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AN APPLICATION OF THE CONCEPT OF DESIRABILITY FUNCTIONS IN EVALUATING ERECTION QUALITY

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Key Words

Desirability scale, 'd' value, geometric mean.

Introduction

Evaluation of quality of any product or service poses a common problem. As Harrison states (1), "in nearly all situations requiring human judgement, one is faced with a multiplicity of measures which must be balanced one against the other, weighted in accordance with their relative importance, compromised where these measures are mutually opposing, and variously manipulated to achieve an optimum judement. Even when the determining factors are precisely measurable, a serious problem exists in symmetrically combining the individual measurements into one equally precise index representing the total comparison." The problem becomes more intensive when it comes to evaluating the quality of erection. This article describes how the quality of erection of an electrostatic precipitator chamber in a power plant can be evaluated.

Working Principle

Before an equipment quality can be evaluated, one has to know its working principles. The electrostatic precipitator (ESP) is one of the most important items in a power station. Its purpose is to collect fly ash particles entrained in the flue gas exiting the boiler, and thus helps to reduce air pollution.

ESP essentially consists of two sets of electrodes: the collecting electrode (CE) and the emitting electrode (EE). Collecting electrodes are made of steel sheet pressed to a definite profile and emitting electrodes are composed of thin wire (2.7 mm in diameter) stainless steel material drawn to helical form.

A unidirectional high voltage is applied between the two sets of electrodes connecting its negative polarity to emitting electrodes and positive polarity to collecting electrodes which are also earthed. High voltage induces ionization of gas molecules adjacent to negatively charged emitting electrodes. When ions travel toward positively charged electrodes they meet with dust particles and thus the dust particles are also electrically charged. Due to high electric field, the particles experience force which causes them to move toward collecting electrodes.

A minor proportion of the particles which acquired positive charge is deposited on emitting electrodes. These dust particles deposited on both CE and EE are dislodged periodically by a rapping system.

The various parts of ESP may be divided into two major groups: (1) electrical parts and (2) mechanical parts.

Mechanical parts are assembled in the site and consist of the following:

1. Casing:
   a. Wall panels
   b. Hoppers
   c. Roof panels
   d. Supporting members
2. Internals:
   a. Gas distribution system
   b. Emitting electrode system
   c. Collecting electrode system
   d. Rapping mechanism system
   e. Insulator housing

Electrical parts consist of:

1. Rectifier transformer
2. Main control panel
3. Auxiliary control panel

Defining Quality

The quality of any product or service can be defined as the totality of features and characteristics of a product or service that bear on its ability to satisfy a given need.

Erection quality is defined as the adherence to the specification, procedure given in the drawing, design, and erection manual during erection, thereby satisfying a given need during its services.

Evaluation

Evaluation of such an erection should be done on the basis of raw material quality, with checks being made at different stages of erection and commissioning. If the raw material itself is bad, no matter how good the erection group, the quality of erection is bound to be bad. On the other hand, if the raw material needed for erection meets the required quality, fault in erection process may adversely affect the quality of erection. Hence the degree of conformance to the requirement of the various checks in precommissioning and commissioning should also be taken into account in any procedure for determining the overall quality of erection.

Since various kinds of checks, for example, visual, dimensional and so on, are involved at different stages of erection and since the units of measurement used may differ for different checks, a unified approach was applied by translating the degree of conformance to specification in terms of a dimensionless quality equivalent scale of '*d*' through a suitable desirability function (1).

All the checks required under the erection manual have been classified into three distinct categories (a) visual checks, (b) dimensional checks having both side specification, and (c) dimensional checks having only upper limit of specification.

Three different kinds of desirability scales are used for three categories of checks. A general summary of the different scales used follows. Even within each category the scale can be varied by taking a stiffer or flatter slope of the scale, depending upon the criticality of the checks.

Scale 1. Scale 'd'; Quality Equivalent of Scale of 'd' Description

1.00	Represents the ultimate in 'satisfaction' or quality, and improvement beyond this point would have no appreciable value
1.00–0.80	Acceptable and excellent, representing unusual quality or performance, well beyond anything commercially available
0.80–0.63	Acceptable and good—representing an improvement over the best commercial quality, the latter having the value of 0.63
0.63–0.40	Acceptable but poor; quality is acceptable, but improvement is desired, and materials are likely to lose out to competition
0.40–0.30	Borderline
0.30–0.00	Unacceptable, materials of this quality would lead to failure of the project
0.00	Completely unacceptable

