ACADEMIC STUDY

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Back to Basics

Accuracy of Shot Peening Measurements

INTRODUCTION

Accuracy of shot peening measurements is a very basic requirement. Three factors comprise a reasoned approach to accuracy. These are:

1. Assumption
2. Precision
3. Bias

Consider, as an example, an analogue wristwatch. It is a fair **assumption** that it will be reasonably accurate because watchmaking is so very well-established. The **precision** will largely depend on whether or not it has a seconds hand. A large **bias** will occur if we travel between time zones without correction. Over time, a small bias will develop—assuming the watch is not radio-controlled. Usually, the more expensive the watch the slower will be the rate of this "creeping bias".

This article considers the implication of the three factors—assumption, precision and bias—on the accuracy of shot peening measurements. Every shot peening measurement has an element of variability. We cannot, however, estimate the variability of measurements unless we have adequate information, aka data. Whole industries rely upon data that they garner meticulously. It was a surprise, when attending an Electronics Inc. Shot Peening Workshop, to discover that most of the students did not retain peening data after they had used it just once. Shot peening data is so easily stored in a data bank such as the ones incorporated into Excel.

Given an adequate number of measurements for a specific aspect of shot peening, we can estimate variability using readily available, simple techniques. Such a technique is called a "Normal Distribution". This technique is applicable to most shot peening measurements. Fig.1 illustrates important features of the technique.

An important feature of Normal Distributions is its sharpness. This is indicated by the Width at Half Height, **WHH** in fig.1. The smaller the value of **WHH** the sharper is the curve. A parameter, **σ**, defines the sharpness. **σ** is called the "Standard Deviation" and it corresponds to the value of **WHH** divided by 2.355. Variance of measurements is defined as being the square of the standard deviation. For fig.1, the mass for each strip in boxfuls of nominally identical Almen strips was obtained using a highly precise balance. Having these multiple values allowed the blue curve to be drawn. This type of curve is sometimes said to be "bell-shaped".

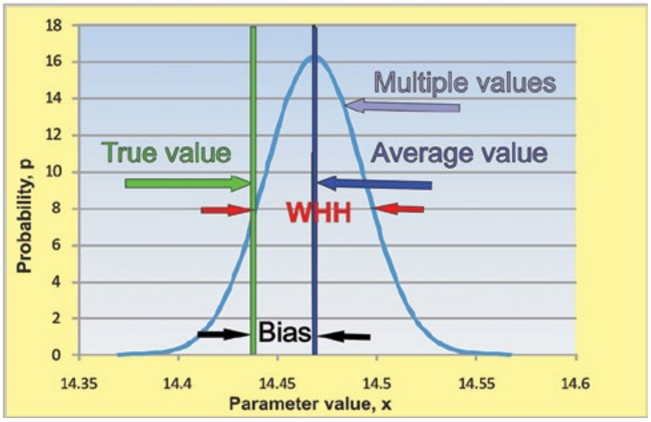

Fig.1. Parameters of a Normal Distribution.

The observed tiny variation of mass could only have been detected by having used a very precise device. The average of the observed multiple values divides the curve into halves.

CALCULATING STANDARD DEVIATION

Knowing the standard deviation of a group of measurements can be very useful. Fortunately, the computerized calculation of standard deviation is simple although tedious if a very large number of measurements is involved. Table 1 shows how Excel facilitates calculation because it includes built-in standard deviation functions. Try it for oneself! In column A of an Excel spreadsheet enter the measurements that require standard deviation calculation—seven for this example. At **8**—below the last entered measurement—type "=STDEV.S(A1:A7)". Press "Enter" and the value of the standard deviation for the measurements appears. Simple!

Table 1. Example of Excel Entries to calculate Standard Deviation.

	Column A
1	14.39
2	14.43
3	14.51
4	14.51
5	14.47
6	14.42
7	14.39
8	**0.051594**

USEFULNESS OF STANDARD DEVIATION VALUE

The value of the standard deviation for a particular variable quantifies the variability. A useful application is to estimate the probability of the parameter satisfying a specified requirement. For any normally distributed variable there is what is called the "68-95-99.7% RULE". This rule is an aid to memory, signifying that 68% of random measurements of the same variable will lie between ±1 standard deviation of the average value, 95% between ±2 standard deviations of the average value, and 99.7% between ±3 standard deviations of the average value. This important concept is illustrated by fig.2.

