6. Dynamics of the Tensile Force and its Importance for Process Stability

6.1 Task

Since the textile fibre formation and fibre processing processes have been carried out the special attention has been aimed at the reaction force of the yarn to an induced longitudinal deformation or elongation. The number of papers on the problem of yarn tensile force has increased meanwhile to probably more than a thousand. At first the steady state or dynamic measurements of the yarn tensile force (its mean value or the statistical description of its fluctuation parts) were, in the textile test lab, a sign of quality and use fitness of the threads. Yarn tensile force measurements have been carried out after the thread line on most different production machines in various manners. The measured signal courses have been analyzed by means of simple or also pretentious algorithms of the signal analysis or signal concentration. It is not the task of this chapter to sort and evaluate this specific textile-technological literature. Rather a row of universal regularities and hints to the measuring-methodical and analytic-technical practice which are worth mentioning should be given. These come from the theory of dynamic measurements as well as from own experimental results and they are not collected (to the knowledge of the authors) in this manner anywhere else.

The following specifics and problems are to be mentioned in connection with the product variable yarn tensile force:

a) Each fibre formation and yarn transport process is connected to a yarn elongation (see Sect. 5.1 - dynamics of the fibre transport). The so-called yarn tensile force therefore appears because each elongated yarn counteracts the elongation, a reaction force which is generally (as time function of the yarn tensile force) an expression for dynamic process reactions.
The mechanism of this appearance comes from the force-elongation diagram of the yarn (Fig. 6.1); each elongation ε (for instance ε_1, ε_2) is correlated with a yarn tensile force F (for instance F_1, F_2).

b) The yarn tensile force is a product variable which only exists during the process run. It provides information unlike any other process or product variable (measurable directly during the process) to the following points:

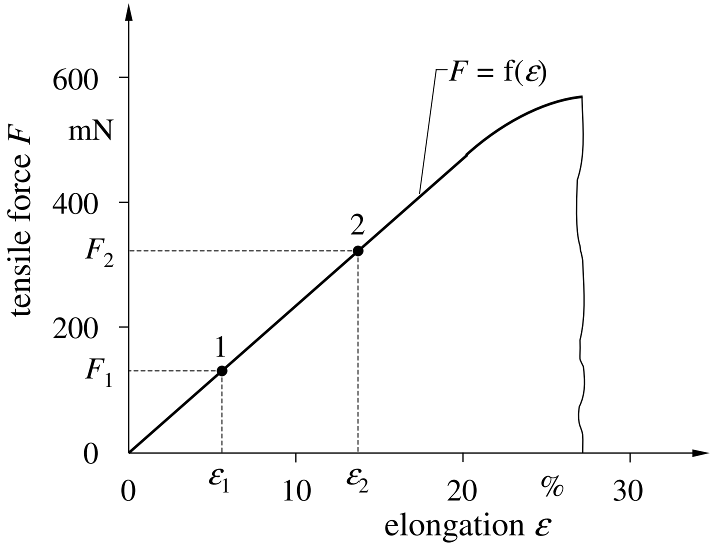

Fig. 6.1. Force-elongation diagram of a yarn (in principle)

- unevennesses of the force-elongation-behaviour of the threads (problem of the “inner unevennesses”).
- unevennesses of the yarn transport (irregularities at the passing of the yarn transport lines which are necessary for carrying out the fibre formation and yarn processing processes).

c) The yarn tensile force is a complex effect quantity. Most of the different causes are reflected to it in the strongest superposed manner.

d) As a rule, only a visual analysis of recorded yarn tensile force signals does not allow an unambiguous research of disturbance causes.

e) The yarn tensile force is the cause of effected structural changes in man-made fibres (for instance orientation changes of the macromolecules). The yarn tensile force is because of that an essential cause quantity to the stress strain properties.

f) The time function of the yarn tensile force can be seen as an indicator of the process stability. High mean values of the yarn tensile force near the breakage limit lead similarly to increased yarn breakages and decrease of the productivity as great changes of the yarn tensile force at its low mean value. It is noticed that the breakage limit itself is not a constant value (see Fig. 6.2).

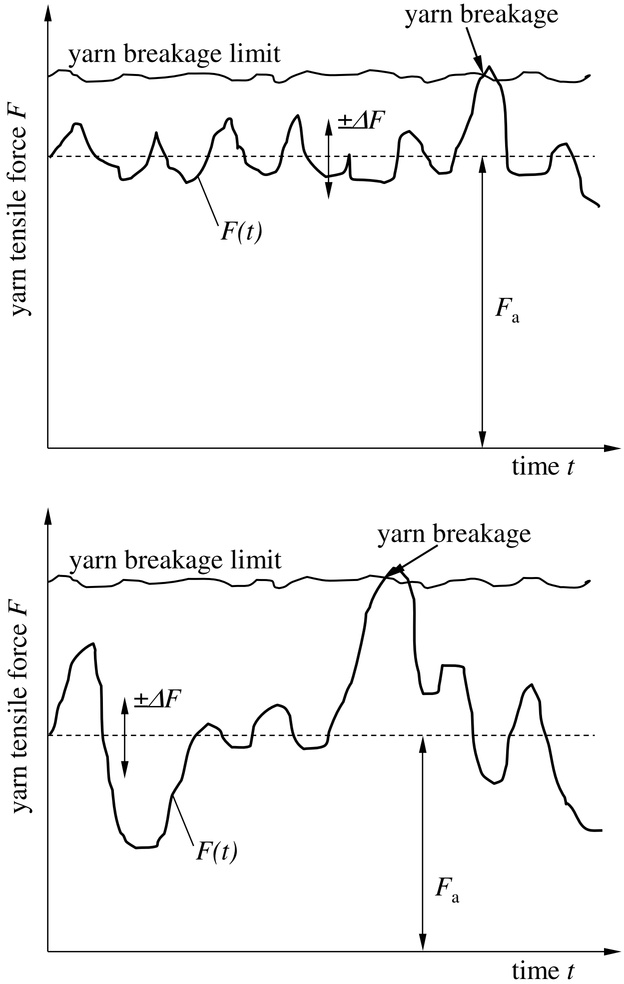

Fig. 6.2. Oscillations of the yarn tensile force – cause for the yarn breakage; *above*: great average F_a, small oscillations $\pm\Delta F$; *below*: small average F_a, great oscillations $\pm\Delta F$

g) The measurement of the yarn tensile force is in most cases without contact. Reactions to the thread line are therefore not excluded.

h) yarn tensile force measuring sensors must have a sufficiently high critical frequency because the time function of the yarn tensile force reflects the dynamics of most of the different disturbance causes (see Sect. 6.3).

6.2 Connection Between Fibre Fineness and Fibre Tensile Force Variations

The derived dynamic functions of fibre formation and yarn transport lines (see Sect. 4.2.1 and Sect. 5.1) place several cause-effect relations for the product variable yarn fineness into the center of view.

All derived dynamic time transient functions, complex frequency responses, amplitude frequency responses and phase frequency response are valid for effected yarn tensile force changes similarly, but, only if the same disturbance causes (as described in Sect. 4.2.1 and Sect. 5.1) take place and if the following developed mathematical relationships between yarn fineness and yarn tensile force will be put into the model equations.

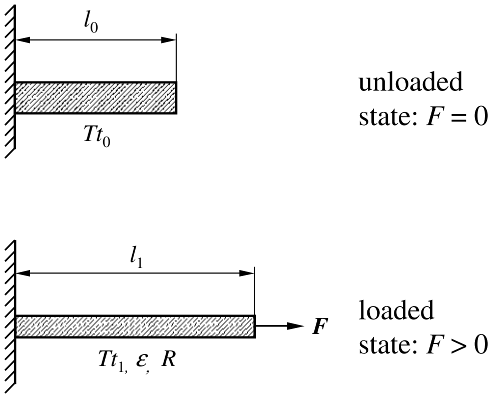

Fig. 6.3. Elongation

The well-known relations are valid between the unloaded (Tt_0, l_0) and the yarn (Tt_1, l_1, ε, R_y) loaded by means of the tensile force F according to Fig. 6.3:

$$R_y = E_y \cdot \varepsilon \tag{6.1}$$

R_y tensile stress $= F/Tt_1$
ε yarn elongation
E_y elastic modulus

Equation 6.1 can be written as:

$$F = E_y \cdot Tt_1 \cdot \varepsilon \tag{6.2}$$

The fineness of the loaded yarn Tt_1 is inserted into Eqs. 6.1 and 6.2 only because this mediates the approach to the tensile stress (fineness related tensile force) which the material will suffer from physically. This differs from the practice of yarn testing in a lab, where for the tensile stress (fineness related tensile force), the fineness of the unloaded yarn is in general use.

The elongation ε can be read as:

$$\varepsilon = \frac{l_1 - l_0}{l_0} = \frac{Tt_0 - Tt_1}{Tt_1} \tag{6.3}$$

Eq. 6.3 put into Eq. 6.2 results in:

$$F = E_{\mathrm{y}} \cdot (Tt_0 - Tt_1) \tag{6.4}$$

If we take F and Tt_1 as variable sizes which consist of a mean value part F_{m} and $Tt_{1\mathrm{m}}$ as well as a change part ΔF and ΔTt then Eq. 6.4 can also be written as:

$$F_{\mathrm{m}} + \Delta F = E_{\mathrm{y}} \cdot [Tt_{0\mathrm{m}} - (Tt_{1\mathrm{m}} + \Delta Tt_1)] \tag{6.5}$$

The fineness of the unloaded yarn Tt_0 should apply to this constantly and designated (formal following the same agreement) with $Tt_{0\mathrm{m}}$. Equation 6.5 now represents the conversion relations between the yarn fineness under elongation load and the appearing yarn tensile force:

$$F_{\mathrm{m}} = E_{\mathrm{y}} \cdot (Tt_{0\mathrm{m}} - Tt_{1\mathrm{m}}) \tag{6.6}$$

The change sizes are obtained through the relationship:

$$\Delta F = -E_{\mathrm{y}} \cdot \Delta Tt_1 \tag{6.7}$$

It is also valid for the interesting output fineness (Tt_{o}, Tt_{om}, ΔTt_{o}) of the yarn which leaves the process line according to the generally used relationship in Sect. 4.2.1 and Sect. 5.1:

$$F_{\mathrm{m}} = E_{\mathrm{y}} \cdot (Tt_{0\mathrm{m}} - Tt_{\mathrm{om}}) \tag{6.8}$$

$$\Delta F = -E_{\mathrm{y}} \cdot \Delta Tt_{\mathrm{o}} \tag{6.9}$$

All dynamic functions which the yarn fineness change contains as effect variable can be converted immediately into the effect variable yarn tensile force by use of the conversion relationship of Eq. 6.9.
The formal procedure should be demonstrated using the dynamic transfer function (see Eq. 4.9) which the relationship represented between a change of the output velocity Δv_{o} and yarn fineness change ΔTt_{o} effected by this. Equation 4.9 in Sect. 4.2 can be read as:

$$G(p) = \frac{\Delta Tt_{\mathrm{s}}}{\Delta v_{\mathrm{s}}} = -\frac{Tt_{\mathrm{sm}}}{v_{\mathrm{sm}}} \cdot \frac{1}{1 + p \cdot \dfrac{l_{\mathrm{m}}}{v_{\mathrm{sm}}}}$$

