

# The long way to reliable inline production measurement in metal wire products manufacture

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**Abstract** – Optical inline measurement is common in textile production, but not in the manufacture of some metal wire products using comparable techniques. The reason is that some ISO standards require highly precise measurements which are hardly feasible in the running production. Major factors for getting results of the aperture - the most important value in this respect - are the time needed to focus the camera, strong vibrations of the weaving machines as well as the light on reflecting surfaces and reference objects. Even in offline measurement, the comparability of the results is limited due to more restricted requirements especially in ISO 3310-1:2016 and ASTM E11-17 (test sieves). In these documents the conformity assessment methods have been updated on the basis of metrological recommendations. An ISO working group decided to pick up this issue and to look into the possibilities to improve the situation. That addresses the number of apertures to be measured, the coverage factors used as well as the overall statistics applied in the standard. Some research project are going to start accordingly in order to make the standards usable in the future.

**Keywords** – metal wire products, optical measurement, aperture, test sieves, measurement uncertainty, conformity assessment

## I. INTRODUCTION

In industrial textile manufacture, inline production measurements are important for high-quality level products. The measuring instruments used are often

highly sophisticated and needed to maintaining specified levels of a continuous regularity of the product. This situation is – from a measurement point of view – quite different in the manufacture of metal wire cloth and screens.



Picture: Manufacture of metal wire cloth

Metal wire products are world market products for a wide range of applications. An important share of these products is used for sieving and filtering as well as for the classification and grading of solid matter. In addition, screens for printing purposes are also often made of metal wire with more or less precise requirements as regards the wire diameters and apertures.

Metal wire cloth and screens are mainly produced in East and South Asia, in Europe and North America. Important standards are ISO 3310-1:2016 (Test sieves) and ASTM E11-17 (Standard Specification for Woven Wire Test Sieve Cloth and Test Sieves) as well as ISO 9044:2016 (Industrial woven wire cloth) and ISO 14315:1997 (Industrial wire screens).

In the last twenty years in the revision processes of these ISO standards the focus was on improving the measurement techniques. This aimed mainly at the precision of the products and/or the evaluation of measurement results with statistical methods. At the same time, users asked for improved documentations of the measurement results. Finally, it had to be clarified whether test sieves according to ISO 3310-1 are measuring devices or not. In sum, the revisions led to more stringent product specifications.

## II. NESSECITY OF REASEARCH

The kick-off for the research on measurement procedures for wire screen and woven wire cloth products was the general observation that the comparability of measurement results of the mean aperture sizes of test sieves for nominal apertures of  $w_N \leq 2.0$  mm is poor. This can be illustrated with the comparison test of the results from six laboratories of a product with a nominal aperture of  $w_N = 0.1250$  mm. The same test sieve claimed to be in accordance with ISO 3310-1 was sent to the participating specialized laboratories. Three of these conformity assessment bodies came to the result that a certificate of compliance can be issued, whereas the three others stated that the test sieve did not comply with the standard. This example is specific but it confirmed a general experience from practice.

The simple reason why the producers have not paid attention before to this phenomenon is that measurement results were mostly generated under repeatability conditions and they were rarely documented. There was no substantial reason to further analyze this kind of data because that rarely raised problems neither in production nor when used in bilateral agreements where one party carried out the task. However, under reproducibility conditions the situation is quite different and problems are emerging with increasing multilateral trade relations.

The analysis of test data from the production sites in the research project has made clear that the general assumption of a Gaussian distribution of apertures is not correct. For the apertures in the weft direction in Fig. 1 both the apex and the average value are very close to each other and normal distribution can be stated using the Shapiro–Wilk test.

However, for the warp direction apex and average value are different, the distribution is obviously asymmetric showing a distinctive negative skew and there is no such tail of larger apertures than it is for

smaller ones. This curve can be described as a specific shape of a beta-distribution, an interpretation which is highly plausible from a production point of view: In the warp the reeds limit rather stiffly the positioning of the wires. But as both the dimensions of the reeds and the wires are not invariable the bounds of the beta distribution are variable too. Hence it is assumed that the test results in the warp direction are beta-distributed with an overlapping Gaussian distribution due to the construction elements.

