XVII IMEKO World Congress
Metrology in the 3rd Millennium
June 22-27, 2003, Dubrovnik, Croatia

MINIATURE TRANSDUCERS FOR DYNAMIC MEASUREMENTS OF YARN TENSILE FORCES

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Abstract – The purpose of this lecture is to show the problems which must be taken into account by the designer in constuction of miniature semiconductor strain gauges for dynamic measurements of yarn tension and to give practical methods for identification of static and dynamic behaviour and a design of such transducer.

Keywords – Transducer, Yarn, Forces

1. MODEL OF TRANSDUCER OF TENSION IN THE TEXTILE MATERIALS

For measuring of time behavior of the force, appearing in the tread in the course of being processed in various textile manufacturing processes, the using of strain gauges, stuck on a spring, in the most of cases single end constrained beam like, is prevailing.

The force S(t) in the textile material is of variable characteristic in time, thus it is necessary, especially then for quickly varying forces, to design dynamic characteristics of measuring system, regarding true transfer of the measured quantity. One of the possible principles of measuring tension is shown on the Fig. 1. The transformation of signals in this mechanical-electrical transducer is possible to be represented by a block diagram (Fig. 2) configured as a series connection

- of a mechanical devices P_1, transforming the measured force S to a force P which is acting on the springs.
- of a mechanical transducer P_1 (spring) realizing functional relationship between the force P and deformation y
- of semiconductor or metallic strain gauges, connected in bridge and stuck on the spring P_3 transforming deformation y to el. voltage U_1
- of reading device P_4 for recording of measured variation of tension in a textile material.

The dynamic characteristics of strain gauges are elaborated for instance in [1, 2]. The strain gauge is of complying characteristics to this measuring, but the single end constrained beam with feeding guide of thread and the way of fixation of the strain gauges on this beam are limiting factors.

Therefore we will concentrate us on the behavior of the transducers P_1 and P_2

A signal *y* is function not only of tension, but also of series of parameters, which are possible to change their values in the course of measuring. We will get investigated the static and dynamic characteristics of these transducers with rotating rollers for the feeding guide of the textile material (Fig. 1). S = S′, effected by small friction in the roller bearings.

The conditions of equilibrium of moments for the rollers 2 and 3 are given by the differential equations:

$$\frac{J}{r}\frac{d\omega_1}{dt}+\frac{M_{P1}}{r}sign\omega_1+\frac{b_T}{r}\omega_1=S_2-S_1 \qquad (1)$$

$$\frac{J}{r}\frac{d\omega_2}{dt}+\frac{M_{P2}}{r}sign\omega_2+\frac{b_T}{r}\omega_2=S-S_2$$

where S, S_1, S_2, S′ (N) are forces in the thread on the segments $\overline{A_1A_2}$, $\overline{A_2B_2}$, $\overline{O'A_2}$, $\overline{B_2O}$, M_{P1}, M_{P2} (Nm), ω_1, ω_2 (s^{-1}) – correspondent moments of friction in the rollers 2 and 3 and their angular velocities

J (kgm^2), r (m), - correspondent moment of inertia and radius of the rollers

b_T ($Nm^{-1}s$) – coefficient of viscose friction of the feeding guide of thread

The mutual relationship of force in the material and angular velocities on the segment $\overline{B_1B_2}$ is possible to be represented by a differential equation of 1st order

$$\frac{dS_2}{dt}=\frac{ESr}{l}\left(\omega_2-\omega_1\right)-\frac{r\omega_1}{l}\left(S_2-S_1\right) \qquad (2)$$

E (Nm^{-2}) - modulus of elasticity of textile material

S (m^2) - area of cross section of thread

l (m) - length of material on the segment $\overline{B_1B_2}$ is a function of translation of the measuring guide by the roller, and it is determined by an approximate relation

$$l\approx l_0+\frac{r}{l_0}y \qquad (3)$$

l_0 (m) . original length in rest position of spring

The dynamics of the spring is generally given by a partial differential equation (a system with distributed parameter). A small beam is possible to be considered as a system of 2nd order with sufficient accuracy.

