Sampling procedure for optical measurements in woven wire production

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1. Introduction

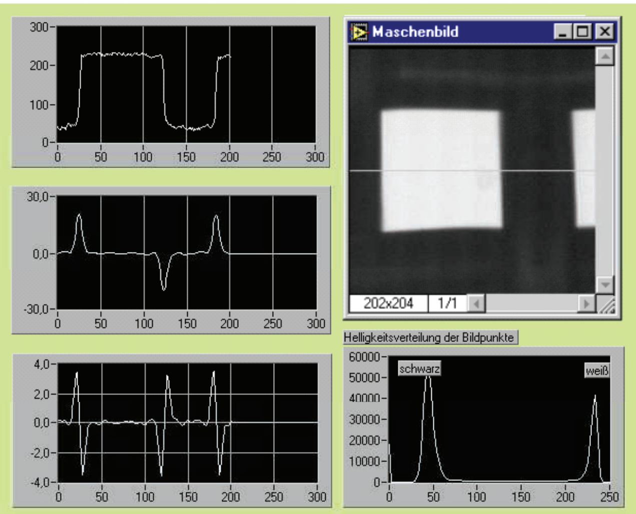
Measurements with optical devices often require a selection of some items from a large amount of measurement objects. Such selection procedures can be described as sampling which is part of the measurement process itself. The measurement results are defined as a quantity which is assumed to adequately represent a property of the measurement objects.

In many branches of industrial production sampling procedures are based on a Gaussian distribution, i.e. the object's properties have a single mean value and the measurement results are clustering around this mean. This assumption is, for example, very prominently expressed in sampling models described in the ISO 2859 [1] and ISO 3951 series [2]. However, generally, the Gaussian distribution is good as a first approach but sometimes thorough investigation reveals that the distribution of the measurement items is not a normal one. This insight may have a considerable impact especially on the use of measurement results.

An increasing precision of optical instrumentation in many fields of application reduces the uncertainty of measurement results, including effects from sampling because it is possible to measure larger numbers of samples. But the uncertainty budget should include possible influences assumptions made for sampling. The inadequacy of an assumed distribution may have a negative influence on the measurement uncertainty. In this presentation woven wire products serve as an example. Some ISO standards for wire cloth and wire screen products [3, 4, 5, 6] use Gaussian distributions for mesh sizes in the conformity assessment but this is not really correct.

2. Measurement procedures

Producers of wire screens and wire cloth produts faced several problems with statements on the conformity of their products on the basis of the ISO standards mentioned above. The industry therefore aimed at better understanding the reasons for the problems and initiated two research projects. The subjects of the first project were measurement procedures and product tolerances and the focus was put on the uncertainty of measurement in the final control of the products. The second research work aimed at finding the main factors for the dispersion of the apertures in the production process.



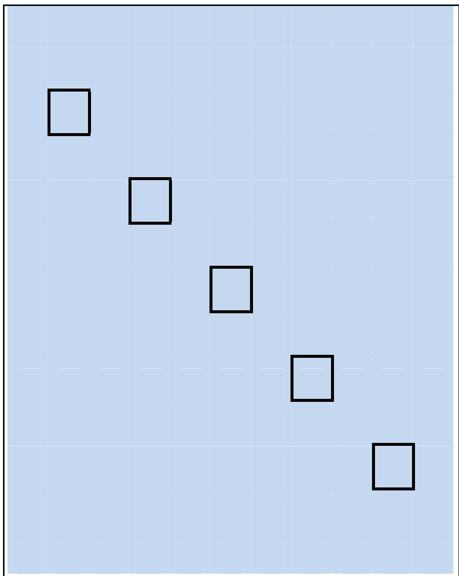
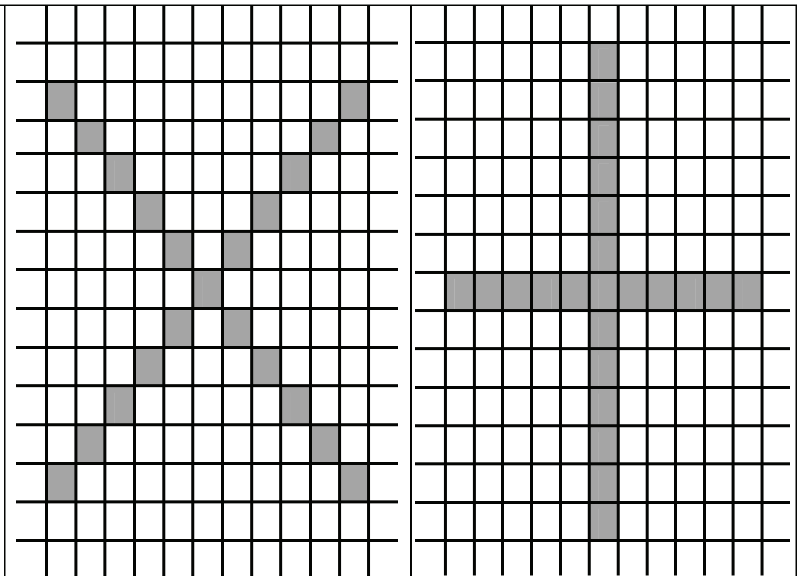
Mesh sizes of woven wire products are measured both in the production and in the issuing area. Transmitted bright field microscopes with collimated light produce images that allow to quantify the mesh size as an average distance of wires in the products. The left figure shows an example of a measurement of a single aperture. The processing of the measurement data is usually done on the basis of industry standard statistical software. The variance of the apertures is usually much larger than the variance caused by testing. The uncertainty of the individual test result is therefore negligible in many cases.

