MEASUREMENT OF YARN VELOCITY IN TEXTILE MACHINES USING A NON-CONTACT TRACER METHOD*

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Abstract

The presented measurement method uses a tracer for measuring the transit time between two fixed points of known distance. For the marking static electric charge is used, which can be impressed by a corona discharge and detected with a capacitive detector. Since the yarn is an insulator, the charge does not move on its surface; therefore the tracer signal is not changed during the transit time. This means that the system is a pure dead-time system, and the transit time can be calculated by measuring the phase-shift between the two detectors. This phase shift is determined by a simplified Fourier-transform done by a microcomputer. This microcomputer is also used for generating all needed signals, input-output and averaging.

Introduction

The presented measurement method is used to measure velocity and length of yarn transported in a textile machine. Mechanical methods are improper for this purpose because of the too big inertia and slip or because of the small edge-life; besides the yarn tension is influenced in intolerable manner. Therefore, efforts were made towards a non-contact measurement method.

The basic idea utilizes the fact that textile yarns mostly carry an electrostatic charge distributed over the yarn lengths stochastically. Because yarn materials are good insulators, the mobility of the charges along the yarn is small. The stochastic charge is used to generate a binary information about the yarn transport. This is done by a capacitive detector, the so called yarn guard, that produces a noise current if the charge is moved through its electrodes.

Now the transit time of the yarn between two detectors of known distance could be measured by computing the cross-correlation of the noise current of the two detectors. This would solve the measurement problem, but

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we will show a different way because a correlator is a rather complex equipment, even in its simplest form, the polarity correlator.

On the contrary, I tried to minimize the expense of signal processing by using a tracer method. This is done by charging the yarn with a simple signal of known periodicity. Besides the saving in signal processing the amplitude of this signal is much less depending on yarn type than the noise amplitude. Therefore it is not necessary to adjust the gain of the detectors.

In the following the parts of the measurement system are discussed. The system consists of three main parts, these are the detector, the charging device and the yarn used as medium for signal transmission.

Parts of measurement system

Detector

To detect the charge transported on the yarn a capacitive detector is used. It consists of a center electrode with the shape of a horseshoe and two outer plates connected to ground (Fig. 1).

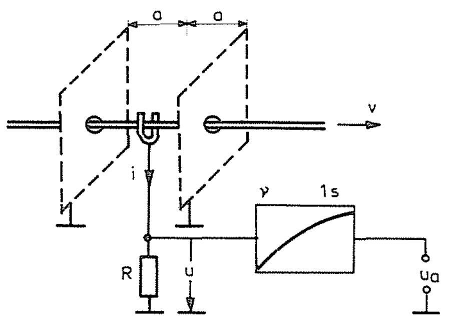

Fig. 1. Detector

With the definition of the charge density on the yarn

$$\eta(x) = \eta(vt) = \frac{dq}{dx},$$

and its Fourier-transform $H\left(\frac{\omega}{v}\right)$ the transmission function of the detector can be written for small ω [1]:

$$U(\omega) = aRj\omega H\left(\frac{\omega}{v}\right), \qquad \omega < 2 \cdot 10^3 \text{ 1/s}.$$

As expected, the detector is a differentiating system. Because the frequency ω of a geometrically constant pattern rises as v rises, $U(\omega)$ is directly dependent on v. To avoid this and to generate a signal proportional to the charge density an integrator is placed after the detector.

$$U_a(\omega) = \frac{v}{T} aR\, H\left(\frac{\omega}{v}\right),$$

$$U_a(t) = \frac{v}{T} aR\, \eta(vt)\,.$$

Now u_a is proportional to $\eta(x)$, all other parameters are constant. Important is the meaning of the plate distance a. $2a$ is a measure for the sensitive zone of the detector; it recognizes only the charge within this distance.

Generating a tracer signal

As said before, the charge density on the yarn is to be influenced artificially. Therefore a charging device is needed.