The effect variable ΔTt_o is to be substituted by the new effect variable ΔF according to Eq. 6.9:

$$G(p) = \frac{\Delta F}{\Delta v_\text{s}} = -\frac{E_\text{y} \cdot Tt_\text{sm}}{v_\text{sm}} \cdot \frac{1}{1 + p \cdot \dfrac{l_\text{m}}{v_\text{sm}}} \tag{6.10}$$

The step response of the yarn tensile force change ΔF owing to a step of the output velocity Δv_o also comes from the step response of the yarn fineness change (Eq. 4.13) similarly:

$$\underline{\Delta F}|\overline{\Delta v_\text{s}} = \Delta v_\text{s} \cdot E_\text{y} \cdot \frac{Tt_\text{sm}}{v_\text{sm}} \left[1 - \exp\left(-\frac{v_\text{sm}}{l_\text{m}} \cdot t\right)\right] \tag{6.11}$$

The elastic modulus E_y of the elongation-loaded transported yarn also appears as the conversion factor with the dimension mN/tex. All diagram representations (for instance Figs. 2.13, 2.14 to 2.16, 4.4 to 4.6, 5.6, 5.8, 5.9, 5.20, 5.21) are usable in principle if the presented conversion relations are used. The appropriate ordinate measure is to be converted from ΔTt_o to ΔF according to the conversion relation. The normalised representation of ordinate measures (Figs. 4.4 to 4.6) do not cause again normalised (relative effect change referred to relative disturbance change) representations after the conversion from ΔTt_o to ΔF! The normalised amplitude ratio $\dfrac{\widetilde{\Delta Tt_\text{o}}/Tt_\text{om}}{\widetilde{\Delta v_\text{o}}/v_\text{om}}$ will be converted into $-\dfrac{\widetilde{\Delta F}/(E_\text{y} \cdot Tt_\text{om})}{\widetilde{\Delta v_\text{o}}/v_\text{om}}$ and ***not*** to $-\dfrac{\widetilde{\Delta F}/F_\text{m}}{\widetilde{\Delta v_\text{o}}/v_\text{om}}$ because of the simple conversion relation $F_\text{m} = -E_\text{y} \cdot Tt_\text{om}$ is ***not*** valid according to Eq. 6.8.

6.3 Dynamic Properties of Tensile Force Measuring Sensors and its Importance for Experimental Process Analytical Investigations

It is useful to remember some general theoretical knowledge of oscillation science and the measuring of dynamics before the evaluation of time functions from the yarn tensile force can be described.

Yarn tensile force measuring sensors are oscillatable elements related to the tools which are turned toward the yarn (usually bend-stiff elastic, one-sided chucked steel tongues are used for force transmission). Therefore, the yarn tensile force changes can only be transmitted up to an appointed upper frequency (the well-known critical frequency) without an amplitude falsification of the measured tensile force change course. Tensile force fluctuations above the critical frequency of the measuring sensor will be reflected damped, that means the amplitudes will either be reflected on a small scale or not even noticeable.

The demand for a measuring quantity transmission without any mistakes is:

critical frequency of the measuring sensor $\geq$ *the greatest occurring oscillation frequency in the time function of the concerned process or product variable* (6.12)

However, the relation 6.12 is only one necessary prerequisite. A further important prerequisite is an optimum dampening of the force transmitting, oscillatable bending tongue. Only then is it possible to fully treat the critical frequency f_c of a measuring sensor. Optimum dampening means that the amplitude frequency response of the (sinusoidal) bending tongue shift $\widetilde{\Delta w}$ is almost constant in the frequency range $0 \leq f \leq f_\mathrm{c}$ by means of a sinusoidal imprinted tensile force at the free end of the bending tongue which is equipped with a yarn guiding element. The optimum dampening is realised by means of special design arrangements either as pure air dampening or as oil dampening (for instance with an oil filling of suitable viscosity between the bending tongue and the fixed sensor case).

Figure 6.4 shows an example of a one-sided chucked measurement sensor bending tongue which's bending way $\widetilde{\Delta w}$ is measured by means of two inductive way sensors (capacitive measurement is likewise possible). The necessary dampening is reached by oil which is filled into the slit between the inductive way sensors and the bending tongue. Such a design solution (here only outlined schematically) is described in [318].

In principle the dynamic transfer properties and the possible amplitude frequency responses are shown in the diagram in Fig. 6.4 for such a system with differently strong dampening of the bending tongue.

The curves are based upon the generally known amplitude frequency response equation of a mass-spring-dampening system which can be found for instance in [5]. For the case of our system:

$$|G(\mathrm{j}f)| = \left|\frac{\widetilde{\Delta w}}{\widetilde{\Delta F}}\right| = K_\mathrm{N} \cdot \left[\left(1 - \frac{f^2}{f_\mathrm{n}^2}\right)^2 + 4 d_\mathrm{f}^2 \frac{f^2}{f_\mathrm{n}^2}\right]^{-1/2} \tag{6.13}$$

The symbols mean:

- $\widetilde{\Delta F}$ amplitude of the induced sinus-like force oscillations at the bending tongue
- $\widetilde{\Delta w}$ amplitude of the sinus-like shifts at the bending tongue
- K_N normalising factor
- f frequency of the induced sinus-like force oscillations
- f_n natural frequency of the bending tongue
- d_f dampening factor

A dampening factor that is too small ($d_\mathrm{f} < 0.6$) as well as a dampening factor that is too large ($d_\mathrm{f} > 0.6$) is unsuitable for a measuring signal trans-

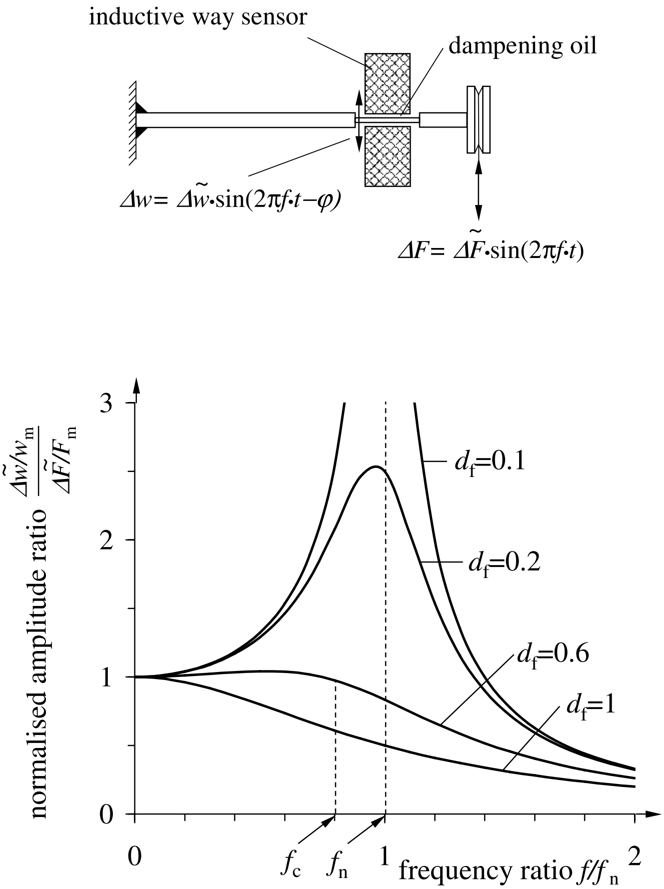

Fig. 6.4. Bending tongue of a yarn tensile force measuring sensor and normalised amplitude frequency responses depending on different dampening factors

mission without mistakes. Strong raised shifts of the bending tongue (caused always by steady exciting force amplitude at the bending tongue) will be recorded in the first case in a large frequency range. These already start near the steady state load ($f/f_{\mathrm{n}} \to 0$) and they decrease quickly to insignificant shifts above the natural frequency of the bending tongue. Such a measuring sensor would only be suitable for the measuring of quasi steady state or very slow yarn tensile force changes. All other frequencies are transmitted with amplitudes that are either too small or too large.

If the dampening is chosen too large then an exact amplitude reproduction is possible only likewise for quasi steady state changes of the yarn tensile force whereas amplitudes that are too small are measured in whole other frequency range.

A nearly exact amplitude measuring in the frequency range $0 \leq f \leq f_{\mathrm{n}}$ is possible if the dampening is optimally adjusted to $d_{\mathrm{f}} = 0.6$. The amplitude frequency response curve is nearly constant in the named frequency range. About 0.8 times of the natural frequency f_{n} of the freely oscillating, undampened bending tongue can be stated as critical frequency f_{c} for such a measurement system which should satisfy higher exactness pretensions. If the measuring sensor is used beyond this, then 20% of the decreasing amplitude (referring to the imprinted signal) appears already for $f = f_{\mathrm{n}}$.

Today offered yarn tensile force measuring sensors have critical frequencies in the range of $f_{\mathrm{c}} \leq 500$ Hz (in special cases also above it) and they fulfill virtually all wishes regarding the dynamic transmission properties. It is indeed problematic to fulfill the demands of a small reaction to the running yarn for narrow yarn tensile forces and for high yarn transport velocities. The latter is evident in high-speed spinning processes of the man-made fibre industry. Yarn guide rolls with light-motionable ball bearings are recommended for such tensile force measuring sensors. The named relations and regularities (collected here for the special case of the yarn tensile force measuring sensors) are of course valid for measuring sensors which measure signal courses of other process and product variables if the signal-recording element is a mass-spring-dampening-system.

6.4 Evaluation of the Tensile Force Time Function

6.4.1 Stationary Evaluation

It is surely correct that still today most recorded yarn tensile force courses are submitted to a steady state evaluation only, although in most cases powerful electronic computers are available. This is a contradiction in so far as just the time function of any process and product variables is an expression of the process dynamic. A pure steady state evaluation of a naturally dynamic measuring quantity gives away a considerable part of the information substance which it contains.

