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Stable Working Conditions of the Twisting-and-Winding System of a Ring Spinning Frame

Abstract
The technological characteristic of the twisting-and-winding system of a ring spinning frame was determined on the basis of a model of the system's dynamics (including its disturbances), which was formulated previously. Next, on the basis of this characteristic, and taking into account the intensity of the dynamic phenomena occurring, an attempt was made to determine the domain of stable working conditions of this twisting-and-winding system. The results of the numerical investigation are presented as examples in the form of graphic presentations of the balloon shape and of the yarn tension-time dependencies.

Key words: *ring spinning frame, twisting-and-winding system, working conditions, model of dynamics, dynamic phenomena, balloon shape, tension-time dependency.*

Introduction

The process of spinning yarn with a given linear density, from a given raw material and with the use of a ring spinning frame, is performed with an appropriate selected mass of the traveller (m_{tr}), and a selected rotational velocity of the spindle (n_{sp}). These are the basic, decisive parameters of the spinning process. Their numerical values should be carefully selected in order not to exceed the value of the safety coefficient (i) within the range of:

$$i = (0.10 - 0.14)\ F_{br} / T_y \qquad (1)$$

where:
F_{br} - the average yarn breaking force, and
T_y - the average yarn tension caused by the spinning machine's working conditions.

The following working conditions should be considered while determining the values of both the decisive process parameters, the traveller mass and the rotational velocity of the spindle:
- the stable working conditions of the system characterised by yarn tension stable over time, and balloon shape stable over time;
- destructiveness by thermal phenomena in relation to the matching ring-traveller, which limits the linear velocity of the traveller;
- high yarn quality and machine efficiency.

In practice, the selection of the decisive parameters for a working spinning frame resolves itself into assessing a sufficiently large number of pairs (m_{tr}, n_{sp}) which fulfil the condition of T_y=*constant*.

Approximating the quantities measured by the general dependency presented in equation (2) we obtain an empirical function which is called the 'technological characteristic of the system' [4].

$$M_{tr} = f\,(n_{sp})_{Ty\ constant} \qquad (2)$$

This function enables the traveller mass (m_{tr}) to be assessed for a predetermined rotational velocity of the spindle (n_{sp}) and average tension T_y=*constant*.

The procedure for obtaining the values of the system's decisive parameters presented above disturbs the manufacturing process, and does not allow any quantitative estimation of the process' dynamics. This means that the procedure is not an efficient or precise tool for the present-day engineer. As a consequence of this situation, numerical investigations appear to be the most effective and uninvasive method of obtaining information. The mathematical model formulated, and the computer program based on this model which is used by the Department of Spinning Technology and Yarn Structure, were the basis for our numerical investigation.

Aims of the Work

The aims of the work were:
- to determine the technological characteristic of the system $M_{tr}=f(n_{sp})_{Ty=constant}$ for a pre-set average value of yarn tension T_y;
- to obtain information about the dynamics of the system for characteristic pairs of values (m_{tr} , n_{sp}), which fulfil the condition T_y=*constant* in the form of:
  - numerical values of: T_{min} - minimum tension, T_{max} - maximum tension, σ_T - standard deviation of tension, A_T - tension amplitude defined as $A_T=T_{max}-T_{min}$;
  - yarn tension-time dependencies $T_y=T_y(t)$;
  - animation of yarn motion in the balloon;
- to determine stable working conditions for the system.

Simulation Program of the System's Dynamics

The mathematical model of the dynamics of the twisting-and-winding system of the ring spinning frame, which was the basis for the development of the simulation program, has been presented and discussed in articles [1-3]. A schematic diagram of the program is shown in [4]. The program enables simulation of the system's dynamics by means of two access paths, which are related to conducting the spinning process at the following technological situations:
- 1st - for a pre-set traveller mass m_{tr}, where m_{tr}=*constant*;
- 2nd - for a pre-set value of the average yarn tension Ty, where Ty=*constant*.

In all the works [1-3], the system's dynamics for the first technological situation have been analysed.

