A STUDY OF TAPERED BEARD SAMPLING METHOD AS USED IN HVI

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Abstract

Beard method is used for sampling cotton fibers to generate fibrograms from which length parameters can be obtained. It is the sampling method used by HVI. HVI uses a fiber comb to sample cotton fibers and form a fiber beard for measuring fiber length parameters. A fundamental issue about this sampling method is its bias. There have been different assumptions regarding the bias of the beard sampling method. The original fibrogram theory for the beard method adopted an assumption that this procedure is length-biased, while other researchers later revised this assumption to that each fiber has equal probability of being sampled regardless its length (unbiased assumption).

In our experiments, we have seen discrepancies in measurements that cannot be explained by using length-biased or unbiased assumptions, especially in the short fiber region. Therefore, it is important to investigate the bias of the beard method. We report a fundamental research, including experimental and theoretical analysis, and computer modeling, that reveals the bias due to this sampling method.

We found that the beard sampling method as used in HVI is not completely length-biased; it is very similar to the original sample except in the short fiber region. Short fiber content by number of the sampled fiber is lower than that of the original fiber, and this difference is inherently introduced by the sampling method.

Introduction

Beard method was developed to test cotton fiber length parameters. Cotton fibers are combed and formed into a beard then measurement devices utilize optical or pneumatic method to scan the fiber beard to generate fibrograms by measuring the rate of airflow or light attenuation. Length parameters can be obtained from the fibrogram. Beard method is the sampling method used by HVI. Because of its speed and accuracy, HVI is now extensively used to measure fiber length parameters such as Mean Length and Uniformity Index. HVI uses fiber comb to pick up fibers from the Fibrosampler through which cotton fibers protrude. A fundamental issue regarding this sampling method is its bias, which concerns that if the length distributions of the sampled specimen are as same as the length distributions of the original cottons. It is also important to investigate if the sampling method introduces systematic bias.

There have been different assumptions regarding the bias of the beard sampling method for measuring cotton fiber length. At the very beginning, when Hertel developed the fibrogram theory, he assumed that the probability of a fiber being sampled for fibrogram is proportional to its length; this is the length-biased sampling assumption (Hertel 1936, 1940). Zeidman and Batra provided a derivation that tried to use the unit step function to prove that sampling for Fibrograph is length-biased (Zeidman and Batra 1991). On the other hand, Chu and Riley later found that sampling using HVI Fibrosampler did not agree with the length-biased measurement assumption. The assumption was then revised to that each fiber has equal probability of being sampled, though no other evidence was provided to justify this assumption (Chu and Riley, 1999).

However, neither the length-biased assumption nor the unbiased assumption can explain some discrepancies in measurements that were observed in experiments, especially in the short fiber region. Therefore we conducted a research for the purpose of investigating the sampling bias of the beard method as used in HVI.

Experimental Observations

We measured length distributions of eight sets of cottons of different staple lengths. At first we measured the length distributions of original fibers, which were directly picked up from cotton bales, then we used AFIS to measure the length of each individual fiber. At least 35,000 fibers were measured for each set of cotton. Data were used to construct the entire length distribution of these "original" fibers.

At last, we used HVI's fiber comb to sample fibers from the HVI fibrosampler and sampled specimen were tested by AFIS. At least 35,000 fibers were measured for each set. The data were used to construct the entire length distribution of these "HVI specimen" fibers.

The results indicated that the length distributions of the specimen sampled by HVI Fiber comb cannot be explained as length-biased.

The following equation reveals the relationship between the length-biased mean length ML_l and mean length by number ML_n (Cui *et al*, 1998):

$$ML_l = ML_n + Var_n / ML_n \tag{1}$$

in which Var_n is the length variance. Equation 1 shows that if the measurement is length-biased, the length biased mean length by number should be always longer than the original mean length by number. But in Figure 1, it can be seen that mean length by number of the original fibers were almost as same as that of the HVI specimen. Both of them are far shorter than the completely length-biased mean lengths, which were calculated by using equation 1. This comparison proves that the HVI beard sampling process is not completely length-biased.

