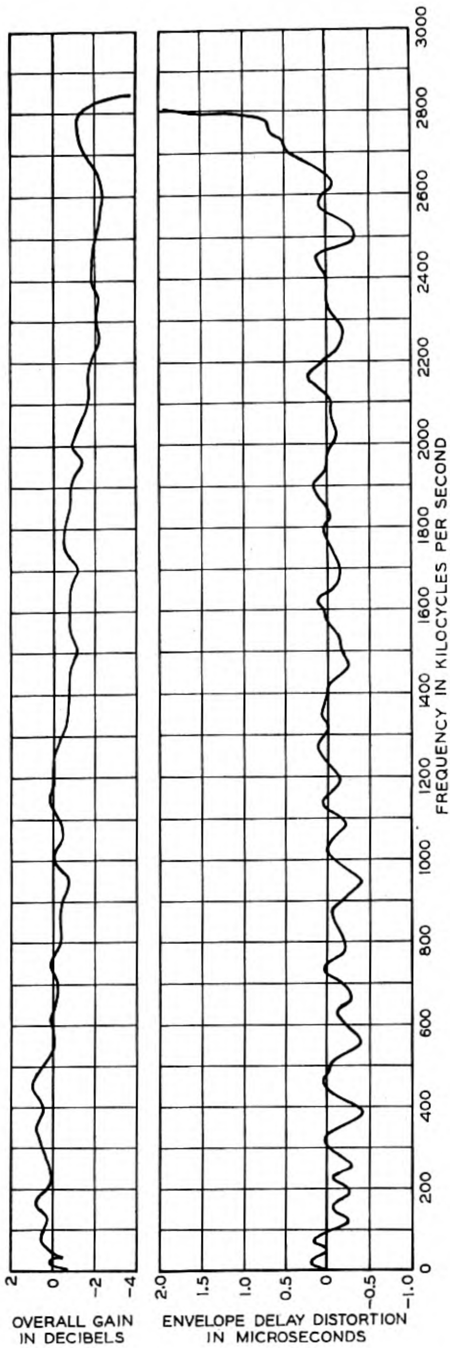

Fig. 17—Attenuation and delay—New York-Philadelphia network

Conclusion

The experiments so far made in the transmission of present-day television indicate that wire lines can be provided at least for moderate size intercity networks; also, that such lines if properly equalized for delay and attenuation do not materially alter or distort the transmission of present-day 441-line images, even though the frequency band is somewhat narrower than the nominal 4-mc band.

The use of ordinary telephone cables for local television connections also has been found to be feasible for all of the conditions so far tested. The $2\frac{3}{4}$ mc television transmission experiments over wire lines reported herein have proved very successful. Experiments with wider band coaxial systems are being undertaken.

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Insulation of Telephone Wire with Paper Pulp*

By J. S. LITTLE

A method has been developed for economically manufacturing insulated wire for telephone exchange area cable by making the paper on the wire. Further, this method has made it possible to increase the number of wires in a full sized cable by 175% over the number in use in 1914. Developments now under way indicate that suitable insulation can be made to replace certain textiles in some classes of wire and that the use of this process may therefore be still further extended in the not so distant future.

Introduction

IN 1887 the leading telephone engineers attempted to standardize telephone cables and specifications, finally deciding upon # 18 B & S gauge wire covered with two wrappings of cotton and twisted into pairs. A maximum cable size of 52 pairs in a two-inch diameter cable sheath 97% lead, 3% tin, and $\frac{1}{8}''$ thick was permitted under the specifications. The grounded capacity of such cable was 0.20 mf. per mile. In 1891 the Western Electric Company had made successful application of manila rope paper as insulating material for dry core cable and by drying this paper immediately before covering with lead by the newly developed extrusion process the core could be kept dry without the old impregnation with hot paraffin. A great improvement in electrical properties resulted from this change, the electrostatic capacity dropping to approximately one-half its former value. The use of manila paper made from old rope from this time on grew in use for insulating purposes (Fig. 1). The telephone demand was increasing all the time, and since the supply of old rope depended in a large measure on maritime sources of supply the price began to increase. Improvements in telephone instruments, together with increased demand for telephones, permitted the use with economy of more and more pairs of finer and finer wires in a given diameter of cable. This trend can be readily seen if we follow the change in maximum number of pairs used at different dates. In 1888—50 pairs of 18-gauge wire were used, 1896—180 pairs 19-gauge, 1912—909 pairs 22-gauge, 1914—1212 pairs 24-gauge, 1928—1818 pairs 26-gauge, and in 1939—1515 pairs 24-gauge and 2121 pairs 26-gauge (Fig. 2). The increasing number of wires demanded thinner and thinner and better and better paper. As the cable demand increased, increased insulating speeds were necessary to aid in keeping down the cost

* Reprinted, with minor changes, from *Wire and Wire Products*, October 1939.

due to the higher priced papers. Increased flexibility of paper without sacrificing strength and greater uniformity were required in these new thinner papers. Considerable time and money were spent in attempting to reduce the amount of manila fibre due to its price and increased scarcity and to substitute cheaper fibres of wood and cotton. It was finally found that mixtures of 45% rope, 40% wood and 15% cotton could be used for all

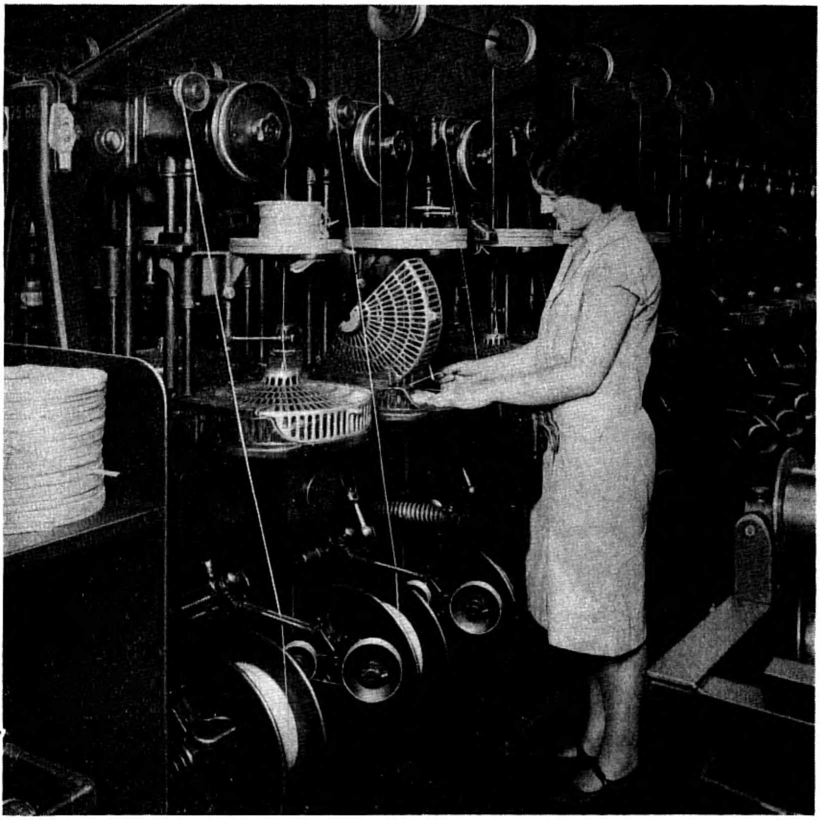

Fig. 1—Paper strip insulating machine

but the very finest insulating papers and that as high as 80% wood and 20% manila rope could be used for the coarser wrapping papers.

In spite of these changes and the improved paper making technique developed by the industry the use of paper $\frac{1}{4}''$ x .0025″ for insulating 26-gauge wire was not entirely satisfactory from a manufacturing point of view. About 1920 some of our engineers began developing the idea of manufacturing the paper right on the wire. If this were possible there seemed to be no reason electrically why wood pulp would not make a suitable insulating material, and from the mechanical standpoint many of the difficulties involved in wrapping the insulation would be eliminated.

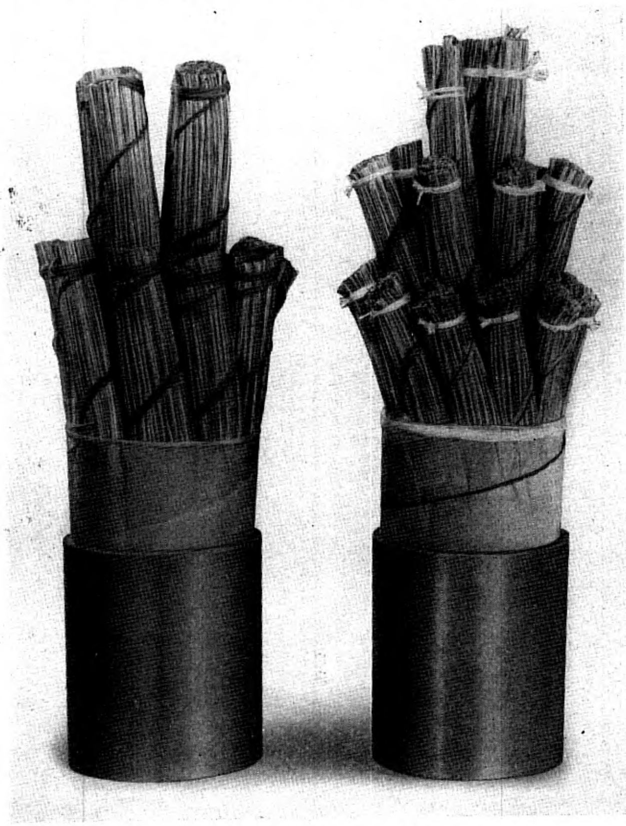

Fig. 2—Comparison of 1212 (left) and 2121 (right) pair cables

The Development of Pulp Insulation

Pulp Machine

The first crude experiments on insulating wire with pulp were done by pouring a suspension of pulp over a wire backed up by a fine mesh screen and after the water was drained away lifting the wire up together with whatever fibers clung to it and then rolling the wire on a flat surface. These samples gave an idea of the type of product to be expected and looked so interesting that a study of equipment and methods was authorized. It developed that the machine most adaptable for our purpose was the standard single cylinder paper machine in use in the paper making industry.

The essentials of this machine are a vat for holding a thin pulp suspension and a hollow cylinder covered with fine mesh screen immersed in the vat. Suitable dams at the ends prevent the pulp suspension passing into the interior of the cylinder. As this cylinder rotates on its axis the water flows through the screen and deposits pulp on its surface. This pulp mat is then picked up by an endless felt belt which is brought into contact with the surface of the cylinder by means of a soft rubber roll which presses it firmly against the pulp mat on the surface of the cylinder. The pulp mat adheres

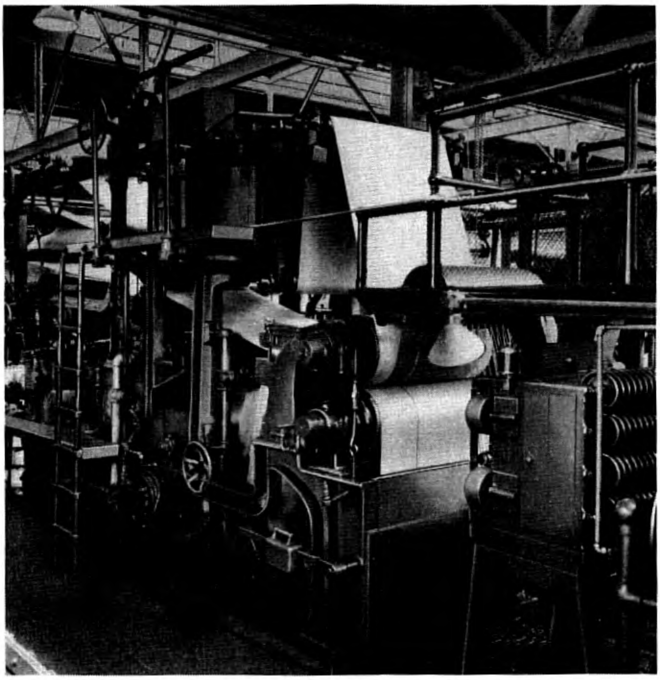

Fig. 3—Forming end of pulp insulating machine

to the felt and together they travel over suction rolls and through squeeze rolls where the excess water is removed. The fibers are thus firmly pressed together so that a sheet of wet paper is formed. After drying and calendering the paper appears in its usual form.

The idea of embedding a wire in the sheet as the pulp was deposited on the cylinder formed the basis of the present development. Usually the paper machines produce a continuous sheet eight or nine feet wide so that it became necessary to devise ways and means of producing sheets only about one quarter inch wide to supply the necessary material for insulating

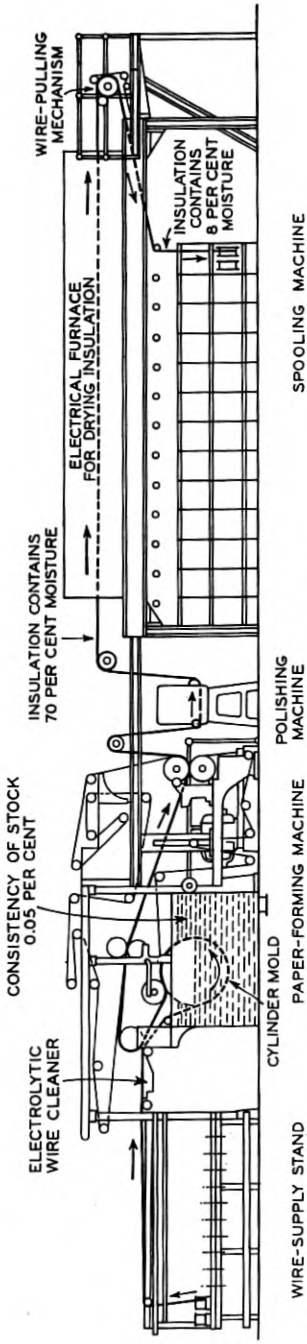

Fig. 4—Schematic of pulp process

wires of 22-gauge and smaller. The most practical size of commercial machine (Fig. 3) was no less than three feet wide but by painting annular rings on the cylinder screen surface the effect of a series of small cylinders all immersed in a single vat could be produced. This was the scheme finally adopted for preparing the paper making machine and we have standardized on a cylinder three feet long with enough rings to simultaneously produce sixty sheets of paper approximately $\frac{1}{4}''$ in width. The layout of the resultant machine is shown schematically in Fig. 4.