An assumed time course according to Fig. 6.5 is estimated normally to the following quantities:

a) mean value F_{m} results from

$$F_{\mathrm{m}} = \frac{1}{n} \cdot \sum_{\mathrm{i}=1}^{n} F_{\mathrm{i}} \tag{6.14}$$

b) maximum amplitude shift $\Delta F_{\max}$

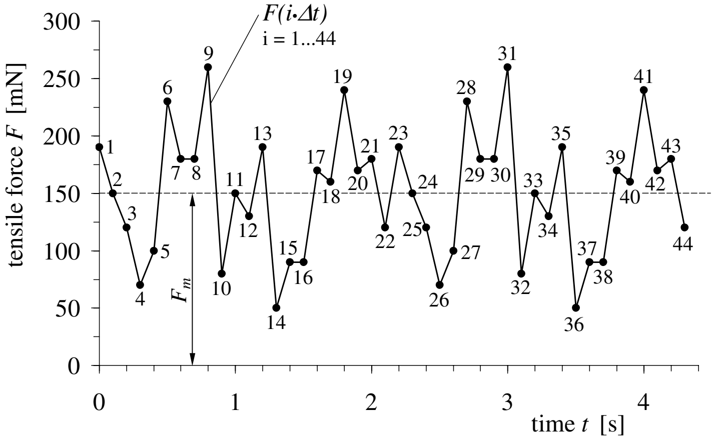

Fig. 6.5. Scanned time function of an assumed tensile force course; scan interval $\Delta t = 0.1$ s. $F_\mathrm{m} = 150$ mN, $d_\mathrm{q} = 56$ mN, $v_\mathrm{c} = 37\%$, $\Delta F_\mathrm{max} = 210$ mN

c) quadratic dispersion (variance), standard deviation or coefficient of variation as summary data for the fluctuation range of the time function course around the mean value. These quantities are calculated according to the following algorithms:

quadratic dispersion (variance) d_q^2

$$d_\mathrm{q}^2 = \frac{\sum\limits_{\mathrm{i}=1}^{n} (F_\mathrm{i} - F_\mathrm{m})^2}{n-1} \tag{6.15}$$

standard deviation d_q

$$d_\mathrm{q} = \sqrt{\frac{\sum\limits_{\mathrm{i}=1}^{n} (F_\mathrm{i} - F_\mathrm{m})^2}{n-1}} \tag{6.16}$$

coefficient of variation v_c

$$v_\mathrm{c} = \frac{1}{F_\mathrm{m}} \cdot \sqrt{\frac{\sum\limits_{\mathrm{i}=1}^{n} (F_\mathrm{i} - F_\mathrm{m})^2}{n-1}} \cdot 100\% \tag{6.17}$$

The single signs mean:

- F_i discontinuous value of time function $F(t)$, taken in steps of Δt
- F_m mean value of the time function $F(t)$ in the range $F_1 ... F_\mathrm{i}$
- n maximum number of available single values F_i
- i running index

6.4.2 Dynamic Evaluation; Auto Correlation and Auto Power Density Spectrum Functions

Fundamentals

The steady state analysis does not give any data about the time behaviour of the recorded time functions, this means no data is given about the frequencies of a fluctuation course. Essentially three possibilities are given in order to get such related data:

a) Visual estimation of the time function. It is possible in exceptional cases to only recognise strong outstanding frequencies because many fluctuation courses are a mixture of frequencies.
b) Calculation of the auto-correlation function of the recorded time function.
c) Calculation of the auto-power density spectrum function of the recorded time function.

Calculation algorithms

The general calculation algorithms for the auto-correlation (ACF) and the auto-power density spectrum functions (APSF) have already been given in Sect. 2.4.4 (see Eqs. 2.16, 2.17, 2.20 to 2.22 and Fig. 2.9). The special equations can be read in the present case of the time function of the yarn tensile force as:

ACF, Integral representation:

$$K_{\mathrm{F}}(\tau) = \lim_{\mathrm{T}\to\infty} \frac{1}{T} \int_0^T [F(t) - F_{\mathrm{m}}][F(t+\tau) - F_{\mathrm{m}}]\mathrm{d}t \tag{6.18}$$

ACF, Sum representation:

$$K_{\mathrm{F}}(k \cdot \Delta t) = \frac{1}{n-k} \sum_{\mathrm{i}=1}^{n-k} (F_{\mathrm{i}} - F_{\mathrm{m}})(F_{\mathrm{i+k}} - F_{\mathrm{m}}) \tag{6.19}$$

Boundary condition: $k_{\mathrm{max}} \leq \frac{n}{5}$, with $k = 0, 1, 2, 3, \ldots k_{\mathrm{max}}$.

APSF, Integral representation:

$$S_{\mathrm{F}}(f) = \lim_{\mathrm{T}\to\infty} \frac{1}{T} \left\{ \left[\int_0^T (F(t) - F_{\mathrm{m}}) \cos(2\pi \cdot f \cdot t)\mathrm{d}t \right]^2 + \left[\int_0^T (F(t) - F_{\mathrm{m}}) \sin(2\pi \cdot f \cdot t)\mathrm{d}t \right]^2 \right\} \tag{6.20}$$

APSF, Sum representation:

$$S_{\mathrm{F}}(f) = \frac{1}{n}\left\{ \left[\sum_{\mathrm{i=1}}^{n}(F(t) - F_{\mathrm{m}})\cos(2\pi \cdot f \cdot i \cdot \Delta t)\right]^2 + \left[\sum_{\mathrm{i=1}}^{n}(F(t) - F_{\mathrm{m}})\sin(2\pi \cdot f \cdot i \cdot \Delta t)\right]^2 \right\} \tag{6.21}$$

Boundary condition: $\frac{5}{n \cdot \Delta t} \leq f \leq \frac{1}{2 \cdot \Delta t}$

APSF, calculated from $K_{\mathrm{F}}(k \cdot \Delta t)$*:*

$$S_{\mathrm{F}}(f) = 2\Delta t \sum_{\mathrm{k=1}}^{m} K_{\mathrm{F}}(k \cdot \Delta t) \cdot \cos(2\pi \cdot f \cdot k \cdot \Delta t) \tag{6.22}$$

Boundary condition: $\frac{1}{m \cdot \Delta t} \leq f \leq \frac{1}{2 \cdot \Delta t}$

$F(t)$	time function of the tensile force
F_{m}	mean value of the time function of tensile force, evaluation range $0 \leq t \leq T$ or $0 \leq k \cdot \Delta t \leq n - k$
F_{i}	discontinuous value of time function $F(t)$, taken in steps of Δt
T	time period of the integration range
$\tau, k \cdot \Delta t$	time shift
k, m, n	running (sequence) indices
$K_{\mathrm{F}}(\tau), K_{\mathrm{F}}(k \cdot \Delta t)$	single values of the ACF of time function $F(t)$ for τ or $k \cdot \Delta t$
$S_{\mathrm{F}}(f)$	single values of the APSF of time function $F(t)$ for f

It has been previously referred to the use and the expanded assertion possibilities of these analysis procedures regarding the fineness unevenness analysis of threads and spun yarns [319]. Nevertheless, various applications have not been induced, because electronic computers were not yet available.

Calculation Example; Estimation Rules; Necessary Measurement and Evaluation Scopes

The formation of the ACF of an arbitrary given yarn tensile force course according to Eq. 6.19 will be demonstrated in the following. This time function is reduced to 44 equidistant values F_{i} which are keyed into the distance Δt (Fig. 6.5). The result are 10 single ACF-values $K_{\mathrm{F}}(k \cdot \Delta t)$ for $k = 0, 1, ... 9$.

The calculation of these few values for the ACF (based on the underlied time function) is as you can see already very expensive. With this it is to be remarked, that an ACF-calculation, which fulfills a useful dynamic analysis requirement, supposes at least 1000 single values F_i (better more) from which 200 functional values $K_\mathrm{F}(k \cdot \Delta t)$ can be calculated.

The expenses for the calculation of the APSF can be much larger because the according equations prescribe a continuous multiplication with sin- and cos-functions of changing frequency. Automatised measuring data recording of the time functions (and their processing) by means of computers are also an absolute prerequisite to an effective use of these methods.

From our simple, roughly divided function $F(t)$ (Fig.6.5) can be read, after the statistic estimation, as:
$F_\mathrm{m} = 150$ mN; $\Delta F_\mathrm{max} = 210$ mN; $d_\mathrm{q}^2 = 3098$ mN^2; $d_\mathrm{q} = 56$ mN; $v_\mathrm{c} = 37\%$.

The 10 single values of the ACF according to Table 6.1 are drawn versus the related time shift $k \cdot \Delta t$ in the Fig. 6.6.

The question is now, how is the ACF and/or the APSF to be evaluated

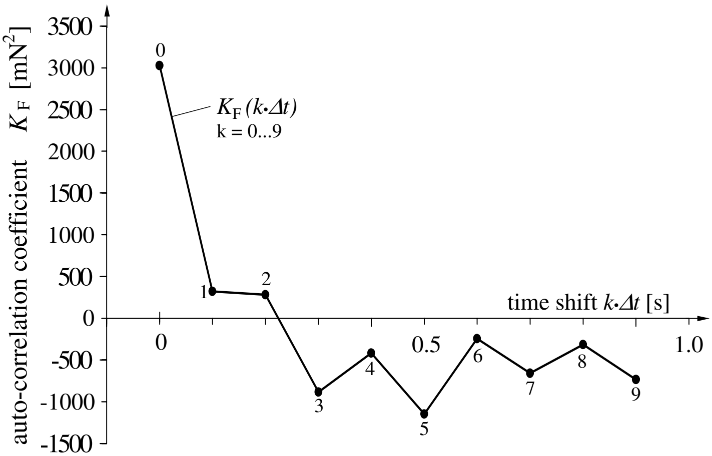

Fig. 6.6. Auto-correlation function (ACF) of the time function corresponding to Fig. 6.5 and Table 6.1

or to be discussed with respect to a deepened time function analysis. Some *simplified estimation rules* will be given for this, in the following, for different courses of the ACF and APSF which also allow a classification of our arbitraril chosen tensile force course according to Fig. 6.5.

a) Periodical parts of the time function appear in the ACF as pure, unadulterated oscillations with the same cycle duration (measured in the units of the time shift τ or $k \cdot \Delta t$) which appears (mostly in a not exact discernible form) in the time function itself.

Table 6.1. Development of the ACF $K_F(k \cdot \Delta t)$ of the time function $F(t)$ corresponding to Fig. 6.5