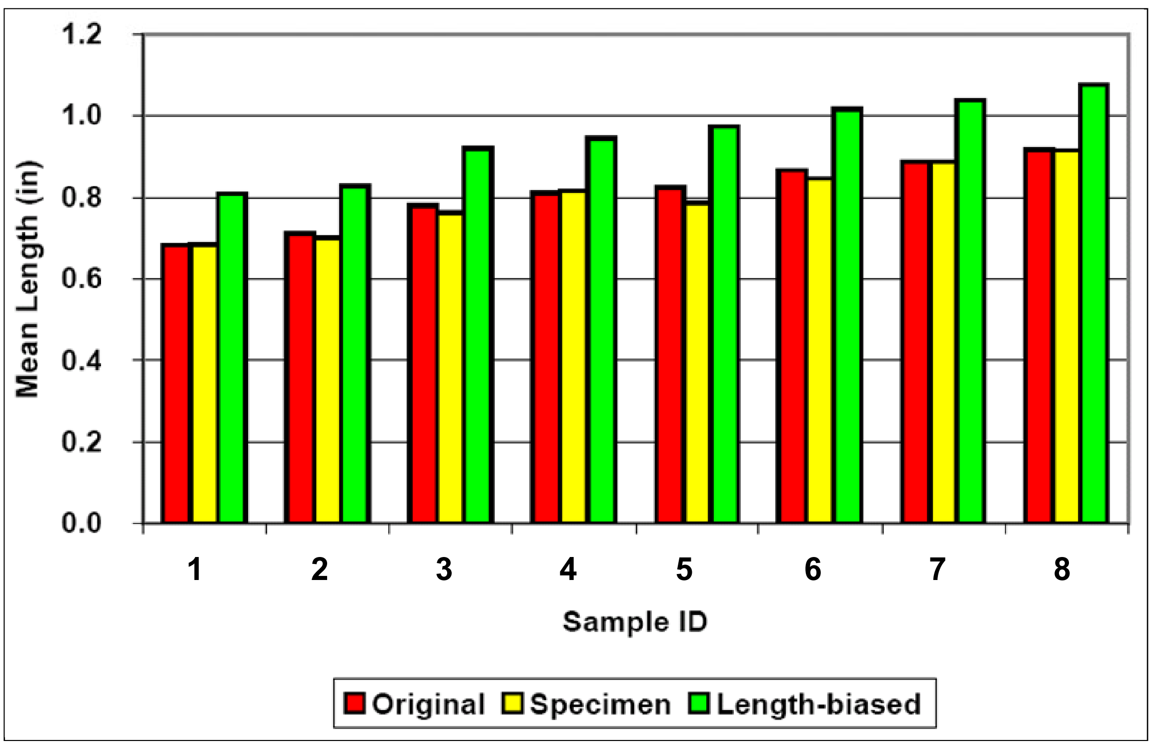

Figure 1 Mean lengths of the original fibers and the fibers picked by the HVI fiber comb

Theoretical Analysis

The characteristics of measurement bias can be obtained by analyzing the probability of the beard sampling method. The following analysis shows that the completely length-biased assumption holds when there is only one needle (sampling position, Figure 2). If the i^{th} group of fibers has N_i fibers of length L_i, then the probability of one fiber in this group being sampled is calculated as $p = L_i /W$, which is the fiber length divided by sampling width, such as the width of the window of the HVI Fibrosampler. Then the number of fibers in this length group being sampled is given by:

$$n_i=N_i \times L_i / W$$

for $L_i < W$. This is length biased and it agrees with the result from Zeidman and Batra's derivation based on the unit step function (Zeidman and Batra, 1991).

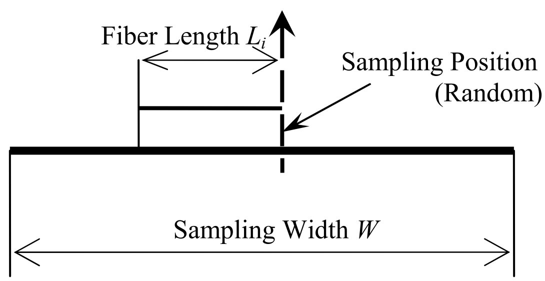

Figure 2 Diagram for analyzing sampling process with one sampling position

Figure 3 shows the analysis for the situation where there are multiple sampling positions. In this case, the probability of one fiber in the i^{th} group being sampled is calculated as $p = L_i / \Delta W$ for $L_i < \Delta W$, and the number of fibers being sampled is still

$$n_i=N_i \times L_i / \Delta W$$

which is length biased. But once $L_i > \Delta W$, no matter how long the fiber is, the probability p is always 1, which means the sampling is unbiased.