Continuous on-line measurements of the apertures are not applicable to the wire weaving process yet. For production control purposes the woven wire products are regularly visually checked and measured using semi-quantitative instruments. These control checks are mainly aimed at maintaining constant production conditions but the results do not provide enough information on the mesh size and the variance. Therefore samples are taken mostly in two steps for some off-line measurements on a regular basis:

1st step: Some small parts compared to the over-all area of the product are cut out as illustrated in left figure below. The choice of the areas to be measured occures on a more or less arbitrary basis but according to the principle of sampling from normal distributions that each part has to have the same probability to be chosen.

2nd step: The parts cut out are then subjects to measurements of the aperture sizes. They are measured simultaneously in both warp and weft (shute) directions mostly according to proposals from the relevant ISO standards (see figures below).

Thus the situation in the wire weaving industry is comparable to many other branches of industrial production, i.e. the number of items (apertures) measured is an extremely small fraction of all of the items (apertures) of the product.

	
Method to choose areas to be measured from a wire cloth	Proposals for sampling for measuring apertures

As said above the ISO standards for woven wire products assume a normal distribution of the properties measured. However, recent research [7] has revealed that, firstly, this general assumption is reasonable for the weft (shute) direction only. The dispersion of the apertures in the warp direction are better described by a beta distribution. This phenomenon can sometimes be clearly seen when there are two peaks in the distribution function. Secondly, especially in woven wire products with precision requirements for the aperture the spread in the warp direction is often larger than that in the weft direction. Therefore the influence of beta distributed apertures should dominante the probability density function.

The specific definition of a normal distribution requires a mean value and an associated variance. For the definition of a specific beta distribution the so-called shape parameters are needed additionally. That means for woven wire products that realistic estimates both for a narrowest and a widest apertures have to be quantified. But how can one get such estimates for production lines where only very small numbers of measurements are performed?

A starting point are the checks in the production control. Extreme values of apertures in a wire screen or a wire cloth tend to cluster in small areas and the personnel is trained to visually identify such areas. They carry out semi-quantitative measurements on a go/no go basis in order to control if a given maximum aperture according to a specification is being exceeded. It is quite simple to use such checks for the definition of a model based on a beta distribution, i.e. such checks could also produce quantitative measurement results, provided that the precision can be made acceptable. When such data are documented and evaluated the results can be used to arrive at estimates that can reasonably be used for the definiton of a probability density function.

3. Sampling procedures

These new results may influence the sampling part of the measurement procedure because sampling procedures require good definitions of the population. A basic principle of sampling for many applications is that the probability to be measured shall be equal for each item in the population. Thus the calculation of both the mean value and the variance encompasses extreme values. The smaller the number of samples the more they widen the variance and thus increase the probability of values lying beyond the maximum and minimum result of the measured sample. Generally, the probability to find a maximum or minimum value in a very limited number of samples is extremely small, so an extrapolation of values is necessary. In the case that the population is beta distributed, however, there are known limits. The application of a normal distribution function would assign certain propabilities to apertures which are not possible. Therefore both the assumption of a normal distribution and the subsequent basic principle of sampling are obviously not applicable.

