White paper

Application of acceptance sampling in testing of optical fiber

Author
Sudipta Bhaumik[a] and Kuldeep Bhargava[b]
[a] Sterlite Technologies Ltd., [b] Kaizen Consultants, India

Abstract
Acceptance sampling is one of the oldest aspects of quality assurance and used primarily for incoming and outgoing lot by lot quality assurance. Sampling is generally less expensive than hundred percent inspection and in case of destructive testing it is the only way. Optical fiber is produced in different length ranging from 2.1 km to 50.4 km or more. Fiber sample on shipping spools are tested for attenuation, wave-guide parameters (Mode Field Diameter, Cut-off wavelength, Dispersion) and geometry parameters (glass and coat geometry). Except attenuation and dispersion, all testing are destructive in nature and conventional way to measure these parameters is to cut few meters of fiber from either/both end/s of the sample and perform measurement. Here underlying assumption is that the end test value is same at any point of fiber sample. Acceptability of this assumption mostly depends upon variations in parameter along the length of the fiber or in statistical terms process variation of the parameters and GRR (Gauge Repeatability and Reproducibility) of the measuring instruments This, paper describes application of variable sampling customized for continuous testing of optical fiber specially for high volume production.The customized sampling is found in good agreement with conventional variable sampling plan. Significant reduction in testing time (upto 70%) is observed when compared with 100% testing. Although benefit of the sampling plan depends upon average length of production and process variation.

Key Words
Optical fiber, Quality testing, Variable acceptance sampling, Gauge performance curve.

1. INTRODUCTION

Acceptance sampling is one of the oldest aspects of quality assurance and used primarily for incoming and outgoing lot by lot quality assurance. Sampling is generally less expensive than hundred-percent inspection and in case of destructive it is the only way. It also leads to less handling of the product and therefore chances of damage to the product are significantly reduced. Besides, by resorting to sampling inspection manpower requirement for testing/inspection and amount of inspection error often considerably reduced. Particularly in production set-up of high-quantity, repetitive inspection such as hundred-percent inspection and exhaustion of inspector normally fails to identify all nonconformities or non-conforming units and some of the nonconforming units inadvertently pass the inspection system. Sampling also plays the role of strong motivator to improve quality as entire batch or lot may be rejected. However, sampling inspection has certain disadvantages. One of the prime disadvantages is probability of acceptance lot of "bad quality" and rejection of lot of "good quality"; however, risk of committing such mistakes is known and is based on the economy of sampling inspection versus hundred-percent inspection. Besides, less information is generated about the product quality compared to that is obtained while carrying out hundred-percent inspection. Implementation of sampling plan requires more planning and documentation where as hundred-percent inspection requires none.

Depending upon the type of data, acceptance sampling can be divided into two categories; attribute and variable. The detail of both types of sampling plans is well described in the literature[1-4]. In both types of sampling inspection, samples are randomly chosen from the batch, lot or process and based upon the acceptance and rejection criteria the lots are accepted or rejected. Design of a sampling plan is basically based on four factors; Acceptable Quality Level (AQL), α (Producer's risk), Reject Quality Level (RQL) and β (Consumer's risk).

AQL- Lot quality that has high chances of acceptance with a particular sampling plan.
RQL – Lot quality that has low chances of acceptance with a particular sampling plan.
α - The risk associated with rejecting a lot of "AQL" quality. (1- α) the probability of accepting lot of AQL quality.
β - is the risk of accepting a lot of "RQL" quality.

Values for these factors are arrived by mutual agreement between producer and consumer. Best sampling plan is the one that satisfies the interest of producer as well as consumer.

If we state that for AQL of 0.02 and α-risk is 0.05, it means that the lots that are 2% nonconforming (AQL) should accepted 95% of time and rejected only 5% time. Likewise, RQL of 0.08 and β -risk 0.10 means that the lots that are 8% nonconforming (RQL) should accepted only 10% of time and rejected only 90% time.

Variable sampling plan is employed where quality characteristics are measured on a numerical scale like weight, pressure, temperature etc. Advantage of variable sampling plan over attribute sampling plan is that for the same level of quality assurance it requires much smaller sample size, provides information in regards to lot quality leading to identification of areas for quality improvement. Some disadvantages of variable sampling plans are separate sampling plan required for each quality characteristics; accuracy of conclusion depends on normality of the measured data and generally requires more expensive measuring instrument.