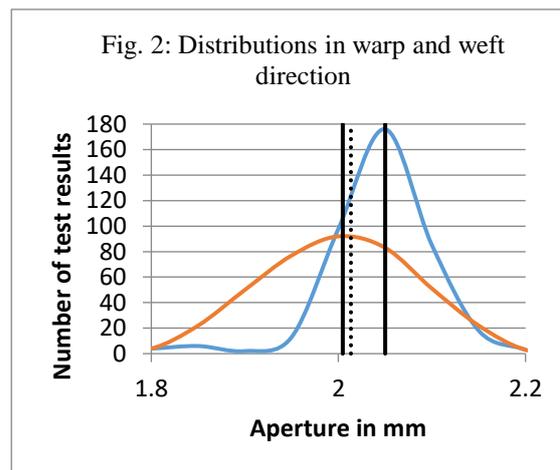


Fig. 2: Distributions in warp and weft direction

As the product standards for wire screen and wire cloth assume normal distributions the calculations in the research project have been made both for Gaussian and beta-distribution in order to see the differences between the outcomes based on the status-quo procedure and that on the basis of the new research results. Table 2 contains an example for the underlying problem in conformity assessment when the distribution of the measurement result is not clear.

Parameter	Gaussian distribution	Modified beta distribution
Without a bias		
Probability of conformity $P_C$	0.805	0.967
With a bias		
Probability of conformity $P_C$	0.764	0.942

Table 2: The probabilities of conformity for  $T_U$  and  $T_L$  for two distributions at  $\sigma = 0.997$

### III. BASIS OF CONFORMITY ASSESSMENT

WILLIAMS and HAWKINS, ROSSI and CRENNNA, PENDRILL and the author of this contribution have published on conformity assessment in industrial production. Further documents used were the Joint Committee for Guides in Metrology 106 and ASME B89.7.4.1.

Their results have been applied to the product standards mentioned above. They all encompass requirements for mean aperture sizes  $\hat{w}$  and maximum aperture sizes  $w_{max}$ .

Generally speaking, a profound impact of measurement uncertainty on conformity decision can be excluded if the uncertainty is small compared to the tolerance zone. A usual method for estimating this possible influence is the test uncertainty ratio (TUR). Another one is the calculation of a process capability index  $C_P$  which is derived from statistical quality control.

$$C_P \equiv \frac{T_U - T_L}{n \cdot \sigma_P} = \frac{T_{-2}}{n \cdot \sigma_P}$$

The choice of  $n$  is arbitrary, it usually differs in the range from 3 to 10.  $T_{-2}$  is the full width of a tolerance zone with  $T_U$  as the upper and  $T_L$  as the lower limit.  $\sigma_P$  is the standard deviation as a convenient measure of the process variability. With an assumed frequency distribution – mostly Gaussian –  $C_P$  quantifies that fraction of products that is within the tolerance zone  $T_{-2}$ . A similar index value is defined as the measurement capability index  $C_m$  which is defined for two-sided tolerances as

$$C_{m-2} \equiv \frac{T_U - T_L}{4 \cdot u_m}$$

Similarly to  $C_P$  the figure  $C_m$  characterizes the quality of the measurement system. A large  $C_m$  indicates low measurement uncertainty.

ISO 3310-1 specifies a maximum acceptable standard deviation  $\sigma_0$ . With the data on the dispersion  $\sigma_m$  of single measurement results collected in the interlaboratory comparison it is possible to calculate an index value for this tolerance figure as well:

$$C_{m-1\sigma} = \frac{\sigma_0}{2 \cdot \sigma_m}$$

The calculation of a measurement capability index focuses on the measurement itself. The index helps

in decisions whether instruments or procedures are generally suitable for conformance or conformity testing. In order to quantify risks the above mentioned draft paper goes more into detail. According to the paper the model of the measurement process for two-sided tolerances is assumed to follow the Gaussian probability density function

$$p(x | I_m) = \frac{1}{u_m \sqrt{2\pi}} \exp \left[ -\frac{1}{2} \left( \frac{x - x_m}{u_m} \right)^2 \right]$$

$I_m$  stands for information available after performance of the measurement,  $x_m$  is the result of a measurement and  $u_m$  is the associated standard uncertainty. The transformation to a cumulative probability  $\Phi(z)$  leads to the conformance probability

$$P_C = \Phi \left( \frac{T_U - x_m}{u_m} \right) - \Phi \left( \frac{T_L - x_m}{u_m} \right)$$

or

$$P_C = \Phi[4 \cdot C_m \cdot (1 - \hat{x})] - \Phi(-4 \cdot C_m \cdot \hat{x})$$

The expression  $P_C$  is the probability of conformance. With the use of uncertainty data from reproduction it can also be defined as the probability of conformity and can be calculated for all levels of confidence.

The assumption for  $u_\sigma$  is numerically done using the mean values  $\sigma_w$  ( $\sigma_w = f(w)$ ) from an interlaboratory comparison. Again with  $T_U = 0$  the probability of conformity runs as follows:

$$P_{C,\sigma_0} = \Phi \left[ \frac{\sigma_0 - \sigma_m}{\sigma_w} \right] - \Phi \left[ -\frac{\sigma_m}{\sigma_w} \right]$$

The requirements for  $\sigma_0$  are based on a confidence level of about 68 % ( $\sigma = 1$ ). It has therefore not been calculated for different confidence levels.