Experimental Conditions

The numerical experiments were carried out using the second access path. The following data measured on a Polish ring spinning frame of the PJ type were accepted for calculation:
- linear density of the yarn manufactured Tt=12 tex,
- yarn breaking force F_{br}=130.0 cN,
- pre-set average yarn tension $T_y=0.1F_{br}$, T_y=13.0 cN,
- rotational velocity of the spindle $n_{sp}\in$<7000-13000> rpm.

Table 1. The static yarn tension T_y parameters calculated over one working cycle of the ring rail for value pairs (m_{tr}, n_{sp}) obtained from the technological characteristic; designations: n_{sp} - rotational spindle velocity, m_{tr} - traveller mass, $T_{y(av)}$, $T_{y(min)}$, $T_{y(max)}$ - spinning tensions: average, minimum, maximum, σT_y - standard deviation of tension, A_T - maximum tension amplitude.

Pre-set values		Traveller mass	Values calculated									
			Static parameters of yarn tension, $r_{tr(max)}$					Static parameters of yarn tension, $r_{tr(min)}$				
$T_{y(pre\text{-}set)}$ for $r_{tr(av)}$, cN	n_{sp} x 1000 rpm	m_{tr}, mg	$T_{y(av)}$, cN	$T_{y(min)}$, cN	$T_{y(max)}$, cN	σT_y, cN^2	A_T, cN	$T_{y(av)}$, cN	$T_{y(min)}$, cN	$T_{y(max)}$, cN	σT_y, cN^2	A_T, cN
	7	115.5	10.77	9.18	12.58	0.699	3.4	15.81	15.37	16.48	0.368	1.11
	8	86.3	10.88	10.68	11.10	0.143	0.42	15.77	15.38	16.34	0.303	0.96
	9	68.2	11.13	10.76	11.47	0.238	0.71	16.23	14.06	18.58	1.192	4.52
13.0	10	53.8	11.13	10.39	11.89	0.515	1.50	16.29	15.58	17.14	0.517	1.56
	11	42.2	10.90	10.23	11.61	0.398	1.38	15.96	15.34	16.75	0.482	1.41
	12	34.0	11.10	9.19	13.40	1.062	4.21	15.85	15.24	16.65	0.468	1.41
	13	28.0	-	-	-	-	-	11.72	9.31	14.23	1.304	4.92

The simulation was conducted under conditions related to yarn winding on the already formed package basis, which are characterised by three package radius values:

- $r_{p(max)}$ - the maximum package radius; the bottom position of the ring rail in one working cycle,
- $r_{p(av)}$ - the average package radius, related to the middle position of the ring rail in one working cycle,
- $r_{p(min)}$ - the radius of the empty bobbin, related to the upper position of the ring rail in one working cycle.

The twisting-and-winding system was characterised by imperfections of values which occurred; however these did not exceed the nominal values.

Results of Numerical Calculations

The $m_{tr}=f(n_{sp})_{Ty=constant}$ technological characteristic of the system

From practice, we know that the first symptoms of instability in the twisting-and-winding system's working conditions which are caused by incorrect selection of these conditions, and which appear as the balloon collapse occur over winding yarn on the package basis already formed, and within the surroundings of the average package radius r_p. This was why by carrying out the numerical experiment, the technological characteristic was determined under conditions representing the real object, which means for the balloon height H_{bn} (which is related to the package basis formed), the average package radius $r_{p(av)}$, and the pre-set value of the average yarn tension T_y=13.0 cN.

While reading the succeeding values of the rotational velocity of the spindle n_{sp} by the computer, the program calculated the traveller mass m_{tr} fulfilling the condition of spinning tension T_y=13.0 cN. The value pairs (m_{tr}, n_{sp}) for the condition $T_y=constant$ are listed in Table 1, columns 1-4. Next, by approximation of the experimental results, the desired technological characteristic was obtained; their graphic shape is shown in Figure 1.

From the shape of the curve, it results that the increase in the spindle's rotational velocity is accompanied by a related drop in the traveller mass. If the traveller mass achieves the critical value $m_{tr}=m_{tr,K}$ indicated by point *K* in Figure 1, then an unstable balloon shape appears, and the balloon collapses. The points lying on the straight line $m_{tr,K}$=28 mg determine the conditions of the balloon's collapse, whereas the points positioned below this line determine the conditions if one-shape balloon does not exist. On the other hand, the points which lie on the curve of the technological characteristic are the graphic representation of static working conditions for a pre-determined average yarn tension T_y.