Scale 2. For Two-Sided Specification

For two-sided specification, mathematical transformation from the measurement of property to scale 'd' is accomplished by the equation:

$$d = e^{-(|Y'|)^n} \tag{1}$$

where e = logarithmic constant = 2.71828
n = positive number $0 < n < \infty$ not necessarily integral
Y' = linear/transformation of property variable Y such that
$Y' = -1$ when Y is equal to the lower specification limit, Y min
$Y' = +1$ when Y is equal to the upper specification limit, Y max.
$|Y'|$ = absolute value of Y'

$$Y_i' = \frac{2Y_i - (Y_{max} + Y_{min})}{Y_{max} - Y_{min}} \tag{2}$$

'n' denotes the slope of the curve and as 'n' becomes large, the curve approaches the limiting case $d = 0$ outside the specification limit and $d = 1.0$ within these limits. For any desirability curve corresponding to above equation 'n' may be calculated by selecting a value of 'd' (preferably between $d = 0.60$ and $d = 0.90$), finding its corresponding $|Y'|$ and substituting in the equation:

$$n = \frac{\ln \ln \frac{1}{d}}{\ln |Y'|} \tag{3}$$

Scale 3. When Only Maximum Deviations are Given

$$d = e^{-(1-Y')^n} \tag{4}$$

$$\text{where } Y' = \frac{\text{Maximum deviation allowed—Actual deviation}}{\text{Maximum deviation allowed}}$$

value of 'n' can be determined using the relation

$$n = \frac{\ln \ln 1/d}{\ln(1 - Y')}. \tag{5}$$

For example, the first scale can be represented graphically as in Figure 1. Depending on the criticality of the check, if we want to give a different scale of 'd,' it can easily be done by considering a stiffer or flatter curve compared to that given in Figure 1.

Transformation of Properties to 'd'

The simplest sort of transformation (this is the one that will be insisted upon by the persons involved in erection) is that in which there exists lower and/or upper specification limits, these limits being the sole and unalterable criteria of quality. Outside these limits the value of d is 0.00 and within, the

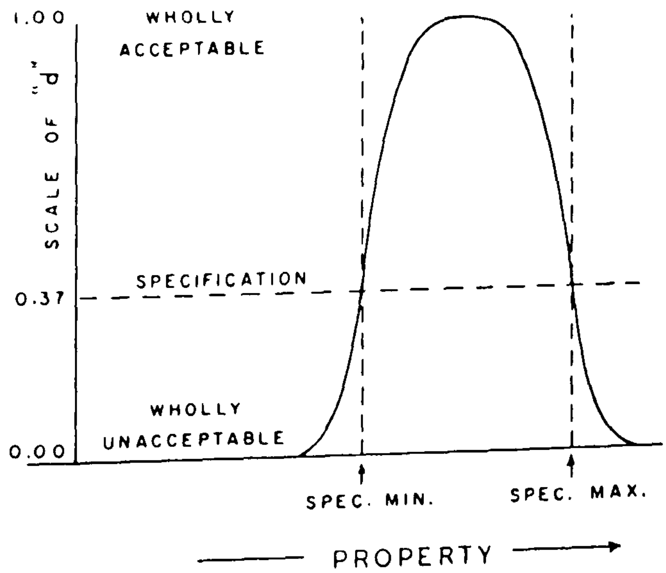

Figure 1. "d" Scale to emphasize midspecification quality.

value of d is 1.00. This almost trivial situation is shown in Figure 2. Even in such a situation it is nearly always desirable from the company's standpoint to stay appreciably within the specification limits, if for no other reason than to avoid substandard quality due to the inherent process variability.

Furthermore, because of sampling and testing imprecision, it is quite impossible to separate borderline quality into two unequivocal groups, the acceptable and unacceptable product. The effect of these considerations is to smooth the discontinuities of Figure 2 as shown in Figure 1.

In Figure 1 the values of the property being considered are represented on the horizontal scale, and the equivalent values of 'd' are obtained by reference to the vertical scale. Mathematical transformation from the measurement of the property to the scale of 'd' is accomplished by the basic equation:

$$d = e^{(-|Y'|)^n}$$

which is no more than the equation given in (1). Note that Scale 1 is a particular case of Scale 2. Scale 1 also is used where the characteristic measured is qualitative in nature.

Although exponential equations similar to (1) are not in common use, they are relatively easy to use and have many properties useful to the desirability function. Equation (1) represents a family of curves, all of which

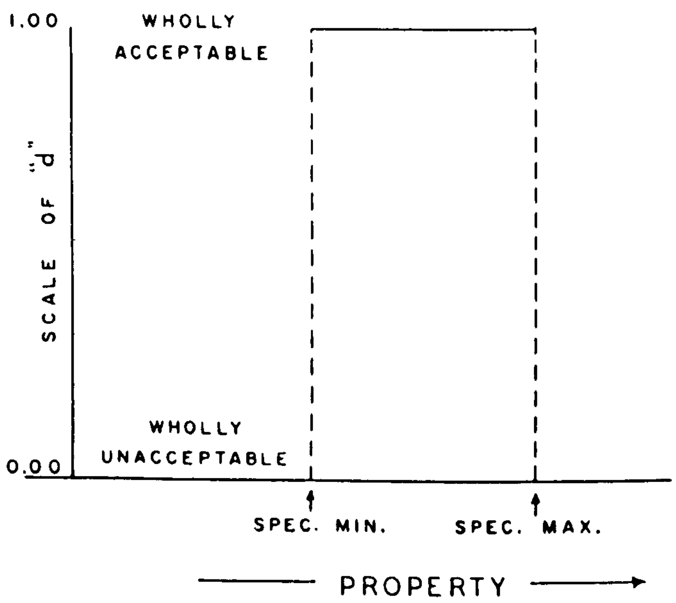

Figure 2. "d" Scale based on specification limits only.