$$my'' + by' + Cy = (S_1 + S_2)\sin\frac{\alpha}{2} \qquad (4)$$

m (kg) – total mass of the roller 2 and of the beam
b ($N\,m^{-1}s$) – coefficient of damping
C (Nm^{-1}) – rigidity of the spring

After have made the equation (1 to 4) linear, it is possible to come to an operator form of notation, what is giving a system of differential equations. Their solution is possible to be give an equation, which determinates mutual relationship between the deformation of spring, tensile forces, friction moment in the bearing and angular velocity:

$$\begin{aligned}&(T_3p^3 + T_2p^2 + T_1p + 1)\Delta y(p) = (T_5p^2 + T_4p + 1)k_1\Delta S(p) -\\ &- k_2\Delta M_{P1}(p) - (T_7p^2 + T_6p + 1)k_3\Delta M_{P2}(p) -\\ &-(T_{10}p^3 + T_9p^2 + T_8p + 1)k_4\Delta\omega_2(p)\end{aligned} \qquad (5)$$

The block diagram (Fig. 3) of the mechanical transducers P_1 , P_2 , is showing a structure of linkage on the transfer functions $\frac{\Delta y(p)}{\Delta S(p)}, \frac{\Delta y(p)}{\Delta M_P(p)}, \frac{\Delta y(p)}{\Delta\omega_2(p)}$ of time constant T_i and coefficient of gain k_i are complicated functions of structural coefficients and therefore we will not present them here.

Values $\Delta M_{P1}(p)$, $\Delta M_{P2}(p)$ a $\Delta\omega_2(p)$ are source of undesirable static and dynamic errors of the transducers P_1 and P_2. A detailed analysis of effects of these input signals of interference on the value $\Delta y(p)$ is possible to be realized on an analogue or digital computer only, and when making a design of transducers with optimal parameters an from the point of view of minimum of static and dynamic errors, it is possible to use with advantage methods of synthesis which have been known in the theory of the regulating circuits.

Methods applied in project of miniature resistive sensor for measuring yarn tension, processed on PC, are provisioned of the following equations system:
Delivered:

$$T \;\rightarrow\; F \in (0 - F_{MAX}),\ \alpha,\ E,\ \rho,\quad S_{MIN} = (bl)_{MIN}$$

Parameters: b, h, l
Applied: graphical approach of dependences y(F), f_0 = g(b, h, l), U = f(F)

$$F = 2T_0\sin\frac{\alpha}{2} \qquad [N, N, -] \qquad (6)$$

$$\varepsilon = \frac{6Fl}{Ebh^2} \le \varepsilon_t$$

$$U \approx U\frac{\Delta R}{R} \qquad [V, \Omega]$$

$$f_0 = \frac{1}{2\pi}\sqrt{\frac{bh^3E}{4l^3(0{,}23m_a + m_b)}} \qquad [Hz]$$

Static error of the Instrument.

Will follow of geometry of the same (Fig. 4b)

$$F = \frac{B}{a}2T_0\frac{1}{1 + \frac{2T_0}{ak}} \qquad (7)$$

$$for\ \frac{2T_0}{ak} \ll 1 \quad\rightarrow\quad \Delta F_S \approx -\frac{2T_0}{ak}\cdot 100\%$$

k – rigidity of the beam

Dynamic error will be delivered by the following equation:

$$\Delta_D(\omega) = 1 - \frac{1}{\sqrt{\left[1 - \left(\frac{\omega}{\Omega}\right)^2\right]^2 + \left(2\delta\frac{\omega}{\Omega}\right)^2}} \qquad (8)$$

Influence of yarn friction on sensor indications. Experiments have proved that results of measuring will be distorted by yarn friction on guide (and measuring elements). Supposing that for friction of yarn on surface cylindrical element EULER relations will be applied, hence we may write:

$$F = F_0e^{\pm f\alpha} \qquad [N, N, -] \qquad (9)$$

where: f - coefficient of friction
α - angle of contact
± - notes indicating direction of guide of yarn

hence for geometry of Instrument done, we may obtain as follows:

$$F' = F_0e^{\pm f\beta}\left(1 + e^{\pm f\alpha}\right)\cdot\sin\frac{\alpha}{2} \qquad (10)$$

Component mentioned will be really indicated by sensor and converted to electrical signal. It will be evident that only for f = 0, correct value of force will be furnished. Friction influence may be lowered by the following provisions:
- by suitable geometry of guide means of yarn and selection of materials of friction yarn guides ($10° \le \alpha \le 30°$)
- by the application of abrasive resistant surface layers on base of Nickel (and Diamond) and thermal processing)
- application of dry lubricating films (slide layers) EMRALON, MoS_2, PTFE, graphit, etc.