Pulp Supply

Kraft pulp is among the toughest of the wood fibers as well as one of the cheapest. It is prepared by an alkaline process and our experience indicated that this process produced pulp of a greater degree of permanence than the acid processes unless special treatments were used. The chief drawback to its use was its color, brown or tan, which necessitated a change in the color code in the cables. Fortunately, cable designs could be made using fewer colors than had previously been employed so that this obstacle was not serious. Standard paper making beating equipment was purchased and used for preparing the pulp to form the sheets although special beating technique for our purpose had to be developed. The older beating method consists of grinding the fibers in the presence of water under a heavy roll. By this continuous maceration the pulp is softened and fibrilated and made suitable for paper making. The longer the grinding the more parchmentlike the final paper becomes, and as we desire as porous a paper as possible it is necessary to control the beating to a point where good strong paper will be made but will still contain a high degree of porosity. Within the last few years a continuous beating system has been developed to replace the original batch system. In this method the pulp mixed with water is run through a preliminary hydrofiner grinder where the pulp is partially beaten before being stored in a large tank. From this tank it is then fed to the various machines and colored by adding the proper dye. A further refiner in the line to each machine finishes the beating for the particular insulation being made in that position. Study showed that fiber from different sources of wood supply handled differently so that standardization of sources of supply had to be made and methods of test developed to check on new fibers or new sources of pulp.

Due to the small thin sheets made on the machine, the amount of pulp required per unit of time is extremely small. No commercial means of measuring such quantities accurately had been developed and it was necessary to spend considerable time in this study. The suspension of pulp to be measured contains only 1.5% fiber and this is further diluted to .05% in the machine vat. The actual quantity of liquid measured is about 8 gallons per minute. The device most recently adopted is similar to the jaws of a pair of pliers held between two stationary guides. As the jaws are separated more liquid flows through them and as they are closed the flow is cut down. A vernier scale adjustment makes close and accurate settings possible when used with a constant head. In the older system the dye for coloring the pulp is added in the beater but the newer system more recently put to use in the Kearny, New Jersey Plant supplies the dye as needed so that only uncolored pulp need be stored in tanks and color changes can be rapidly made with little loss of stock.

Wire Supply

A machine of this size and difficulty of control necessitated a continuous supply of wire to avoid large losses in junk and lost time. It was necessary to devise methods of continuous feed, and to do this wire supplied on spools was utilized. On the earliest machines spools 8″ x 8″, containing sixty pounds of bare copper wire, were used, the wire being removed over the head of the spool by means of a flier. At each supply position two spools were placed side by side and a flier placed on one. When the first spool was emptied to the last few turns, an operator, by means of a special hook, pulled out one turn and brazed it to the outer end of the other spool. A flier was then placed on the second spool, and when the braze was reached the transfer to the new spool took place.

Using the new 400-pound spools from the new Kearny Wire Mill, a larger supply space is needed (Fig. 5), and the two spools per position are set opposite one another instead of side by side. The inner end of wire on these spools is brought out and coiled in the head of the spool so that the two spools can be brazed at any time the operator wishes and the wire will be completely used from each spool. Either a stationary flat ring or a rotating type flier can be used for removing the wire. The latter type has certain operating advantages which at present warrant its introduction and use, although the flat disc has so far been used. With the disc type take-off, a tensioning device consisting of a system of three small rollers is used. One roller can be varied in size and as the three come together the slip between them supplies the tension. With the flier type take-off, a tension device is not essential.

Wire Cleaning

In our early efforts to make insulated wire by this process very erratic results were obtained in the continuity of the insulation. It was finally found that small traces of drawing compound left on the wire made it difficult for the wet pulp to adhere to it during the subsequent polishing operations. Therefore, it became necessary to clean all the wire. Con-

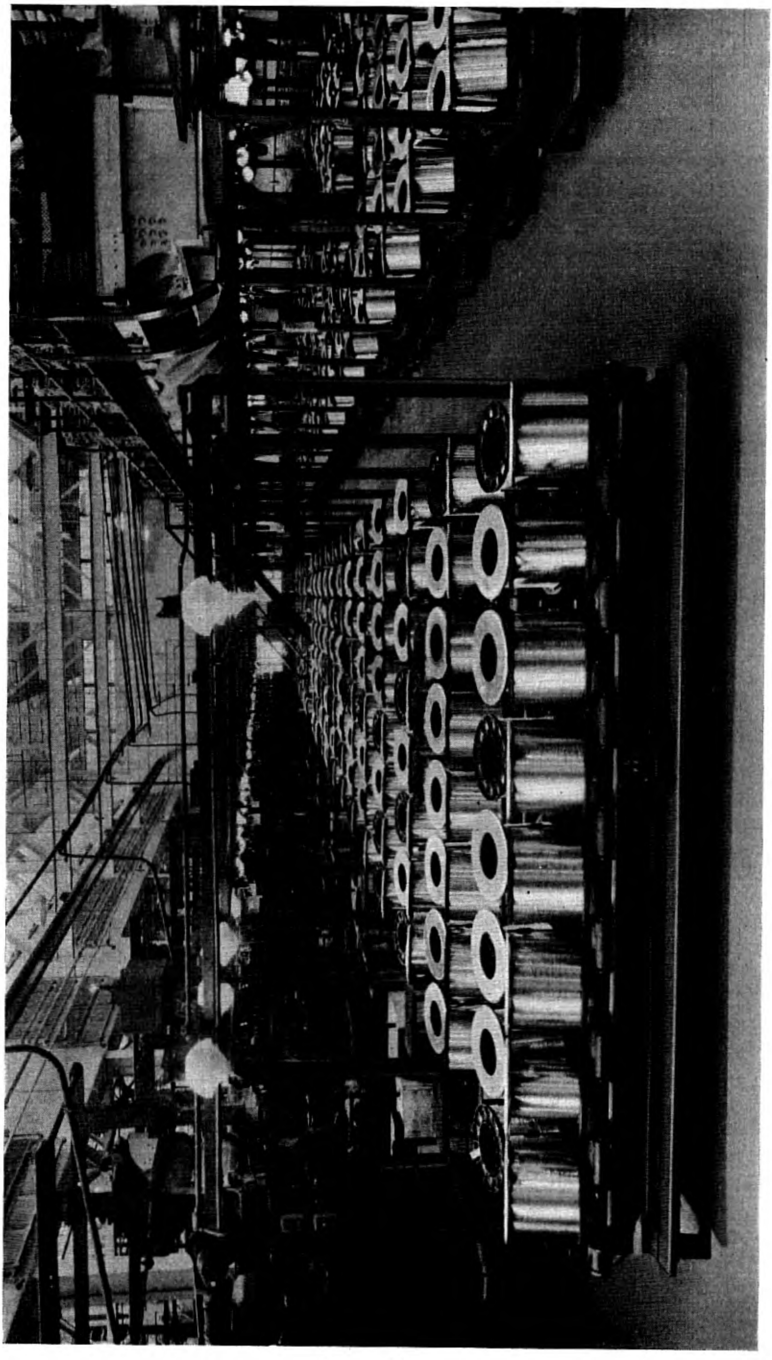

Fig. 5—General view of wire supply

siderable difficulties in designing a suitable cleaner were experienced, but ultimately the use of alternating current together with an alkaline cleaning bath, was found most suitable. The wire passing to the machine comes in contact with the surface of a cleaning solution for a short distance. Electrical contact with the wire is made through guide rolls and the current flows from the wire through the solution to the container. Originally a mixture of cyanides was used as the cleansing agent and the current flow was held to about 8 amperes per square inch surface at 12 volts. Recently a more effective non-poisonous cleansing agent has been developed by using sodium ortho silicate and ivory soap. The passage of the current in either case heats the solution and liberates a rather violent evolution of gas at the surface of the wire. With the soap solution a foam is built up which is continually floated off, carrying the grease, copper, dust, etc. to the sewer. This method keeps the cleaner from concentrating the dirt and consequently eliminates frequent cleaning both of the cleaner and the screen on the cylinder which formerly used to get plugged up with particles of grease carried over from the cleaner by the wire.

Embedding the Wire in the Pulp

From the cleaner the wire is guided into the cylinder machine. It is extremely important at this point that the wire be guided into the center of the small sheets and at such a point on the periphery of the drum that some pulp is deposited below and some over the wire. After passing around the cylinder the wire travels along with the felt and pulp through the presses and finally emerges at the last press embedded in a small sheet of wet paper (Fig. 6). It was found that poor pick-up of the fibers often occurred unless the surface tension of the water was lowered by some means. Ordinary soap is used for this purpose. Approximately ten pounds per thousand pounds of pulp are dissolved in the storage tanks to give effective results and to smooth out the pick-up to give a high degree of uniformity to the weight of pulp per unit length of wire.

Polishing

Polishing of the insulation on the wire is brought about by passing the wire and pulp sheet over polishing blocks which are rotated rapidly around the wire as an axis. Three blocks are used and are so placed that the wire is slightly deflected from its course as it passes first over one block, then the second and finally the last (Fig. 7). The rapid rotation of the polishing head produces a light rubbing action on the sheet which is rolled down without tearing and results in a good round smooth wrapping of wet paper about the wire. With the wire running at a linear speed of 130 feet per minute the polishers are rotated at 5000 r.p.m. to give satisfactory insulation.

Drying of the Insulation

The method of drying the insulation is very important. In the early experiments low-temperature air drying, high-temperature air drying and finally moderate-temperature-controlled humidity drying were studied.

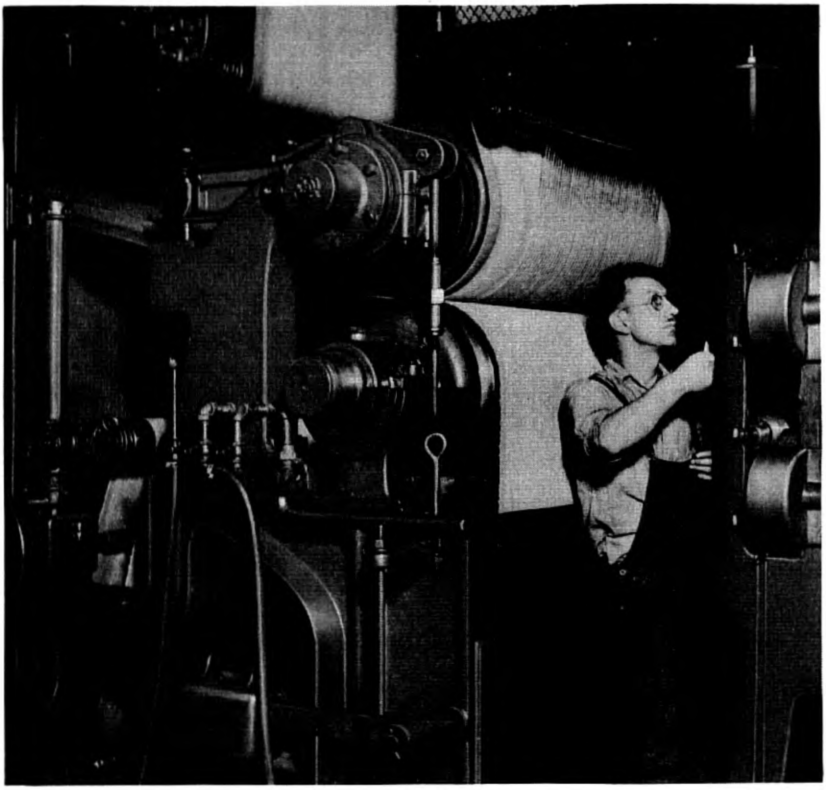

Fig. 6—Wire and pulp from presses

A temperature of about 180°F. and 20% humidity was finally adopted. For a number of years this method was used for experimental cables but it was impossible to get electrostatic capacities below .095 mf. per mi. With such values it appeared that the use of pulp would be strictly limited to certain sizes of wire and certain cables. Study indicated that lack of porosity and close adhesion of the pulp to the wire were large factors in this difficulty and steps were taken to determine what could be done to improve these values. It was found that by drying the wire at very high speeds by passing it rapidly through high temperatures, the natural shrinkage of the pulp could be greatly reduced and that increased porosity could be obtained. Results on capacitance from such wire were markedly better, and so high-temperature radiant-heat drying was introduced into the process. In this method a box type electric furnace with a heating chamber approximately 26 feet long, 3 feet wide and 8 inches high is used. The wire passes through

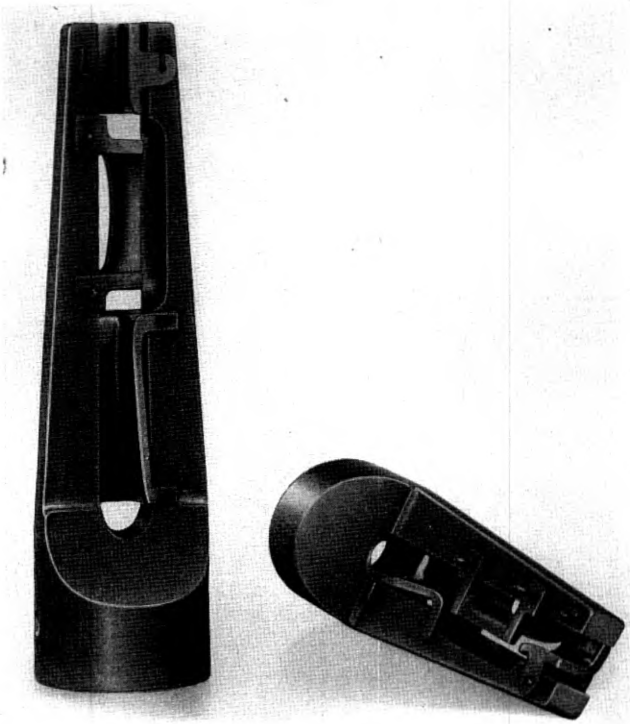

Fig. 7—Individual polisher

this furnace horizontally. In the first third of the furnace 1500°F. is maintained, 1200°F. in the second third, and 800°F. in the last third. The water is literally exploded out of the pulp in this process and leaves a soft porous insulation which is easily stripped from the wire. Electrostatic capacitance values of about .072 mf. per mi. on 24-gauge cables are obtained with this method of drying and improved centering of the wire and roundness of insulation. These values are practically the same as those obtained with wrapped paper. At wire insulating speeds of 140 feet per minute the insulation is dried in approximately 11 seconds. Since in case of a shutdown the wire is immediately burned off, a band of nichrome tape is kept in the furnace at all times so that the wires can be tied to it and carried through for restringing. Broken wires are strung in by tying them to adjacent wires to be carried through.

