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FULL WIDTH WARP TENSION SENSOR

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Abstract: *The manufacturing of a fabric, it is to say the process of weaving, is based on the creation of binding points between the yarns of weft and the yarns of warp. While the tension of weft is given principally by the type of weft picking and there are few means to control it, the tension of warp yarns is set by the weaver and depends on the textile technology parameters such as the fabric sett, the yarn strength, etc. Thus the control system must enable the operator to set it with a reasonable precision. With the use of servos on the modern looms the designers have all assets to reach a good level of control. In this paper we present a new approach to the problem of the warp tension monitoring which is important in the control loop. We use a statically indeterminate bar with a given number of load cells in the bearings. Based on the read values in the load cells we can estimate the distribution of the warp tension along the woven width.*

Keywords: Weaving, Process monitoring, Statically indeterminate structures.

1. Introduction

During the creation of a binding point in a fabric the yarns are subject to a number of forces of which the tension forces along the yarn axis are the most important. Their values determine the shape of the final product. While the weft tension is hard to control, especially on the air jet looms, the warp tension is controlled relatively easily. It is given principally by the difference of angular velocities of the warp beam let-off and the cloth roll take up. This tension changes within the weaving cycle due to the beat-up forces, movement of the compensating backrest, the shed creating harness action etc. These changes are cyclic and the tension forces in the warp yarns may change by several orders during the working cycle. Anyway the maximum given by the yarn strength must never be exceeded, such a failure leads to the yarn breakings and the machine stops. Nevertheless this phenomenon is well known and relatively easily predictable. Its effect on the tension monitoring may be well compensated using suitable technique of tension value reading.

To complicate the things, this warp tension is not constant along the woven width. This is caused partly by the warping process which is subject e.g. to some imperfections in the warping machine setting and partly by the weaving itself. Different tension in the weft yarn on the left and right edges respectively causes also differences in the fabric shape on the left and right hand side. In consequence this charges differently the warp yarns. Such an effect increases greatly with different types of weaves along the cloth width.

Actually the simple load cells are used to monitor the warp tension. This single cell can pick either a limited number of yarns either all the yarns along the whole woven width. The cell of the former concept is usually placed at about one third of the woven width according to some empirical data (e.g. CAM EL 220, 2014), the latter one measures the reaction forces in one of the backrest side bearings (VEGA). In the rare cases where two load cells are used, the second one is placed in an area of warp where problems are to be expected and usually does not intervene in the control loop. In any case the use of a single load cell does not allow the weaver to obtain more than one value characterizing the warp tension.

In order to overcome this shortcoming we opted for a multi cell solution. The number of cells determines the number of information we can obtain about the warp tension distribution. Due to the textile technology requirements we were obliged to use a one piece bar spanning over the whole woven width. This bar is supported by a certain number of bearings, of which some are fitted with load cells.

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2. Methods

The use of multi cell tension sensor means to find the relation between the reactions in the bearings and the parameters chosen to describe the tension distribution. The statically indeterminate bar does not facilitate the task, nevertheless it is not quite difficult.

2.1. Calculation of bearing reactions

Using the theory of thin beam and the Euler-Bernoulli's differential equation of beam we obtain the system of equations (Höschl, 1971):

$$u_i^{IV} = \frac{q(x)}{E \cdot J} \tag{1}$$

where index i denotes i-th section of the measuring bar and goes from 1 thru the number of sections n, $E.J$ are cross sectional and mechanical properties of the bar, constant along the span of the sensor, and q is distribution of yarn loading. Its form may be chosen arbitrary but must be linear in coefficients Q_j. We opted for a polynomial shape of distribution, thus j is going from zero up to the degree of polynomial.

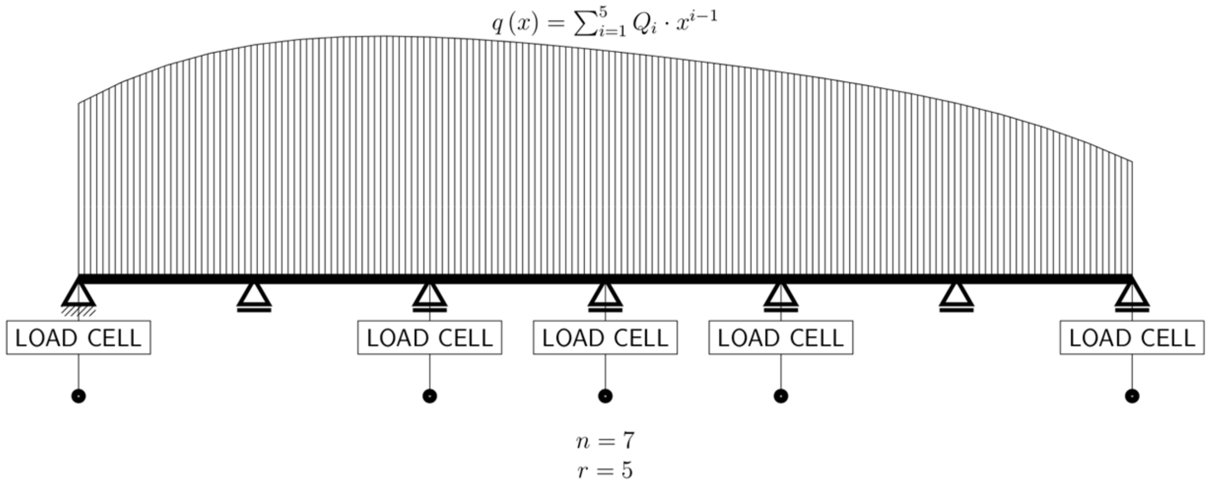

Fig. 1: Example of the multi load cell tension sensor with a typical warp load.