2. DISTORTION OF TRIANGULAR PULSE BY THE SYSTEM OF SENSOR

We suppose that the transfer function of sensor of tensile force has form

$$F(p) = \frac{U(p)}{S(p)} = \frac{K}{T^2p^2 + 2\xi Tp + 1} \qquad (11)$$

ω_0 (s^{-1}) - proper angular velocity
ξ (-) - coefficient of damping
from thence

$$u(t) = L^{-1}\{F(p)S(p)\} \qquad (12)$$

If the unit step is input function, then the forms of responses for various ω_0, ξ are known.

In an idealized case, we are reflecting what a distortion of the triangular pulse will be after have passed this system.

In [3, 5], dynamic errors of sensor of yarn tension, described with a model of 2nd order, are investigated. Regarding that it may occur impulses at the stress of yarn, it has been investigated its behavior (of the sensor) at the course of idealized triangle-like impulse. as well of other forms with pulse width 0.5 - 500 ms for various proper frequency and damping (solved on PC). By means of integral criterions, it has been evaluated the dynamic errors of sensor and optimal parameters ω_0 and ξ have been found (Fig. 5).

The samples of graphic records for isosceles triangle are (for different parameters of sensor and pulse width) on the Fig. 6, 7, 8. If we want to transmit a very narrow pulse t_i = 4 ms without distortion, the proper frequency $f_0 \geq 10$ kHz at optimal damping $\xi = 0.707$. Computations of dynamic errors, the graphic interpretation in accordance to various criterions and parameters of the system included, are in the work [5].

A dimension of dynamic error is depending also the form of input signals. The optimal values of damping coefficient in relation to the integral criterion type for various responses of input signals are in the interval $0.5 < \xi < 0.707$.

Studies of dynamic errors is useful both at designing of equipment (for an entered measuring error and supposed spectrums of input quantities, we preset ω_0 and ξ) or at the identification of features of completed instrument sample, when verifying its behavior by testing by means of the typical input signals and from the response of those we would determine experimentally (for the needs of a technical documentation) real parameters ω_0 , ξ and by that also operational frequency range, in that we are reading the measured quantity with an allowed dynamic error.

3. ANALYSIS OF MEASUREMENT

The measurers of tensile force have been usually equipped with an output for a registration instrument. The result of measuring is time behaviors of tension force (pertinently relationship of force on another quantity – trajectory, velocity, angle) written on a registration paper. The evaluation may be realized visually, or more often by means of defined mathematical operations, realized either with hardware (in analog or digitally) or with software, if we would have connect the measuring system trough the analog-to-digital transducer with a numerical computer mean. For the present, it has not been dedicated an appropriated attention in the literature related to measuring of tensile force. Nevertheless, certain typical characteristic or parameters of system of curves, representing the measured quantity are possible to be traced:

- Typical response of the measured signal, ensued of making mean of repeated measuring cycles, producing certain variance and disturbing noise (Fig. 9a, b).
- Essential values of the response – mean, maximal, minimal value of tensile force (at weaving, e. g. force in the moment of beating-up or tensile force in top and shed, at reeling off the weft from magazine f. e. the quantities in top and bottom dead center and the like).
- Selected characteristic parametres of course, for instance. Unevenness in tension

$$\delta\, S = \frac{S_{MAX} - S_{MIN}}{S_{MIN}} 100\% \qquad (13)$$

Impulse of tensile force $I(t) = \int_0^t S(t)dt$ (14)