Since the yarn consists of dielectric material, the lines of force concentrate around it, if it is put in an electric field (Fig. 2). If there are charges in the field, they move along the lines of force. Therefore they hit the yarn where they are trapped, at least partially. The charged field is generated by a corona discharge. A corona is a spontaneous gas discharge in an inhomogeneous electric field; its current is automatically limited by the space charge [2].

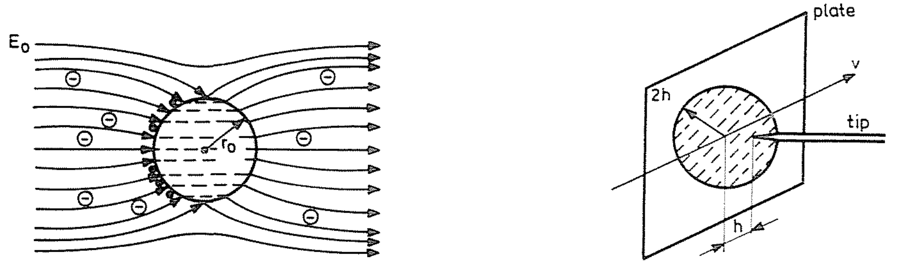

Fig. 2. Yarn in electric field, corona arrangement

A typical arrangement is the tip-plate arrangement (Fig. 2). Here the tip carries the negative voltage because the break-through voltage of negative corona is much higher than that of positive corona.

It can be shown, that the radius of the effective field zone is about two times the distance from tip to plate. This parameter is important because the charge signal rises on the yarn length $2h$ from zero to its maximum value, if the corona is switched. Therefore the constant length $4h$ is added to the on-time of the corona; this is the lower value in the picture (Fig. 3) because a negative corona is used.

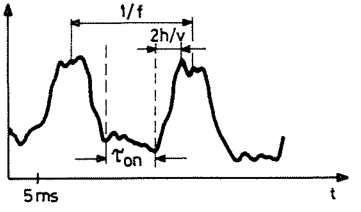

Fig. 3. Rise time

Through this the cutoff frequency for the charging is fixed. If

$$v \cdot \tau_{on} = v \cdot \frac{1}{2f} = 4h\,,$$

the discrete corona pulses are not distinguishable anymore.

$$f < \frac{v}{8h}\,.$$

The effective field zone can be reduced by a screen; it is possible to have a zone width of $4h^* = 1$ cm at $h = 0.7$ cm.

The charge on the yarn does not rise infinitely; there exists a saturation charge density. This saturation charge is proportional to the applied field E_0 and the yarn radius r_0:

$$\eta_{max} = 2r_0\varepsilon_0 \frac{2\varepsilon_r}{\varepsilon_r + 1} E_0\,.$$

As the diagrams (Fig. 4) show, this relation is fulfilled quite sufficiently.

The build-up time of the corona and the time to charge the yarn up to its saturation charge are smaller than 0.1 ms. For this reason they are not important for the measurement system. Important for the system is the clear

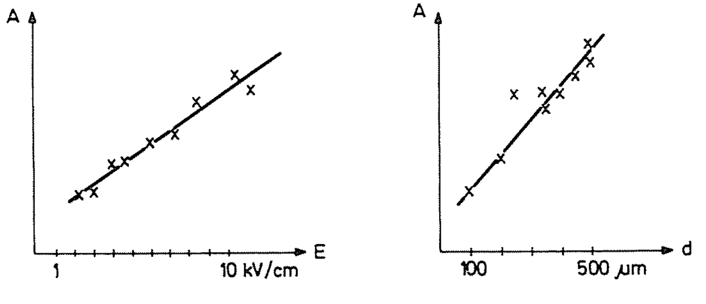

Fig. 4. Charge vs. Field E_0 and yarn diameter d

out time of the tip-plate arrangement, that is the time until all space charges have disappeared after switching off the corona. The experiment shows times in the range of ms, which means that the charge pulse is elongated in noticeable manner.

At last a typical example for the charge signal is shown (Fig. 5), generated by periodically switching on and off the corona. The signal was taken with a wool fibre of very inhomogenous diameter, which creates a large noise, if the corona is switched on. In the power spectrum the first harmonic has an amplitude of $(3.5\ V)^2$, the noise is assumed to be white with a power density of ca. $(0.08\ V)^2/Hz$.

