Adaptive adjustment of grading machine settings

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INTRODUCTION

The current European standard for machine strength grading of structural timber EN 14081 provides two different methods for the control of grading machine settings. These are either *machine controlled* or *output controlled*; however, both methods do not facilitate the efficient use of information which is gathered prior and during the runtime of the grading machine [2]. In addition, the mentioned control methods are broadly considered to be much too complex and ambiguous. Throughout Europe there are only a few experts who know how to deal with the required procedures for approval of grading machines which are addressed in the standard.
As a consequence different projects and activities have recently been initiated to investigate how EN 14081 could be reorganized:

- There are extensive discussions within COST Action E53 about the existing procedures provided by EN 14081, especially with regard to the identification of common growth areas and the development of efficient control procedures for grading machine settings.
- Participants of a large pan-European project (GRADEWOOD) investigate both: the comparability of data bases of different European countries containing data of machine graded and destructively tested structural timber, and the development of alternative approaches for machine grading procedures.
- EN 14081 is currently taken under revision by the responsible experts of the Technical Committee CEN TC124/WG2.

All of these investigations can be considered to contribute to future simplifications and modifications of the relevant standard for grading of structural timber – EN 14081.
In that sense, this paper introduces the *probabilistic output control* method as an alternative framework for modelling the grading of structural timber. The developed model is expected to meet the demand for efficient control procedures applicable on the European situation of timber production. For this purpose flexible and fast adjustable grading models are required that utilize all available information gathered previous and during the grading procedure.

Since the investigations prescribed in the following chapters have recently been discussed by the international experts of CIB-W18 (meeting 41st, 24-28 August 2008) the interested reader is referred to the paper presented at this occasion [4] to find a more detailed description of the methods and experimental results.

BACKGROUND OF MACHINE STRENGTH GRADING

Grading machines operate according to similar principles; one or more strength related properties of the timber to be graded are measured by the machine and based on these measurements the so-called *indicating property* (IP) of the specimen is assessed.
The central element of machine grading of structural timber is to predict the *grade determining*

property (GDP; e.g. timber strength, stiffness or density) by given observations of the indicating property. The grade determining property is the crucial timber material property for the assessment of the *characteristic values*, which have to be fulfilled for every assigned *strength grade* in accordance to EN 338.

In general grading acceptance criteria are formulated in form of boundary values for the indicating property which have to be matched to qualify a piece of timber to a certain grade. These boundaries are commonly termed *grading machine settings*. The performance, i.e. the statistical characteristics of the output of grading machines strongly depends on the settings, and in general very much attention is kept on how to control them.

In Fig. 1, the relationship between the indicating property and the grade determining property is illustrated. The vertical lines represent the boundary values of the indicating property (IP1 and IP2) which subdivide the sample into sub-samples assigned to grade 1, grade 2 and grade 3.

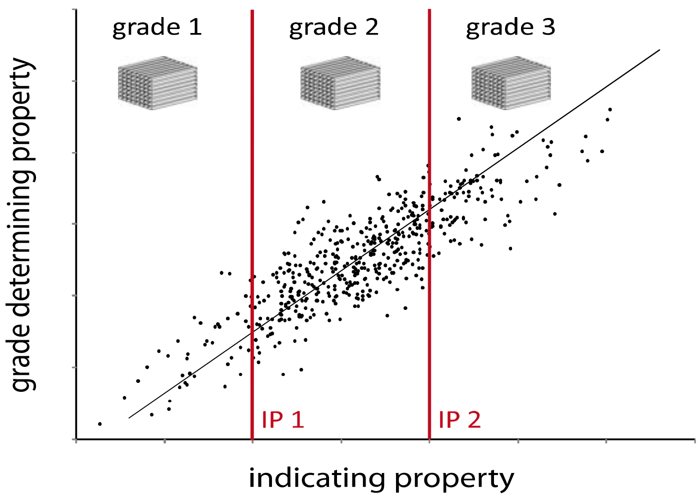

Figure 1: Relationship between the grade determining property and the indicating property. Boundary values of IP subdivide the total sample into different sub-samples, denoted as strength grades

MODELLING APPROACH

When timber products are utilized in high performance timber structures i.e. whenever the load bearing capacity or the stiffness determines the design, it is an end-user requirement that the timber products are graded to ensure sufficiently high performing mechanical properties. At the same time, modern industrial process management desires stages of production that can be included into the overall production process seamlessly and which are able to keep pace with the speed and accuracy of the latest technological developments. This demand cannot be satisfied by traditional visual grading methods but only be accommodated by means of efficient and reliable machine grading of structural timber.