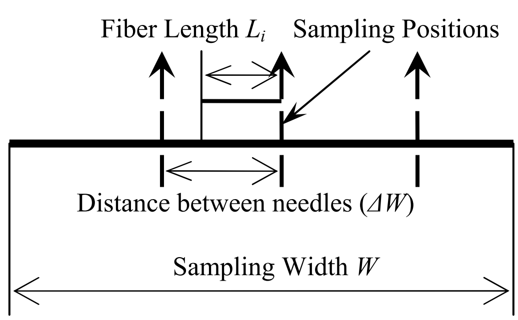

Figure 3 Diagram for analyzing sampling process with multiple sampling positions

In real situations, fiber orientation is random, which projects more "short" fibers in the direction that is perpendicular to the sampling direction. From the above analysis we can find that for short fibers, the measurement could be length-biased, but for fibers longer than certain length, the measurement is unbiased. The distance between pins/needles of the HVI Fibrosampler's fiber comb is ~ 2 mm. There are more than 30 needles in the fiber comb. Length biased assumption does not hold considering the small distance between needles, but length bias still has its influence in the short fiber region.

Computer Simulation

We simulated the sampling procedure based on our theoretical analysis. At first, in order to validate the change of sampling bias as the distance between needles changes, we simulated the sampling procedure of 50,000 3.0 cm long and 50,000 1.5 cm long fibers that have randomly distributed orientations and positions on a plane. The simulation results agreed with the theoretical analysis. The measured distribution changes from completely length-biased to less length biased when the distance between needles decreases.

Figure 4 shows the sampling ratio of 3.0 cm fibers to 1.5 cm fibers. If the sampling procedure is completely length-biased, then the sampling ratio should equal to the length ratio, which is 2, because those two groups has equal number of fibers. If the sampling procedure is unbiased, then the ratio should be 1 because it is not related to length. From figure 4 we can also see that the sampling ratio started from 2 when the distance between needles was larger than 3 cm. This indicates the length-biased sampling situation. Nevertheless it eventually approaches to 1 as the distance between needles decreases; this indicates that the sampling process is nearly unbiased.

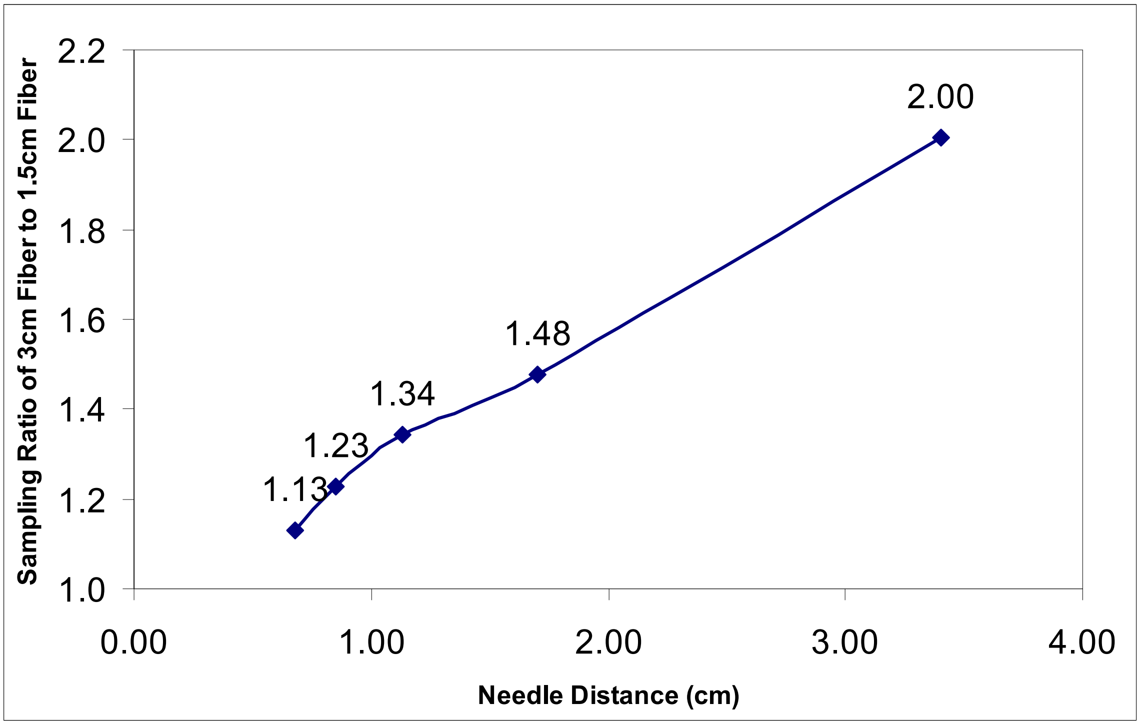

Figure 4 Simulation that shows the relationship between sampling ratio and needle distance