From the experiment carried out, it results that the domain of the system's stable working conditions, characterised by the stable balloon shape alone, is an open domain limited by the boundaries of the technological characteristic $m_{tr}=f(n_{sp})_{Ty=constant}$ and the straight line $m_{tr,K}=constant$.

The use in practice of only the technological characteristic and the limited open domain for determining stable working conditions for the pre-set yarn tension $T_y=constant$ is a rather imprecise tool. Thus, the need for investigating the system's dynamics arises.

Dynamics of the twisting-and-winding system for value pairs (m_{tr}, n_{sp}) obtained from the technological characteristic $m_{tr}=f(n_{sp})_{Ty=constant}$

While winding yarn on the package basis already formed, the yarn tension changes cyclically in one wound layer within the range:

$$T_{y(max)} \geq T_y \geq T_{y(min)}$$

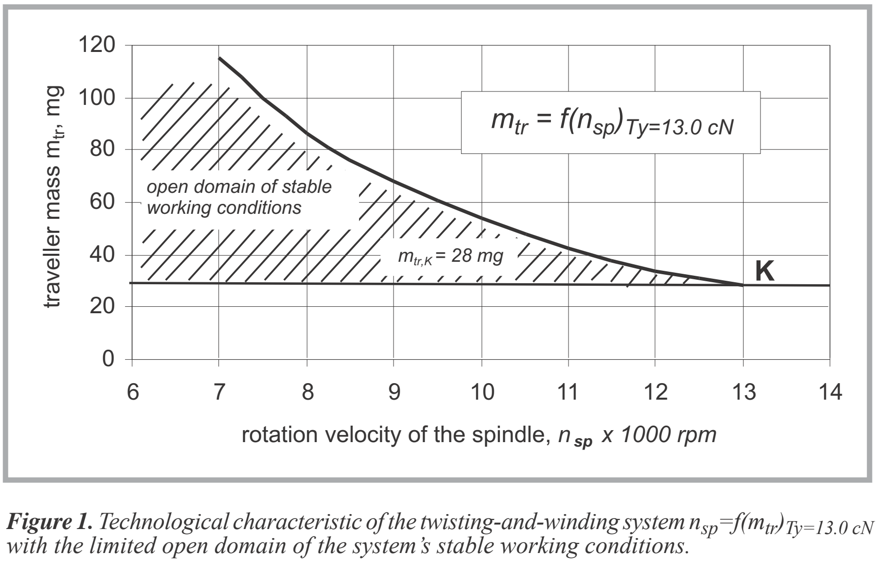


Figure 1. Technological characteristic of the twisting-and-winding system $n_{sp}=f(m_{tr})_{Ty=13.0\ cN}$ with the limited open domain of the system's stable working conditions.