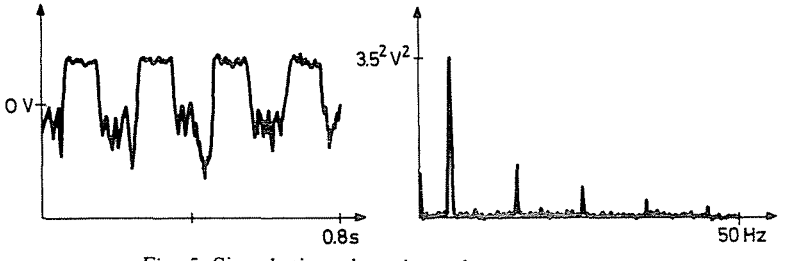

Fig. 5. Signal: time domain and power spectrum

Signal transmission

This part deals with the yarn as a medium for signal transmission. If the yarn is charged at the point of origin at time $t=0$, there will be a signal at the point $x=d$ for $t>0$ (Fig. 6). This signal is transformed from the input signal by the superposition of the yarn velocity and the movement of the charges on the yarn. The movement on the yarn is depending on the surface conductivity of the yarn, which is zero under ideal circumstances.

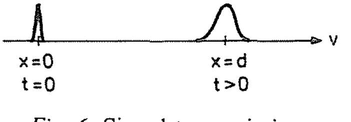

Fig. 6. Signal transmission

The signal transmission can be characterised by the impulse response or by the transmission function; they are depending on the distance d and the yarn velocity v.

An example for the broadening of impulse response due to the movement on the yarn is shown in Fig. 7.

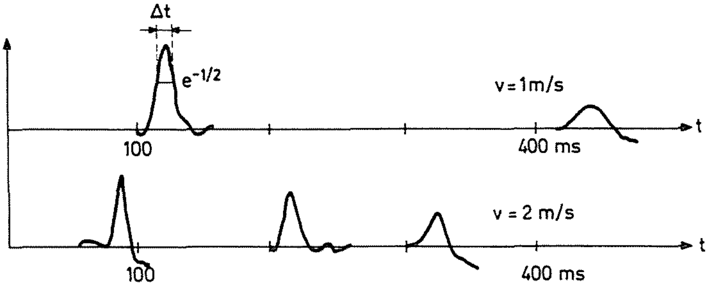

Fig. 7. Impulse response

It can be seen that broadening is symmetric to the center in the first order and that the amount of charge is constant. The width of the impulse response and the cutoff frequency for signal transmission are related:

$$\Delta t_{1/2} = f_g = \text{const.} \qquad v, d = \text{const.}$$

Therefore the cutoff frequency is a measure for the broadening of the impulse response, too. In the following diagram (Fig. 8) the cutoff frequency is shown versus the relative humidity at different temperatures.

The cutoff frequency decreases with increasing humidity caused by the rapidly increasing surface conductivity. Since the measurement works with frequencies from 5 to 20 Hz, the transmission for the displayed yarns is quite bad, if the humidity exceeds values of 70%. However, this is not so bad as it seems to be because Fig. 8 shows the worst case for minimum yarn velocity. If the velocity increases, the cutoff frequency increases as the width of the impulse response decreases (Fig. 7).

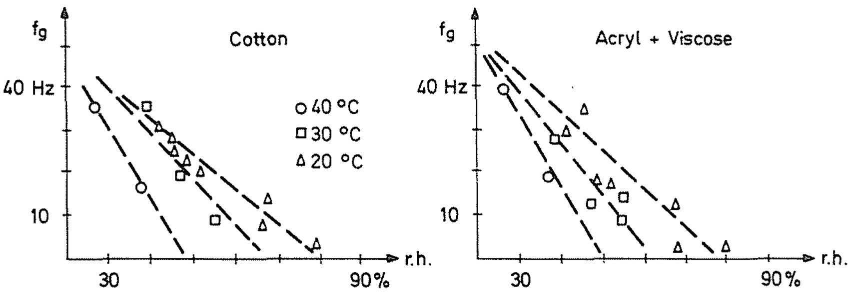

Fig. 8. Cutoff frequency vs. relative humidity

The measurement method introduced below is not affected by the broadening of the impulse response, if this broadening is symmetric. This is fulfilled in first order, but in second order there exists an asymmetric broadening, that causes a measurement error (Fig. 9). This asymmetry is due to