Integrating four times those n ordinary differential equations we get a system of n algebraic equations, each containing 4 constants of integration. Assuming continuity of slopes $u^{(I)}$ and moments $u^{(II)}$ above the bearings we get 2 additional equations for each section which, with the addition of known – e.g., vanishing - moments on the outer bearings and zero flexion in all bearings, closes the system of $4.n$ algebraic equations for $4.n$ unknowns.

N.B.: In reality the calculation was complicated by the flexibility of the bearings whose known stiffness is of the same order as the stiffness in flexure of the measuring bar. More complex procedure than presented in the previous paragraph must be actually used.

Once the system of algebraic equation is solved we can find the values of reactions in the bearings as:

$$R_i = E \cdot J \cdot \left(u_{i+1}^{III} - u_i^{III}\right) \tag{2}$$

with special respect to the outer bearings to which only one section adjoins.

Reactions as given by (2) are linear functions of coefficients Q_j, as far as the q is linear function of these coefficients (which is satisfied in the case of a polynomial distribution):

$$R_i = \sum_{j=1}^{r} K_{ij} \cdot Q_j$$

where r is degree of polynomial augmented by 1 (or generally number of coefficients Q_j).

We can rewrite this relation in a matrix form:

$$\left|\mathbf{R}\right|_{((n+1)x1)} = \left[\mathbf{K}\right]_{((n+1)xr)} \cdot \left|\mathbf{Q}\right|_{(rx1)} \tag{3}$$

where ***R*** is matrix (or column vector) of dimension (n+1,1), ***Q*** has dimension (r,1) and ***K*** is matrix of coefficients of dimension (n+1,r). Generally there is no restriction on the values of *n* and *r*, but as the number of load cells actually cannot be greater than the number of bearings we cannot get more than *n+1* information values on the load distribution, thus the number *r* of independent coefficients Q_i cannot be greater than *n+1*.

2.2. Relation between reactions and the load distribution

While we have determined the reactions in all bearings only a limited number of load cells is used. Then we have to choose those values of R_i which match the "measured" bearings. Of course their number must be equal identically to the number of coefficients *Q*.

We can reduce the relation (3) as follows:

$$\left|\mathbf{R}\right|_{(rx1)} = \left[\mathbf{K}_{\mathbf{red}}\right]_{(rxr)} \cdot \left|\mathbf{Q}\right|_{(rx1)} \tag{4}$$

by using only appropriate lines of ***K*** (i.e. appropriate values of K_{ij}).
Then we get

$$\left|\mathbf{Q}\right|_{(rx1)} = \left[\mathbf{K}_{\mathbf{red}}\right]^{-1}_{(rxr)} \cdot \left|\mathbf{R}\right|_{(rx1)} \ . \tag{5}$$

Relation (5) express explicitly the values of ***Q*** as function of measured values ***R***.

For a given geometry the $\boldsymbol{K_{red}}$ is constant so a very simple linear relation can be coded into the control system in the form:

$$Q_i = \sum_{j=1}^{r} k_{ij} \cdot R_j \tag{6}$$

Actually, in order to keep the device simple (and cheap) the number of cells should not exceed 4 per one warp tension sensor. Thus even with a higher number of bearings we get only 4 values of Q_i and thus a parabolic distribution of no more than third degree can be modelled.

2.3. Result processing

The use of ***Q*** in a control loop requires some more processing. Analogically to the use of one cell sensor we must find one constant of regulation. Unlike the simple case we can use a whole set of values. Using expression (6) for Q_i we can for example calculate a mean value of *q*:

$$\overline{q} = \frac{1}{L}\int_0^L q(x) \cdot dx = \sum_{i=1}^{N} \frac{Q_i \cdot L^{i-1}}{i} = \sum_{j=1}^{r} C_j \cdot R_j \tag{7}$$

where C_j are for the given configuration constants, in principle used as weights for the measured values of ***R***.

Yet again, by expanding the original expression and reordering the terms we get a simple linear combination of values R_j. Analogically we can calculate maximum or minimum of *q* on the given interval, it is to say, along the woven width.

Then any of these values can be used as constant of regulation to be put into the control loop. For example we can regulate the warp tension so that the minimum tension be equal to a required value, by checking in the same loop the maximum tension in the interval in order to not to exceed the strength of yarns. Another possible way to process the values of ***Q*** is to use all values disposable with some user defined weights, for example.

In any case the processing of ***Q*** offers a fair opportunity to the weaver to monitor the tension distribution in the warp.

2.4. Actual implementation in the control system

All the previous calculations were made by using a symbolic mathematic calculus software so that the coefficients k_{ij} in (6) were determined explicitly in function of E, J and other geometric characteristics. Numerical values of C_j were then implemented in the evaluation of regulation constant in the control loop using relation (7). As the control system is still under development actually no other enumeration of e.g. local minima or maxima in the interval is implemented in the control loop. For now the values of Q_j serve as a monitoring parameters only.

3. Conclusions

Actually the warp tension sensor of presented pattern is installed on the prototype of the new generation loom. It is in the stage of vigorous testing using a rather complicated weave of a 3D fabric which - should a simple load cell sensor be used - could not even be produced.

Nevertheless, there are some issues in the sensor system that will require more attention. For example calibration of the gauges should be done using some regression technique, actually a simple loading with single weights at several levels is used. Although very simple yet the evaluation of the regulation constant could be further simplified by using a low level programming language in the control system.

The use of multi signal tension sensor represents a new approach to the monitoring of weaving process. It allows the loom control system to handle better the irregularities in the weaving and thus increase the final product quality.

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