- Statistic characteristics are informing about the distribution of sequence of measured values and specifying the probability of abundance of overrated or underrated values; figuring $\overline{S}, \sigma_S$, as well of higher statistic moments and others.
- Extremal distribution, the distribution of peaks of tensile force in yarn in the textile machine, distribution of yarn strengths and so like.
- Frequency response characteristics are showing dependence of the measured quantity on velocity of investigated process or discovering, which mechanism of the machine has been showing itself in measured response of tensile force with such an undesirable way.
- Spectral density of power output (power output spectrum). By means of this function is possible to determine how many % of frequency, ranging between the preset values f_1 and f_2, are taking a part on the considered casual process in regard of total dispersion. The output spectrum indicates mean output in the frequency range f_1 to f_2 on the base of analogy of the electro-technical engineering (relation for the output of power, browsed trough a resistor of $R = 1\Omega$).
- Correlating and autocorrelating functions – define the mutual relation between two processes running in the engine, for instance between the velocity of yarn transfer and tensile force.
- Static and dynamic model of investigated process in the form of functional dependences between variables and parameters in two- or eventually three-dimensional space or in the form of system of differential equations, representing the relation of process changes in time. The measured responses emblematize the construction and technological parameters and state variables in the appropriated equations. At the same moment, the measuring is ranking a significant position at verifying and specifying more precisely model in the process of simulating.

4. CONCLUSION

Supposing correct dimensioning of beam, apt geometry of yarn guide and perfect interconnection of Instruments to beam, the same may be able to meet demands of plant application. It is essential to be informed as to natural frequency of the same, coefficient of damping and dynamic error of the Instrument.

Further research of transducers applied in measurement of yarn tension used in precise laboratory measurements should be suitably oriented on application of recent physical principles, for example piezoresistance on semiconductors.

If accomplishing research in propagation of waves in textile materials at the time of their passage across electromechanical system of the Transducer up to output of recording device.

For more objective evaluation of doings appeared in textile materials, contactless measuring procedure would be of importance, which would be able to assess local tension level and distribution of the same in longitudinal direction and in cross section of the yarn.

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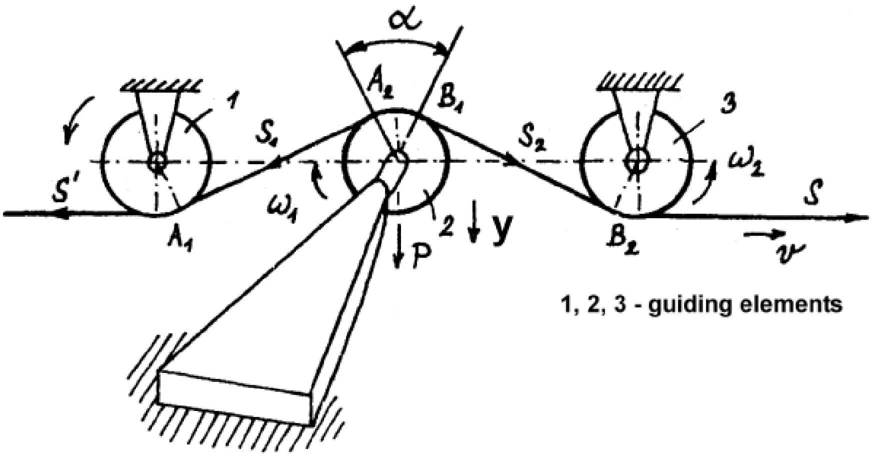