Reeling up the Finished Wire

Because it is necessary to shift from full to empty spools without shutting down the machine, dual take-up positions are supplied just as dual feed

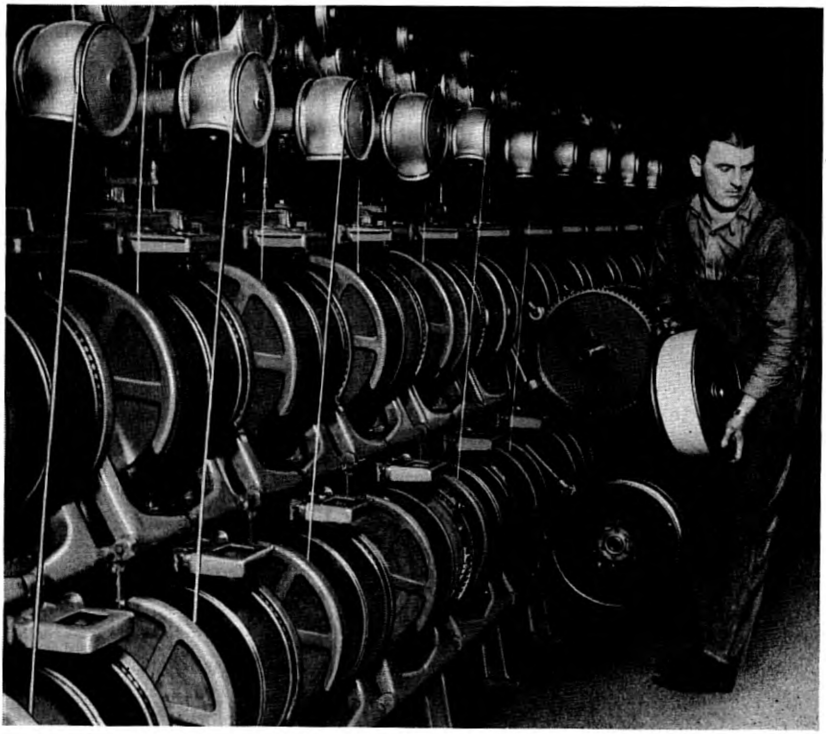

Fig. 8—Insulated wire take-up

positions are used. The take-up spools are rotated through a slipping disc clutch, the pressure on the clutch being controlled by the tension in the wire. Before reaching the take-up spool the wire is passed over a tension drum made up of two capstan pulleys separated by a movable housing enclosing and fastened to a coiled clock spring. By running the wire first around one pulley then reversing it by passing it around a pulley on the spring housing and then around the second capstan pulley any tension variation in the wire causes the spring housing to rotate. The rotation of this housing is communicated by a system of rods to the clutch so that it tends to speed up or reduce the speed of the take-up spool. With the long coiled spring wound to a definite tension a predetermined pull on the wire can be maintained. Two spools are driven simultaneously side by side through suitable gears. Each spool, however, is held on a separate arbor which can be pulled out of mesh with the driving gear so that the take-up spool can be stopped and removed. When it is desirable to do this the wire being taken up is simply switched over to the other spool and when a few turns have been taken up the wire between the spools is cut so that the first spool can be removed from the machine (Fig. 8). Sixty spools are run at one time at an average speed of 140 feet per minute or a total wire footage of 8400 feet per minute of running time. Improved beating, better pulp, better cleaning and improved drying and polishing as well as better trained employees in the last few years have greatly improved the product over the original and simplified the control of the process.

Types of Wire Insulated

As mentioned in the first few paragraphs the trend in telephone cable construction has been toward finer and finer wire. The insulating equipment and process described are particularly well adapted to apply coatings of pulp from six to ten mils in thickness to gauges of wire between 19 and 30-gauge. Changes in the mechanical equipment would be necessary for handling wire finer than 30-gauge or wire heavier than 19-gauge. As little demand for these gauges exists in exchange area telephone circuits, no attempt has been made to adapt the machine to these sizes. However, use of the process can be extended quite widely both in the type of materials used for insulating and kind of wire covered, if demand for such extension exists. So far the development of this insulation process has made it possible to produce wires with insulations so thin that 1515-pair cables of 24-gauge wire and 2121-pair cables of 26-gauge wire are now commercially available to the telephone companies with no increase in external diameter of the lead sheath now used. More effective use of existing underground ducts can therefore be made, eliminating possible large expenditures by the telephone companies for such facilities.

Design and Operation of New Copper Wire Drawing Plant*

A new wire mill for the drawing of copper wire is described. The speeds attained are close to the theoretical limit set by the breaking strength of the wire under the centrifugal stress of winding. The No. 1 machine which draws from rod down to No. 16 A.W.G. and has 10 dies operates at 6000 ft. a minute. The No. 2 machine redraws to finished sizes of No. 19 A.W.G. down to No. 30, possesses 12 dies, and operates at 10,000 to 12,000 ft. a minute. With the single installation at the Western Electric Company at Kearny, N. J., over 2,500,000 pounds of annealed wire are now delivered monthly to the insulating machines for processing into lead covered cable. Part I deals with the design of the machines; Part II with the wire mill installation and operation.

PART I—DESIGN AND OPERATION OF HIGH SPEED COPPER WIRE DRAWING MACHINES

By H. BLOUNT

Introduction

COPPER wire is used extensively in the making of facilities for communication purposes, the Bell Telephone System alone now using over 40 billion conductor feet per year. It is essential that this wire be of high quality with deviations in diameter kept to the minimum so that the apparatus with which it is to be used will function properly.

A study made some years ago showed it would be economical for Western Electric to manufacture its wire, with the possibility of greater production by increasing the speed of drawing. The equipment provided at that time operated at speeds much higher than were then in general use.

A few years later it became evident that the speeds selected were far from the ultimate at which wire could be drawn, and another development was started to determine a practical and economical speed, resulting in the design, construction, and placing into operation of two sizes of wire drawing machines. One, which will draw rod to sizes as small as No. 16 A.W.G., is called the No. 1 and is of 10 die capacity, designed to operate at 6000 ft. per minute. Figures 1, 2, and 3 show the front and rear views of this machine. A second machine for redrawing to finished sizes No. 19 A.W.G., and smaller, is called the No. 2, and is of 12 die capacity, designed to operate at 10,000 and 12,000 ft. per minute. Figure 4 shows the front

* Reprinted, with minor changes, from *Wire and Wire Products*, October 1940. This paper was presented at the Wire Association Convention in Cleveland, Ohio, October 24, 1940, receiving Honorable Mention in Recognition of its Contribution to the Research Literature of the Wire Industry during the Year 1940.

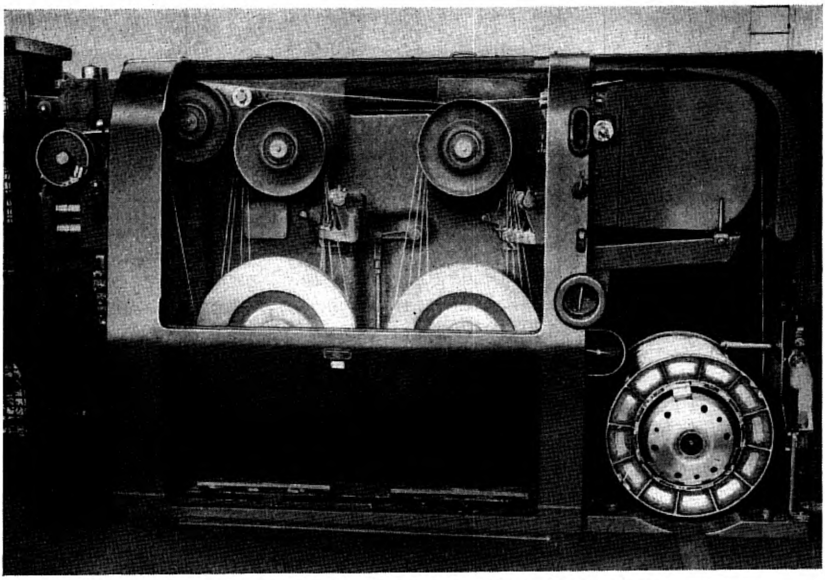

Fig. 1—No. 1 wire drawing machine—front view

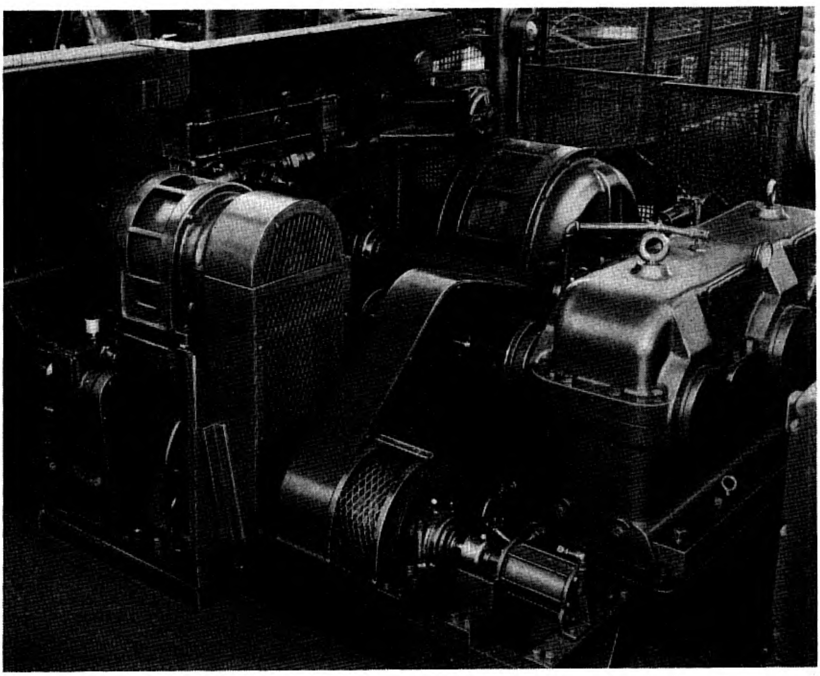

Fig. 2—No. 1 wire drawing machine—rear view

view of this machine. The design features outlined in the following text deal largely with the No. 2 Machine. Similar features are incorporated in the No. 1 Machines and reference is made to changes in design applicable only to that machine.

The Problem

Continuity of operation is essential to higher drawing speeds; therefore, wire should be delivered in as large a unit package as practicable to secure

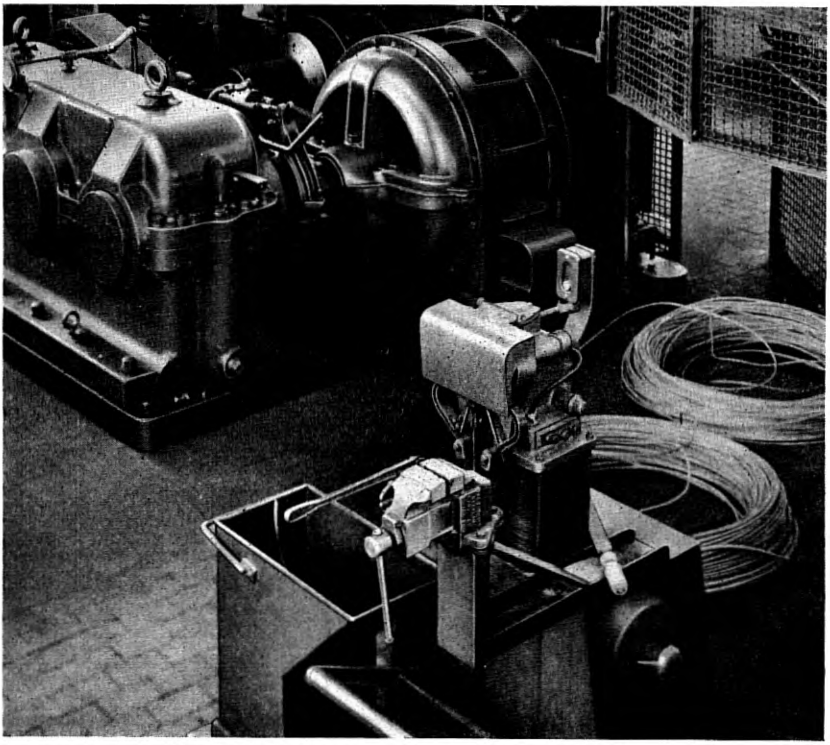

Fig. 3—No. 1 wire drawing machine—rear view

this continuity with a minimum of scrap at the subsequent operations. A survey of the wire using equipment showed that reels as large as 18″ diameter could be used with a capacity of 400 lbs. of wire. This requires that a suitable drive be introduced on the reel takeups of the wire drawing machines to allow for gradual deceleration of speed as the reels fill up with wire.

The drive for the takeup reel should be capable of producing a uniform tension in the wire as taken up for its entire length on the reel. This tension must be controllable for the different sizes of wire, in order that after being annealed it can be easily removed at the subsequent operation.

The application of torque motors on several installations at Western Electric to secure uniform tension in the product being taken upon a reel had demonstrated this to be a very satisfactory form of takeup drive, as the motor will slow down with build up of wire on the reel without changing

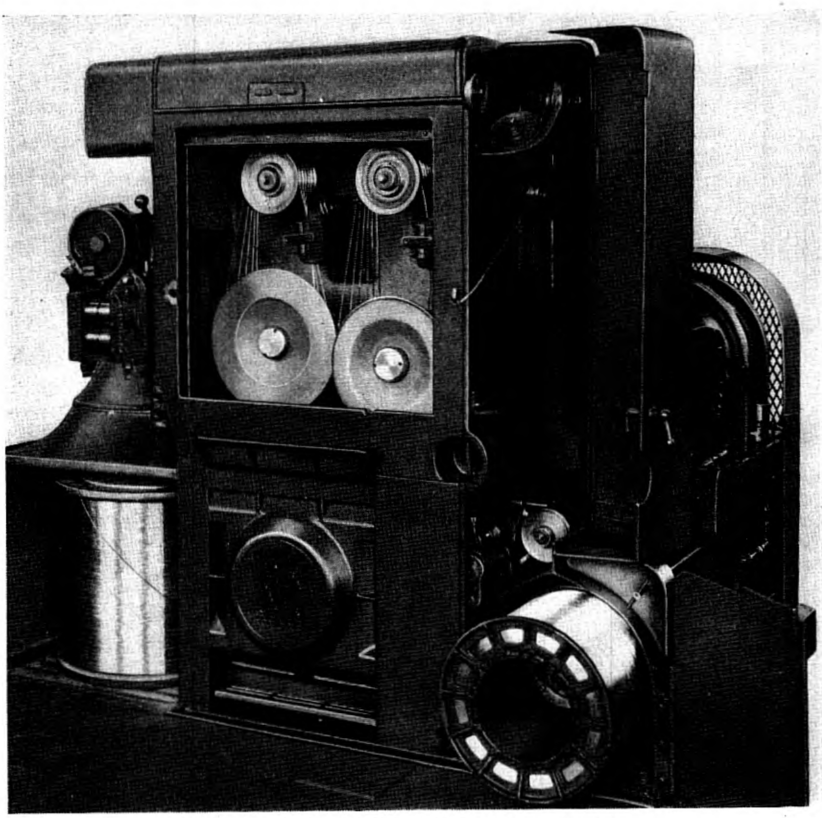

Fig. 4—No. 2 wire drawing machine—front view

the wire tension to any appreciable extent. By changing the stator voltage of this type of motor, the torque can be regulated to give tension suitable for drawing the various sizes of wire within the capacity of the machine. By a proper selection of motors, variations in speed, without undue heating, can be obtained with a ratio of 1–1.8, which is of sufficient range to permit the use of reels of 400 lb. capacity.