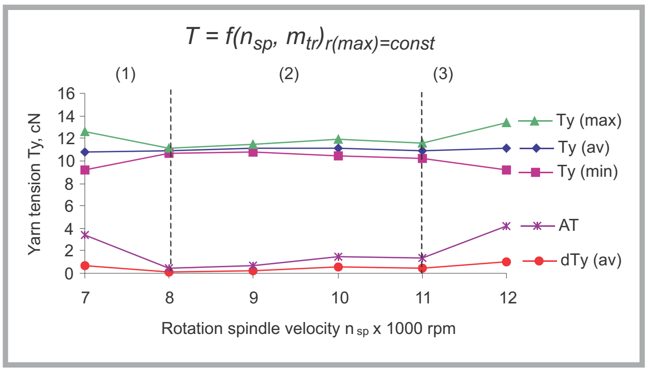


***Figure 2.** Parameter values characterising yarn tension T_y for $r_{tr(max)}$.*

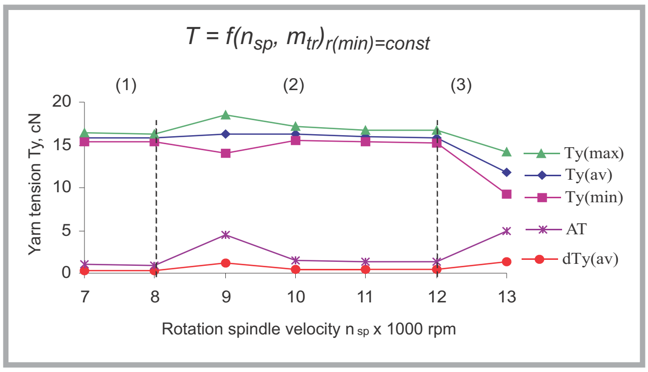
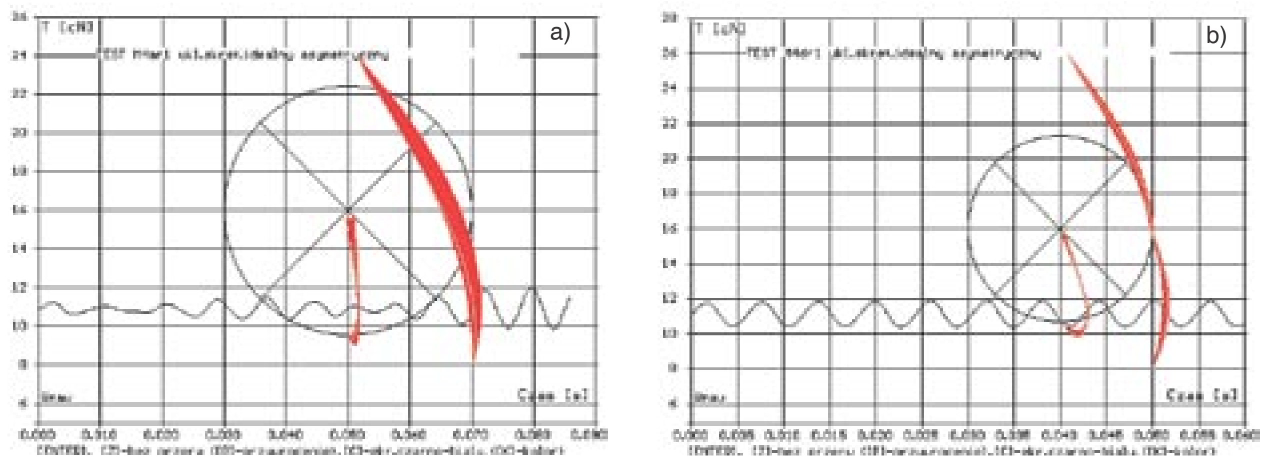


***Figure 3.** Parameter values characterising yarn tension T_y for $r_{tr(min)}$.*



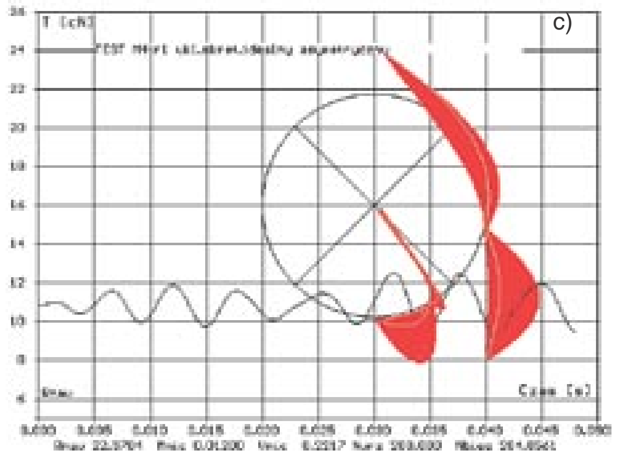


***Figure 4.** Animation of yarn motion in the balloon and yarn tension-time characteristic for working conditions of sub-domain: a) region of unstable working conditions (1), b) region of stable working conditions (2), and c) region of unstable working conditions (3); the regions 1, 2, 3 are marked in Figures 2 and 3.*

according to the change of the package radius within the range:

$$r_{p(max)} \geq r_p \geq r_{p(min)}$$

The following static yarn tension parameters calculated, T_y for $r_{p(max)}$ and $r_{p(min)}$ in one package layer, for the pre-set traveller mass m_{tr} and rotational velocity of the spindle n_{sp}, are listed in Table 1. The graphic interpretation of the yarn tension data calculated is shown in Figures 2 and 3.