Fig. 1. Mechanical part of sensor

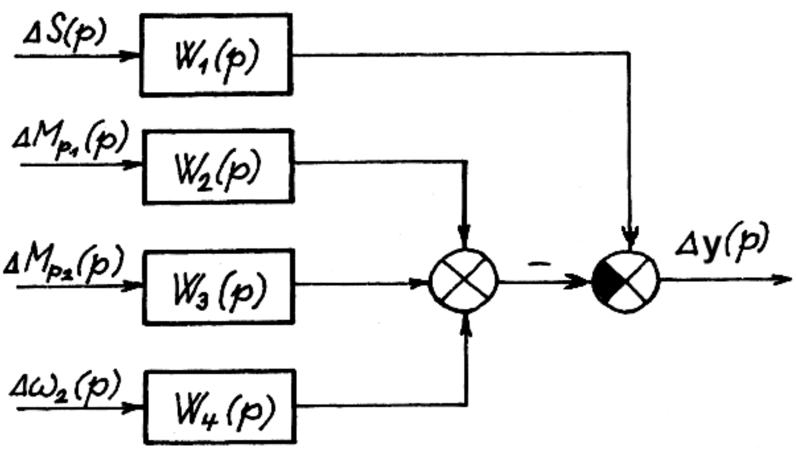

Fig. 3. Mechanical part of sensor

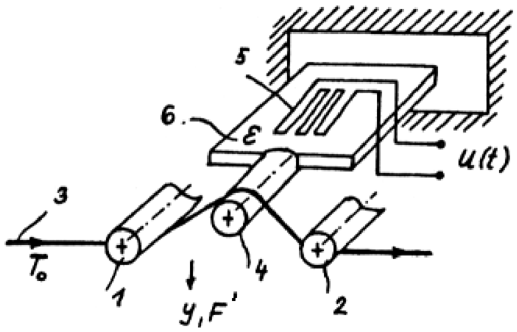

Fig. 4a. Resistive Transducer of yarn tensions

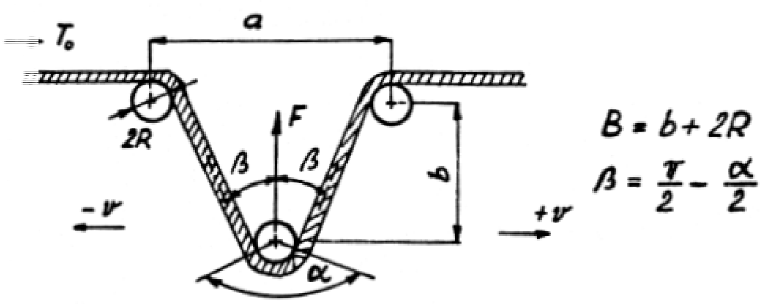

Fig. 4b. Geometry of sensor

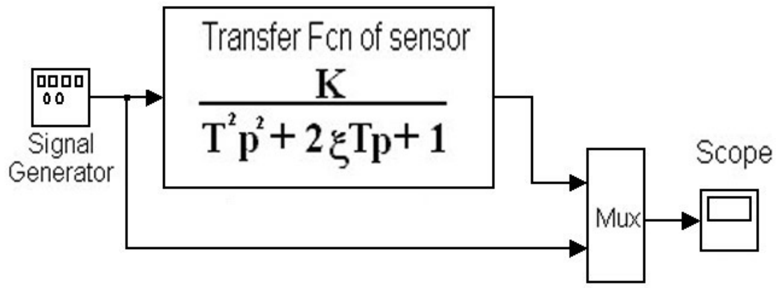

Fig. 5. Model of distortion of the triangular pulse in Matlab

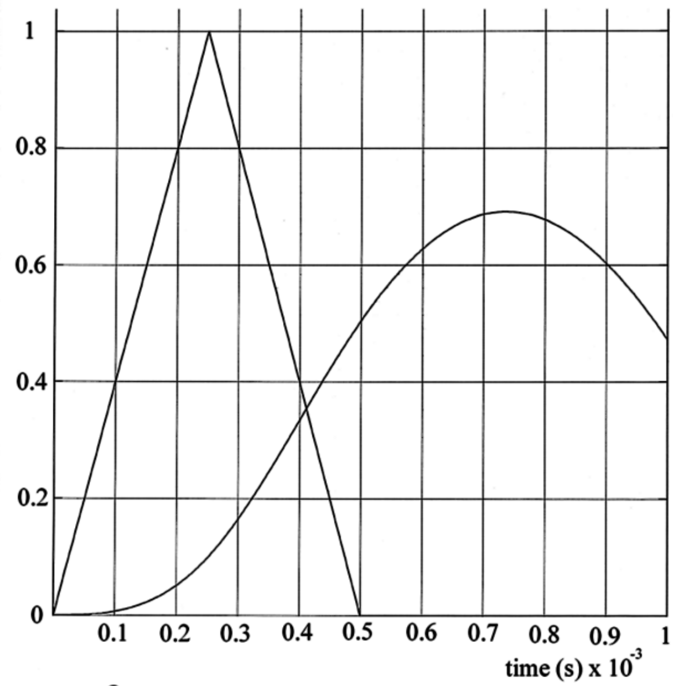

Fig. 6. Distortion of the triangular pulse (1)