When taking a beta distribution into account the sampling procedures for measurements of woven wire screens and cloth during the production process (1^{st} step as given above) would not have to be changed and samples would be taken as before. Also the simultaneous measurement of apertures in warp and weft (shute) directions of the final product (2^{nd} step as given above) including the sampling would remain same. The only important change would be the minimum number of samples as a sampling based on a beta distribution would allow to reduce that number. Why is that so?

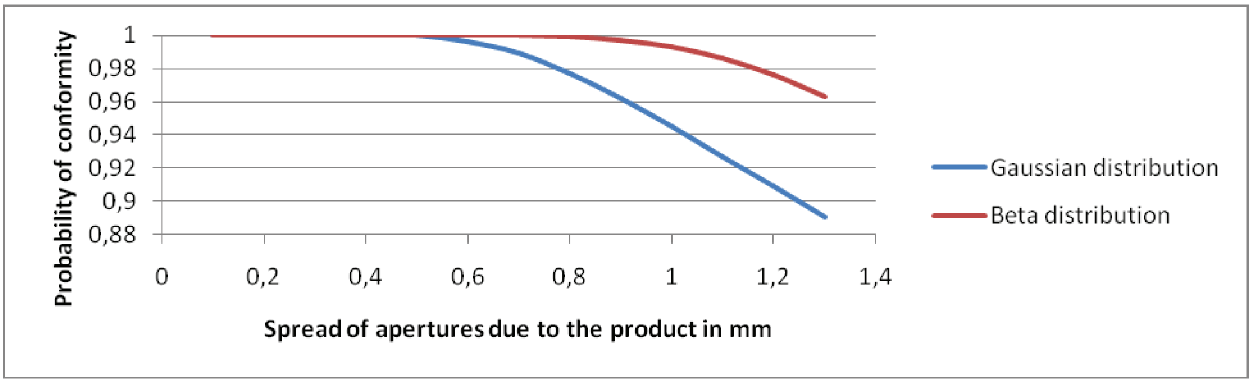
In contrast to the normal distribution the application of the beta distribution function requires explicit information about the product, i.e. the model is based on both specific and detailed measurement results. And, generally speaking, the more you already know about the measured object the less new knowledge through measurement you have to produce. In order to define the model measurements have already been carried out, additional work is only necessary to get information about the specific items of the product. Provided stable production conditions the number of samples can be further reduced in the long run because the model parameter can be based on an increasing amount of data.

The following provisions should be considered for setting up a model that is (partly) based on a beta distribution:

- Normal distribution should be assumed
  - generally for apertures in the weft direction.
  - for uncertainties due to the measuring instrument.
  - when the variances in the weft are larger than in the warp direction.
  - when the over-all variances are small. In such case both distributions are very similar.
- Beta distribution should be assumed
  - when the variances in the warp are larger than in the weft direction.
  - when the variances are large compared to the possible spread of all apertures.

4. Conclusion

These results may have considerable consequences for risk assessments on conformity statements if the dispersion of apertures is not small. The figure below shows an example: The producer's risks are lower when the modified procedure using the beta distribution is applied. However, the producer has to invest in measurement for the definition of his production-specific parameters if he wants to enjoy this advantage.



5. Literature

[1] ISO 2859 series Sampling procedures for inspection by attributes

[2] ISO 3951 series Sampling procedures for inspection by variables

[3] ISO 9044:1999 Industrial woven wire cloth – Technical requirements and testing

[4] ISO 14315:1997 Industrial wire screens – Technical requirements and testing

[5] ISO 3310-1:2000 Test sieves technical requirements and testing – part 1: Test sieves of metal wire cloth

[6] ASTM E11-09 Woven wire test sieve cloth and test sieves

[7] Hinrichs, WH; Specific assessment of conformity risks vs. application of a general procedure; Proceedings of the 8th International Probabilistic Workshop, 18/19 November 2010, Szczecin