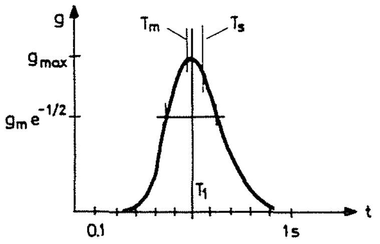

Fig. 9. Asymmetric broadening

the broadening of the pulse after the first part has already passed the detector. As can be seen, the center of gravity T_s is moved away from the true transit time T_1; the same happens with the measured value. If the humidity exceeds 70% relative humidity, the error can be in the range of 5 to 10%.

Measurement method

Basic idea

The method for transit time measurement is based on the assumption, that the transmission system is a pure dead time system in the first order.

$$G(\omega)=e^{-j\omega T_1}.$$

Then the change of signal s_2 with respect to signal s_1 is only the phase shift:

$$\Delta\varphi=2\pi f_0 T_1$$

$$\Delta\varphi=2\pi f_0 \frac{d}{v}, \qquad \omega_0=2\pi f_0=\frac{2\pi}{T_0}.$$

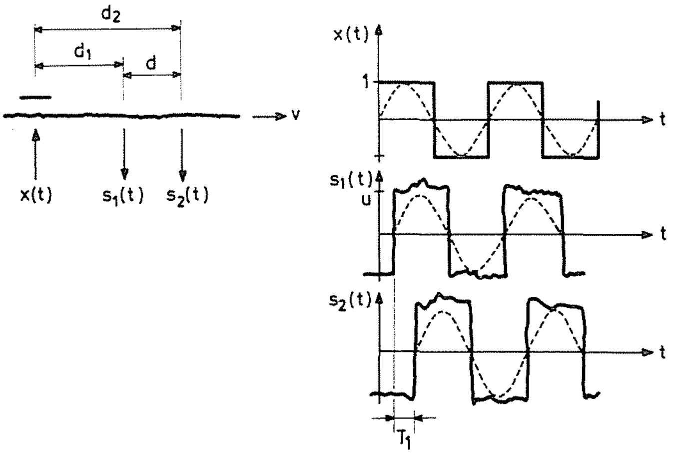

Fig. 10. Measurement system and signals

If the phase shift is measured, it is equivalent to the transit time and therefore it is a measure for the velocity. Theoretically the measurement could be done with one detector, if the phase of the yarn signal could be impressed by the corona exactly. Due to the clear-out time this is not possible, therefore the phase shift between two detectors is measured. This phase shift can be measured by computing the following integrals, which means a Fourier-transform for one frequency [3].

$$-\operatorname{Im} S(\omega) = \frac{1}{nT_0} \int_0^{nT_0} s_{1/2}(t) \sin(\omega_0 t)\, \mathrm{d}t = \frac{1}{2} u \sin \varphi_{1/2} ,$$

$$\operatorname{Re} S(\omega) = \frac{1}{nT_0} \int_0^{nT_0} s_{1/2}(t) \cos(\omega_0 t)\, \mathrm{d}t = \frac{1}{2} u \cos \varphi_{1/2} .$$

$$\tan \varphi_{1/2} = \frac{\operatorname{Im} S}{\operatorname{Re} S} ,$$

$$\varphi_{1/2} = \omega_0 T_{1/2} ,$$

$$\Delta\varphi = \varphi_2 - \varphi_1 .$$

Now all relevant parameters for the measurement system can be listed up:

a) rate of measurement as high as possible; this means signal frequency as high as possible;
b) distance d as small as possible;
c) sensitive zone of detector is about 3 to 4 mm; distance d should be much longer;
d) by the corona f is limited:

$$f < \frac{v}{8h} = \frac{1\ \mathrm{m/s}}{0.02\ \mathrm{m}} = 50\ \mathrm{Hz},$$

$$f = 20 \ldots 30\ \mathrm{Hz};$$

e) to provide uniqueness the phase shift over the whole measurement distance must be less than π; on the other hand it must be as big as possible for a good resolution.