The next step was to determine the maximum speed at which wire might be drawn and the speed at which it could be wound onto a reel. The maximum drawing speed was considered to be that speed where the stress set up by centrifugal force would equal the safe stress for copper of 25,000 lbs. per sq. in. A maximum drawing speed of 27,400 ft. per minute was determined by the following calculations:

Let W = Weight of drawn copper wire per cu. in. in lbs. = .3212 (A.I.E.E.)

V = Speed of wire in feet per second.

G = Acceleration due to gravity.

1. Stress in Wire due to Centrifugal Forces = S

$$S = \frac{12 \times W \times V^2}{G} = \frac{12 \times .3212 \times V^2}{32.2} = .1197\ V^2$$

2. Maximum Wire Speed Considering Only Stress Due to Centrifugal Force. The speed at which S would produce a stress of 25,000 lbs. per sq. in.

$$V = \sqrt{\frac{25000}{.1197}} = 456 \text{ f.p.s. or } 27400 \text{ f.p.m.}$$

With the possibility of a range of speed of 1 to 1.8, the stress set up in the reel rim at a wire speed of 27,400 f.p.m. would equal 62,000 lbs. per square inch when the wire is being taken up on the core of the reel, and the rim running 80% faster. Since this speed and resulting stress are above the safe limit for low carbon steel, a speed of 12,000 f.p.m. was selected which provided a factor of safety of approximately five to one. The stresses set up in the wire and reel rims for the various speeds are shown on diagram, Fig. 5.

The horsepower requirement of the torque motor for the takeup is made up of three components:

1. Tension in Wire
2. Bearing Friction for Takeup
3. Reel Windage.

Wire should be taken up on the reel under sufficient tension to offset that created by centrifugal force. The tension in the wire resulting from centrifugal force is shown on diagram, Fig. 6, and is determined by taking the stress in copper wire at 12,000 ft. per minute, Fig. 5, and multiplying this by the area of each size of wire. The tension in the wire changes for each size of wire and remains practically constant throughout the entire reel; therefore, the horsepower required to take up wire on the reel remains constant from the core to the outside of the reels, the speed of the reel slowing down with the build-up of wire on the reel. The lower curves on diagram, Fig. 7, show the horsepower requirements for taking up wire of different sizes.

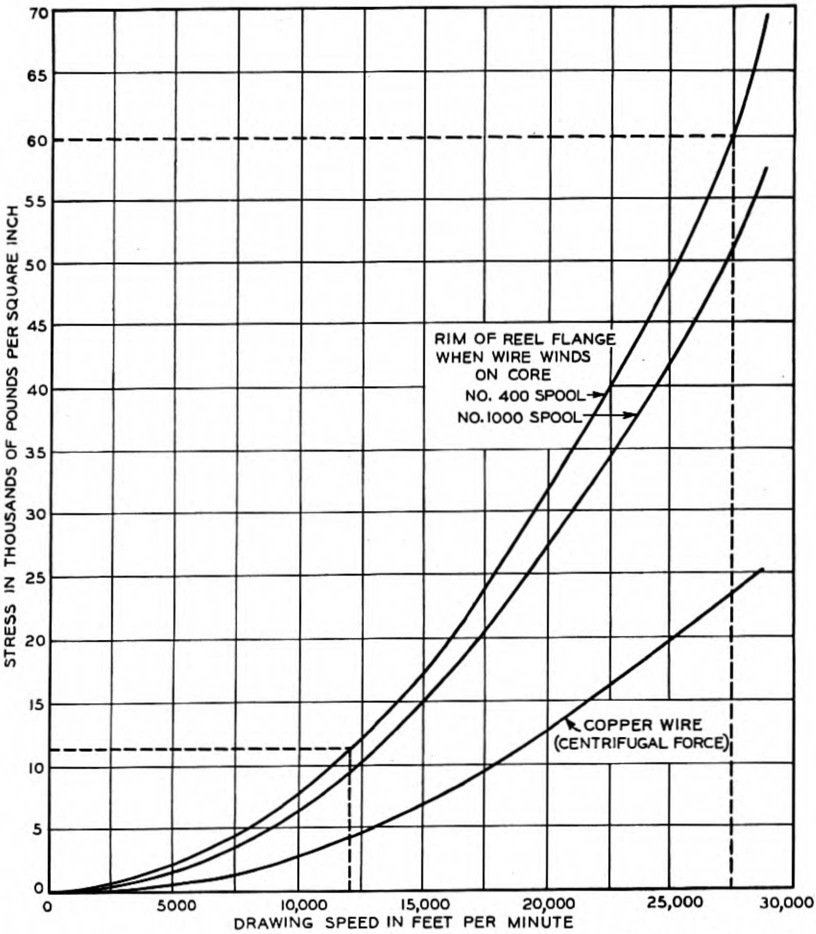

Fig. 5—Stresses produced in wire and takeup reel at various wire drawing speeds

Power Requirement

The horsepower required to overcome bearing friction was calculated and is constant for all sizes of wire. The windage is governed by the design of the reel and the horsepower was determined by test for the minimum and maximum reel speeds. The data for these components are shown by the upper curves of diagram, Fig. 7.

The constant horsepower requirement for uniform tension when converted into torque shows that the torque increases as the wire on the reel builds up due to the lengthening of the radius arm.

The decreasing horsepower requirement to overcome windage and friction when converted into torque shows that the torque decreases with this build-up of wire due to the slowing down of the reel when using a uniform

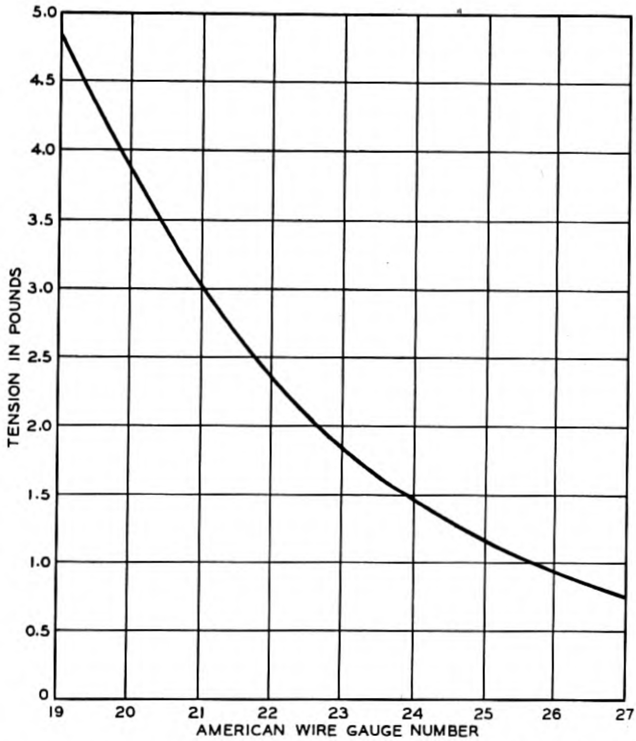

Fig. 6—Tension in wire due to stress set up at wire speed of 12,000 F.P.M.

speed of drawing. This decrease will be at a faster rate than the increase resulting from tension.

The calculated torques when plotted for the different sizes of wire within the scope of the machine show curves gradually diverging as the reel decreases in speed. To simplify the electrical control it was found these curves could be made parallel and still be within the allowable variation of wire tension and the required tolerances of the supplier of the electrical equipment. It was decided to select as the base curve that condition which would be most favorable to the making of the smallest size of wire and to use the average torque value from an empty to a full reel for the different tension requirements for the other curves. Therefore the composite curves as shown by diagram, Fig. 8, show the result of this compromise.

The curves showing the results of the test run of the takeup motors are shown by Fig. 9, which demonstrates how closely the motor manufacturer met the requirements of Fig. 8, which are superimposed for reference.

The minimum of slip between the wire and capstans has been incorporated

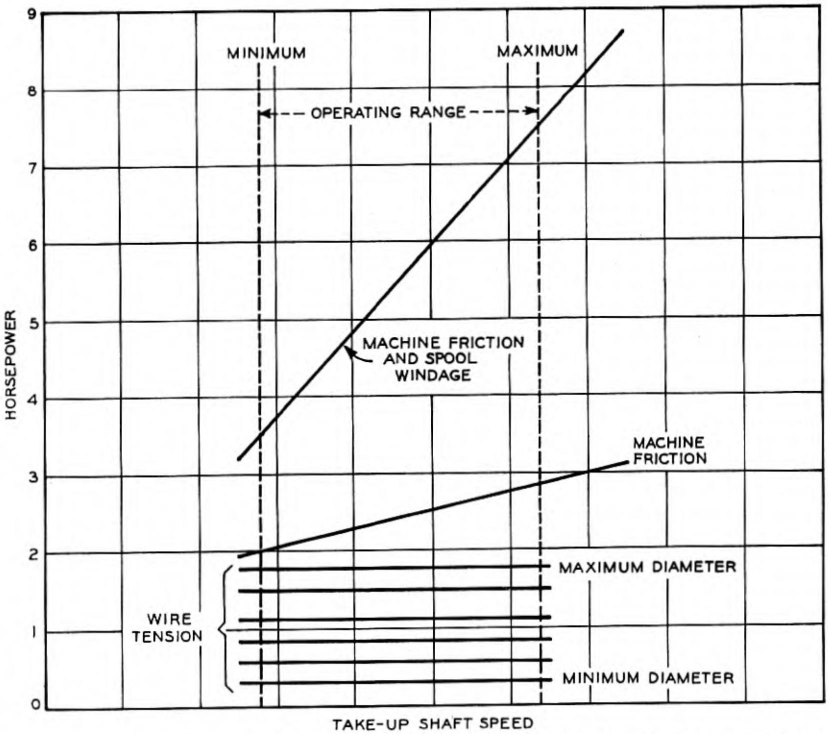

Fig. 7—Power requirements for torque motor for takeup of wire sizes No. 19 A.W.G. and smaller to secure uniform tension

into the design to secure the greatest economy of power. Each reduction of one size A.W.G. increases the length by 26%; and a ratio of 23% between each capstan step has been found most economical. To further reduce power required, ratios of 25% have been used, but because of the uneven wear of diamonds this ratio is disturbed and excessive breaks occur at the location where the die has worn the fastest. With the ratio of 25%, dies must be kept more evenly matched for reduction in area, and the expense of rematching dies, and the loss of production during the period of rematching, make this expense greater than the power charge with the 2% greater slip.

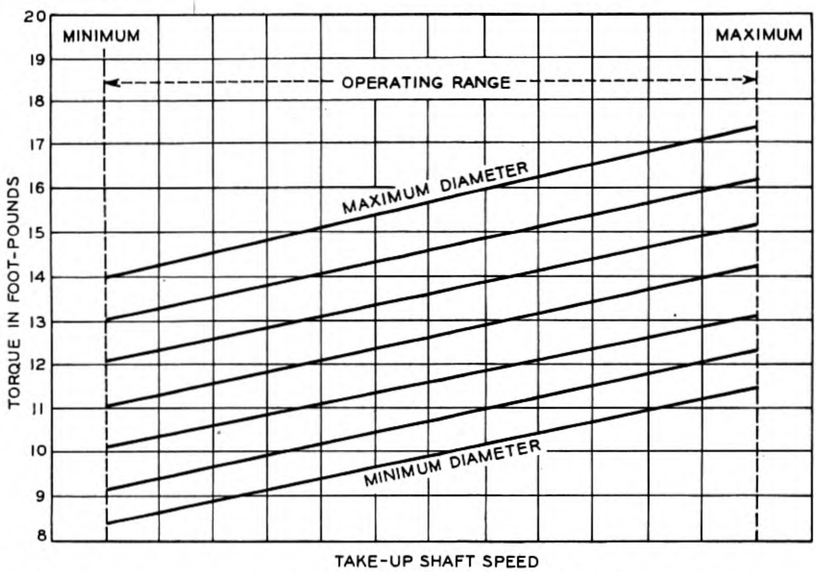

Fig. 8—Torque requirements of takeup motor with tension, friction and windage combined for wire sizes No. 19 A.W.G. and smaller

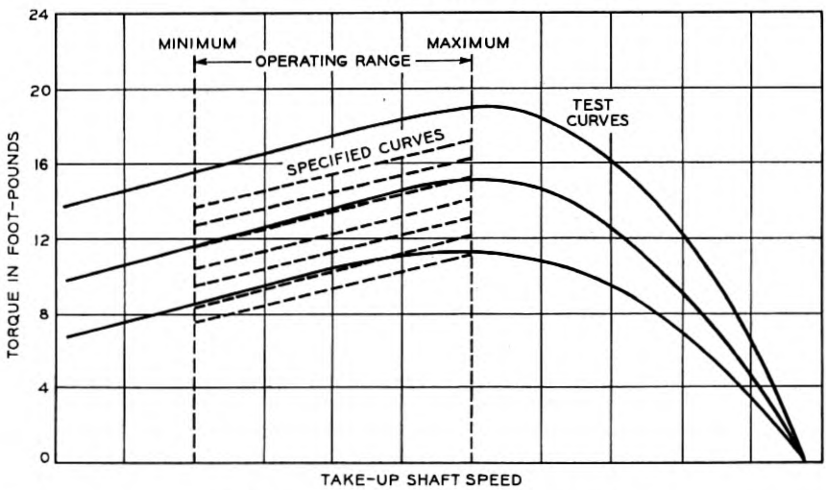

Fig. 9—Speed torque curves for takeup motor

Inasmuch as it is economical to maintain dies within definite ratios of reduction of area, by the same token it is also necessary to keep the diameter of the capstan steps within like proportion.

The die pulls and power required to draw copper wire of any size are determined by referring to the chart, Figs. 10 and 11, applicable for Tungsten Carbide and Diamond Dies respectively.

