some of our data. Equations [5] and [6] for ϵ_l, the error of duplicate instrumentation, are complicated, and would be a serious extension and warping of the meaning of standard deviation. Hence we use the general word error to represent all the different kinds of data listed in the summary, whether they are derived as simply a standard deviation, as a root-mean-square value of several standard deviations, or by Equation [5] or [6].

The words root-mean-square describe these errors in two ways: By their derivation and by what fraction of a group they represent.

First, we combine errors of various types as the square root of the sum of their squares. Hence we believe it somewhat suitable to use the root-mean-square value of the errors of a specific type for the various turbines to represent that error.

The statisticians show that a range of plus or minus one times the standard (or root-mean-square) deviation each side of average performance for a group tends to include 68.2 per cent or two thirds of the group. This leaves one sixth of the group below average performance by more than one root-mean-square error and one that much above average, as noted in the footnote early in the text. A range of $\pm 2\ \hat{\sigma}$ leaves 2.2 per cent of the group at each extreme; $\pm\ 3\hat{\sigma}$, 0.14 per cent. We believe the range for the root-mean-square error is suitable for the analysis of this paper.

Discussion

N. R. Deming.[5] The author has made a rather thorough analysis of the various errors or uncertainties affecting the accuracy of tests on industrial-size steam turbine-generator sets. In the abstract of the paper he summarizes his findings with numerical values for each type of accuracy. While showing figures ranging from 0.2 to 0.5 per cent he reasserts his belief that it is proper to accept or reject a turbine-generator set on the basis of precision tests with no allowance for test error.

Now it would appear that this could be a satisfactory arrangement to a turbine manufacturer only if adequate margin were included in the design to cover the largest value of anticipated test error, thus insuring that all tests would meet the guarantee. For units designed with small margin this 0.5 per cent test uncertainty could become important. For units with plenty of design margin, an allowance for test error becomes unnecessary.

The writer concurs with the author that the use of station instruments increases greatly the uncertainties of a test. The author's figures, of course, assume a turbine in good mechanical condition free of blading deposits.

It should be emphasized that the steam-flow nozzles, used by the author for assurance that the weighed condensate is an accurate measure of throttle flow, are carefully built, low-diameter ratio, ASME type nozzles properly installed with flow straighteners in the approach pipe—hence the low apparent uncertainties involved. These figures would not apply to the ordinary station steam-flow-nozzle installation for which the apparent discharge coefficient, in the writer's experience, may vary from 0 to 2¹/₄ per cent above published ASME data.

R. M. Johnson.[6] The author's discussion of methods for evaluating the reliability of turbine tests is of particular interest to members of the Society. He correctly lists five measures of uncertainty available in his analysis of test data.

1 Comparison of results from duplicate units.
2 Comparison of repeat test runs on the same unit.
3 The deviation of readings from duplicate instruments.
4 Comparison of alternate methods such as the flow nozzle versus the weighed condensate.
5 Comparison of enthalpy drop efficiency, with efficiency computed from measured power and steam flow.

There are other measures of test accuracy, not discussed, such as the deviation between test and specified operating conditions, and the fluctuation of operating conditions during any one test run. The magnitude of adjustments for deviation in load, throttle pressure, initial temperature, and back pressure cannot be ignored. Likewise, the magnitude of fluctuation in the instrument readings, due to drift or unsteady operating conditions, is the first index of test accuracy.

Probably the most significant contribution of this paper is the illustration of a method for expressing the various uncertainties of a test in precise numbers. Here a word of caution is necessary. Chances are the percentage figures do not mean what was thought at the first reading. The spread of the deviations is always greater than the average, and the average differs from the root mean square by a formula which gives weight to the number of values used. It is the writer's feeling that the method is of little value for comparing two or three tests as in Figs. 5 and 6. It has greater meaning when a larger number of tests are compared as in Fig. 2. The author's conclusions would have considerably greater value if they were supported by tables of the original test readings.

For obvious reasons, the author has averaged the steam rates for the range of ²/₄, ³/₄, and ⁴/₄ of rated load. There is some objection to this practice, in that it can distort the true picture of spread in plots Figs. 1 and 2.

In Table 1, the average steam flows for the tests on duplicate turbines differ by as much as 16 per cent and in several cases the indicated deviation in available heat is appreciable. The author should explain how these variations were handled.