i	F_i [mN]	$F_i - F_m$ [mN]	$(F_i - F_m)(F_{i+k} - F_m)$ for $k = 0$ [mN^2]	$k = 1$ [mN^2]	$k = 2$ [mN^2]	$k = 3$ [mN^2]	$k = 4$ [mN^2]	$k = 5$ [mN^2]	$k = 6$ [mN^2]	$k = 7$ [mN^2]	$k = 8$ [mN^2]	$k = 9$ [mN^2]
1	190	40	1600	0	-1200	-3200	-2000	3200	1200	1200	4400	-2800
2	150	0	0	0	0	0	0	0	0	0	0	0
3	120	-30	900	2400	1500	-2400	-900	-900	-3300	2100	0	600
4	70	-80	6400	4000	-6400	-2400	-2400	-8800	5600	0	1600	-3200
5	100	-50	2500	-4000	-1500	-1500	-5500	3500	0	1000	-2000	5000
6	230	80	6400	2400	2400	8800	-5600	0	-1600	3200	-8000	-4800
7	180	30	900	900	3300	-2100	0	-600	1200	-3000	-1800	-1800
8	180	30	900	3300	-2100	0	-600	1200	-3000	-1800	-1800	600
9	260	110	12100	-7700	0	-2200	4400	-11000	-6600	-6600	2200	1100
10	80	-70	4900	0	1400	-2800	7000	4200	4200	-1400	-700	-6300
11	150	0	0	0	0	0	0	0	0	0	0	0
12	130	-20	400	-800	2000	1200	1200	-400	-200	-1800	-400	-600
13	190	40	1600	-4000	-2400	-2400	800	400	3600	800	1200	-1200
14	50	-100	10000	6000	6000	-2000	-1000	-9000	-2000	-3000	3000	-4000
15	90	-60	3600	3600	-1200	-600	-5400	-1200	-1800	1800	-2400	0
16	90	-60	3600	-1200	-600	-5400	-1200	-1800	1800	-2400	0	1800
17	170	20	400	200	1800	400	600	-600	800	0	-600	-1600
18	160	10	100	900	200	300	-300	400	0	-300	-800	-500
19	240	90	8100	1800	2700	-2700	3600	0	-2700	-7200	-4500	7200
20	170	20	400	600	-600	800	0	-600	-1600	-1000	1600	600
21	180	30	900	-900	1200	0	-900	-2400	-1500	2400	900	900
22	120	-30	900	-1200	0	900	2400	1500	-2400	-900	-900	-3300
23	190	40	1600	0	-1200	-3200	-2000	3200	1200	1200	4400	-2800
24	150	0	0	0	0	0	0	0	0	0	0	0
25	120	-30	900	2400	1500	-2400	-900	-900	-3300	2100	0	600
26	70	-80	6400	4000	-6400	-2400	-2400	-8800	5600	0	1600	-3200
27	100	-50	2500	-4000	-1500	-1500	-5500	3500	0	1000	-2000	5000
28	230	80	6400	2400	2400	8800	-5600	0	-1600	3200	-8000	-4800
29	180	30	900	900	3300	-2100	0	-600	1200	-3000	-1800	-1800
30	180	30	900	3300	-2100	0	-600	1200	-3000	-1800	-1800	600
31	260	110	12100	-7700	0	-2200	4400	-11000	-6600	-6600	2200	1100
32	80	-70	4900	0	1400	-2800	7000	4200	4200	-1400	-700	-6300
33	150	0	0	0	0	0	0	0	0	0	0	0
34	130	-20	400	-800	2000	1200	1200	-400	-200	-1800	-400	-600
35	190	40	1600	-4000	-2400	-2400	800	400	3600	800	1200	-1200
36	50	-100	10000	6000	6000	-2000	-1000	-9000	-2000	-3000	3000	
37	90	-60	3600	3600	-1200	-600	-5400	-1200	-1800	1800		
38	90	-60	3600	-1200	-600	-5400	-1200	-1800	1800			
39	170	20	400	200	1800	400	600	-600				
40	160	10	100	900	200	300	-300					
41	240	90	8100	1800	2700	-2700						
42	170	20	400	600	-600							
43	180	30	900	-900								
44	120	-30	900									
Sum [mN^2]			133200	13800	11800	-36300	-16700	-44700	-9200	-24400	-11300	-25700
$n - k$			44	43	42	41	40	39	38	37	36	35
$K_F(k \cdot \Delta t)$ [mN^2]			3027	321	281	-885	-418	-1146	-242	-659	-314	-734

Periodical parts of the time function appear in the APSF as a maximum at these frequencies which the periodic parts themselfs possess in the time function.
The appropriate analysis situation is shown in Fig. 6.7. If the time function shows strict periodical oscillations then the ACF does not die-away to zero with increasing τ but it will monotonously oscillate like the time function itself. If the time function shows strict periodical oscillations then the APSF shows a narrow high maximum.

b) If the time function only has stochastic (statistic) parts then the ACF does continuously die-away like an exponential function and will be zero in

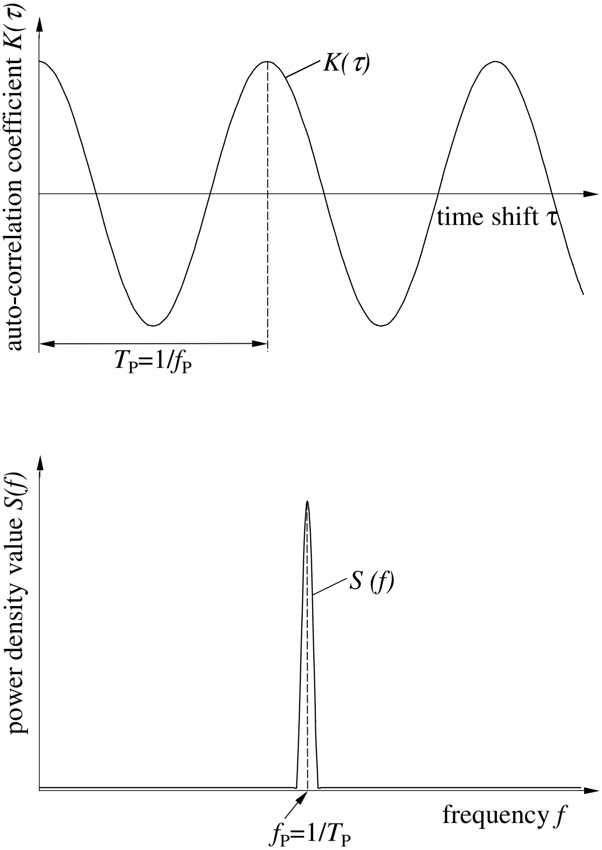

Fig. 6.7. Auto-correlation and auto-power density spectrum functions of a time function with a pure periodic (sinusoidal) change; T_P cycle duration of the change, f_P frequency of the change

the end. The APSF does not have any sort of maximum but it shows a more or less equalised (in the ideal case a constant) course (see Fig. 6.8).

c) If the time function has superimposed, periodic and statistic parts then these appear in good separated form in the ACF and APSF appropriate to the given criteria under a) and b). Figures 6.9 and 6.10 show two (separate) examples for the superposition of statistic and 1- or 2-times periodic parts in the basic time function.

The time function of the yarn tensile force Fig. 6.5 is to be characterised by means of its ACF (Fig. 6.6) as a function which consists of statistic parts and a one-time periodic part. Nevertheless, such an assertion would be supported more exactly by means of a longer analysis interval, an essentially greater

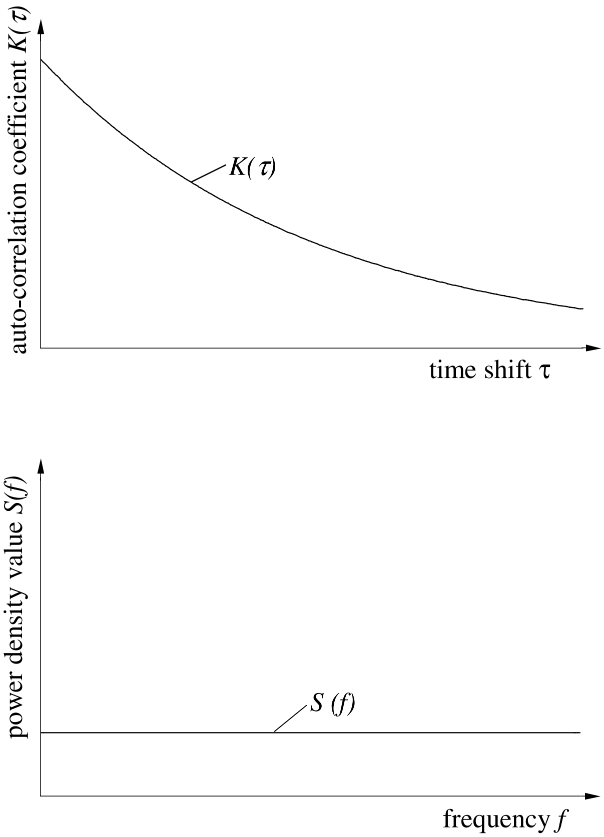

Fig. 6.8. Auto-correlation and auto-power density spectrum functions of a time function with pure stochastic changes

number of single tensile force values and a more extensive ACF-analysis. The necessary measuring and estimation volume to the calculation of the ACFs and APSFs (from more intensive analyzing time functions) can be fixed according to the following rules of thumb. Some likeness exists about the problem of the necessary measuring and gauge length of threads for the purpose of analysis of dynamic disturbances (see Sect. 4.5).

It is necessary to estimate the probable highest and lowest occurring frequencies f_{max} and f_{min} (by means of test records or a-priori knowledges) before appointing a measuring and analysis strategy, because the time functions of the product variable yarn tensile force can consist of high- as well as low-frequency fluctuation parts in proportion to the process step.

The necessary maximum analysis time T_{A} of the time function (and with it the measuring time for the complete recorded function) results from the condition that also a low frequency periodic change (f_{min}) could be run at

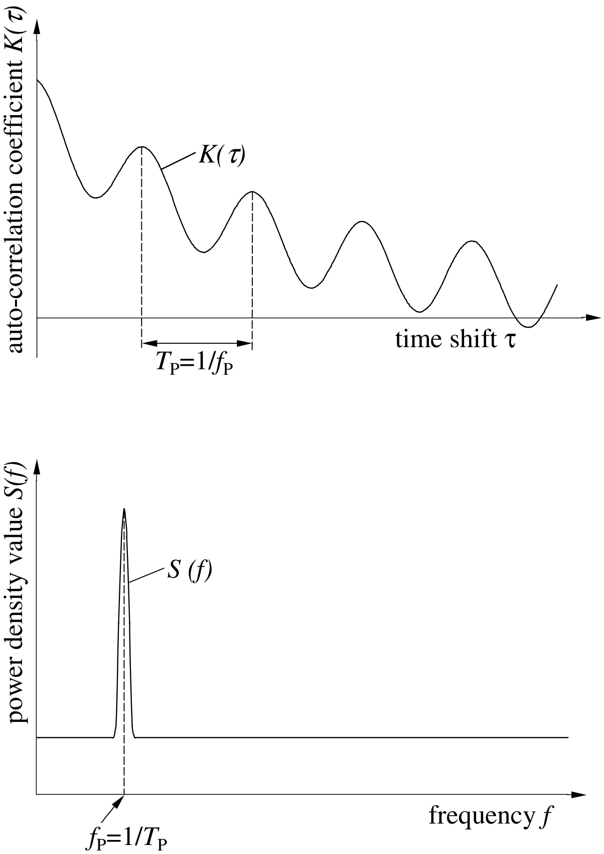

Fig. 6.9. Auto-correlation and auto-power density spectrum functions of a time function with (superposed) one periodic (sinusoidal) and stochastic changes; T_{P} cycle duration of the periodic change, f_{P} frequency of the periodic change

least 5-times. The condition for T_{A} is therefore:

$$T_{\mathrm{A}} \leq \frac{5}{f_{\min}} \tag{6.23}$$

If the calculation of the ACF and/or the APSF are realised according to the sum equations (Eqs. 6.19, 6.21) then the number n of equidistant taken single values F_{i} of the time function $F(t)$ can be derived from the following condition. A periodic change which runs with $f_{\max}$ should take at least 5 equidistant single values. This means that the taken interval Δt must be:

$$\Delta t \leq \frac{1}{5 \cdot f_{\max}} \tag{6.24}$$

The necessary number of single values $n_{\min}$ results with this to:

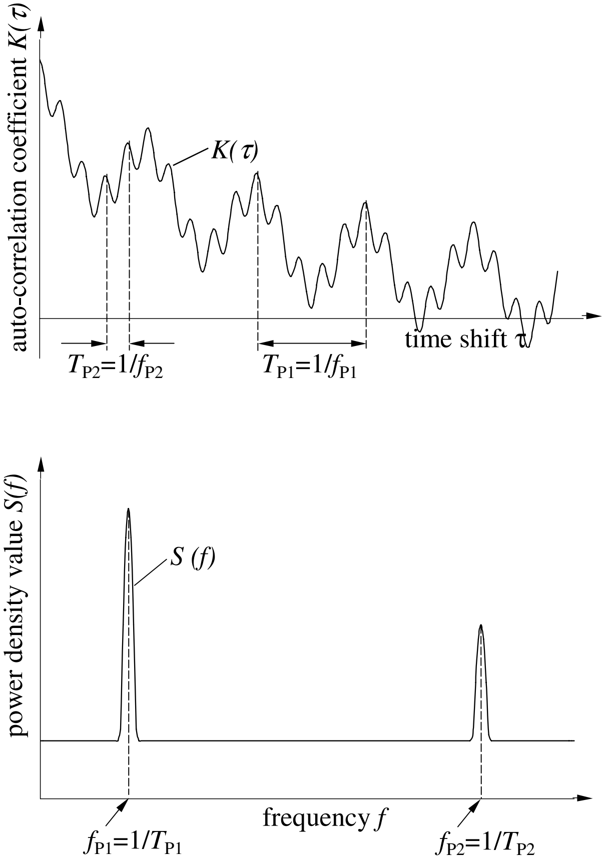

Fig. 6.10. Auto-correlation and auto-power density spectrum functions of a time function with two periodic (sinusoidal) and stochastic changes; $T_{\mathrm{P}1}$ and $T_{\mathrm{P}2}$ cycle durations of the periodic changes, $f_{\mathrm{P}1}$ and $f_{\mathrm{P}2}$ frequencies of the periodic changes

$$n_{\mathrm{min}} \geq \frac{T_{\mathrm{A}}}{\Delta t} = 25 \cdot \frac{f_{\mathrm{max}}}{f_{\mathrm{min}}} \tag{6.25}$$

A maximum possible time shift τ_{max} can be recommended for the ACF-calculation as follows:

$$\tau_{\mathrm{max}} \leq \frac{T_{\mathrm{A}}}{5} = \frac{1}{f_{\mathrm{min}}} \tag{6.26}$$

If this condition is observed then the slowest can also occur.

It is easy to estimate according to Eq. 6.25 that the number of single values n_{min} must be more than 1000, if the ratio is $f_{\mathrm{max}}/f_{\mathrm{min}} = 40$ (for instance $f_{\mathrm{max}} = 4$ Hz, $f_{\mathrm{min}} = 0.1$ Hz).

Technological Example

The preceding statements will be demonstrated once more by means of the concentration of five yarn tensile force courses to their auto-correlation and auto-power density spectrum functions. We choose, in retrospect, five measured time functions of the yarn tensile force in the input line according to Fig. 5.15 in Sect. 5.1.5. The technological situation of this yarn input line has already been discussed in detail. It is a characteristic of this that extremely different, but overlookable time functions, can be submitted to the ACF- and APSF-calculation. The five time functions $F(t)$ have been characterised by an input line length $l_{\mathrm{m}} = 0.42$ m in the first case, an extended input line of $l_{\mathrm{ext}} = 0.45$ m in the second case, an extended input line of $l_{\mathrm{ext}} = 1.60$ m in the third case, an extended input line of $l_{\mathrm{ext}} = 4.80$ m in the fourth case, and an extended input line of $l_{\mathrm{ext}} = 6.40$ m in the fifth case, all according to the technological scheme of Fig. 5.12. The analyzed time functions and the, in each case attached, ACFs and APSFs are shown in Figs. 6.11 to 6.15.

The following conclud statements which confirm the discussion in Sect. 5.1.5 can be made:

a) The ACF of the undamped yarn tensile force course clearly has a strong periodic character with a main disturbance frequency of $f = 0.75$ Hz (equivalent yarn length of 1.3 m; see Fig. 6.11). It is equivalent with that to the basic type, outlined in Fig. 6.7. A second disturbance frequency ($f = 4.65$ Hz, equivalent yarn length 0.21 m) appears clearer with the increasing dampening of this main disturbance frequency. This can only be made visible by a drastic changed ordinate measure of the ACF-diagrams (see Figs. 6.12 to 6.15), because the main disturbance frequency in the undamped case (Fig. 6.11) dominates and covers all the other. This second disturbance frequency also correlated with the periphery of a small eccentric running input godet of the twister. The ACF passes over from the basic type of the one periodic disturbance to that of two periodic disturbances without discernible stochastic parts (compare Figs. 6.11 to 6.15 with Fig. 6.10).

The strong different ordinate measures of the ACFs (and APSFs) in the Figs. 6.11 to 6.15 demonstrate, in another way, the utmost effective calming of the tensile force course. It is to be remarked at this point that the start value of the ACF (for $\tau = 0$) corresponds to the well-known quadratic dispersion (variance).

b) The same interpretation is valid for the APSFs ($S(f)$-values) of the five time function courses. The Figs. 6.11 and 6.12 show the main disturbance frequency of 0.75 Hz clearly and independently, Fig. 6.13 also shows the second disturbance frequency of 4.65 Hz clearly, and in Figs. 6.14 to 6.15 (greatest dampening) show the second disturbance frequency only independently. One also notes here the different ordinate measures!

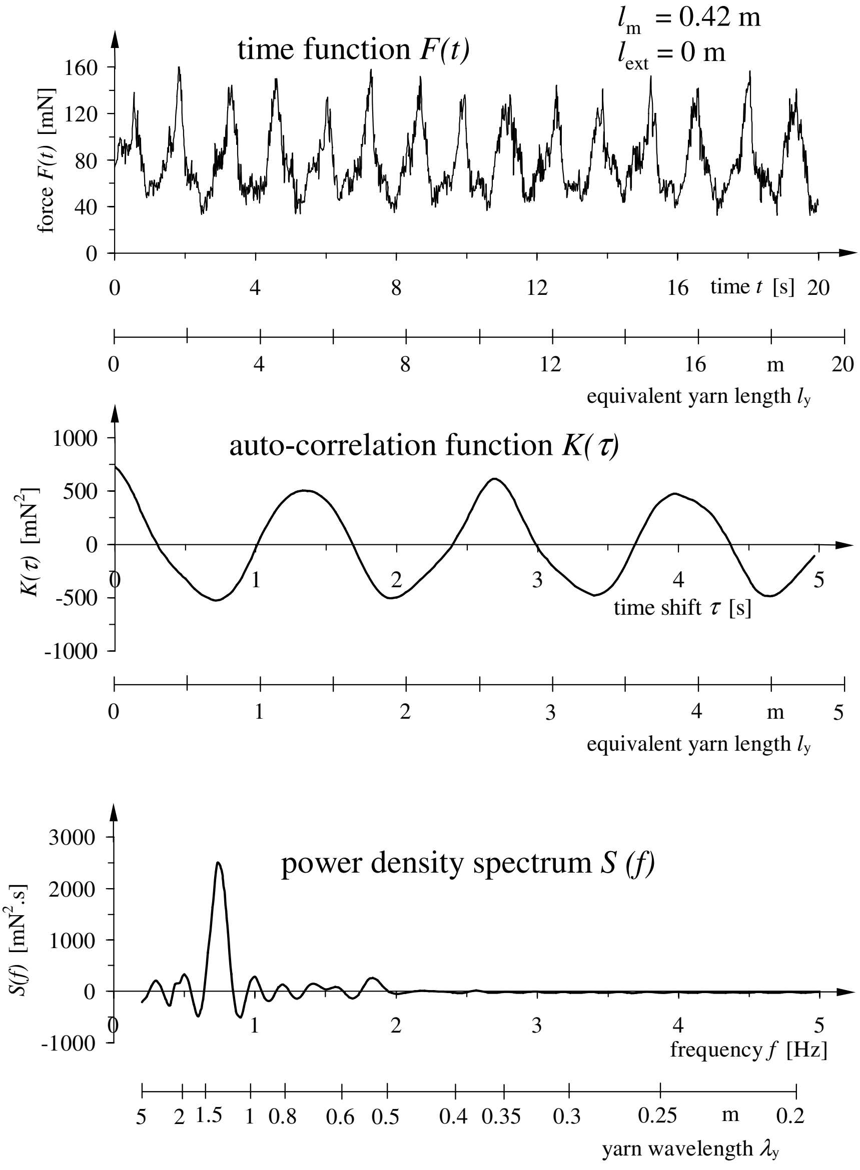

Fig. 6.11. Auto-correlation and auto-power density spectrum functions of the time function $F(t)$, input line not extended corresponding to Fig. 5.12

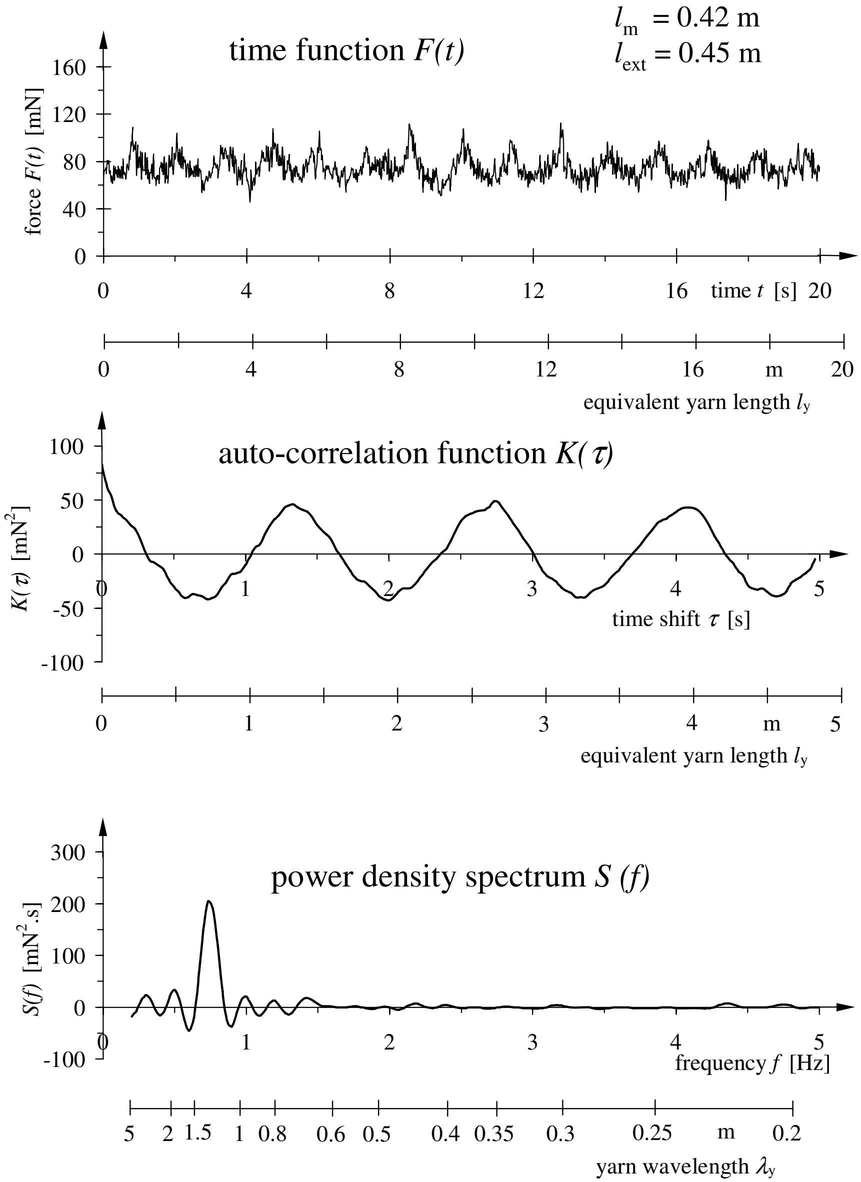

Fig. 6.12. Auto-correlation and auto-power density spectrum functions of the time function $F(t)$, extension of the input line $l_{\text{ext}} = 0.45$ m corresponding to Fig. 5.12