a. Asymptotically approach $d = 0$ as the absolute value of Y', $|Y'|$, exceeds 1.0
b. Pass through $d = 1/e = 0.37$ when the absolute of Y' equals 1.00
c. Pass through $d = 1.00$ at the midpoint between the upper and lower specification limits

Unlike Harrington (1), who used a special form of Gompertz growth curve

$$d = e^{-(e^{-Y'})} \tag{6}$$

for one-sided specifications we have used Eq. (4) for the ones for which only the upper limit is given. The advantage of using Eq. (4) is that it looks simpler to the working engineers and almost the same computer program can be used in both cases with a change $|Y'|$ to $(1 - Y')$ for finding the value of n.

Establishing the Transformation Relation

The method used to get an idea of the transformation relation is as follows:

1. For measurable checks irrespective of whether one-sided or two-sided specification is given: Consider a particular value of the characteristic under consideration. Transform this value in Y'. Consult the concerned person having reasonable experience in that particular characteristic, after describing the background idea, and get a suitable value of 'd' that he or she is willing to give to that value of Y'. Then find the value of n using either Eq. (3) or (5) as the case may be.

If there is more than one item of similar kind required for erection, then 'd' values for each item are calculated using the corresponding equation, and these 'd' values are averaged over all the items. This average represents the single 'd' value for the corresponding check in question.

2. For visual checks, generally, there exists a difference between an evaluation of visual checks by a customer's inspector and a supplier's inspector. Hence an evaluation only from one of the parties could be misleading. In this particular case, for each characteristic where visual check was applied two inspectors, one from the customer and another from the supplier, were asked to evaluate the visual check result by giving a 'd' value in accordance with, say, Table 1. The values thus obtained for two inspectors were tested for equality by sign test and finally one representative 'd' value was obtained.

The precomissioning checks like air leak test and gas distribution test results are also assigned 'd' values using either Scale 2 or Scale 3 as the case may be. Actual commissioning test results were not available and hence not considered for evaluation.

Overall Desirability (D)

Overall desirability 'D' measures the overall quality. It is the geometric mean of all component 'd's, that is,

$$D = \left| \prod_{i=1}^{m} d_i \right|^{1/m} \tag{7}$$

where m is the number of checks for which 'd' values are obtained. The logic behind taking the geometric mean for calculation of 'D' is that no poor quality components are expected to go into the final erection since any 'd' of zero means $D = 0$ by the above relation.

Calculation of Scale 'd' and Overall Desirability D: An Example

Consider the readings of distance between the roof beam bottom and collecting electrode suspension frames top for which a two-sided specification is given as 175 ± 5 mm.

Suppose the concerned engineer wants to give a value of 0.67 to the reading 178 or 172 (since in both the cases taking the value equals Y, the absolute value of Y' as given in (2) are the same and equals 0.6) that is, if we take $Y = 178$ then from (2)

$$Y' = \frac{2 \times 178 - (180 + 170)}{180 - 170} = 0.6$$

and for $Y = 172$

$$Y' = \frac{2 \times 172 - (180 + 170)}{180 - 170} = -0.6$$

then

$$n = \frac{\ln \ln(1/0.67)}{\ln(0.6)} = 1.7914 \qquad \text{from (3)}$$

Once the value of n is known equal to 1.7914, a distance read as, say, 176 mm will have a desirability value

$$d = e^{-(0.2)^{1.7914}} = 0.9456 \qquad \text{from (1)}$$

Note that for $Y = 176$,

$$Y' = \frac{2 \times 176 - (180 + 170)}{180 - 170} = 0.2 \qquad \text{from (2).}$$

For the quality characteristic 'distance between the roof beam bottom and collecting electrode suspension frames top, a representative '*d*' value is obtained by taking the average of all the '*d*' values corresponding to the actual distance readings.

If, for example, only two readings are obtained, say, as 177 mm and 176 mm, then the representative '*d*' value will be

$$\frac{0.8239 + 0.9456}{2} = 0.88475$$

Suppose there are only three such quality characteristics for the erection of ESP and each has got a representative '*d*' value equal to say 0.88475, 0.94558, and 0.51145, the overall '*D*' value can be obtained as

$$D = (0.88475 \times 0.94558 \times 0.51145)^{1/3} = 0.7535 \qquad \text{from (7)}$$

Conclusions

The value of D obtained in this case using (7) was found to be $D = 0.77$. Since there was no standard established for the quality of erection of ESP to date, and this being the first attempt toward evaluating a quality of this kind, there was no other figure available for comparison. Nonetheless, if we compare the value of $D = 0.77$ with the scale given in Scale 1, it becomes acceptable and good.

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Reference

1. Harrington Jr. E. C., The desirability function. *Ind Qual Control* pp. 494–498, April (1965). Figures 1 and 2 are reprinted herein with the permission of the copyright owner, the American Society for Quality Control.

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