99.7% Probability

For quality control purposes, the 99.7% probability is particularly important. Consider the following example, which uses simple values for ease of mental arithmetic. Imagine that we have tested a representative sample from a large batch and found that it had an average value of 10 and a standard deviation of 1. We can be 99.7% sure that any other specimen from the same large batch will have a value that lies between 7 and 13—average 10±3. For most shot peening operations, the standard deviation would be much smaller than 1. For a standard deviation of say, 0.1, our 99.7% certainty is that any other specimen will have a value between 9.7 and 10.3.

Variance

The variability of one particular property is called its "Variance". Variance is defined as being the square of its standard deviation. As examples, standard deviation of 2 converts to a variance of 4 and a standard deviation of 0.1 converts to 0.01.

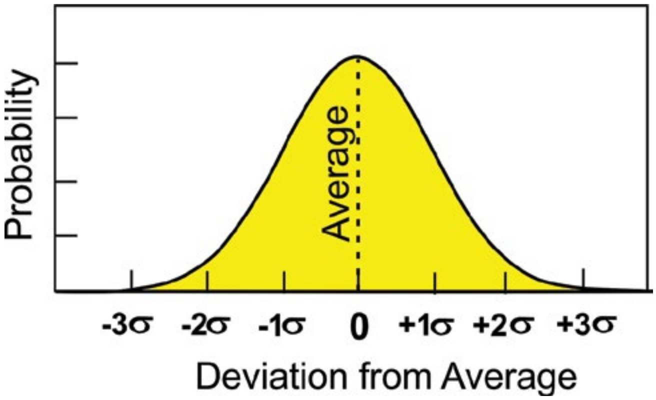

Fig.2. Probability versus Deviation from Average.

VARIABILITY

Variance, **V**, is the square of the measured standard deviation, **σ**, of a set of measurements. Hence:

Variance, V = σ^2

The key to understanding and using variances is to appreciate three of its features:

1 - Constituent variances are additive,
2 - Contributing variances must be identified and
3 - Contributing variances with small standard deviations can be ignored.

1 - Constituent variances are additive. Assume, for example, that single measurements of mass made on each of 50 Almen A strips indicated an interstrip variance of 11 (in arbitrary units). Fifty repeat measurements made on just one of the 50 strips indicated a measurement variance of 1. The interstrip variance is 11 and the measurement variance is 1. Now:

Interstrip variance = Measurement variance + Mass variance

so that, for this example:

11 = 1 + Mass variance

Hence, we can deduce that the mass variance, for this example, is **10** (11 – 1).

2 - Contributing variances should be identified. For example: the variances that contribute to the mass (weight) of an Almen strip can be identified as being length, width, thickness and steel density. No other properties of an Almen strip (such as hardness) contribute to its mass. If, for example, it was established that the variances of length, width and steel density for the strips were all equivalent to 1 then for a mass variance of 10 we have that:

10 = 1 + 1 + 1 + Thickness variance

from which we can deduce that the thickness variance must be **7** (10 - 1 -1 -1).

3 - Contributing variances with small standard deviations can be ignored. This is a very important practical point that is rarely highlighted. Imagine that a particular set of measurements gave a standard deviation of 11 that was contributed by 4 factors having standard deviations of 10, 4, 2 and 1 respectively. This means that:

$$11^2 = 10^2 + 4^2 + 2^2 + 1^2 \text{ or}$$
$$121 = 100 + 16 + 4 + 1$$

Ignoring the contributions of 16, 4 and 1 only makes a small change in the estimated variability. The practical importance is that we should concentrate on trying to reduce any factor that has a much larger variance than any of the other factors. As another example, imagine that the observed standard deviations for length, width and steel density for a given batch of Almen strips all had a magnitude of 1 and that the observed standard deviation for mass was 10. Converting these into variances gives that:

100 = 1 + 1 + 1 + 97 (thickness variation)

That means that 97% of the observed variability can be attributed to thickness variation so that variations of length, width and steel density can effectively be ignored (as being insignificant).