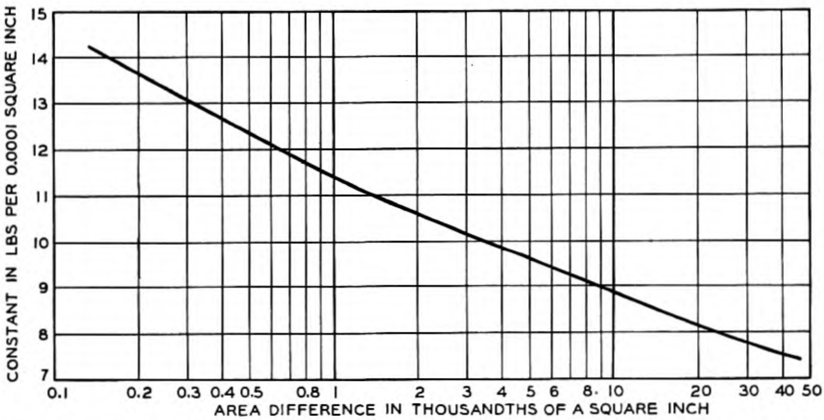

Fig. 10—Constants for determination of die pulls for tungsten carbide dies drawing copper

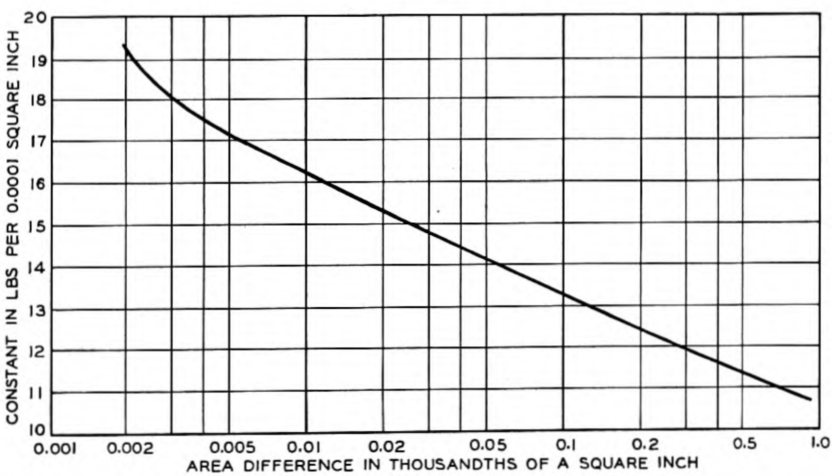

Fig. 11—Constants for determination of die pulls for diamond dies drawing copper

In using these charts the diameters of wire being drawn from and to are selected. The difference in areas represented by these diameters is determined, the curve is then chosen in the range of this difference, and by reading up from this difference to the proper range curve, the constant can be determined per .0001 sq. in. area reduction, which, when multiplied by the difference in area, will give the total pounds pull required to draw to the size selected.

Capstan diameters are determined to secure minimum slip, and from the die diameters selected the pull through the dies is calculated. The horsepower for the main motor is determined from these die pulls and capstan speeds, to which is added machine and motor losses.

As the drawing machine is required to start up and accelerate under full load, a high torque squirrel cage induction motor was selected. This type

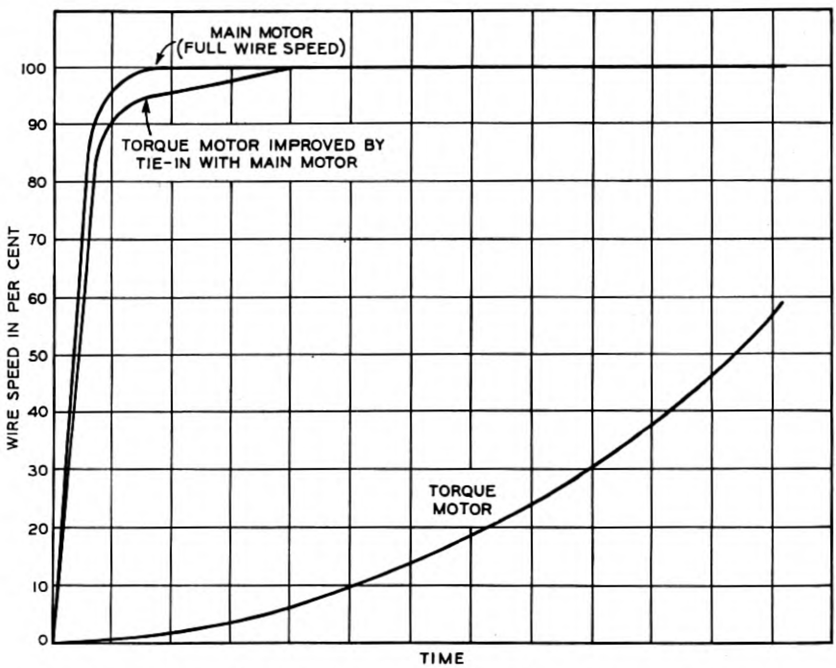

Fig. 12—Relative acceleration curves of main and takeup motors

of motor accelerates to full speed very rapidly, whereas the acceleration of the torque motor for the takeup is very much extended and would therefore result in very high slip between the wire and capstan. It was therefore necessary to introduce some auxiliary means to assist the torque motor to come up to speed. This has been effectively accomplished through the introduction of a magnetic clutch for coupling together the main and takeup motors during the starting period. This clutch is energized as soon as the starting button is operated and before the contactors for the main motor make contact. A time relay releases the magnetic clutch as soon as the main motor is up to speed. During this acceleration period on the No. 2 Machines a slip of 5% between wire and capstan occurs when the capstans are new, and no slip when the capstans are reduced to the minimum diameter. Curves showing the relative acceleration between main and takeup motors are shown on diagram, Fig. 12, which also represents the improvement of acceleration by the tie-in. An electric time clock is connected into the motor circuit for stopping the machine when the 400 lb. reel is full, a time setting being made for each size of wire. On the No. 1 Machine the takeup is accelerated by the magnetic clutch to full reel speed of the 1000 lb. reel and the contact made by the time clock re-energizes the clutch so that the takeup will slow down in synchronism with the main motor.

An under current relay is also interposed in the motor circuit to stop the machine should a break occur while drawing.

Lubrication

Introduction of oil lubrication introduced difficulties in securing effective sealing against oil leakage. It has been our experience that commercial seals are effective when used on shafts revolving at surface speeds below 1200 f.p.m., but above this speed they were inadequate. For the capstan bearings the seals have to be effective in both directions to prevent the leakage of mineral oil from the bearings into the wire drawing compound, and also to prevent the wire drawing compound from mixing with the lubricating oil. This has been accomplished very effectively by the use of multiple slingers, the design of which is shown by Fig. 13. The two front slingers throw off the compound which drains back into the compound system and the two rear slingers do the same with the oil. There is no friction and corresponding wear between surfaces and only occasionally can small drops of compound be seen in the drain reservoir, which shows the effectiveness of this type of seal. As an extra precaution against contamination of oil with wire drawing compound, only a small amount of oil is permitted to flow to the capstan bearings, sufficient for adequate lubrication. This is drained to a reservoir and clarified before re-use.

Another form of seal is shown by Fig. 14. This is used at the takeup arbor where oil was driven through any commercial gasket material by centrifugal force. The oil was thrown out into the inside of the reels and caused discoloration during the annealing. This has been effectively sealed by making a ring of dead soft copper wire carefully joined. The end cap is bevelled to force the ring to the inside of the arbor and against the edge of the bearing, making a tight three-point contact. These rings are never used more than once.

Reels:—The reels are provided with a magazine on the outside of the

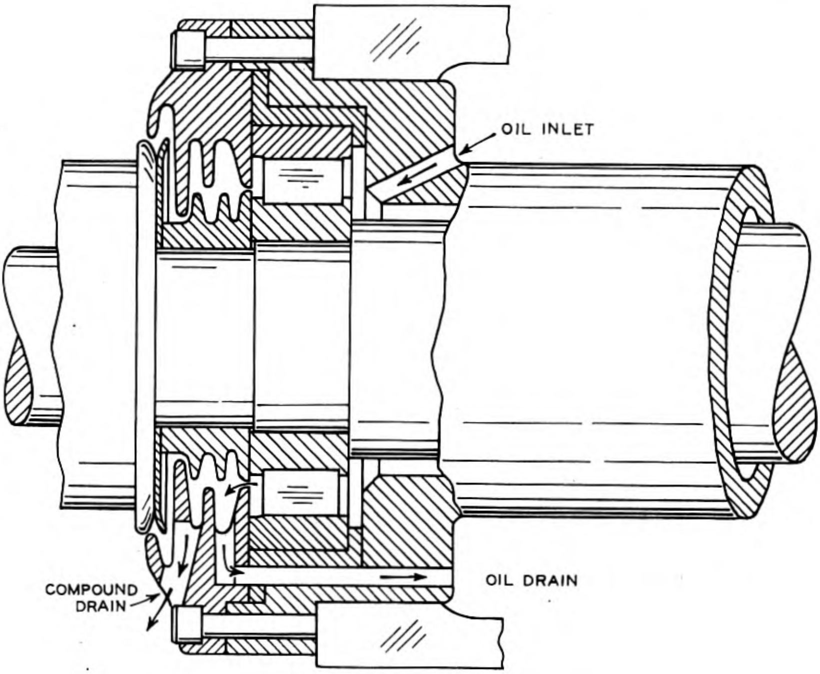

Fig. 13—Labyrinth oil seal

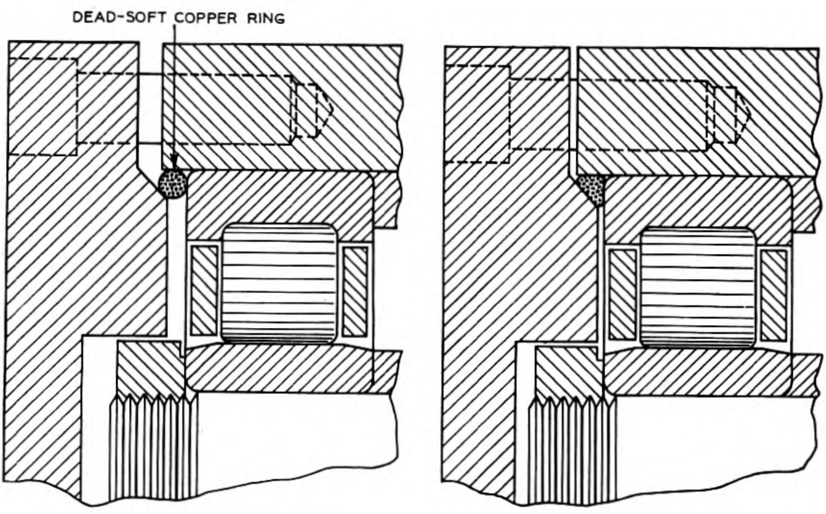

Fig. 14—Assembly of oil retaining ring

flange, in which magazine approximately 10 to 12 feet of the inside end of the wire is stored. At the subsequent operation this inside end is removed from the storage and joined to the outside end on the next reel, by which means continuous production with a minimum of scrap is secured.

Consideration was given to a reel machined all over to get it in correct balance. However, it was realized that distortion would occur as a result of annealing the wire on the reel, and from the handling. Therefore it was decided to provide a very substantial construction of the takeup unit, with bearings of ample capacity to provide for any eccentric loading which might result from spools which had become irregular by use.

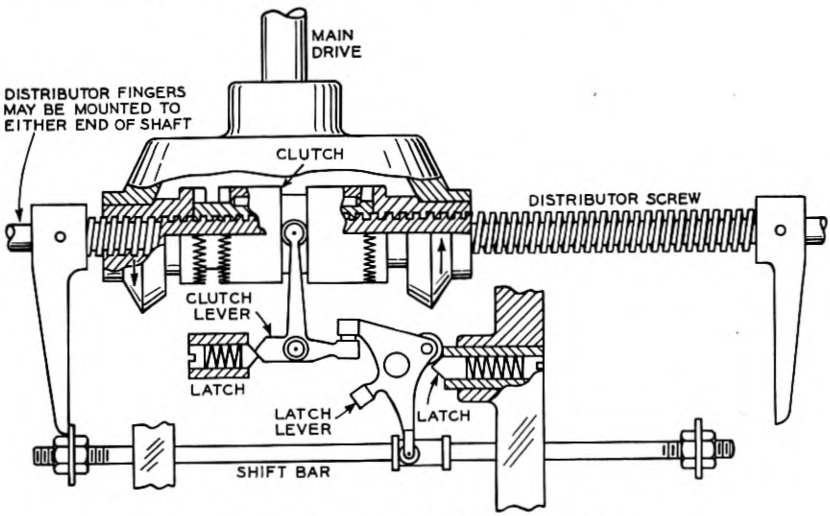

Fig. 15—Diagrammatic view of distributor

Welding facilities are provided to join the ends of wire on successive supply reels at the No. 2 Machines. A special hood permits the transfer of supply from the emptied reel to the succeeding reels. The contour of this hood had to be developed to reduce the noise from the wire which is whipping around. The noise is further minimized by suitable ribbing of the hood, irregularly spaced to break up the frequency of vibration.

A roller conveyor is installed beneath the hood with a capacity of three 1000-lb. reels. These reels are up-ended with magazine down before welding the ends of two reels. After emptying the front reel, the three reels are pushed forward, the empty one being discharged at the front, leaving space for another full reel at the rear.

A turntable is furnished at the supply end of the No. 1 Machine, which can be seen in Fig. 3, with capacity for four coils sufficient for one full takeup reel. In operation, the bottom of the coil of rod is welded to the top of the succeeding coil, thus securing continuity of drawing. With the emptying of one position, the table is revolved through one quarter of a revolution, leaving the empty space for reloading the next coil which is then welded to the one ahead, the welding and loading being performed during the period of drawing.