Output controlled systems in general supply for adjustment of settings on the basis of destructive testing or proof loading. Since the settings are adjusted during the production process, the initial type testing for the grading procedure is considered to be much less substantial than during the machine control method (EN 14081, parts 2 and 3).

When grading structural timber in an output controlled system, grading accuracy has to be monitored by testing samples which are taken directly from production. The output control method given in EN 14081, part 3 requires frequent destructive tests or proof loading procedures which shall take place at equal time or quantity intervals during the production shifts. These tests are rather periodical and arbitrary than dependent on occurring fluctuations of timber material quality.

Nowadays machine grading procedures in Europe use the information of the indicating property to simply compare the IP value to the settings of the grading machine and based on this to assign a particular specimen to a specific strength grade.

The core element of the described model is in the continuous observation and probabilistic analysis of the indicating property which enables the detection of shifts in the quality of the input material without any temporal delay. Monitoring of the material quality can directly be performed during the grading procedure, since the indicating property is observed continuously. This provides means to define quantitative threshold values for the aberration of material quality. If these threshold values were exceeded, demand for additional test or proof loading procedures would be indicated. As a consequence, destructive testing only has to be performed if quality shifts in the timber material properties were observed. Thus, monitoring efforts as well as monetary expenses may be reduced noticeably. At the same time it is important to note, that the continuous observation and analysis of the indicating property is without any additional costs.

The general framework for probabilistic output control is illustrated in Fig. 2.

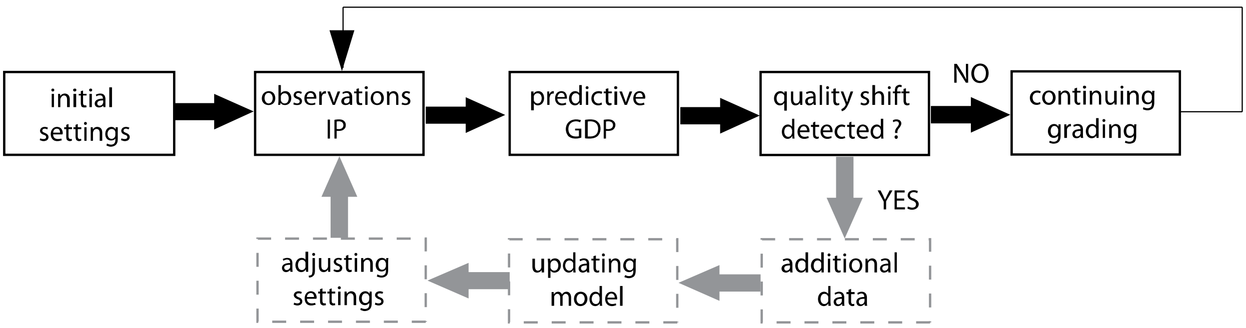

Figure 2: General framework for probabilistic output control of grading machine settings

Based on observations of the indicating property the predictive characteristic value of the grade determining property is assessed by means of Bayesian regression analysis. Continuous monitoring of the predictive characteristic value of the grade determining property allows for detection of shifts within the timber material quality. Since this feature can be implemented into the software of the grading device, indications of quality shifts are detected without any temporal delay. In case of such indications additional destructive tests or proof loading procedures have to be performed based on which the parameters of the grading model are updated. In consequence, the grading machine settings are adjusted to guarantee the characteristic values and to optimize the yields of the particular strength grades.

If no aberrations of the timber material quality were indicated, no additional data would have to be provided and the grading process could continue.

INDICATION OF QUALITY SHIFTS

Indication of timber material quality shifts can be realised by continuous observations of the predictive characteristic values of the grade determining property which is illustrated in Fig. 3.

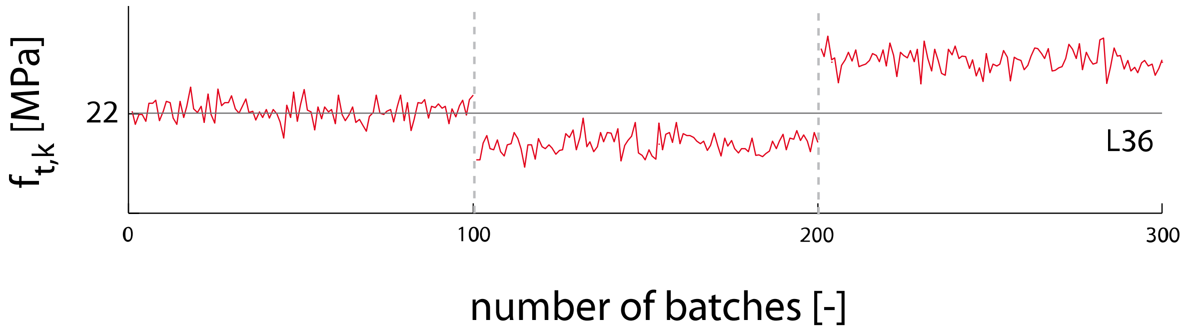

Figure 3: Predictive characteristic values of the tension strength monitored during grading the total sample into strength grade L36 and Reject. Every particular peak of the jagged line represents the 5th percentile value of the tension strength assessed on samples containing 1000 datasets of the indicating property. Datasets are simulated based on real measurements of the grading device GoldenEye706 (MiCROTEC GmbH, Brixen, Italy)