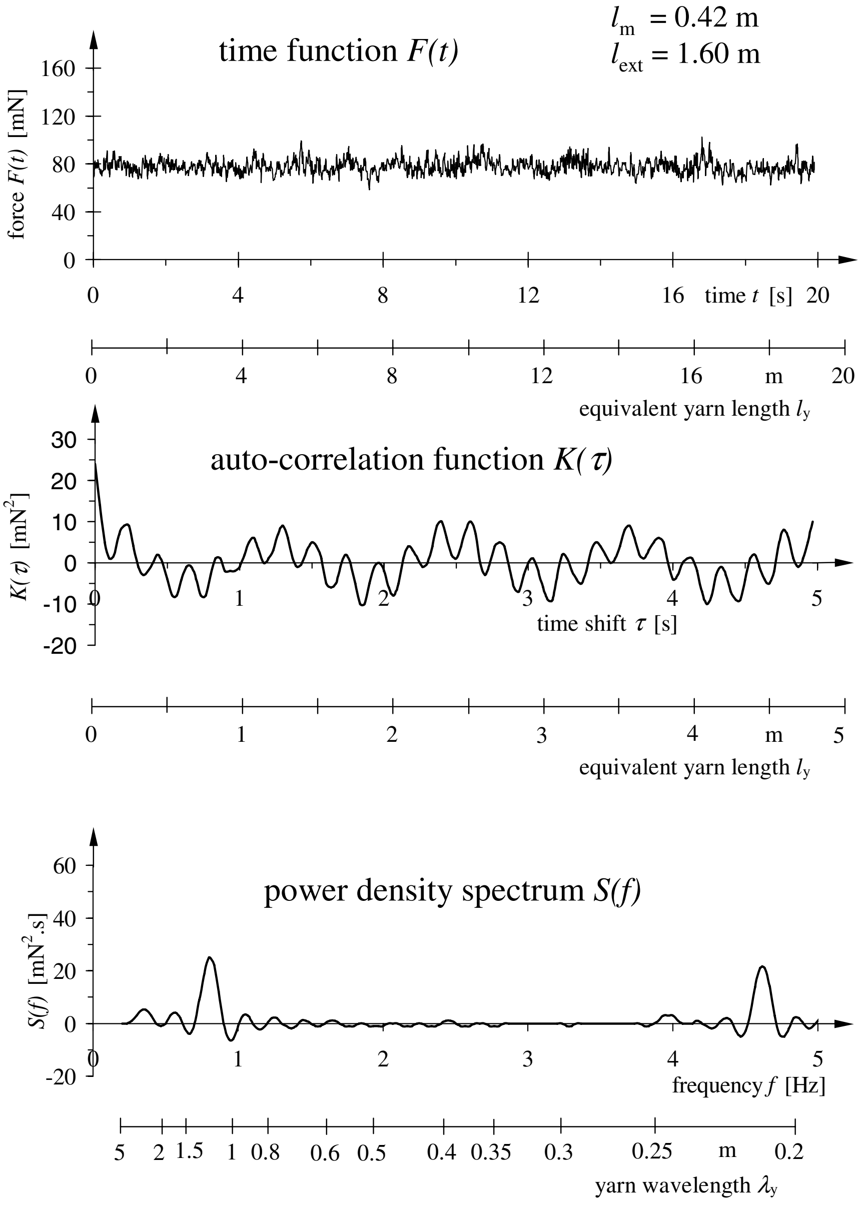

Fig. 6.13. Auto-correlation and auto-power density spectrum functions of the time function $F(t)$, extension of the input line $l_{\text{ext}} = 1.60$ m corresponding to Fig. 5.12

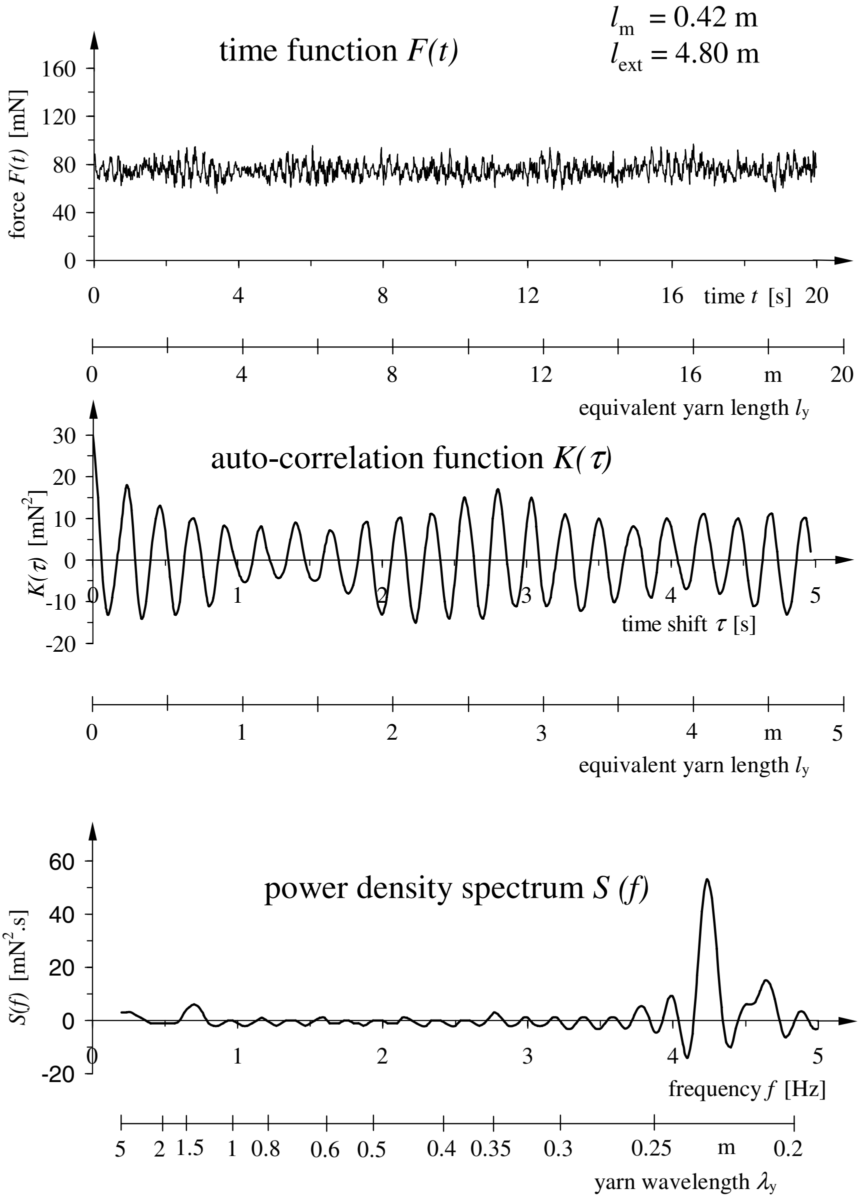

Fig. 6.14. Auto-correlation and auto-power density spectrum functions of the time function $F(t)$, extension of the input line $l_{\text{ext}} = 4.80$ m corresponding to Fig. 5.12

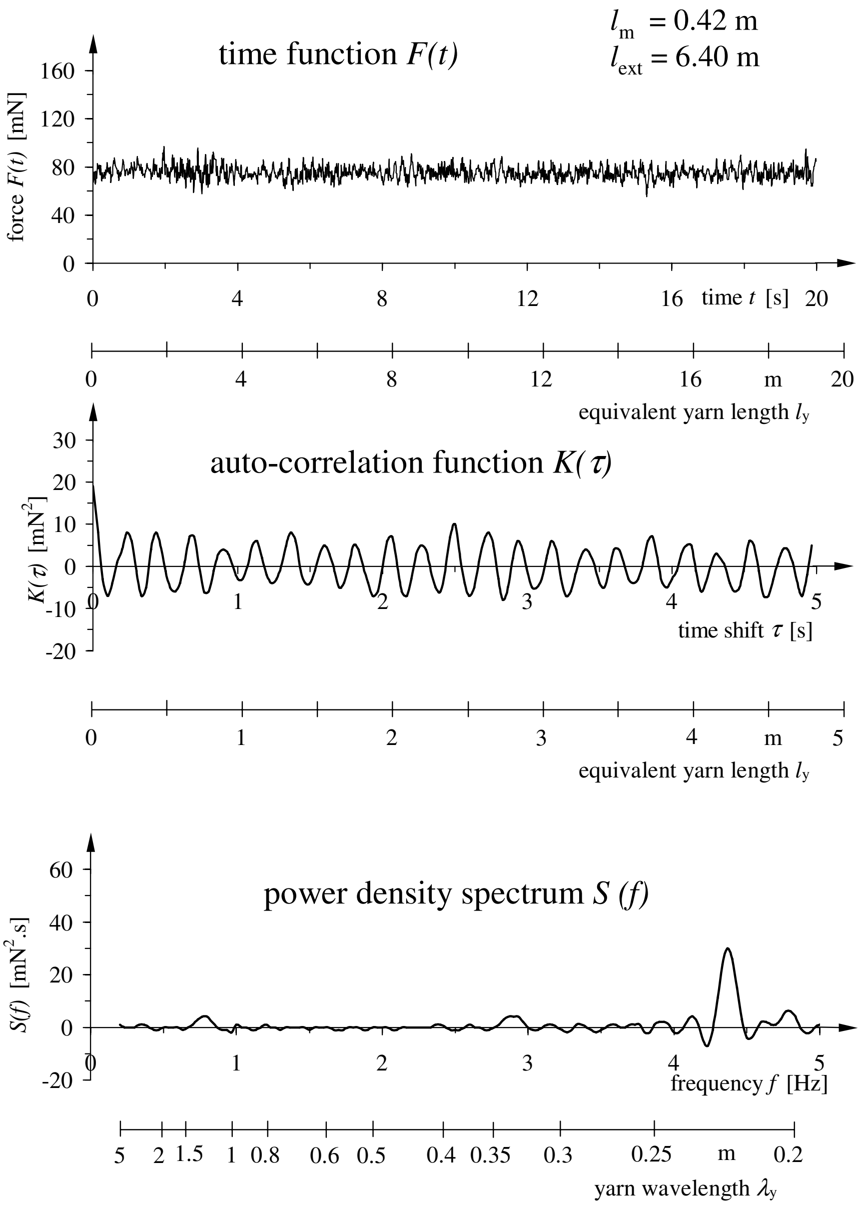

Fig. 6.15. Auto-correlation and auto-power density spectrum functions of the time function $F(t)$, extension of the input line $l_{\text{ext}} = 6.40$ m corresponding to Fig. 5.12

The overswing of the *S(f)*-curves to negative values near the main maximum (which theoretically should not occur) is caused by mistakes which arise from a too coarsely taken interval ($\Delta t = 1/30$ s), from the small number of single values for the time functions ($n = 600$), and from the small number of single values for the correlation function ($m = 150$). The limits of the used sum represent the APSF by means of Eq. 6.22. Nevertheless, the general statement is not even called into question in the presented case.