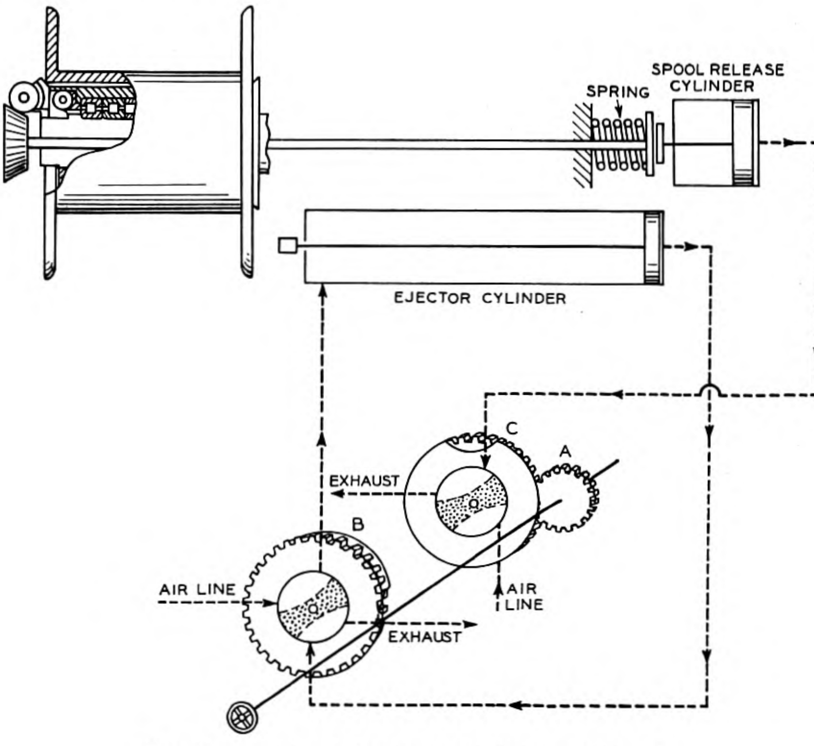

Fig. 16—Diagram of clamping and releasing mechanism

A slow speed stringing block and die support are provided for stringing the larger dies onto the wire and by depression of a foot switch the machine can be operated at slow speed for stringing the dies and wire into the machine.

Good distribution of wire on the reels is essential to permit of easy removal of wire from the reel. The distributor designed for this machine is of the reversing screw type with a reversing clutch as shown by diagram, Fig. 15. At the speed with which wire is being delivered to the reel, any pause at either end of the traverse would result in considerable build up of wire against the flanges. This type of distributor is practically instant-reversing.

Breaking of wire during drawing is not frequent, the average weight of wire on the takeup reel being well over 1000 lbs. for the No. 1 Machine and 300 lbs. for the No. 2 Machine.

Replacements and Safety Features

The design provides for readily replaceable unit assemblies so that the machines are out of production for the minimum of time when any repairs are necessary.

To reduce the effect of vibration to a minimum, the main frame of the machine was constructed to keep as much weight as possible close to the floor and thus secure a low center of gravity. All parts revolving at high speed are given a dynamic balance. Welded construction was not as readily adaptable as castings, and would have been noisier.

Safety features have been incorporated into the design for the protection of the operators. Doors are provided so that the wire is fully enclosed during the drawing process and all revolving parts are amply protected. The clamping of the reel on the arbor is effected through spring pressure, air being used for releasing and ejecting the reel. An interlock is provided between the reel release and ejector as shown by Fig. 16, Air Valve "C" effecting the reel release and air valve "B" controlling the ejector. Only one valve can be operated at a time, and they must be operated in proper sequence. The master control "A" is left in contact with the gear segment of Valve "C" until it is fully opened and the reel released. When "A" registers with the segmental opening, it can be withdrawn and moved over into mesh with segmental gear on Valve "B"; the master Control "A" cannot be disengaged from "B" until the ejector plunger is back in correct position. Additional safety was introduced into the reels by making the flanges of an alloy casting, changing the factor of safety from 4-1 to 8-1.

The use of high speed machinery with large capacities of the takeup unit and introducing the minimum of slip between the wire and capstan has resulted in meeting the performances anticipated from this development.

PART II—EQUIPPING AND OPERATING THE NEW WIRE MILL

By J. E. WILTRAKIS

Alloy and Diamond Dies

The experience gained in operating the older Hawthorne and Point Breeze wire mills demonstrated the importance of providing and maintaining dies of high quality. The hardest materials, alloys such as tungsten carbide and flawless diamonds, are used in these dies.

The alloy dies are used in the No. 1 drawing machine where the wire surface and resulting die wear are relatively small per pound of wire produced.

Diamond dies are used exclusively in the No. 2 machine. Definite problems were solved in maintaining dies to rigid specifications which include correct die contours, a finely polished surface, and definite die pull values.

The cross section of a diamond die, Fig. 17, illustrates the general contour found to be most satisfactory for high speed wire drawing. The approach blends smoothly into the reduction angle where the wire is reduced in diameter one AW gage. The bearing is approximately 40% of the wire diameter. With the use of a contour projector, 100X enlargements of die impressions are periodically made to control the process.

Well graded diamond dust is used to enlarge the hole in the die and for polishing operations. Dust graded by flotation methods, closely checked, offers the best results.

For final polishing 6 micron diameter dust is used. A 30X wide angle binocular microscope is used to check the various stages of die making operations and of inspection as shown in Fig. 18.

The following die pull requirements have been set up for each gage when reducing wire one AW gage size:

AWG Size	Pounds Pull	AWG Size	Pounds Pull
15	75	21	21
16	60	22	17
17	49	23	13.5
18	40	24	11
19	32	25	9
20	25	26	7

After grouping dies of a certain diameter according to the pounds pull required, they are matched into sets for use in the No. 2 drawing machines. Records are kept of the characteristics and output of each die.

The increase in speeds up to 12,000 f.p.m. does not appear to have an appreciable effect on die wear. In other words, the same quality and quantity of wire can be obtained from high speeds as from low speeds if (1) the dies are made to definite specifications, (2) the dies are matched into sets, and (3) the drawing machine factors are the same.

The drawing machines have been designed and are maintained with the view of overcoming some of the serious causes of short die life. Long die life is not only obtained by good die shop practice but also control of the following machine factors; (1) smooth drawing capstans and minimum slip, (2) minimum whip of wire entering dies, (3) adequate lubrication of capstans and cooling of dies, and (4) elimination of foreign particles from the drawing compound.

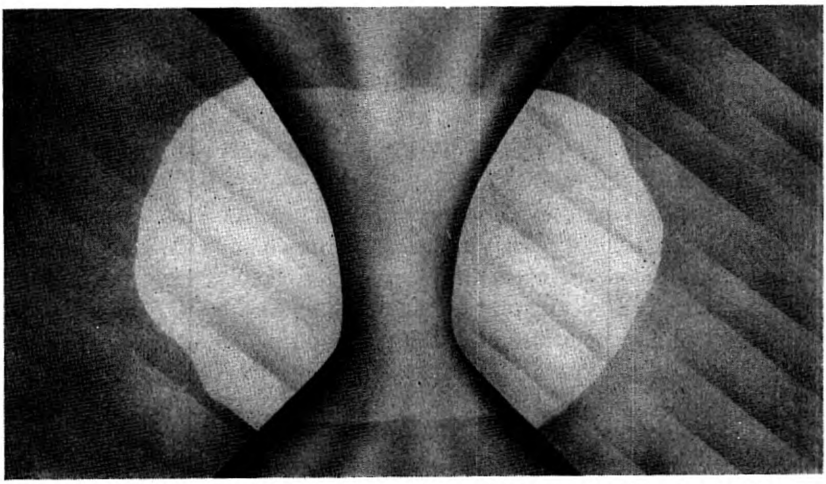

Fig. 17—Schematic showing cross-section of diamond die used in high speed wire drawing

Drawing Compound and Equipment

A one-story building is used for manufacturing wire. In the basement the drawing compound tanks, piping, heat exchangers, pumps, power services and controls are installed. The compound solution used to lubricate and cool the capstans and dies in the drawing machines consists of a homogenized solution of soap, fat and oil mixed with water. This compound returns to a self-cleaning distributing launder in an enclosed steel tank. The launder consists of a pipe with slots evenly depositing the compound over the entire width of the tank. The copper sludge settles to the bottom and the lighter impurities rise to the surface to be held back by a skimmer plate. The clarified super-natant solution rises over a dam into the pump suction chamber to be pumped at the rate of 200 gallons per minute to each No. 1 machine and 100 gallons per minute to each No. 2 machine. The heat from the clean compound is removed in heat exchangers as the compound is delivered to the machines. The compound is maintained at approximately 130°F by a closed recirculating water system thermostatically controlled, Fig. 19.

Layout of Principal Wire Mill Equipment

The building used for wire drawing is ideally situated adjacent to the cable manufacturing unit and has facilities for water, rail and motor truck

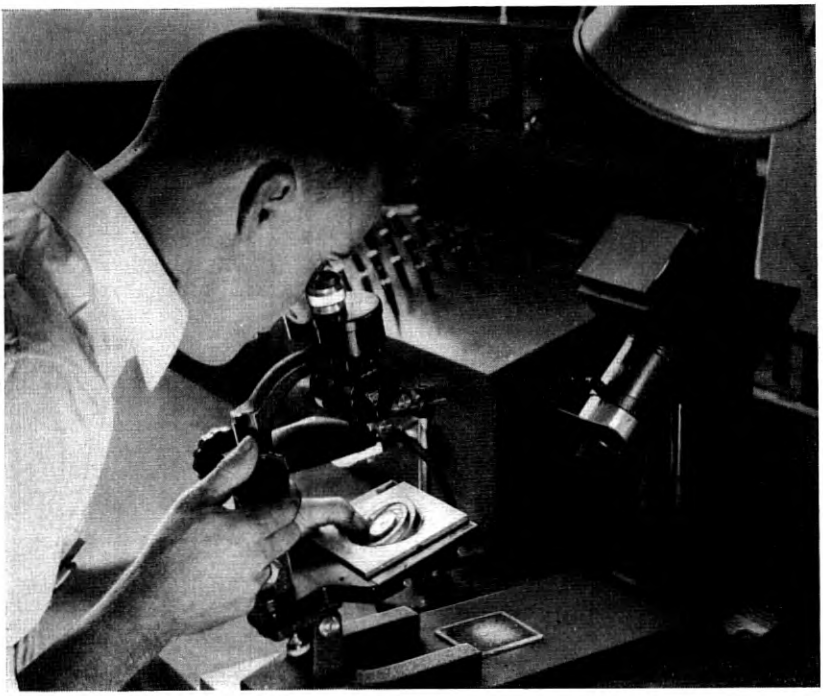

Fig. 18—Microscopic examination of diamond die polish by die maker

deliveries. The area is easily ventilated and has excellent illumination provided by mercury vapor lamps, close to a high ceiling yet providing an average of more than 20-foot candle illumination. Stroboscopic effect is practically eliminated by staggering the lamps over separate phases of the three-phase circuit.

The No. 1 machines are located adjacent to the copper rod receival area. The No. 2 drawing machines, nine of them in a row, are placed in the center of the building. Along the wall, five annealing bases for the electric bell type furnace are located. A bridge type crane handles all the material between the No. 2 machines, annealing and inspection. This layout, Fig. 20, of the equipment makes possible quick and easy transfer of material

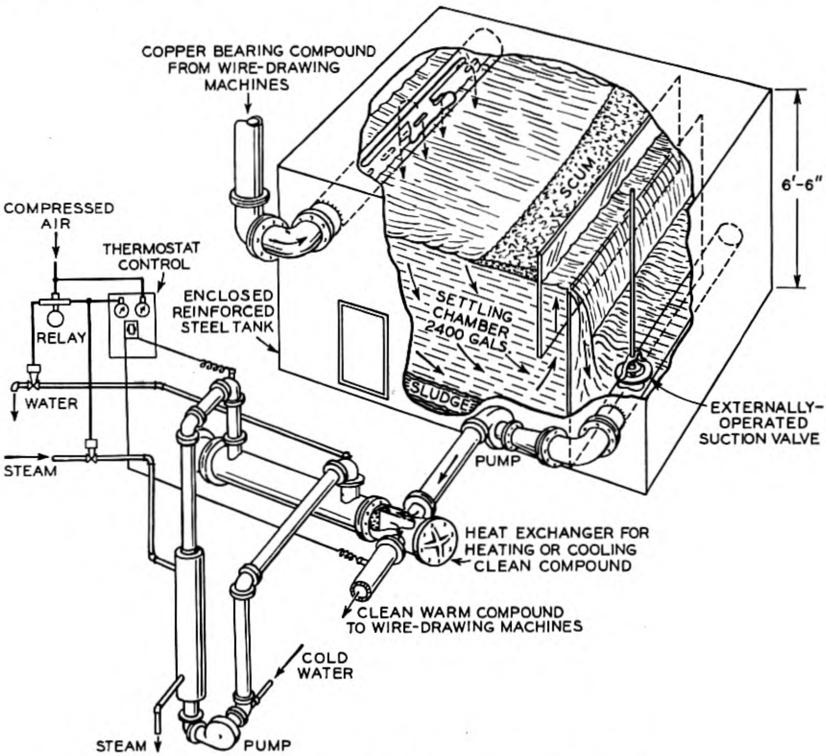

Fig. 19—Sectional sketch of compound system

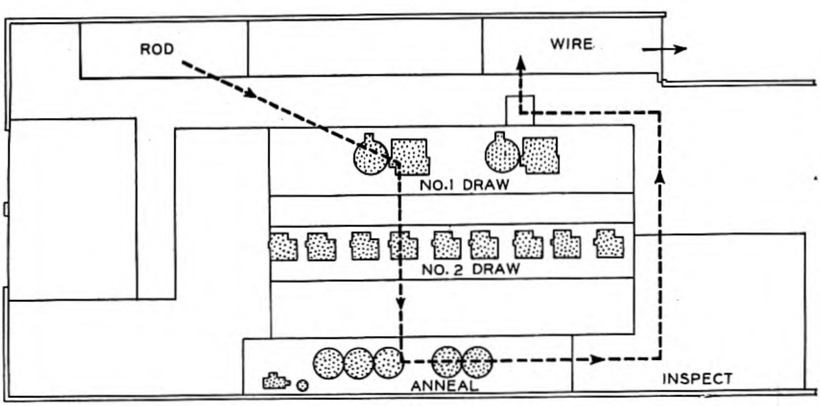

Fig. 20—First floor layout of wire mill

between operations, low inventories and multiple operation of machines by operators. Capacity can be increased without rearrangement. Adequate space has been provided to facilitate maintenance. The entire distance from the receival of rod to the wire shipping area is 100 feet. One electric truck and the crane just mentioned, suffice to handle and transport all materials in the building.

On either side of the main flow of material, space is provided for storage of rod, shop maintenance machines and racks.

Processes in the Wire Mill and Flow of Material

Copper rod is delivered on double prongs of an electric truck, approximately 4,000 pounds at a time, and is placed adjacent to each of the No. 1 drawing machines, Fig. 21. Here each 250-pound coil is placed on the floor of the eight-foot diameter supply table. A maximum of four coils is maintained on the table at a time. The rod ends are electro-welded to form a continuous supply. As rod from one coil is converted to wire, the operator pushes a button and rotates the table 90° to locate the next coil. This process of supplying coils, welding rod ends and rotating the supply table is repeated while the machine continues to fill the 1000-pound reel with 14 gage (.064″) wire at 5000 f.p.m.

When the machine automatically stops, the operator opens the spooler compartment and actuates an air operated mechanism which releases and pushes the two-foot diameter 1000-pound reel off the take-up arbor. An empty reel is placed on the arbor and locked. The guard is closed and the push button starts the machine with no additional attention on the part of the operator, who returns to the welding operation after placing the filled reel in the storage area.