### IV. RESULTS

In wire screen products the variance of the apertures is usually much larger than the variance caused by testing in conformity assessment, i.e. the uncertainty of individual test results is usually negligible. However, if test results from different stations of production are used it must be considered that they are afflicted with larger uncertainties than those from the final conformity assessment itself. It is also important to highlight that the quantification of risks

with a focus on tolerances does not allow neglecting even small influences, if the number of test results close to the tolerance limit is not small.

With large dispersions of a property of a measurand and a position that the uncertainty of test results is usually negligible it is only possible to get at data by reducing the effects of the variance of the measurement object. This has been done by creating wire screen samples with different apertures for use in an interlaboratory comparison test where all participants get the same sample, one after another, and with a detailed prescription for the performance of the test.

ISO 3310-1 (test sieves) sets the toughest requirements. Statements on conformity are not possible for products with aperture sizes of  $w \leq 0.5$  mm on a 68 % confidence level and aperture sizes of  $w \leq 2$  mm on a 99.7 % confidence level with the given state-of-the-art measurement procedures. This statement is generally in line with the  $C_m$  results.

In contrast to woven wire cloth products for wire screens according to ISO 14315 the whole range of the scope can be used for conformity assessment.

For the maximum aperture size  $w_{max}$  the provisions of ISO 3310-1 are such that statements on conformity are possible down to  $w_N = 0.06$  mm. The specifications for the maximum standard deviation  $\sigma_0$  do not cause a general conflict.

The measurement capability indices  $C_{m-2w}$  (mean aperture size  $\hat{w}$ ),  $C_{m-1w}$  (maximum aperture size  $w_{max}$ ) and  $C_{m-1\sigma}$  (maximum standard deviation  $\sigma_0$ ) have been calculated for a very wide range of aperture sizes (32 mm ... 0.06 mm) with the assumption of favourable measurement conditions (calibrated instruments with a readability of 0.01 mm, trained personnel, well described measurement procedures etc.).

Wire screen samples with apertures between 4 mm and 32 mm and wire diameters between 1 mm and 5 mm were sent to 19 participants. For the tests a vernier caliper was used which is a major test instrument in production and in conformity assessment. The results are given in table 1. The standard deviation for the aperture is  $\sigma \approx 0.04$  mm. It is necessary to adapt the measurement uncertainty to the purposes of risk calculation, i.e. the standard deviation as a measure for the measurement uncertainty  $u_m$  should be larger because

- interlaboratory comparison tests are usually done both by specialized personnel and with particular care.

- the instruments as used in production have usually a smaller resolution.
- it is necessary to pay attention to possible systematic effects. The results of some participants lay all above or below the median which underlines a general impression from the visits on the production sites.

Hence an assumption of  $u_m = 0.1$  mm is regarded as appropriate for general tests in production and  $u_m = 0.05$  mm for conformity tests in internal laboratories. If the applicant cannot reasonably exclude a bias of the results which is not negligible, it is deemed appropriate to assume a possible bias of  $u_{m,b} = \pm 0.03$  mm.

The probability of conformity is strongly affected by the application on the basis of the modified beta-distribution. An example for the distribution can be seen in Fig. 2.

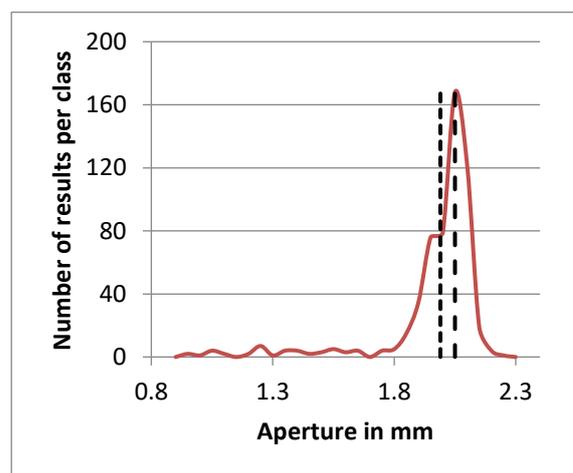


Fig. 2: Example for the distribution of the apertures

This result was not surprising because the number of test results within the tolerance limits is much larger than with the normal distribution. It becomes already clear that the application of a general procedure is not appropriate for these specific products. If the probability of conformity  $P_C$  would really be at a level of 0.8 testing would be a major issue in production and conformity assessment. In order to maintain a probability of conformity of  $P_C = 0.967$  on the basis of the Gaussian distribution the tolerances would have to be expanded from  $w_{max} = 8.40$  mm to  $w_{max} = 8.68$  mm. However, this would not be accepted by the clients and it is not necessary as in practice it is already implicitly known by the producers. Possible measures are regular checks of the wear of the reeds, increasing the awareness for the need of some safeguarding limits and tests of the apertures when setting up the machines. This reflect a situation that is much more understandable from a high probability

of conformity point of view. The situation becomes more important when there is a significant bias in testing. This is a relevant issue as the producers are mainly acting in a bilateral structure. Here both partners can adapt their testing procedures according to their needs. From this point of view a bias is much less important but it would become a problem when entering a multilateral market. Here the bias may lead to discussions on the validity of test results.