Microprocessor implementation

In order to determine the phase shift, the detector signal is multiplied with sin ωt or cos ωt and the products are summed up. For simplicity, sin and cos were substituted by step functions (Fig. 11); now only a few factors are left.

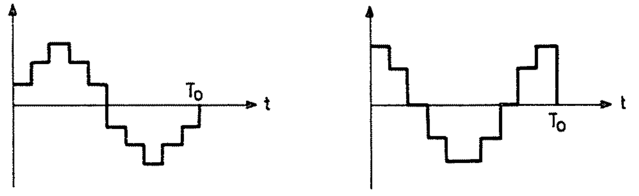

Fig. 11. Step functions

Evaluation and measurement show that this is possible, if the steps are narrow enough. Here sin and cos are divided into 10 steps.

For A/D-conversion (Fig. 12) a time pulse is generated, its duration is a measure for the amplitude of the detector signal. This pulse opens the gate of a counter. If the counting frequency is varied in accordance to the step functions, the state of the counter is a measure for the product of the detector signal and the sin or cos function. If the counter is not reset, the state of the counter becomes a measure for the integrals to be computed.

With the help of this the whole extension is reduced to a counter and some electronics, and the implementation is possible with a simple 8085 microprocessor. The computer itself generates the step functions and the corona signal; besides it does the arithmetic and system routines as input-output and averaging.

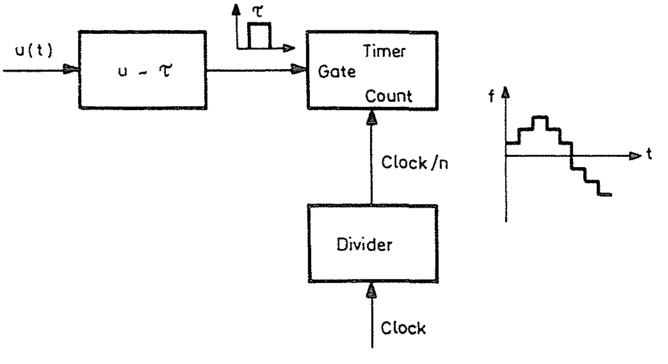

Fig. 12. A/D conversion

Errors in phase measurement

With the Fourier-integrals the phase shift of the first harmonic of the detector signal can be calculated. If the integration is extended over a multiple of the period length, there is no error due to higher harmonics; the remaining error is introduced by noise. The variance of this error is calculated in the following, this is done in a very approximate way since the difference measurement between two detectors is not considered. The first harmonic of the corona generated signal $y(t)$ can be written:

$$y(t) = \frac{4u}{\pi} \sin(2\pi f_0 t) .$$

This signal is delayed by the dead-time system and a noise with known power density is added.

$$L_n(f) = N_w$$

$n(t)$: white noise

$$s(t) = \frac{4u}{\pi} \sin(2\pi f_0 t - \varphi) + n(t).$$

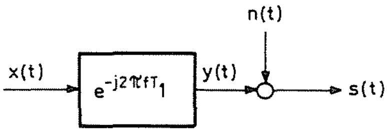

Fig. 13. System and noise

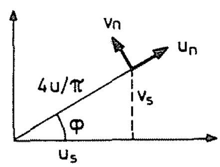

Fig. 14. Rotating vector diagram

This signal has the phase shift φ relative to the origin, but the phase shift is affected by the noise $n(t)$. To see the influence of $n(t)$ the signal is transformed to its rotating vector diagram [4].