The 1000-pound reel must be up-ended before it can be placed under the supply compartment of the No. 2 machine. The up-ending device, Fig. 22, consists of two floor castings, a pneumatic hoist and cables. The operator first rolls the large reel on the first floor casting and then actuates the pneumatic hoist. The cables hinge upward two castings like covers of a partly closed book, forming 45° angles with the floor. At this position the weight of the reel settles onto the second casting. The operator releases the air and the reel is gently lowered upon floor rollers. The axis of the reel is now vertical.

One end of the copper wire is electro-welded to the wire end of one of the two reels in the supply compartment. As the machine empties the first reel, the operator pushes the second and third reels into the supply position within a compartment. A continuous supply is thereby provided with safety and ease of handling.

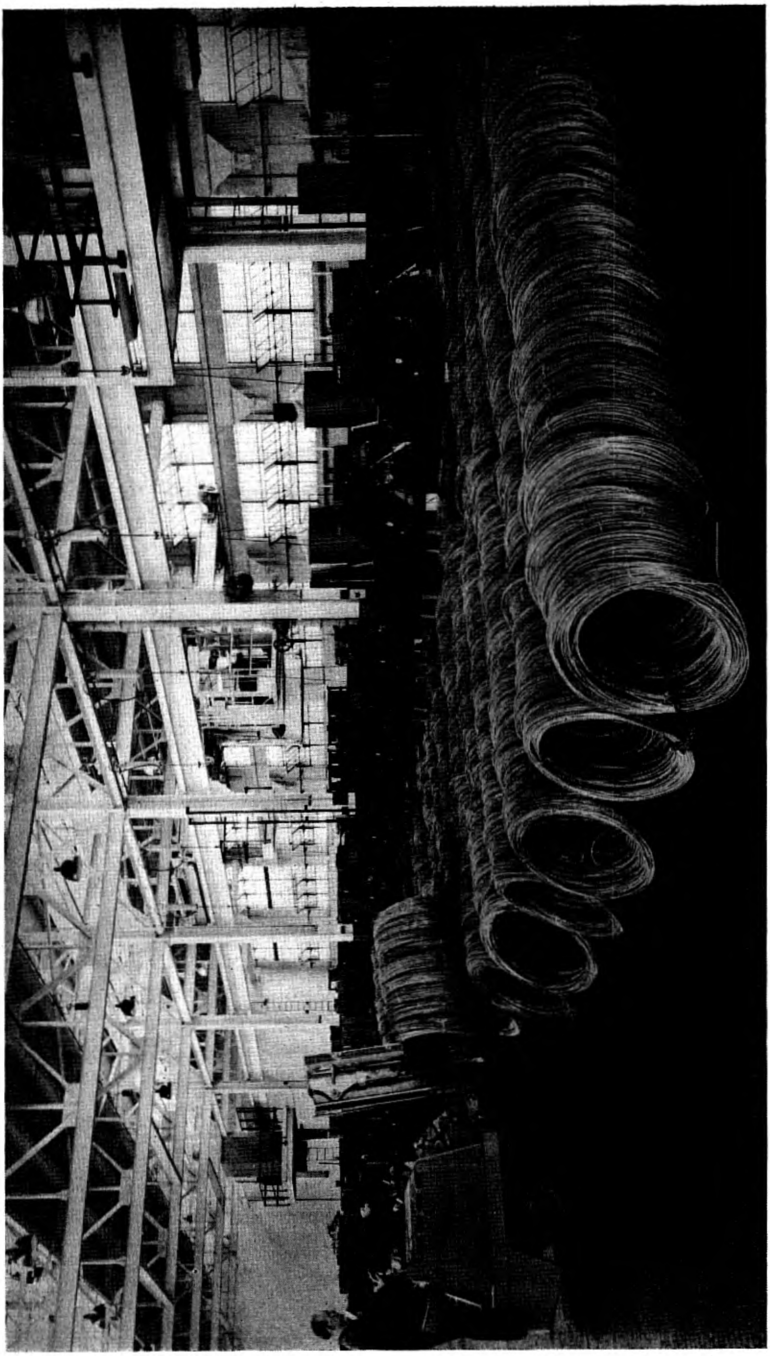

Fig. 21—Electric truck delivering copper rod

The duties of the No. 2 machine operator, Fig. 23, principally consist of furnishing several machines with supply wire, removing filled reels of drawn cable wire, gaging wire, starting the machines and periodically adjusting for tension. Breaks are infrequent as evidenced by the fact that the average weight of reels shipped was over 340 pounds. When these

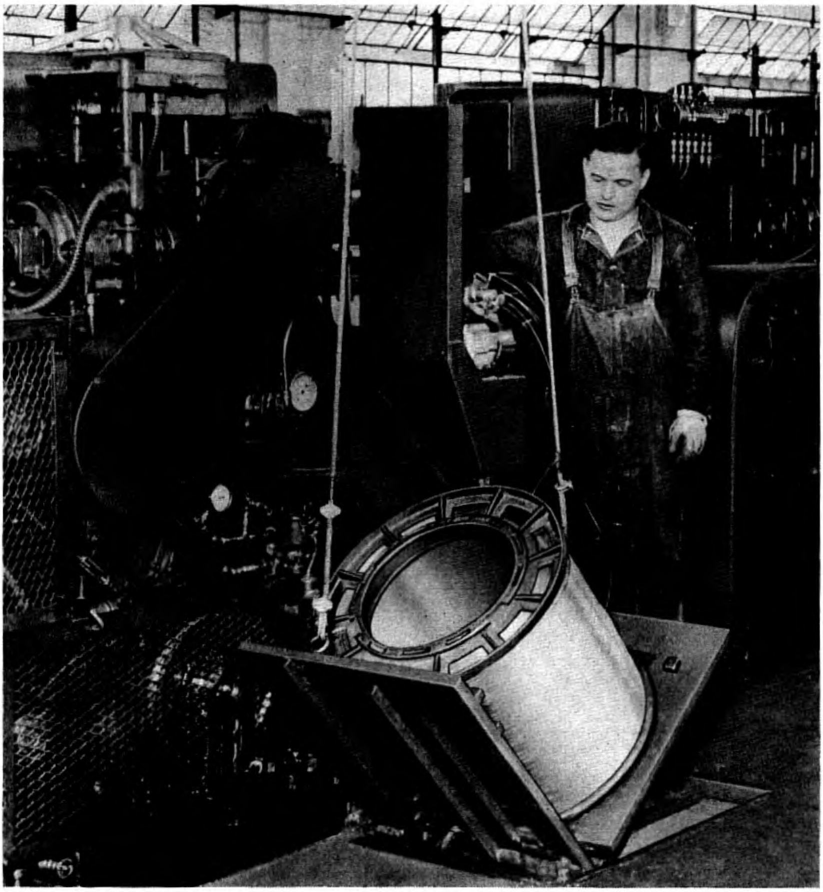

Fig. 22—Up-ending device for 1000-pound supply reel at back of No. 2 machine

breaks occur or when a change is made in the die sets, this operator also strings up the machine.

On these machines wire is drawn at 10,000 f.p.m. The importance of the various mechanical and electrical details mentioned in the first section of this paper can therefore be visualized. One of the No. 2 machine has, for the past year, operated with certain refinements at the finishing speed

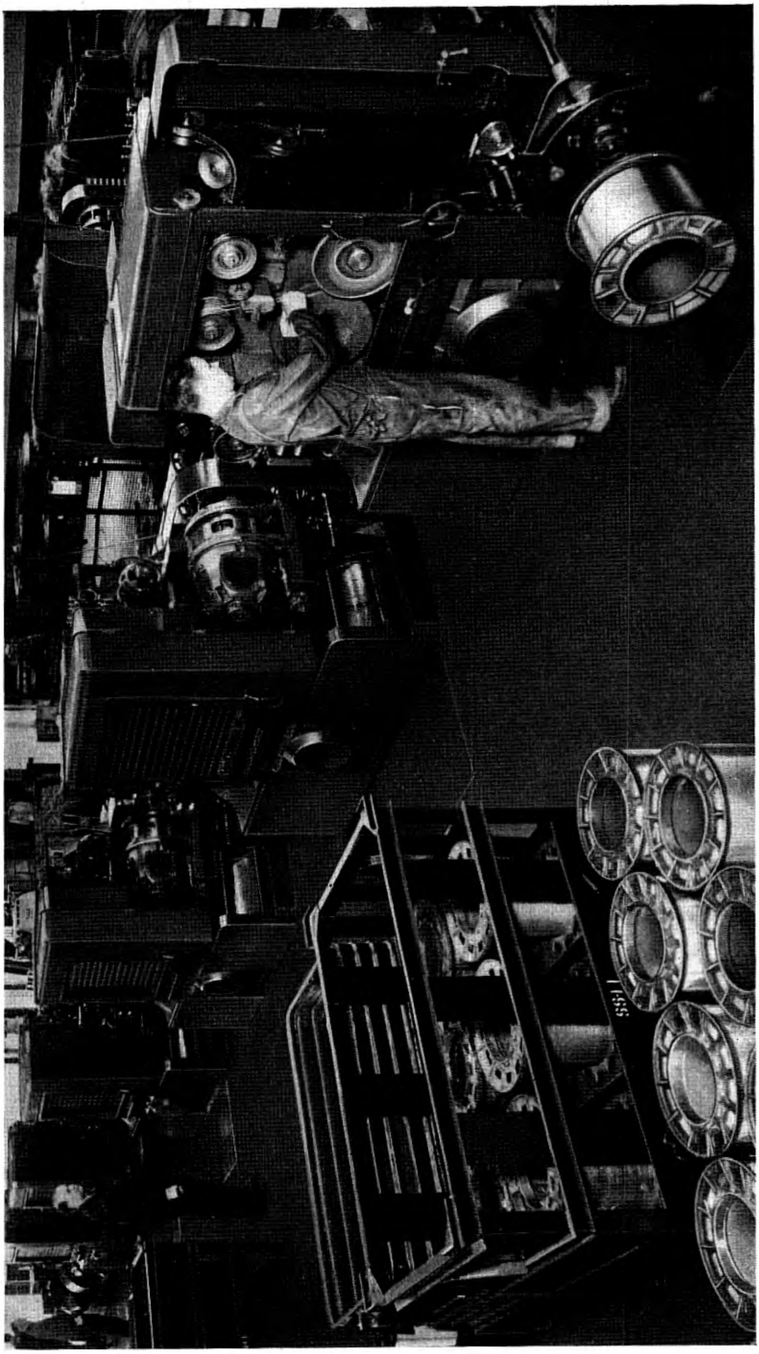

Fig. 23—Line-up of No. 2 machines

of 12,000 feet. The data being collected so far are favorable and it is expected that this study will justify the conversion of additional machines to the higher speed.

After the take-up reel is released and pushed off the arbor by the air operated mechanism, it is rolled to the area below the bridge crane and up-ended by hand.

Fig. 24—Solenoid operated chuck grapple being located to lift reel of wire

Multi-Purpose Crane

The movements of the bridge crane and grapples are controlled from the crane cab by the operator. A six-ton grapple handles the baskets of wire, the electric furnace bell and the furnace details. The crane is also equipped with an auxiliary hoist to lift the wire reels into the annealing basket. To this hoist, a locating device has been attached together with solenoid operated, internal expanding jaws which engage in the wire reel core, Fig.

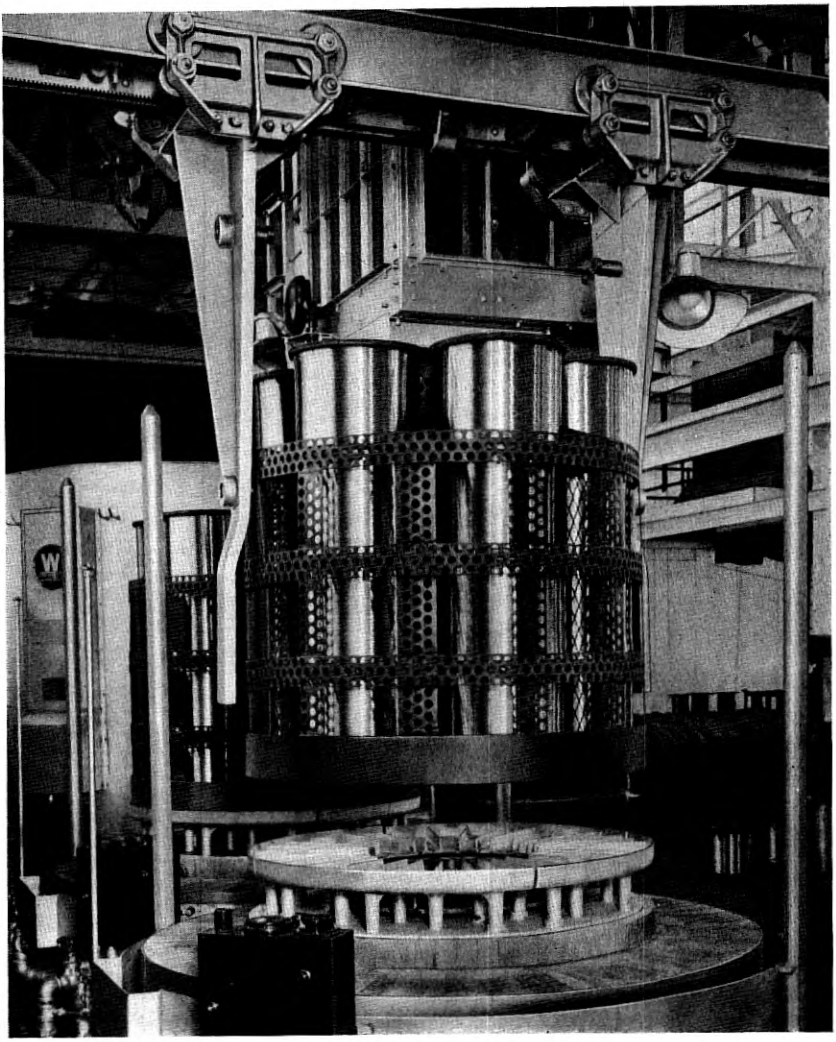

Fig. 25—Six-ton crane grapple placing basket of wire on annealing base

24. With safety and facility of operation, twenty-eight reels, a total of 10,000 pounds of wire, are loaded into a 56″ diameter light-weight perforated steel basket, Fig. 25.

BATCH TYPE ELECTRIC ANNEALING FURNACE

The operation of electric batch type annealing furnaces and the use of reducing gas atmospheres, with an average composition of about $1\frac{1}{2}\%$ CO, 2% H_2 and 14.5% CO_2, produced by combusting city gas, are generally known to the wire industry. Certain provisions in the Kearny installation may be of interest.