2. OPTICAL FIBER MANUFACTURING AND TESTING

Optical fiber production is basically batch type process where fiber is drawn form a cylindrical glass rod (called preform). Fiber drawn from one preform can be considered as one batch. Length of fiber drawn from one preform can be as long as 1000 km. After drawing, fiber is sent for proof testing where a pre-determined tensile load is applied on the fiber to eliminate weak regions and wind the fiber on shipping spool. Length of fiber in shipping spool is varied from 2.1 km to 50.4 km or more (usually 25.2 km). Fiber length depends upon consumer's length requirement, break rate during proof testing and requirement of fiber cutting during reworking to eliminate defective portion. Usually all lengths are tested for optical losses (attenuation), wave-guide parameters (Mode Field Diameter, Cut-off wavelength, Dispersion) and geometry parameters (glass and coat geometry) as consumer of optical fiber like to have numerical measurement data for all shipping spools. Other than attenuation and dispersion, all testing are destructive in nature and conventional way to measure these parameters is to cut few meters of fiber from either/both end/s of the sample and perform measurements. Here underlying assumption is that the end test value is same at any point of the sample fiber. Acceptability of this assumption is mostly depends upon variation of the parameter along the length of the fiber or in statistical terms process variation of the parameters and GRR (Gauge Repeatability and Reproducibility) performance of the measuring instruments. Variation is controlled to a minimum level so as to avoid any parameter going out of specification limit at any point of the tested sample. As optical fiber testing generates numerical data, for quality assurance of the parameters variable sampling plan is most appropriate.

3. PROBLEMS WITH CONVENTIONAL VARIABLE SAMPLING PLAN

Implementation of conventional variable sampling plan for optical fiber testing faces below issues for high volume production:

1. In high volume production of optical fiber several preforms are drawn simultaneously and fibers from different preforms (batches) are proof tested. After proof testing, shipping spools with fiber from different batches come randomly for optical and geometry measurement where fiber from different batches are not segregated and tested 'first come first test' basis. However, it requires more measuring instruments, which are very expensive, and results high holding time between different testing stages. Batch wise testing also needs high storage capacity in between proof testing & attenuation testing and attenuation & waveguide-geometry testing. As every shipping spool having unique identification number, which is traceable to different batches, batch wise measurement can be done and conventional variable sampling plan, which needs samples representing the batch, can be employed. .

2. As per standard practice, all shipping spools must have information of individual test values of attenuation, wave-guide, and geometry parameters. In conventional variable sampling plan, samples are selected and measured randomly. Average value of measured samples is reported against un-measured samples of accepted batch. For the performs (batches) where quality parameters distributed with a trend (increasing or decreasing) from start to end of drawing process, the average of measured value may be significantly different than the actual value particularly two ends regions. Thus there is a possibility of reporting of wrong values against the un-measured samples.

3. Once AQL, RQL, α-risk, and β -risk are fixed; acceptability of a batch as per conventional variable sampling plan is dependent on Upper Specification Limit (USL), Lower Specification Limit (LSL), average and standard deviation of the measured samples. We have seen the batches where quality parameters are very close to USL or LSL but low standard deviation of measurements of sample; conventional variable sampling plan accepts the batch even though few measured values fall outside of USL or LSL. In that case the adjacent piece that has high probability of failure, of the failed sample is accepted (if not measured).

4. CUSTOMIZATION OF SAMPLING PLAN

A sampling plan customized to high volume optical fiber quality testing has been designed to overcome the hurdles with conventional variable sampling plan. Two variations– process and measurement are considered to design sampling plan.

4.1 Process variation

Measurement of waveguide and geometry parameters of optical fiber is destructive in nature. Here top or bottom measured values are assumed to be same at any point of the fiber. The measurements of the sample are analyzed for the normality using “Normal Probability Plot” and Anderson Darling (AD) Test. If the measurements of sample appear as straight line on normal probability plot and the P-value of AD test is more than 0.05 then the mean of the sample is used for assigning the values for the spools of the entire batch. Below example is given for Secondary Coating Diameter (SCD in μm).

Table 1 shows base data of secondary coating diameter and corresponding cumulative length of a preform (batch). Fig.1 shows result of normality test of base data. The base data passes Anderson-darling normality test as P-value (0.609) is above 0.05.

Cummulative Length (km)	SCD (in μm)	Cummulative Length (km)	SCD (in μm)	Cummulative Length (km)	SCD (in μm)
20	245.3	213	245.3	340	244.8
35	245.6	220	246.0	351	244.8
57	245.0	225	245.5	364	244.4
76	244.7	230	246.7	375	244.8
101	244.6	239	245.3	389	245.6
126	244.6	253	245.8	391	245.5
132	245.9	264	245.8	394	244.0
140	245.2	278	245.2	403	245.2
152	245.5	282	245.7	428	244.8
160	246.1	290	244.8	429	245.4
165	246.5	303	246.7	455	246.1
169	246.7	303	246.5	470	245.9
177	246.0	315	245.5	483	245.6
194	245.8	319	246.0	488	245.2
203	245.3	-	-	-	-