The writer agrees with the author that it is proper to accept or reject a turbogenerator set on the basis of precision tests without allowance for test error, but from a slightly different approach. What else can be done in reality? If we define a precision test as the best there is available from the standpoint of instruments, control of operating conditions, trained personnel, and test procedure, regardless of the evaluated error, nothing can be done about it. The approximate test is always a compromise test and is likely to raise more questions than it settles.

W. A. Pollock.[7] This paper is a valuable contribution to a subject on which there has been very little published.

The author's conclusion that precision-turbine-test results conducted in the manufacturer's shop may be accepted with no allowance for test errors is of interest. This conclusion is arrived at based on experience with weighing tanks.

Field tests with weighing tanks and specially calibrated instruments can be equally accurate and the writer described how this was practical at low cost in a paper[8] presented at the 1953 Annual Meeting.

It has been the writer's experience that field tests can be equally as accurate as shop tests and that field tests may be conducted on very large turbines with complex cycles, including several stages of feedwater heating.

To obtain accuracy within 0.35 per cent with precision flow nozzles in field tests as mentioned by the author, it is necessary to install the flow nozzle just prior to testing in order that there is not time for deposits to build up and produce errors. It has

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[7] Technical Engineer of Power Plants, Wisconsin Electric Power Company, Milwaukee, Wis. Mem. ASME.

[8] "Testing Large Steam Turbines With Weighing Tanks," by W. A. Pollock, ASME Paper No. 53—A-66.

been shown that very minute deposits on flow nozzles can result in sizable errors. Recently, a 7.0 per cent meter error was confirmed in one installation as being due to deposits on the flow nozzle.

Author's Closure

The author wishes to thank the discussers for their many comments. He notes with interest that no discusser takes strong exception to the belief that it is proper to apply no allowance for test error when using precision tests as the basis of accepting or rejecting a turbine-generator set.

Mr. Johnson notes his feeling that the method of expressing the various uncertainties in precise numbers is of little value for comparing two or three tests as in Figs. 5 and 6. For several years the author has used statistical methods with small samples cautiously. However, we have found such methods very valuable for drawing proper conclusions from small samples. And we have often found these conclusions still apply when we extend the analysis to include later data. Further, we must be prepared to obtain whatever sound conclusions can be drawn from tests on only a few pairs of turbines and a few more pairs of duplicate runs, as in these plots. Actually, we were somewhat amazed by how consistently the magnitudes of the various types of uncertainties decreased when arranged in logical order as in the summary of the paper.

Mr. Johnson notes that the deviations between test and specified operating conditions, the adjustments for such deviations, and the fluctuations of readings are measures of test accuracy. Actually, the effects of these variations are automatically included in the paper's comparisions of the over-all performance of two or more turbines which are based on Figs. 1, 2, 5, and 6 of the paper.

Mr. Johnson comments on the differences between the average test steam flows and steam conditions of duplicate turbines. Most of these differences were caused by having more runs at high loads on one turbine than on the other and by having somewhat different steam temperatures, pressures, and vacuums available. All tests of this paper were corrected to contract conditions by proper factors; each type of performance data for each turbine is the average of one value each for $^1/_2$, $^3/_4$, and $^4/_4$ loads.

The author believes that Mr. Pollock's 1953 paper[7] on weighed flow tests in the owner's plant is very interesting and valuable. There seems to be a slight misunderstanding in his discussion however: Mr. Pollock refers to the author's conclusion about accepting turbines with no allowance for test error as applying to tests in the manufacturer's shop and being based on weighed flows.

Certainly, 80 per cent of the tests reported here were weighed-flow factory tests. But the 20 per cent of them which were tested in the owner's plants have test uncertainties fairly consistent with the factory tests; and Mr. Kratz's 1954 paper on tests on large steam turbine-generator sets in their owner's plants shows comparable accuracy.

The author agrees with Mr. Deming that a test uncertainty of 0.5 per cent could become important for units designed with small margin. However, it seems out of order to make a guarantee on a turbine-generator and then qualify that guarantee to include an allowance of about 0.5 per cent for the uncertainty of precision tests.

Hence the author reaffirms his belief for many years that it is proper to accept or reject a turbine-generator set on the basis of the direct comparison of guaranteed performance with the performance of precision tests, with no allowance for test error.