τ_i = 0.5 ms, ξ = 0.05, f_0 = 500 Hz

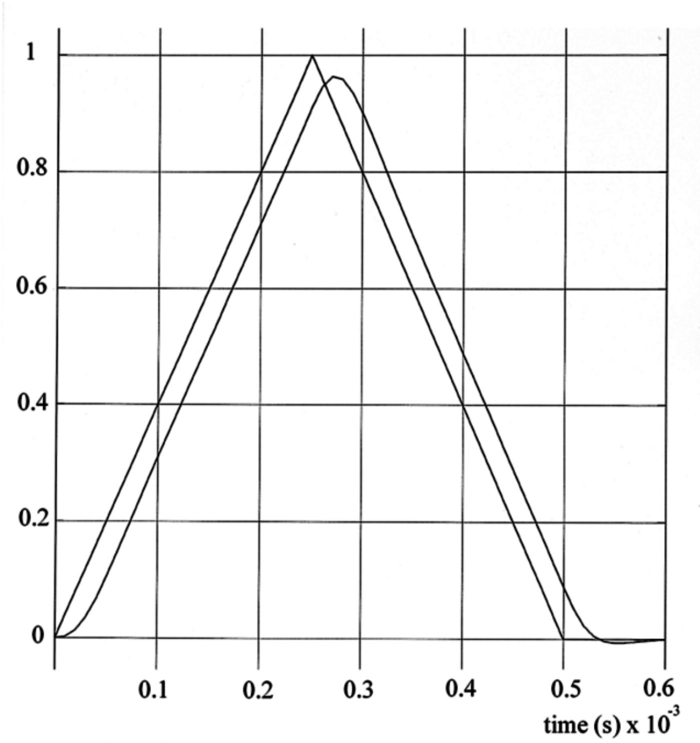

Fig. 8. Distortion of the triangular pulse (3)
$\tau_i = 0.5$ ms, $\xi = 0.707$, $f_0 = 10$ kHz

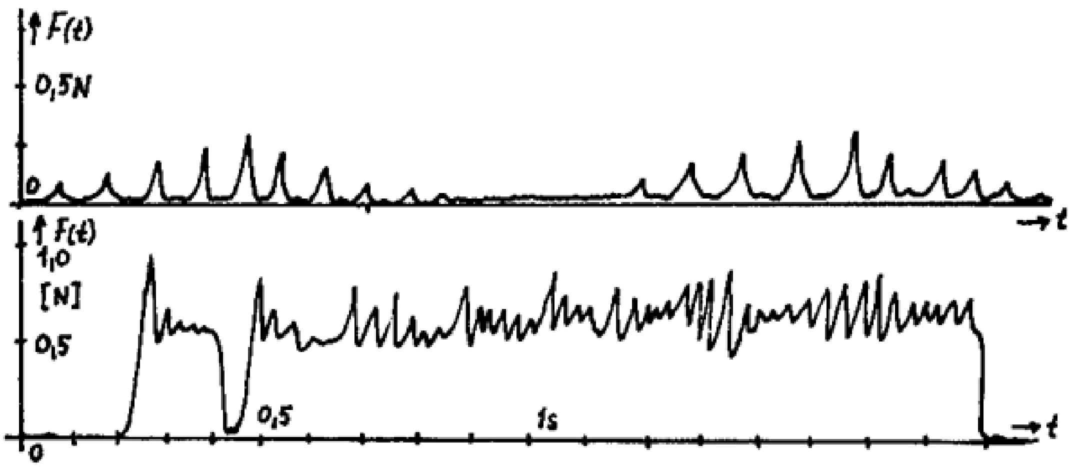

Fig. 9. a) Measuring of strain in weft at the time of winding-off the bobbin
b) Measuring of strain in weft on multi-shed weaving machines