Furthermore, we simulated the sampling procedure to obtain sampled length distributions of the original fibers that had their lengths measured by AFIS. The measured lengths of the original fibers were used as inputs for generating computer simulated HVI specimen length. The parameters of the simulations adopted the configurations of a fiber comb of HVI Fibrosampler, which had 36 needles and the distance between two needles was 2 mm. Computer simulated HVI specimen length distributions of staple lengths 30 and 33 were compared to AFIS measured HVI specimen length distributions in Figures 5 and 6.

Figures 5 and 6 demonstrated that both computer simulated and AFIS measured length distributions of the fibers selected by the HVI fiber comb were far way from the completely length-biased distributions, which were computed from the length distributions of the original fiber. They are closer to the distribution curve of the original fiber. Results show discrepancies between the simulated sampling distribution and the distribution of the original fibers especially in the short fiber region, which means that short fiber content by number of the sampled fiber is lower than that of the original fiber. But for the region that fiber length is longer than 1 inch, the two distributions almost match each other. These findings agree with the experimental data and support the theoretical analysis discussed in previous section.

The length distributions from simulation with 2 mm needle distance are less biased than the AFIS measured ones from the HVI fiber comb. This may be a result that 1) even some shorter fibers were selected by the HVI sampler, but lost during sample combing/brushing process, 2) currently the simulation is a two-dimensional process, in real situations that is three-dimensional, more fibers could be projected as shorter fibers.

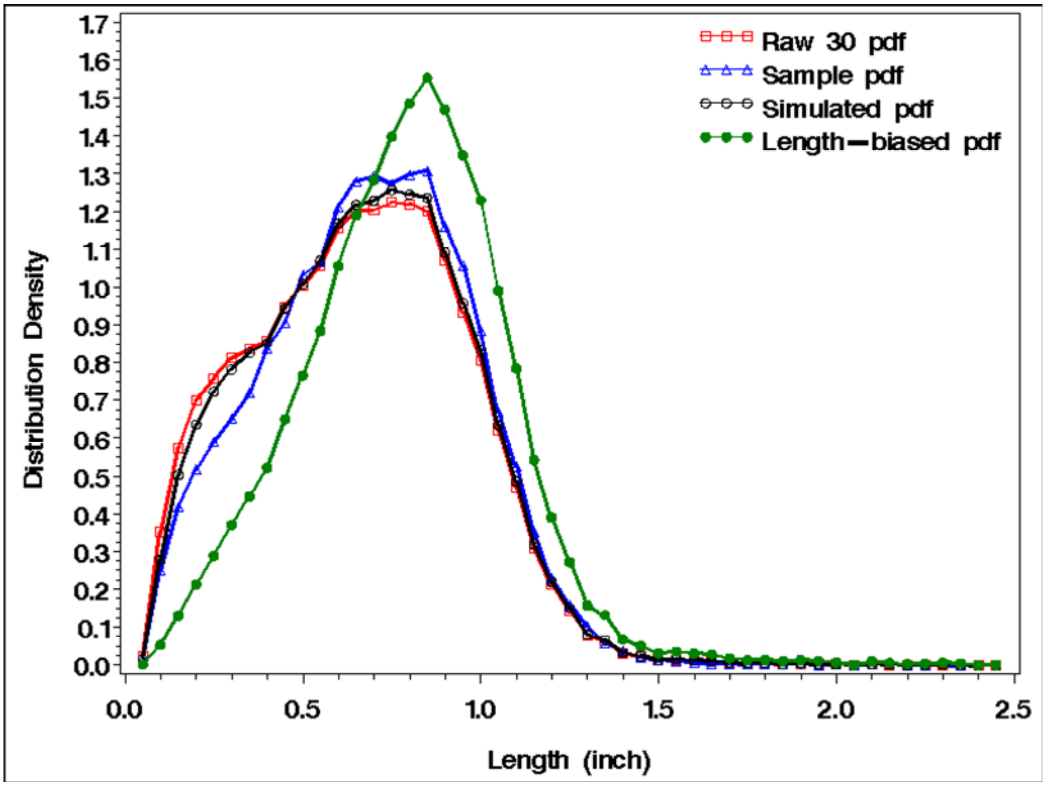

Figure 5 AFIS measured and computer simulated length distributions of staple length 30 fiber