In this diagram the noise signal is divided into a component u_n parallel to the signal vector and a component v_n orthogonal to it. The variances of the components are known; they are

$$\sigma_{u_n}^2 = \sigma_{v_n}^2 = \frac{2N_w}{T_m}, \qquad \text{where} \quad T_m = n\,T_0\,, \text{ (integration time).}$$

If $\frac{4u}{\pi} \gg \sigma_u, \sigma_v$, it can be written:

$$\tan \varphi_n \approx \varphi_n = \frac{v_n}{4u/\pi},$$

$$\sigma_\varphi^2 = \frac{v^2 N_w}{8unT_0}, \qquad \sigma_{T_1}^2 = \frac{N_w T_0}{32\,u^2\,n}.$$

Typical values are:

$$\sigma_{T_1}^2 = 4 \cdot 10^{-6}\,\mathrm{s}^2, \qquad N_w = (80\,\mathrm{mV})^2/\mathrm{Hz},$$

$$F_r = \frac{\sigma_{T_1}}{T_1} = 10\%, \qquad T_0 = 0.25\,\mathrm{s},$$

$$u = 3.5\,\mathrm{V},$$

$$T_1 = 25\,\mathrm{ms}.$$

As it will be seen later, this error is in good agreement with practical results. These results show the relative error of velocity measurement, but if the variance $\sigma_{T_1}^2$ is small enough, this has the same error:

$$\frac{\sigma_{T_1}}{T_1} = \frac{\sigma_v}{v}.$$

This equation is not correct, if σ_{T_1} is not small enough compared to one; in this case the velocity calculation gets a bias:

$$E(v) = \frac{d}{T_1}\left(1 + \frac{\sigma_{T_1}^2}{T_{12}}\right).$$

Results

Now some measurement results will be discussed. The results were taken with a system operating at 12 or 4 Hz, respectively.

$$d_1 = 3\,\mathrm{cm}, \qquad d = 5\,\mathrm{cm}.$$
$$d_2 = 8\,\mathrm{cm},$$

To compare the measurement method with other methods the evaluation of the integrals and the following computations were done on a process computer and compared with transit time measurement by searching the maximum of the cross correlation function. The cross correlation method is referenced to be the optimal method in a theoretical way.

Not only with a measurement time of one period but also with averaging over some periods both methods show the same mean value (Fig. 15); the spread of measurement values is about two times that of the CCF method for the phase measurement.

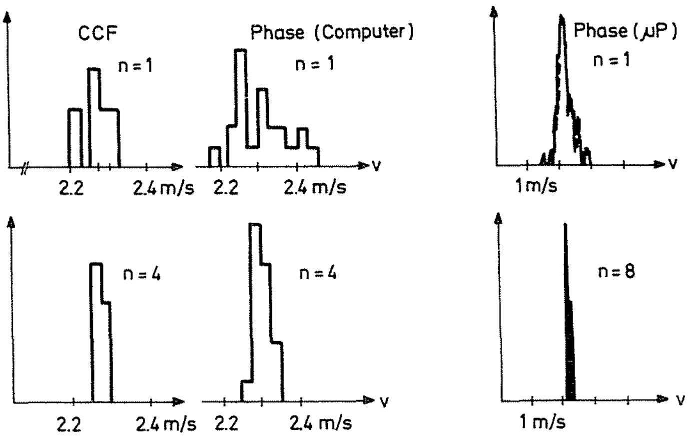

Fig. 15. Histograms of measurement data

This figure also shows results taken by the microprocessor implementation. Displayed are the histograms of measurement values with averaging over one period and over eight periods. Compared with the phase measurement done on the process computer there is no increase in spread or error in the mean value though all described simplifications are used.

a) process computer:

method	yarn type	σ_1/v_s	σ_4/v_s
CCF	polyamid	2.5%	1.0%
phase	polyamid	4.5%	2.0%

b) microprocessor:

phase	polyamid	5.0%	1.5%
phase	polyester	4.0%	1.5%
phase	wool	7.0%	2.5%

Summary

- the measurement system is assumed to be a pure dead time system;
- therefore the phase shift is proportional to transit time;
- the phase shift is computed by a Fourier-transform;
- for microprocessor implementation the Fourier integral is done by a counter;
- a comparison shows, that variances are two times greater than that of the CCF method for computing the phase shift.

References

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