6.5 Combination Measurements and Evaluations

6.5.1 Task and Measurements

The dynamic behaviour of a process is normally distinguished not only by the time functions of *one* process or product variable. *Several* time functions and their mutual influence are to be analysed. The *combined* measurement and analysis of the time functions of

- the yarn tensile force $F(t)$,
- the yarn fineness $Tt_\mathrm{o}(t)$,
- the tensile stress $\sigma(t) = F(t)/Tt_\mathrm{o}(t)$

have hardly been used in the past with respect to the research of dynamic cause-effect relations in the beginning and the transmission of inner and outer yarn unevennesses and their relationships. A related analytical method has been presented until now only in just a few (own) papers [320, 321]. The following statements are essentially a brief conclusion of these.

The following two possibilities are practically given to the measurement recording of the named time functions:

a) Two channel synchronous measuring signal records of $F(t)$ and $Tt_\mathrm{o}(t)$ in which the third time function $\sigma(t) = F(t)/Tt_\mathrm{o}(t)$ is *simultaneously calculated* as the tensile stress (fineness related tensile force) by means of a quotient computer.

b) Two channel synchronous measuring signal records of $F(t)$ and $Tt_\mathrm{o}(t)$ in which the time function of the tensile stress $\sigma(t)$ is calculated *after* the measuring signal records, point by point, by means of the division for each temporal related values. This calculation can be carried out either "by hand" or – better – also by means of a quotient computer.

It is an advantage for both methods, the primary records of the time functions of the yarn tensile force $F(t)$ and the yarn fineness $Tt_\mathrm{o}(t)$, that they can be to stored by means of a two channel measuring magnetic tape device or of a quick external computer memory. It is then possible to temporally

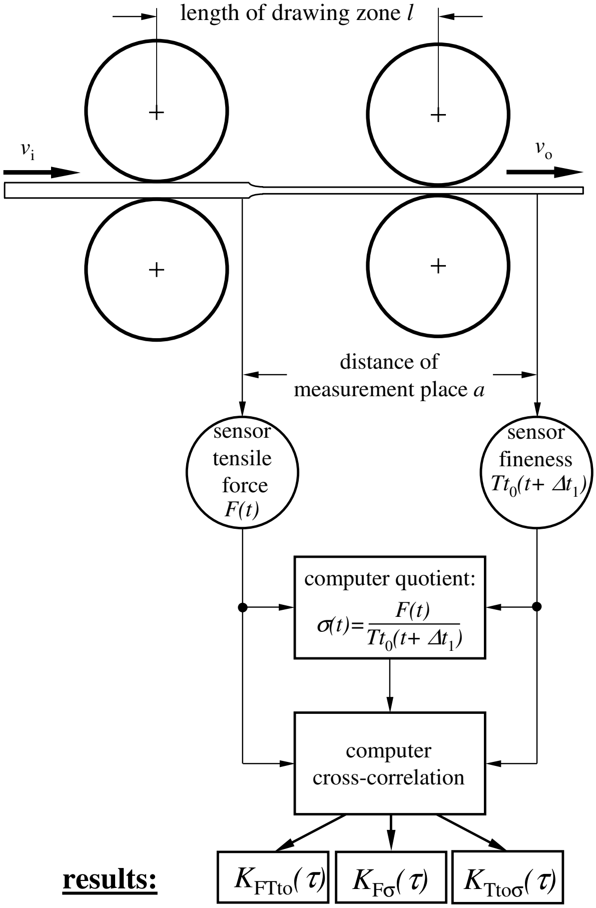

Fig. 6.16. Technological scheme of a combination measurement of yarn tensile force, yarn fineness and tensile stress in the drawing process with correlation evaluation

and locally separate the measuring signal records on the machine and the analysis in the lab. In this way, it is possible to carry out later the measuring process at any time to repeat in the slow or fast motion manner or the quotient calculation to the time function of the tensile stress $\sigma(t)$. It is possible in the same way to produce a data memory of the time functions which is available to the further described analysis as follows.

Figure 6.16 shows a conventionally designed variant which proposes a storage of the measuring values by means of a measuring magnetic tape device which the time function can be submitted to in a (cross-)correlation evaluation.

6.5.2 Dynamic Evaluation and Cross-Correlation Functions (CCF)

Fundamentals

First of all several synchronously determined time function courses of different process and product variables can also be evaluated visually, similarly as to Sect. 6.4 for the evaluation and analysis of the time function course of the yarn tensile force independently. This can take place, for instance, to observe whether changes of the $F(t)$-, $Tt_{\mathrm{o}}(t)$- and $\sigma(t)$-courses correspond to each other and whether this correlation will be positive or negative.

Further analytical statements can give the cross-correlation function (CCF) or to the cross-power density spectrum function (CPSF) for the mutual dependences or the dynamic relationship of time functions of two process or product variables.

The calculation rules for the CCF of two time functions in the integral and sum representation has been already described in Sect. 2.4.4 (see Eqs. 2.18 and 2.19). We will only regard the CCF in the following. The interested reader can inquire as to the numerical more expensive formation rules and the (until now only little used) statement possibilities of the cross-power density spectrum function in [8] and [9].

Cross-correlation functions (CCF) of yarn tensile force, yarn fineness and tensile stress in the draw process

The following three cross-correlation functions can be formated (in each case in the integral and the sum representation) from the time functions of the yarn tensile force $F(t)$, the yarn fineness $Tt_{\mathrm{o}}(t)$ and the tensile stress $\sigma(t)$:

CCF of the yarn tensile force and the yarn fineness

$$K_{\mathrm{FTt_o}}(\tau) = \lim_{\mathrm{T}\to\infty} \frac{1}{T} \int_0^T [F(t) - F_{\mathrm{m}}][Tt_{\mathrm{o}}(t+\tau) - Tt_{\mathrm{om}}]\mathrm{d}t \tag{6.27}$$

$$K_{\mathrm{FTt_o}}(k \cdot \Delta t) = \frac{1}{n-k} \sum_{\mathrm{i}=1}^{n-k} (F_{\mathrm{i}} - F_{\mathrm{m}})(Tt_{\mathrm{o(i+k)}} - Tt_{\mathrm{om}}) \tag{6.28}$$

Boundary condition: $m = k_{\max} \leq \frac{n}{5}$, which $k = 0, 1, 2, 3, ...m$

CCF of the yarn tensile force and the tensile stress

$$K_{\mathrm{F}\sigma}(\tau) = \lim_{\mathrm{T}\to\infty} \frac{1}{T} \int_0^T [F(t) - F_{\mathrm{m}}][\sigma(t+\tau) - \sigma_{\mathrm{m}}]\mathrm{d}t \tag{6.29}$$

$$K_{\mathrm{F}\sigma}(k \cdot \Delta t) = \frac{1}{n-k} \sum_{\mathrm{i}=1}^{n-k} (F_{\mathrm{i}} - F_{\mathrm{m}})(\sigma_{\mathrm{i+k}} - \sigma_{\mathrm{m}}) \tag{6.30}$$

Boundary condition: $m = k_{\max} \leq \frac{n}{5}, \quad \text{which} \quad k = 0, 1, 2, 3, ...m$

CCF of the yarn fineness and the tensile stress

$$K_{\mathrm{Tt_o}\sigma}(\tau) = \lim_{\mathrm{T}\to\infty} \frac{1}{T} \int_0^T [Tt_{\mathrm{o}}(t) - Tt_{\mathrm{om}}][\sigma(t+\tau) - \sigma_{\mathrm{m}}]\mathrm{d}t \tag{6.31}$$

$$K_{\mathrm{Tt_o}\sigma}(k \cdot \Delta t) = \frac{1}{n-k} \sum_{\mathrm{i}=1}^{n-k} (Tt_{\mathrm{oi}} - Tt_{\mathrm{om}})(\sigma_{\mathrm{i+k}} - \sigma_{\mathrm{m}}) \tag{6.32}$$

Boundary condition: $m = k_{\max} \leq \frac{n}{5}, \quad \text{which} \quad k = 0, 1, 2, 3, ...m$

The signs and symbols in Eqs. 6.27 to 6.30 mean:

$F(t), Tt_{\mathrm{o}}(t)$,	time functions of the tensile force, yarn fineness,
$\sigma(t)$	tensile stress
$F_{\mathrm{m}}, Tt_{\mathrm{om}}$,	mean values of the tensile force, yarn fineness,
σ_{m}	tensile stress in the range of
	$0 \leq t \leq T$ or $0 \leq k \cdot \Delta t \leq n-k$
$Tt_{\mathrm{oi}}, Tt_{\mathrm{o(i+k)}}$,	discontinuous values of the time functions
$F_{\mathrm{i}}, \sigma_{\mathrm{i+k}}$	$F(t), Tt_{\mathrm{o}}(t), \sigma(t)$, taken in steps of Δt
T	length of the integration range
$\tau, k \cdot \Delta t$	time shift
k, m, n	running (sequence) indices
$K_{\mathrm{FTt_o}}(\tau)$,	
$K_{\mathrm{F}\sigma}(\tau)$,	
$K_{\mathrm{Tt_o}\sigma}(\tau)$,	
$K_{\mathrm{FTt_o}}(k \cdot \Delta t)$,	
$K_{\mathrm{F}\sigma}(k \cdot \Delta t)$,	single values of the CCF of the time functions
$K_{\mathrm{Tt_o}\sigma}(k \cdot \Delta t)$	$F(t)$, $Tt_{\mathrm{o}}(t)$ and $\sigma(t)$ for τ or $k \cdot \Delta t$

The CCFs practically express the *interconnected dispersion* of the single time functions among one another and not only in the simple known manner for $\tau = 0$. This is enabled by means of the continuously or step-like realised time shift τ or $k \cdot \Delta t$ (change values of the one time function are related to the temporal with τ or $k \cdot \Delta t$ shifted change values of the other time function). The CCFs also enable an estimation of the *statistical relationship* between the values of the one time function and values of the other time function which are more or less distantly temporal.