### III. INLINE MEASUREMENTS

The assessment of conformity of wire screen and woven wire cloth products on the basis of ISO 14315, ISO 9044 and ISO 3310-1 is not always possible with state-of-the-art measurement procedures. This statement does not necessarily include conformance testing.

Inline measurements in the production would be most useful for the aperture of woven metal wire cloth or of screens. However, this is still a problem: Ongoing production operations require measurements on the object being in motion. These operations work to assess the regularity of the product and help to identify some kinds of non-compliances. However, it is already difficult to produce reliable results for the aperture dimensions under (offline) ‘laboratory’ conditions. Therefore, in general, results from inline measurements have not been satisfactory. An important reason is that usually geometric pattern on applied on glass surfaces serve as ‘two-dimensional’ reference objects and the results are different from those produced with ‘three-dimensional’ reference objects made of wire.

Optically based online measurement techniques are applicable for controlling the regularity of the product but that would not be very helpful. There are two major reasons for this situation:

- The apertures are usually measured using bright-field microscopy. Here the time needed for focusing of the camera is an essential issue. Even when, compared to industrial textile manufacture, the production speed in wire cloth and screen manufacture is quite low the focusing process during the ongoing operations within a few microseconds in this heavily vibrating environment is still an unsolved problem.
- The measurement results strongly depend on the light intensity. It is possible to protect the measured objects in the ongoing production although

they have light-reflecting surfaces. Nevertheless, a constant distance from the light source can hardly be maintained.

The situation is that for production control reasons the producer needs information whether the product meets the requirements especially as regards the aperture. But the uncertainty of these results is still too large for reliably monitor the production. Therefore additional, more precise offline measurements are necessary. In the long run, a combination of online and offline measurement provides data for a better production control. An example of a screen shot is Fig. 3.

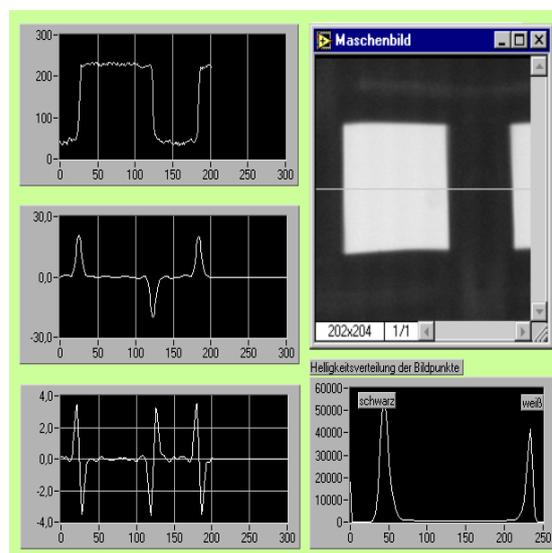


Fig. 3: An example of a screen shot in off-line measurement

Suppliers of measurement instruments claim that their products can cope with this situation. In principle, this claim is not wrong, at least from a production control point of view. However, the comparability of results arrived at using different industrial optical measurement techniques is usually quite poor. So the problem remains the applicants when they calibrate and/or check the products.

#### IV. REVISION OF THE STANDARD

Apart from problems with reliable results both in the production and in use the requirements for the measurement of the product in the standard for test sieves are quite extensive. The ISO working group are busy to improve them in order to reduce the number of single measurement items, keeping in mind that the confidence levels which are now 99 % or 99.73 %, must be maintained.

Moreover, there are other problems with ISO 3310-1:

- As the probability distribution functions applied in the standard does not reflect the distributions found in the measurement results, the influence on conformity assessment results must be somehow quantified.
- The coverage factors  $k$  used in the standard are not justifiable.
- The term ‘calibration’ is not in line with the VIM.

The research results of the last about ten years have been used to adapt the 2016 versions of the standards. Now the ISO working group is asking new questions calling for additional research projects.

- Is it possible to stop the measurement process when the product meets the requirements on a certain conformity level?
- Under which conditions is it possible to refer to a normal distribution even when it is known that the measurement results are beta-distributed? This would make the application of commonly used statistical instruments much more probable.
- How can the measurement data be used for improving the production process (process capability index)? For example, can be used on this basis operators like the acceptable quality limit or rejectable quality level for testing incoming goods?

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