Table 1 Base data of secondary coating diameter

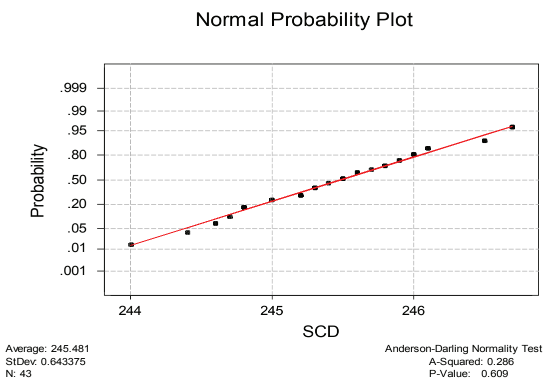
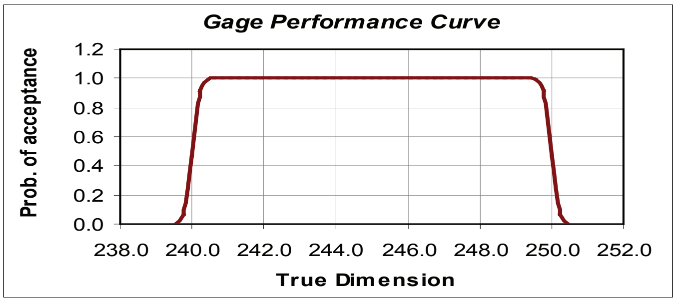


Figure 1 Normal Probability plot of base data

4.2 Measurement Variation (Gauge Performance Curve)

Gauge performance curves are determined for each parameter and for each measurement system from gauge repeatability and reproducibility (GRR) study[5]. GRR study is carried with five samples covering entire specification range, three operators, and three readings per sample per operator. Fig.2 is Gauge Performance curve of SCD having upper and lower specification limit 250μm and 240μm respectively. The 99% zone for the measuring system is 240.4 to 249.6μm. It means that if the actual measurement of SCD is between 240.4 and 249.6 then probability of making correct decision 99% of time. Table 4 shows 99% acceptance zone of different waveguide and geometry parameters. The frequency of measurement system analysis is normally six month until and unless there is breakdown or major maintenance work.



Zone for accepting 99% times			
From	240.4	To	249.6
%Tolerance	91.6		

Figure 2 Gauge Performance Curve of Secondary Coating Diameter

Parameter	Specification range	99% accepting zone
Mode Field Diameter (in μm)	8.8-9.5	8.9-9.4
Cutoff Wavelength (in nm)	1140-1315	1152-1303
Clad Diameter (in μm)	124.3-125.7	124.33-125.67
Core-Clad Concentricity error (in μm)	≤ 0.5	≤ 0.47
Clad Ovality (%)	≤ 0.8	≤ 0.6
Secondary Coating Diameter (in μm)	240-250	240.4-249.6
Secondary coating concentricity (in μm)	≤ 10	≤ 9.7
Coat Ovality (%)	≤ 3	≤ 2.4
Fiber Curl (in m)	≥ 4	≥ 7.7

Table 4: 99% acceptance zone of waveguide & geometry parameters

4.3 Design of sampling plan

In optical fiber testing all testing instruments are connected with centralized data storing system with two-way communication. When samples from various batches come randomly for waveguide or geometry testing, from centralized data storing system the operator understand whether the sample is required to test or not. Preference is given to test at least one shipping spool per 100 km proof tested fiber to capture any localized variation. After completion of testing of all samples of a batch, the centralized data storing system checks for acceptability of the batch using conventional variable sampling plan. The sample size for a sampling plan (AQL=0.02, α=0.05, RQL=0.10, β=0.07) is 12. Twelve values are picked up randomly from the measured samples and using specially developed software acceptability of the entire lot is determined. Sample mean and standard deviation is computed. The point (sample mean, standard deviation of sample) is plotted decision graph. If plotted point falls in acceptance region, the lot is accepted else rejected. If the measured sample values pass Normality test, sample mean value is reported against the unmeasured sample. Otherwise nearest tested value within 100 km length is to be chosen. Good agreement between customized and conventional sampling is found when compared for around 10 batches of each parameter. However, few cases found where conventional sampling accept the batch, but customized sampling plan ask for 100% testing of some regions where tested values go out of 99% accepting zone.

4.4 Benefits

Benefits accrued by introducing customized sampling plan for high volume production of optical fiber are:

- No extra holding time is required for customized sampling plan.
- Insignificant difference between reported and actual values for un-tested samples.
- As measurement variation is considered during designing of sampling plan, there is much less possibility of passing failed fiber because of sampling particularly for the batches where population is close to the extreme limit of specification range.

- With variable sampling plan, 70-80% less samples are required to test and one set of waveguide and geometry testing instrument can do testing of same volume of production for which four sets of instruments would be required when 100% testing in place. This incurs a saving of Rupees 4 crore approximately.

- Other benefits of sampling like less manpower, power, and handling damages are accomplished. Saving towards instruments maintenance and consumables are approximately Rupees 27 lacs /year.

5. CONCLUSION

A customized variable sampling plan is designed for high volume optical fiber testing to overcome various implementation issues like high holding time for batch-wise testing, passing of fail fiber and high difference between actual & reported values. The customized sampling is found in good agreement with conventional sampling.

6. REFERENCES

1. MIL STD 105E
2. MIL STD 414
3. Douglas C. Montgomery, Introduction to Statistical Quality Control, Fourth Edition, John Wiley & Sons, Inc.
4. Amitava Mitra, Fundamentals of Quality Control and Improvement, Second Edition, Pearson Education.
5. Measurement Systems Analysis, Third Edition, March 2002.