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Weld Quality Validation – Sample Size Selection
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Introduction

Weld quality validation involves the need to select lot sizes and sample sizes when performing the *Welding Process Qualification (PQ)* and *Welding Process Validation (PV)* steps within the overall validation process. Refer to our microTip on "Laser and Resistance Welding - Process Validation Fundamentals-2" for a complete description of the validation process.

Unless the customer requires an ISO based sampling plan or one of the former MIL-STD sampling plans, a true sampling plan for determining lot and sample size is rarely implemented. Typically, lot and sample sizes are based on:

- "We have always done it this way before"
- "A lot size of 30 sounds like a statistically significant number"
- "Inspect 2-samples at the beginning and end of each production lot run"

Welding Process Qualification (PQ) involves establishing the weld quality metrics, performing Design-of-Experiments (DoE's) to find out what welding parameters are important in the welding process, optimizing the welding parameters, and conducting a series of small confirmation runs that involve 100% destructive testing of all welded parts made using the optimized weld schedule.

Unfortunately, there is a prevailing belief that destructively testing all 30 optimized parts and comparing the results to a set of limits provides adequate evidence of validation. Some companies use a more sophisticated approach. Three different operators make 30 parts on the same machine or three different operators make 30 parts on three machines for a total of 90 parts. The problem with this "snapshot in time" approach is that it doesn't represent the entire production population made in a series of continuing lot runs.

Over time, resistance welding electrodes wear and oxidize and particles can cover the laser output lens over the defined lot run. These changes decrease the production lot weld quality mean from x-bar to μ and increase the standard deviation as shown in Figure-1[1].
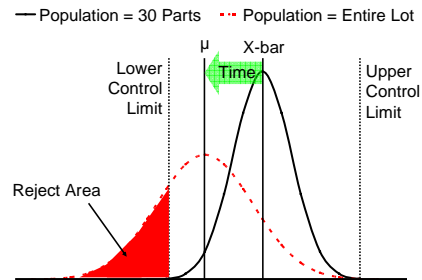

Figure 1

The good news is that a PQ confirmation run of 30 to 90 parts does provide important information that can be utilized to create a statistically significant sampling plan when welding consecutive production lots as required by the *Welding Process Validation (PV)* step. This valuable information includes:

- Distribution shape of the confirmation run
- Standard deviation (s_c) of the confirmation run

Roadmap to Confusion

Confidence Intervals, Margin of Error, AQL, Cpk, Ppk, PPM, Six-sigma, Sampling by Variables, Sampling by Attributes etc seem very confusing. What statistical metric do you choose? For example, the political polling industry employs *Confidence Intervals* and *Margin of Error*. Manufacturing industries demand *Cpk* and *Six-sigma*. Mathematically, these terms are all related, but it is not easy to find a Rosetta stone that can translate *Six-sigma*, *PPM*, or *Cpk* into a meaningful sampling plan.

Roadmap to Simplification

The diagram in Figure-2 represents a practical method for creating a Variable Sampling Plan for the *Welding Process Validation (PV)* step using Minitab® statistical software[2]. ISO 3951 and MIL-STD-414 (ANSI/ASQ Z1.9) contain tables that define sample size based on lot size, AQL, and Inspection Level. The AQL values are limited to 0.10% in the ISO document and 0.04% in the MIL-STD document. These documents do not provide AQL values representing Five and Six-sigma or Cpk metrics. Minitab provides the capability to use any AQL value but does not yet offer the capability to set up a sampling plan using Cpk values.

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Minitab® Sample Size Procedure

This microTip begins by converting user selected Cpk values to the AQL and RQL values required by Minitab. The conversion from Cpk to sigma to PPM is based on the following formulae[2,3]:

Sigma = Cpk x 3
PPM = e $((29.37 – (sigma - .8406)^2) / 2.221)$
% AQL = PPM / 10,000   %RQL = % AQL x 6.55

Cpk	Sigma	PPM	AQL (%)	RQL (%)
1.67	5.0	229	0.023	0.15
1.83	5.5	32	0.0031	0.02
2.00	6.0	3.5	0.00035	0.0022

AQL represents the largest number of defectives or defects in a process that will still be considered acceptable. Typically, a sampling plan is designed to give a high probability of acceptance at the AQL value[2]. RQL represents the number of defectives or defects in an individual lot that you are willing to tolerate[3]. Typically, a sampling plan is designed to give a low probability of acceptance at the RQL[2]. The Ratio of AQL/RQL represents an *Inspection Level IV* contained in MIL-STD-414[4] and a *Normal* inspection level for ISO 3951[4].

The flow chart in Fiugre-2 below makes the following major assumptions[1]:

1. The sampling plan is based on variable data only.
2. The PQ confirmation run data is stable and normally distributed.
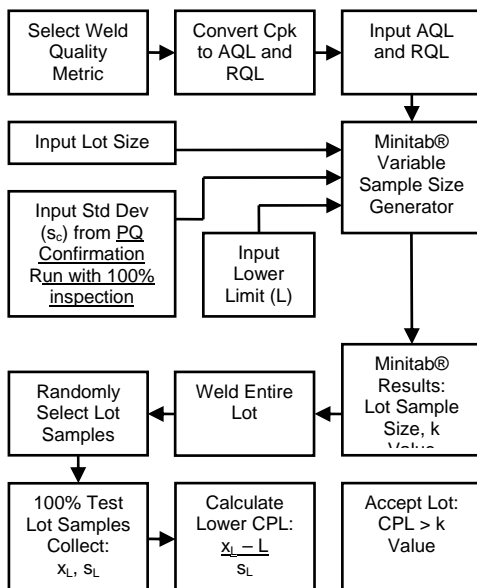3. Standard deviation (s_c) from the PQ confirmation run is available.

Figure 2 – PV Lot Weld Validation

Select Weld Quality Metric

There are two types of weld quality metrics[1], variable and attribute. Tensile/shear and peel represent variable data. Attribute data represent discrete levels, such "Pass/Fail" or failure mode break codes. Using variable data result in fewer samples.

Input Minitab® Data

Input AQL, RQL, Lot Size, PQ Confirmation Run Standard Deviation (s_c), and the desired Production Lower Limit (L) into the Minitab Variable Sampling Plan Generator. Note, specifying a Upper Limit for laser and resistance welding processes has no practical meaning and in some cases, can cause usable parts to be unnecessarily rejected.

Minitab® Results

Minitab will generate the minimum PV lot sample size and the *k Value*, which is the target quality statistic for comparison with the CPL statistic.

Weld Entire Lot

Weld the entire lot under normal production conditions so that electrode wear or cover glass contamination effects are included.

Randomly Select Lot Samples

Randomly select welded samples from the entire lot using the sample size generated by Minitab.

100% Test Lot Samples

100% test all of the randomly collected samples from the lot run. Obtain the lot mean (x_L) and the lot standard deviation (s_L).

Calculate CPL

Calculate the lower Cpk statistic, CPL as follows:
$CPL = (x_L – L) / s_L$, where L = lower production limit

Accept or Reject Entire Lot

If CPL > k Value, accept the entire lot, otherwise reject or 100% inspect.

References:

1. Quality Control Handbook, Third Edition, J.M. Juran, Frank M. Gryna, Jr. and R.S. Bingham, Jr.
2. Minitab® Statistical Software, Release 15.
3. http://www.faravesh.ir/files/1198666243Six%20Sigma%20Calculator.xls
4. MIL-STD-414, ISO 3951