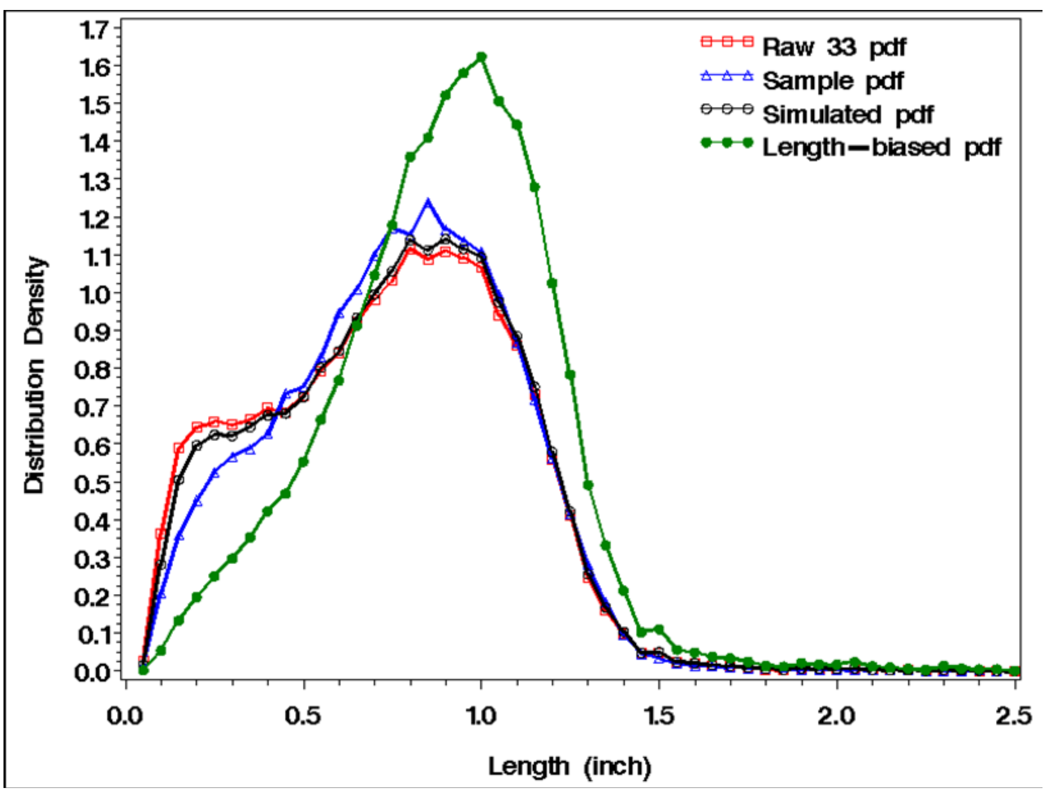

Figure 6 AFIS measured and computer simulated length distributions of staple length 33 fiber

Conclusions

We report in this paper a fundamental research that included experimental and theoretical analysis, and computer modeling to investigate the bias due to the beard sampling method as used in HVI.

We found that the beard sampling method as used in HVI is not completely length-biased; it is nearly an unbiased method. But original fiber's length distribution still impacts sampled fibers' length distribution especially in the short fiber region. Short fiber content by number of the sampled fiber is lower than that of the original fiber, and this difference is inherently introduced by the sampling method. This research reveals the nature of the bias caused by this sampling method and helps us understand better how the sampling method affects the length distribution of sampled fibers.

Acknowledgements

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References

Chu, Y.T. and Riley, C.R., 'New Interpretation of the Fibrogram', *Textile Research Journal*, 67(12), 897-901 (1997).

Cui, X., T.A. Calamari, and M. Suh, 'Theoretical and Practical Aspects of Fiber Length Comparisons of Various Cottons', *Textile Research*, 68(7), 467-472 (1998).

Hertel, K.L. and Zervigon, M.G., 'An Optical Method for the Length Analysis of Cotton Fibers', *Textile Research Journal*, 6, 331-339 (1936).

Hertel, K.L., 'A Method of Fiber-Length Analysis Using the Fibrograph', *Textile Research Journal*, 10, 510-525 (1940).

Zeidman, M.I. and Batra, S.K., 'Determining Short Fiber Content in Cotton', *Textile Research Journal*, 61(1), 21-30 (1991).