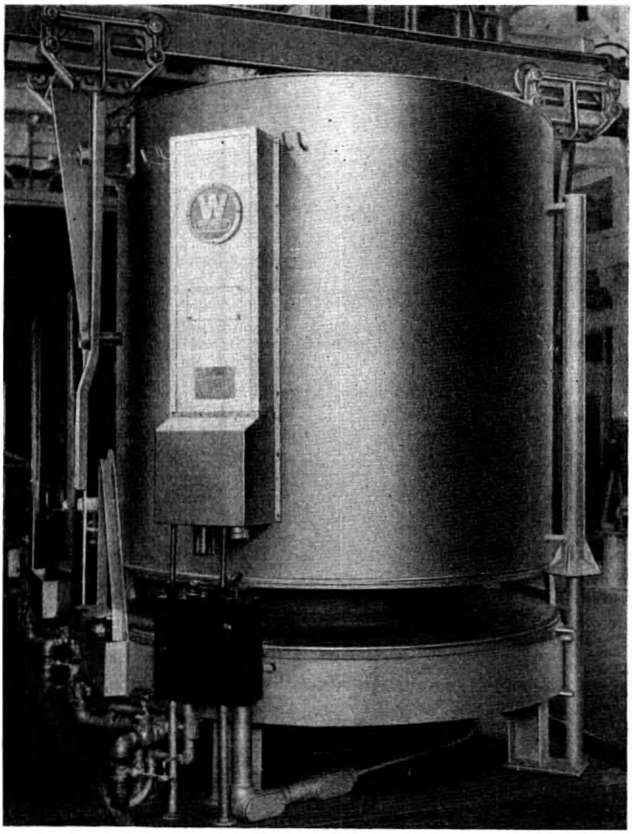

Fig. 26—Electric furnace bell, with automatic plugging equipment, being placed over covered charge

Details of the annealing baskets and bases, the steel alloy retorts used to cover and water-seal the charges, and the electric furnace moved from base to base have been designed so that the arms of the six-ton crane grapple can engage, handle and move all these items.

The electrical connections to the furnace bell are made automatically.

This design consists of control and power plugs located on the exterior of the furnace and a floor stand with positions for electrical receptacles. Two pins align these units, one of which opens the receptacle covers as the furnace is lowered over the retort, Fig. 26.

Features such as these make it possible to perform all the furnace and crane operations, to deliver wire to the inspection area, to load skids for shipment of wire with a minimum of effort on the part of the operator. He attends these operations from a crane cab and as required, operates and adjusts the gas, water and drain valves from floor positions.

In the event of power, gas or generating equipment failure, automatic indicating equipment summons the operator who then connects an 8%

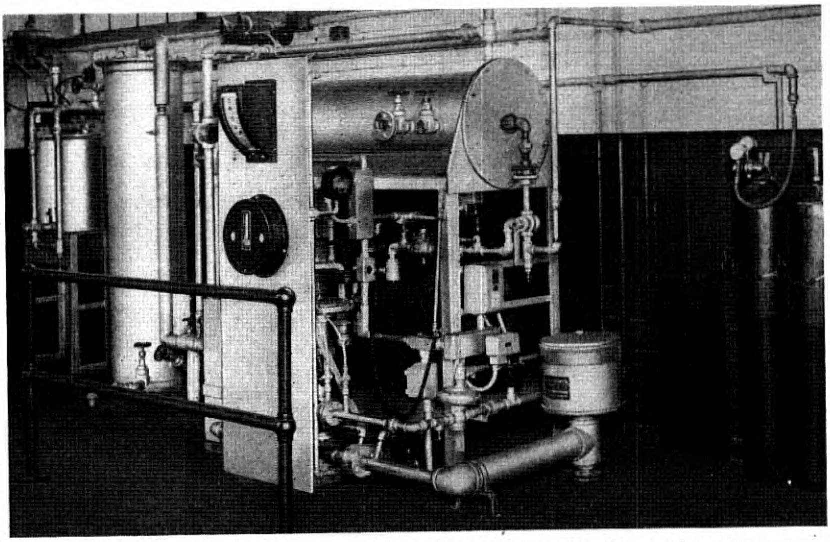

Fig. 27—Gas generator and N_2 tanks used as standby equipment

H_2-92% N_2 mixture into the annealing gas lines. This has provided inexpensive stand-by equipment and constant production of bright annealed copper wire, Fig. 27.

Capacity and Results

This mill is set up to produce wire on a three-shift basis. The equipment of the type described, including space for rod and wire storage, occupies an area of approximately 14,000 square feet. Training time was not excessive for the average operator—efficiencies of 80% to 90% being attained in a few months. Rotation of operators to the next shift every two weeks has worked out satisfactorily.

Periodic checks and maintenance of electrical circuits and apparatus, with adjustments of mechanical assemblies before major repairs arise, have kept repair costs low. Additional training and experience should further reduce maintenance and repair time. The use of diamond dies in diameters

Fig. 28—Inspection and shipping area

up to and including 15 AWG has been found economical for high-speed machines. Cracked dies are negligible when properly mounted clear stones are used. After the first year of operation, the Wire Mill has bettered the anticipated performance objectives.

Acknowledgements

In setting up and operating this project at Kearny, the engineering group responsible was greatly assisted by the Wire Mill experience and developments at the Hawthorne and Point Breeze Works and by the recommendations and designs of the material handling and factory planning engineers at Kearny. This cooperation, together with that obtained from the men on the machines and the maintenance groups, has been reflected in the results.

Abstracts of Technical Articles by Bell System Authors

Two papers by Reverend Thomas Bayes—A facsimile publication from the Philosophical Transactions, Vol. LIII, for the year 1763. This facsimile has been prepared under the direction of W. Edwards Deming, Senior Mathematician of the Bureau of the Census, Washington, from a copy of the Philosophical Transactions in the possession of the Naval Observatory in Washington. An interesting foreword to the volume has been supplied by Edward C. Molina of the Bell Telephone Laboratories. The volume is available at the Department of Agriculture, Washington, D. C., price $1.00.

The Subjective Sharpness of Simulated Television Images.[1] M. W. BALDWIN, JR. Small-sized motion pictures, projected out of focus in simulation of the images reproduced by home television receivers, are used in a statistical study of the appreciation of sharpness. Sharpness, in the subjective sense, is found to increase more and more slowly as the physical resolution of the image is increased. Images of present television grade are shown to be within a region of diminishing return with respect to resolution. Equality of horizontal and vertical resolutions is found to be a very uncritical requirement on the sharpness of an image, especially of a fairly sharp one.

Synchronized Frequency Modulation.[2] W. H. DOHERTY. Probably the foremost practical problem in FM transmitter design is that of stabilization of the mean or carrier frequency. Crystal stability is required, but the direct use of a crystal would necessarily give rise to a conflict between the factors which stabilize the frequency and those which are to produce the desired variation.

In Synchronized Frequency Modulation, which makes its first appearance in the 1000-Watt Western Electric 503A-1 Radio Transmitting Equipment, this problem is solved by associating the crystal indirectly with the system in a monitoring role which ignores the rapid frequency variations due to modulation and responds only to variations in the mean frequency. This is done by taking a sample of the output of the frequency-modulated electric oscillator and shrinking the spectrum down through a succession of frequency dividers to about 1/8,000th of the transmitted carrier frequency. It then consists of a strong central carrier (about 5,000 cycles) with a few degrees of phase modulation. This is then compared with a

[1] *Proc. I.R.E.*, October 1940.
[2] *Pick-Ups*, August 1940.

crystal standard (likewise about 5,000 cycles) in a device which produces a rotating magnetic field at the difference frequency. An armature which follows this field controls the tuning condenser of the original electric oscillator, coming to rest when exact synchronism is attained. The small phase vibrations accompanying modulation are not followed because of the inertia of the system.

The stability thus obtained for the mean frequency is identically that of a crystal oscillator. Since the actual control is mechanical, no sustaining voltage is required, so that failures in the control system do not result in sudden departures in frequency. Mechanical control, moreover, completely relieves the modulating elements of any connection with the stabilization of the mean frequency, so that the modulation range is not restricted. This and other refinements in design permit frequency excursions of hundreds of kilocycles with extremely low distortion.

Ultra-Short-Wave Transmission Over a 39-Mile "Optical" Path.[3] C. R. Englund, A. B. Crawford, and W. W. Mumford. Continuous records of ultra-short-wave transmission on wave-lengths of 2 and 4 meters, over a good "optical" path, have shown variations in the received signal strength. These variations can be explained as being due to wave interference; an interference which varies with the changes in the composition of the troposphere.

Some of the variations are due to changes in the dielectric-constant gradient of the atmosphere near the earth. Other variations are explicable in terms of reflections from the discontinuities at the boundaries of different air masses. The diurnal and annual meteorological factors which affect the transmission are discussed.

A Decade of Progress in the Use of Electronic Tubes. Part I—In the Field of Communication.[4] S. B. Ingram. The dependency of the art of communication on the science of electronics is so great as to make a review of progress in electronics almost of necessity a review of the field of communications itself. While it is true that the early forms of telephone and radio communication advanced to a degree without the use of electronic devices as we know them today, the recognition of the vacuum tube as an amplifier and generator of high-frequency alternating currents in the years just preceding the first World War marked a turning point in the development of the communication art. From that day to this the progress of electronics and communications has gone hand in hand. The need of the communications engineer for new electronic tools has kept him continually

[3] *Proc. I.R.E.*, August 1940.
[4] *Electrical Engineering*, Transactions section, December 1940.

urging the electronics engineer to improve old devices and to originate new ones, and each time the efforts of the latter have been rewarded with success the fruits of his work have been immediately applied to produce new and more startling miracles of long-distance communication.

Because of the close relationship of electronics and communications it is necessary in reviewing the progress of the last decade to keep in mind that it is progress in electronics and not in communications which is our theme. It will be necessary to survey the trends in communications during the period under review, but then it will be necessary to ask to what extent the progress which has been made is due to advances in the electronic field and what advances in the electronic devices themselves have laid the foundation of this progress. There has been no attempt made to make this review comprehensive in the sense that it include all items of progress which are of individual interest. To do so would make it merely a catalog of these many advances and an index to the periodical literature of the subject. Rather the object has been to trace the most significant trends of development in the various fields and to emphasize those lines of advance which appear to be most closely related to the general direction of progress in the several fields of electrical communication.

The Location of Hysteresis Phenomena in Rochelle Salt Crystals.[5] W. P. MASON. Measurements of the elastic properties of an unplated crystal, the piezoelectric constant f_{14}, and the clamped dielectric constant of a Rochelle salt crystal show that practically all hysteresis and dissipation effects are associated with the clamped dielectric properties of the crystal. A theoretical formulation of the equations of a piezoelectric crystal has been made which takes account of the dissipation effects. The formulation is given for the polarization theory. The frequency variation of the clamped dielectric constant when interpreted by Debye's theory of dielectrics, modified to take account of hysteresis losses, indicates that there are two components, one of which has associated with it a high viscous resistance, whereas the other one does not. The non-viscous component has a dielectric constant of about 100 at 0°C and is probably due to the displacement of the ions in the lattice structure. The viscous component has a dielectric constant of about 140 at 0°C and is probably due to the dipoles of the Rochelle salt. Both components have higher dielectric constants and hysteresis between the Curie points indicating a cooperative action of the molecules for both components in this temperature region.

A New Broadcast-Transmitter Circuit Design for Frequency Modulation.[6] J. F. MORRISON. The problem of generating wide-band frequency-modu-

[5] *Phys. Rev.*, October 15, 1940.
[6] *Proc. I.R.E.*, October 1940.

lated waves is first reviewed in order to ascertain specifically the desired performance capabilities for a commercial transmitter circuit. The factors which influence or limit these performance capabilities in the two methods available for the generation of frequency-modulated waves, compensated phase modulation, and direct frequency modulation, are then explored. It is found that each method possesses desirable fundamental characteristics not present in the other, but with the circuits now generally employed with either method the modulation characteristics and carrier frequency stability are interrelated so that one has a limiting effect upon the other.

A new circuit is described in which these two important characteristics are independent of each other. Owing to this independence and to other circuit refinements the modulation capabilities are unrestricted with low distortion over an exceedingly wide range.

A balanced electric oscillator operating at one-eighth the radiated frequency is modulated by balanced reactance-control tubes and negative feedback is used to minimize amplitude modulation and harmonic distortion. A system of *frequency division* is employed together with a crystal-controlled oscillator and synchronous motor in such a manner as to control mechanically the mean frequency of the modulated wave with the same stability as that of the crystal-controlled oscillator. The carrier, or mean, frequency stability is that of a single crystal-controlled oscillator and is independent of any other circuit variations. A carrier frequency stability of 0.0025 per cent is possible without the use of temperature-controlled crystals or apparatus.

Neutron Studies of Order in Fe-Ni Alloys.[7] F. C. NIX, H. G. BEYER and J. R. DUNNING. Neutron transmission measurements are used to study order in Fe-Ni alloys. The difference in neutron transmission between fully annealed and quenched alloys when plotted against the nickel content displays a broad peak around Ni_3Fe and falls to vanishingly small values near 35 atomic per cent Ni and pure Ni. The higher the degree of order the greater the neutron transmission. The substitution of 2.3 atomic per cent Mo or 4.1 atomic per cent Cr for Fe in the annealed 78 atomic per cent Fe-Ni alloy caused a decrease in the neutron transmission, relative to the annealed 78 atomic per cent Fe-Ni alloy, of 15.6 and 21.2 per cent, respectively. The cold working of an annealed binary 75 atomic per cent Ni alloy, a treatment known to produce disorder, gave rise to a decrease of 20.6 per cent in neutron transmission. These results demonstrate that neutron techniques serve as a useful tool to study order in Fe-Ni alloys, and suggest that they can be extended to study other solid state phenomena.

[7] *Phys. Rev.*, December 15, 1940.

Contributors to this Issue

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M. E. STRIEBY, A.B., Colorado College, 1914; B.S., Harvard, 1916; B.S. in E.E., Massachusetts Institute of Technology, 1916. New York Telephone Company, Engineering Department, 1916–17; Captain, Signal Corps, U. S. Army, A.E.F., 1917–19. American Telephone and Telegraph Company, Department of Development and Research, 1919–29; Bell Telephone Laboratories; 1929–1940; American Telephone and Telegraph Company, Long Lines Department, 1940–. Mr. Strieby has been associated with various phases of transmission work, more particularly during the last ten years with the development of coaxial systems for telephone and television. At the present time he is Engineer of Transmission of the Long Lines Department.

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