Measurement Variance

Measurement variance arises when an instrument indicates different values for repeat measurements made on the same specimen. For example, a high-precision Almen gage may well indicate slightly different values for arc height when the same peened strip is measured several times. The causes of measurement variance are normally identifiable and involve a combination of operator and instrument factors. Reputable instrument manufacturers usually try to offset measurement variance. Every case, however, is different making it difficult to generalize.

The standard method for countering measurement variance is to take the average of repeat measurements on the same specimen. If two successive measurements are identical then it is generally assumed that there is no significant variance and the average is self-calculated. If, on the other hand, two successive measurements are different then further action is necessary. If the difference is only one instrument unit one can either take the average or take a third measurement. For three measurements with two the same and one differing by only one measurable digit then the value of the two identical measurements is generally accepted.

Parameter Variance

Every shot peening parameter varies. For example, Fig.3 illustrates the variability of indent size. Different parameters vary, however, in different ways. For example the variability of cut wire shot diameter is quite different from that of cast steel shot. Fig.4 shows, schematically, the size distribution of a cast steel shot sample. Cut wire shot shows a Normal Distribution of size.

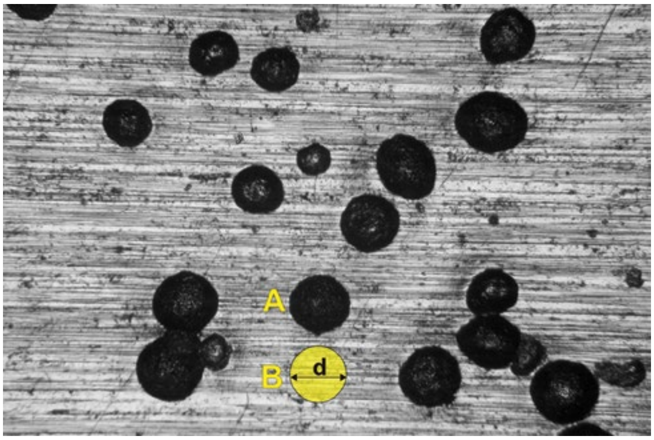

Fig.3 Variability of indent size.

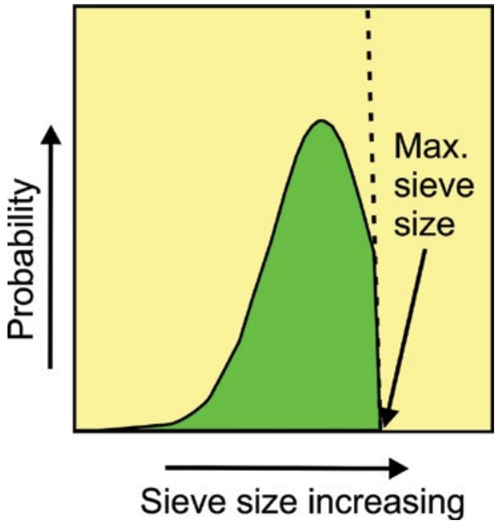

Fig.4. Cast steel shot sieved size distribution.

APPLICATION OF VARIANCE TECHNIQUES

Management and control of variability requires that it can be measured quantitatively. Standard deviation and variance can then be calculated automatically, for example by using an Excel program.

Studies of parameter variability involve several other defined terms. These include:

Population – this is the total number of identifiable objects that could be measured. A 50 kg bag of 110 size steel shot will contain about two hundred and fifty million particles. The population size would therefore be two hundred and fifty million. Taking ten seconds per particle to measure just one parameter would take eighty years to measure the whole population. This leads to the need for selecting a truly representative sample!

Sample Size – this is the number of identifiable objects properly selected as being adequately representative of the whole population. An "adequate number" will depend on the variability of the object and the ease of making individual measurements. The greater the variability the greater is the sample size needed to be representative.

Parameter Distribution – the measured parameter values for a particular sample may have different "distributions". A frequently encountered distribution is the "Normal Distribution" which has a bell shape and would be appropriate for cut-wire shot. As-cast shot, on the other hand, has a different size distribution with zero probability above a certain sieve size but tailing off to very, very fine particles that have passed through the smallest sieve.

Range and Average – range is the difference between the largest and smallest measurements made on a sample. Average (or Mean) is the total of the measurements divided by the number of measurements.