As an example a grading process of lamellas for glulam is considered in Fig. 3 where 300 batches (each n=1000) of structural timber are graded into strength grade L36 (according to EN 14081, part 4) and reject. For every particular batch the characteristic value (5^{th} percentile) of the tension strength is assessed resulting in small variations within the sections of every 100 batches.

The first section of the illustration (batch nr. 1-100) represents the average timber material quality mainly processed and graded at the facility. The values of the predictive characteristic values are fluctuating slightly however, the mean value of all characteristic values is located on the line of the required characteristic value of the strength class L36 at 22 MPa.

Assuming the timber material for the second section (batch nr. 101-200) is provided by a different supplier or coming from a different growth area with timber material properties lower than average, a remarkable leap of the predictive characteristic value beyond the required value of 22 MPa can be observed. That proves that the developed grading model reacts reliably to the shift in the distribution of the indicating property by predicting lower characteristic values for the tension strength.

Timber material in the third section (batch nr. 201-300) is provided by a supplier or coming from a growth area with considerably higher quality level. Again, the upward shift of the quality is detected by the model and illustrated in the jagged line of the predicted characteristic values being much higher than the requirement for this strength grade.

The machine control method provided by EN 14081, part 2 would not be capable to react on these variations of timber material quality since the settings of grading machines once approved according to this method cannot be changed afterwards (except for high additional costs for a new approval). Grading structural timber with the illustrated quality shifts by grading machines approved according to the machine control method would result in strength grades with either too low characteristic values or unsatisfactory yields. In both cases the end user requirements would not be sufficiently fulfilled.

The introduced model for a probabilistic output control facilitates first to update the model parameters according to the new material quality and afterwards, to adjust the grading machine settings for optimized yield and sufficient characteristic values.

STATISTICAL BACKGROUND

For the representation of the relationship between observations of the grade determining property and the non-destructive measurements of the grading device (indicating property) Bayesian linear regression analysis is the main statistical method applied within the recent investigations. The substantial goal addressed by the regression model is to predict the grade determining property by given observations of the indicating property.
Since the Bayesian regression analysis takes into account all types of aleatoric and epistemic uncertainties which are connected to variability of timber material properties, statistical uncertainties and model uncertainties, a consistent grading model for the probabilistic output control of structural timber can be established. This modelling approach is capable to assess the predictive characteristic values for different occurring quality levels and sample sizes during the production process. In case, that aberrations within the input material quality are detected and considered to have significant influence on the ongoing grading process, the regression coefficients and covariance matrices of the grading model are updated by means of Bayesian regression analysis for the recent sub-sample. Together with the subsequent adjustment of the grading machine settings the criteria for the characteristic values as well as the optimized yields in the particular strength grades can be fulfilled.

CONCLUSIONS & OUTLOOK

Up to now, machine controlled systems require an extensive initial type testing procedure which results in high monetary efforts and fixed grading machine settings which are not adjustable in daily production to changes of the input timber material quality (e.g. caused by different origins or suppliers).
On the other hand the output control procedure given in the standard is in many cases difficult to be applied since the situation on the European timber market is characterized by a large number of species, sizes, growth conditions and strength grades. Different investigations have shown that the CUSUM method for output control provided in EN 14081, part 3 reacts to quality shifts too decelerated [1] [3]. In addition, this method requires high monetary efforts since destructive tests are required frequently as a function of working shift and productivity.
Adaptive adjustment of grading machine settings by means of the *probabilistic output control* for structural timber can be considered as a functional tool for the production of timber as a reliable building material. On this way not only the end-user requirements are accomplished but also the efficiency of production is ensured.
Since the introduced modelling approach still is not fully developed, future investigations will concentrate on the following problems:

- Definition of quantitative threshold values for aberrations within the monitoring of the predictive characteristic value. Indication of shifts in timber material quality based on concepts of decision theory.
- Number of specimens for assessment of particular predictive characteristic values has to be defined as a function of production capacity.
- In case that quality shifts are indicated, number of specimens for additional destructive testing or proof loading.
- Verification and implementation of the modelling approach within industrial production processes.

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