The methods of combination measurements and evaluations of time functions have been applied extensively in the past to the draw process of polymer yarns. This process imprints on the yarn *drastic* fineness and E-modulus changes (consequently quality changes) which are effected by yarn tensile force. The following statements and ideas are not only applicable to the draw deformation but also to all fibre formation and fibre deformation processes which are similar to the draw process. Examples are the yarn deformation processes of classical melt spinning, of high speed spinning, but also of simultaneous or sequential draw texturing. It has already been hinted to the sharpened analysis situation at yarn deformation processes in a first extensive paper [321]. Through this it has been given that the effecting quantities for F and Tt_o can be correlated (temporal stable or instable) among one another in different manners with a more or less phase shift and that the changes of the secondary product variable tensile stress $\sigma(t)$ must be generated by an additional quotient calculation of $F(t)$ and $Tt_\mathrm{o}(t)$.

The following dependences on other process and product variables can be formally formulated for the primary quantities F and Tt_o which generate the tensile stress σ (see also Fig. 2.1 in Sect. 2.1.1):

$$Tt_\mathrm{o} = f(Tt_\mathrm{i}, v_\mathrm{o}/v_\mathrm{i}, l, E_\mathrm{yi})$$

$$F = f(Tt_\mathrm{i}, E_\mathrm{yi}, v_\mathrm{o}/v_\mathrm{i}, v_\mathrm{o}, l, T_\mathrm{y})$$

The difficulties from these mutual interweavings will be distinctly special if the characterising yarn quantity E_yo at the output of the drawing zone is included into the estimation of the inner yarn unevenness:

$$E_\mathrm{yo} = f(E_\mathrm{yi}, v_\mathrm{o}/v_\mathrm{i}, v_\mathrm{o}, l, Tt_\mathrm{i}, Tt_\mathrm{o}, F)$$

The combined measurement and estimation of time functions of yarn tensile force $F(t)$ and yarn fineness $Tt_\mathrm{o}(t)$ can give answers to the following questions:

a) Did induced fluctuate fineness changes to the yarn during the elongation or deformation process? Which quantity exists at the process input?
b) Did induced fluctuate substance property changes (E-modulus, tensile stress, plastic deformation part) on the yarn during the elongation or deformation process?
c) Which relation exists between form changes and reaction stresses? Which process influences are causally responsible for these changes?
d) Is a change of the yarn tensile force (which is marked often wrongly as yarn stress, though of no sort cross section relation exists) the effect of a change of the imprinted elongation or the effect of a change of the momentary yarn elasticity (which again depends on the cross section or the fineness as well as on the E-modulus of the yarn)?

Tendencies of disturbance transmission in the drawing process are compiled in Table 6.2. These come from theoretical considerations and experimental investigations for different combinations of possible process input disturbances. We should remember: Fineness changes $\Delta Tt_{\mathrm{i}}/Tt_{\mathrm{im}}$ are an expression of outer, of elastic modulus $\Delta E_{\mathrm{yi}}/E_{\mathrm{yim}}$ are an expression of inner unevennesses of the input yarn. The following conclusions can be deduced which emphasise the necessity of a detailed time function analysis:

a) Tensile force changes of the yarn in the drawing zone do not allow, in any case, for an unambiguous assertion about the situation of disturbance causes at the process input. The direction of the tensile force changes can be predicted when at least one input size or both input sizes change in the same direction. If fineness and E-modulus change turn out to contradict then the change dimensions of the one input size compared to the change dimensions of the other input size are responsible for the direction of the output disturbance. The absence of some reaction is imaginable, in the special case, if the contrary imprinted inner and outer unevennesses of the yarn at the drawing zone input are just canceled.

Table 6.2. Tendencies of disturbance transmission in the drawing process

Yarn disturbances at the process input: (length of the disturbance < length of drawing zone)		Yarn disturbances at the process output		
Fineness $\Delta Tt_{\mathrm{i}}/Tt_{\mathrm{im}}$	E-modulus $\Delta E_{\mathrm{yi}}/E_{\mathrm{yim}}$	Tensile force $\Delta F/F_{\mathrm{m}}$	Fineness $\Delta Tt_{\mathrm{o}}/Tt_{\mathrm{om}}$	E-modulus $\Delta E_{\mathrm{yo}}/E_{\mathrm{yom}}$
0	+	+	↑	↓
0	−	−	↑	↓
+	0	+	↑	↑
−	0	−	↑	↑
+	+	+	↑	↓
−	−	−	↑	↓
+	−	+,−,0	↑,↓	↑,↓
−	+	+,−,0	↑,↓	↑,↓

↑ increasing unevenness
↓ decreasing unevenness
\+ positive deviation to the mean value
− negative deviation to the mean value
0 no deviation to the mean value

b) The calculation of the quotient of the (draw-)yarn tensile force to the yarn fineness (the real fineness related draw yarn tensile force) is a necessary but is not a sufficient prerequisite to the desirable separation of geometrical and material influences to the yarn reaction (outer and inner unevenness).

Identification Matrix to the Unevenness Analysis of Man Made Fibres in the Draw Process

An identification matrix of the unevenness analysis of man-made fibres in the draw process has been developed from the authors in the past which is based on physical-analytical and mathematical-logical ideas. This identification matrix allows a secure general valid assertion conclusion to the unevenness cause structure of the relative unoriented yarn at the drawing zone input and the oriented yarn at the drawing zone output. It has been tested in a row of simulation calculations for the start values (that means for $\tau = k \cdot \Delta t = 0$) of the three CCFs (Eqs. 6.27 to 6.32) which allow for a conclusion to the constellation of the unevenness causes of the investigated yarns.

These investigations have been carried out according to the signal scheme of Fig. 6.16 and included step-like (aperiodic) as well as rectangular and sinusoidal periodic changes of the fineness in the input yarn ΔTt_{i} and/or changes of its E-modulus ΔE_{yi}.[1]

The identification matrix is shown in Table 6.3. Disturbance constellations of the E-modulus and of the fineness of the yarn at the drawing zone input are indicated symbolically in the left columns, in which positive and negative disturbances of both product variables as well as positive and negative disturbances of only one product variable have been assumed. In the three right-hand columns the awaiting start value constellation of the three possible CCFs is inscribed according to the disturbance constellation. Complex composed and superimposed primary measurement signals of the yarn tensile force and the yarn fineness can be decoded with this (occurring for the first time) by means of the third measurement size tensile stress and with concentration on their three CCFs. A decoded disturbance cause description is similarly possible.

The identification matrix shows that disturbances and their combinations lead to the same start value constellations if they only differ in the sign of

[1] The following is to be remarked at this point: The calculation of the CCFs from the recorded time functions of the yarn tensile force, the yarn fineness and the tensile stress must be secure. This means only real, each other physical attached value of the yarn tensile force and the yarn fineness, will be related one upon another for the calculation of the tensile stress. This means (see Fig. 6.16) that the measuring value of the fineness at the drawing zone output correlates with the measuring value of the tensile force when this yarn piece has passed the position of the tensile force measuring sensor in the drawing zone. It is the moment $(t - \Delta t_1)$ according to the chosen draw conditions (output velocity v_{o}, draw ratio DR, distance of measurement place a), which Δt_1 can be signified as the necessary phase shift between the time functions of the tensile force and the fineness for the continuous quotient calculation to the tensile stress (see Fig. 6.16).

Table 6.3. Identification matrix to the unevenness analysis in the draw process

Variant of disturbance	Disturbance in the yarn at the process input (length of the disturbance <length of drawing zone)		Start value of the cross correlation function ($\tau = 0$)		
	Fineness ΔTt_{i}	E-modulus ΔE_{yi}	$K_{\mathrm{FTto}}(0)$	$K_{\mathrm{F}\sigma}(0)$	$K_{\mathrm{Tto}\sigma}(0)$
1	+	0	+	+	–
2	–	0	+	+	–
3	+	+	–	+	–
4	–	–	–	+	–
5	–	+	+	$-(0,+)$	–
6	+	–	+	$-(0,+)$	–
7	0	+	–	+	–
8	0	–	–	+	–

\+ positive deviation to the mean value; start value of the CCF positive
– negative deviation to the mean value; start value of the CCF negative

the disturbance (see Table 6.3, applicable to disturbance variants 1 and 2, 3 and 4, 5 and 6, 7 and 8). The following secure statements can be submitted from the named simulation calculations:

a) Disturbance variants 1 and 2 always result for disturbance lengths > 4 mm and any formed ΔTt_{i}

$$K_{\mathrm{FTto}}(0) > 0, K_{\mathrm{F}\sigma}(0) < 0, K_{\mathrm{Tto}\sigma}(0) < 0$$

A characteristic influence of the sign of the disturbance does not equate to the values of CCFs(0).

b) Disturbance variants 7 and 8 always result for any disturbances and any formed ΔE_{yi}

$$K_{\mathrm{FTto}}(0) < 0, K_{\mathrm{F}\sigma}(0) > 0, K_{\mathrm{Tto}\sigma}(0) < 0$$

The sign of the disturbance is also not provable here by the values of the CCFs(0).

c) The rectified synchronous disturbance of the E-modulus E_{yi} and the fineness Tt_{i} according to the disturbance variants 3 and 4 leads at the start values of the CCFs to the same results as with the disturbance variants 7 and 8. However, the variants 3 and 4 on the one hand and 7 and 8 on the other do further differ in the course of the CCFs by increasing τ-values. The sign of the $K_{\mathrm{F}\sigma}(\tau)$ changes from + to – with the unique E_{yi}-disturbance, whereas the function $K_{F\sigma}(\tau)$ is positive (and for a larger τ nearly zero) for rectified synchronous E_{yi}- and Tt_i-disturbances. This example shows that the whole function course of the CCFs (beyond the start values) can be nevertheless necessary for a detailed analysis of mistake causes for the draw process in the particular case.

d) Different effects superimpose themselves due to contrary synchronous E_{yi}- and Tt_i-disturbances depending on the disturbance parameters.
$K_{FTto}(0) > 0$ and $K_{Tto\sigma}(0) < 0$ is valid when disturbances are contradictary. The sign changes for $K_{F\sigma}(0)$ depending on the length of the disturbance. $K_{F\sigma}(0)$ is negative for disturbances longer than 12 mm. If the disturbance is shorter then the $K_{F\sigma}(0)$ will be positive or zero.

The preceding informed investigations demonstrated problems of the signal analysis and their process-analytic importance contrary to most of the other dealt with questions of this book. It is obvious that the presented method of the qualitative unevenness analysis of man-made fibres in the classical draw process is not only valid for this process stage but in principle it is also transferable to analysis situations of the same kind on other continuous realised thread deformation processes during the thread formation and thread processing.

Finally, an idea for a device realisation for the described measuring and evaluation method should be developed. It is imaginable by means of the microelectronic tools available today that the electrical measuring signals (coming from both measuring sensors for the yarn fineness and the yarn tensile force) will be supplied by a specifically designed and appropriately programmed micro processor system, in which

- the calculation of the fineness related thread tensile force and the CCF-calculation repeatingly (appropriate selected integration times) can be realised,
- the appropriate results to the presented (or an expanded) identification matrix can be evaluated, and
- for instance the number of the identified disturbance variant (and if necessary, other intermediate results) displays as total result on a small digital screen.

Such a procedure of intelligent measuring value concentration would be serviceable not only for simplified handling but also for broader applications of the presented method [320].