ANALYZING ACCURACY VARIABILTY

Three variability factors determine the accuracy of any individual measurement. These are:

1. Parameter Variability,
2. Instrument Variability and
3. Technique Variability.

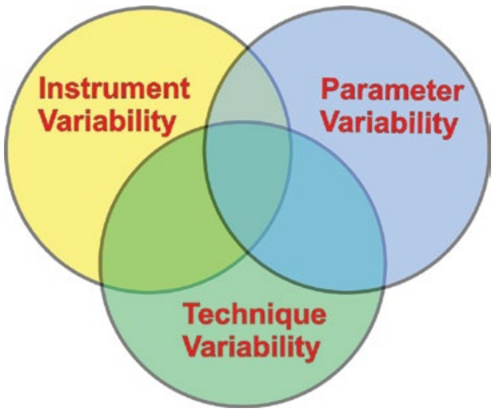

Fig.5. Factors affecting accuracy.

Parameter Variability

Every shot peening parameter has variability. For example, Fig.3 illustrated the variability of indent size. Different parameters vary, however, in different ways. For example, the variability of cut wire shot diameter is quite different from that of cast steel shot. The type of variation affects how it can be measured and controlled together with its significance.

Instrument Variability

Instrument variability is when an instrument indicates different values for repeat measurements made on the same specimen. For example, a high-precision Almen gage may well indicate slightly different values for arc height when the same peened strip is measured several times. The causes of measurement variance are normally identifiable and involve a combination of operator and instrument factors. Reputable instrument manufacturers usually try to offset measurement variance. Every case, however, is different making it difficult to generalize.

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Technique Variability

Errors arise when a measurement technique has an element of subjectivity. A classic shot peening example is the measurement of arc height using an Almen gage. Workshops include training in how to minimize variability of measurement.

IMPLIED PRECISION AND ACCURACY

We must beware of dubious implied claims for precision and accuracy. For example: A manufacturer may display that a coverage measurement of 36.8279634% has been made on a particular sample using their equipment. This cannot be taken to mean that the true coverage has precisely that value. It actually reflects the method that has been employed—such as counting the pixels of an area that has been scanned and allocating them on a yes-or-no basis as to whether or not they correspond to dents. The importance of measurement technique can be illustrated by considering the following: Imagine the lengths of two objects were measured, using an office ruler, to the nearest millimeter. The objective being to obtain the ratio of their lengths. If the two lengths were measured to be 4.7 and 7.1 mm what should be expressed as the ratio? Microsoft Calculator returned a value of 0.661971 83098591549295774647887324. Implying such precision and accuracy is clearly erroneous. We can only properly include one digit more than those of the measurements themselves. Hence 0.662 is far more appropriate (4.7 and 7.1 having two digits).

GRAPHING ACCURACY

Graphs are a splendid way of illustrating trends but only if they are a reasonably accurate utilization of the data involved. The shape of a fitted curve can also reveal useful information.

All shot peeners are familiar with so-called "Saturation Curves". Appropriate equations are fitted to test data of deflections measured on a set of at least four peened Almen strips. Fig.6 illustrates the benefits of employing more than four. The proper shape of a saturation curve is well-established so that using six peened strips reveals any significant deviation.

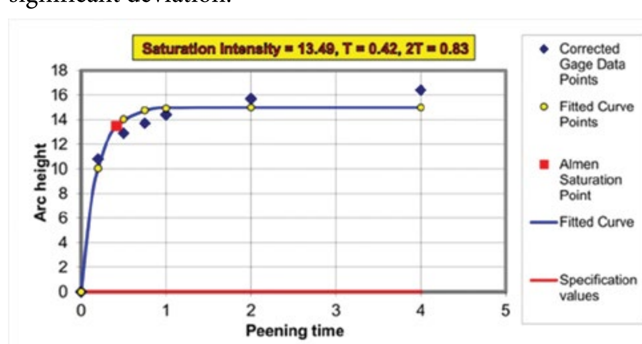

Fig.6. Saturation curve revealing significant deviation.