The analysis of the results presented in Table 1 and Figures 2 and 3 gives evidence for separating three sub-domains {(1), (2), (3)} from the open domain of stable working conditions. These sub-domains of working conditions are characterised by an essentially different intensity of the dynamic phenomena occurring. The examples of animation of yarn motion in the balloon and the tension-time dependencies presented in Figure 4, illustrate in detail the working conditions of the sub-domains, separated in Figures 2 and 3 by vertical dotted lines.

As is visible in Figure 4a, in sub-domain (1) a at spinning balloon is formed of a stable shape, but the tension-time characteristic is not stable, and is characterised by relatively great amplitude A_T. This is especially valid for winding yarn on the radius $r_{p(max)}$ (Figure 2). Thus, the sub-domain (1) is a region of non-stable working conditions in the system, caused by the instability of the tension-time

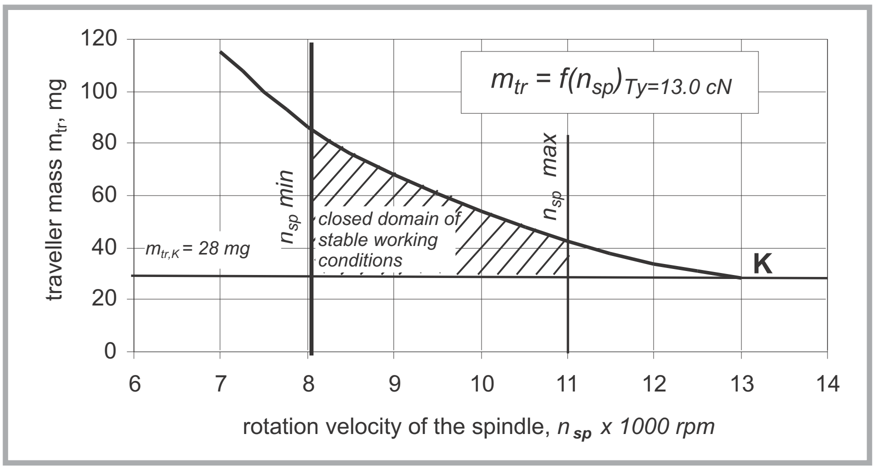


***Figure 5.** Technological characteristic of the twisting-and-winding system $m_{tr}=f(n_{sp})_{Ty=13.0\ cN}$ with a marked closed domain of the system's stable working conditions, limited by the four boundaries.*

dependency. If only the information obtained by testing the statics of the system is used, the sub-domain cannot be discovered. Only the numerical investigations of the dynamics of the system allowed this region to be separated and described.

Sub-domain (2) is characterised by a correct and stable balloon shape (Figure 4b) and a stable course of tension with a relatively small amplitude. This is a region of stable working conditions of the system.

Sub-domain (3) is the next region of non-stable working conditions in the spinning frame, caused by the balloon collapse and instability of the yarn tension course with a great amplitude. The instabilities of the balloon and tension are shown in Figure 4c.

Determining the region of stable working conditions obtained from the technological characteristic, as extended by the analysis of dynamic phenomena in working conditions, enabled a more precise description of this region.

Finally, it can be stated that the domain of stable working conditions of the twisting-and-winding system is a closed domain, limited by the following four functions: the technological characteristic $m_{tr}=f(n_{sp})_{Ty=constant}$, and the straight lines $m_{tr,K}=constant$, $n_{sp(min)}=constant$, and $n_{sp(max)}=constant$. The technological characteristic, together with the domain marked, is presented in Figure 5.

Summary

The course of the technological characteristic of the twisting-and-winding system $m_{tr}=f(n_{sp})_{Ty=constant}$, together with the existence of the limited closed domain, expose the undeniable need for a complex approach to determining the operating working conditions of the system.

By connecting information included in the technological characteristic of the system with the results of investigating its dynamics, we obtain objective information about the stable and non-stable working conditions of the system.

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