ALL THINGS CONSIDERED

In order to accurately interpret shot peening graphs it is important to consider all of the things that might have affected the data. The deflection of peened Almen strips depends, for example, upon the elastic modulus of the strips. Equation (1) is a simplified form of the equation (5) that appears in *The Shot Peener* Fall 2009 edition.

$$\mathbf{h = K/E} \tag{1}$$

where **h** is Almen arc height, **K** is a constant and **E** is the strip's elastic modulus. Hence the lower the strip's elastic modulus the greater will be the arc height induced by a given shot peening treatment. Elastic modulus can be affected in several ways mainly by preferred orientation of the steel's grains. A factor commonly overlooked is the testing temperature because it has only a small effect on measured arc height of a given peened strip. Fig.7 shows how the elastic modulus of an Almen strip is affected by room temperature.

Reading from fig.7, the elastic modulus at 28˚C is 2GPa lower than it is at 16˚C. 2GPa is about 1% of the elastic modulus. Hence, the measured arc height on a given peened strip will be some 1% greater at 28˚C than if measured at 16˚C.

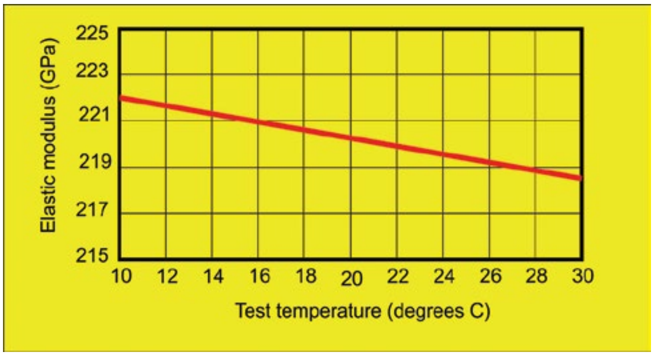

Fig.7. Effect of temperature on the elastic modulus, E, of Almen strips.

DISCUSSION

This article has attempted to highlight the problems associated with achieving accuracy of shot peening measurements. Most of the problems are familiar to shot peeners. Navigating through the various problems is, however, like crossing a minefield. Constant vigilance is required.

Storing data is of vital importance and is not difficult to achieve. Trends can be detected to show what changes are taking place over time. Correction can then be applied where necessary. Measuring equipment must be maintained and routinely calibrated.

Not all the problems affecting accuracy are governed by specifications. A prime example is that of the elastic modulus of Almen strips which can vary significantly.

Cavitating Jet: A Review

The following paper can be downloaded in its entirety at www.shotpeener.com

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Featured Application: Cavitation peening, Cleaning, Drilling

Abstract: When a high-speed water jet is injected into water through a nozzle, cavitation is generated in the nozzle and/or shear layer around the jet. A jet with cavitation is called a "cavitating jet". When the cavitating jet is injected into a surface, cavitation is collapsed, producing impacts. Although cavitation impacts are harmful to hydraulic machinery, impacts produced by cavitating jets are utilized for cleaning, drilling and cavitation peening, which is a mechanical surface treatment to improve the fatigue strength of metallic materials in the same way as shot peening. When a cavitating jet is optimized, the peening intensity of the cavitating jet is larger than that of water jet peening, in which water column impacts are used. In order to optimize the cavitating jet, an understanding of the instabilities of the cavitating jet is required. In the present review, the unsteady behavior of vortex cavitation is visualized, and key parameters such as injection pressure, cavitation number and sound velocity in cavitating flow field are discussed, then the estimation methods of the aggressive intensity of the jet are summarized.

1. Introduction

Cavitation is a harmful phenomenon for hydraulic machineries such as pumps, as severe impacts are produced at bubble collapse [1,2]. However, cavitation impacts are utilized for mechanical surface treatment in the same way as shot peening, and this is named "cavitation peening" [3,4]. The great advantage of cavitation peening is that shots are not used in the peening process, as cavitation impacts are used in cavitation peening [5]. Thus, the cavitation-peened surface is less rough compared with the shot-peened surface, and the fatigue strength of cavitation peening is better than that of shot-peening [6]. In conventional cavitation peening, cavitation is generated by injecting high-speed water jet into water [3,4], and a submerged water jet with cavitation is called a "cavitating jet". The cavitation peening is utilized for the impacts of cavitation collapses, and it is different from water jet peening, in which water column impacts are used. To use the cavitating jet for peening, it is worth understanding the mechanism of the cavitating jet.