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## Design and Petri Net Modeling of New Crimp Contraction Tester Control System

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**Abstract:** Aiming at the complicated structure and high cost existing in the crimp contraction tester products, based on the analysis of the procedure for testing the crimp contraction properties of deformed yarns, the hardware structure of the automatic crimp contraction tester control system with ARM chip as the core is introduced firstly. The formal definition of one new class of Petri nets called generalized synchronous self-modifying net (GSSN) is developed. By using GSSN, a new method for modeling and analysis of the control process is discussed. For making up the insufficiency of the traditional Petri nets models, which is difficult to synchronize with external events and has a simple description algorithm, this method takes advantage of the characteristics of GSSN: one is that transitions are associated with external events and the other is that arc weights are controlled by places. Through the simulation analysis of the reachability graphs of the designed model obtained by using the GSSN modeling tool, the correctness of the control process was confirmed. Practical applications show that the instrument meets the needs of textile and chemical fiber enterprises and has the characteristic of reliable performance and low cost.

**Key words:** crimp contraction tester; ARM; Petri net; modeling

## 新型卷缩率测试仪控制系统设计与 Petri 网建模

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**摘要:** 针对现有的卷缩率测试仪产品存在着结构复杂和成本高的问题, 在深入分析变形丝卷缩性能测试流程的基础上, 设计了以 ARM 为核心的全自动卷缩率测试仪控制系统硬件结构, 提出了一类新的 Petri 网-广义

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同步自控网系统(GSSN)的形式化定义,讨论了一种新的基于 GSSN 对控制流程进行建模与分析的方法。为了弥补传统 Petri 网模型存在的不易与外部事件同步和描述算法简单等不足,该方法充分利用了 GSSN 的变迁与外部事件关联以及弧权值受库所控制的特性。通过使用 GSSN 建模工具得到设计模型可达图并进行仿真分析,确认了控制过程的正确性。经实际应用表明所设计的仪器满足纺织和化纤企业的需求,且具有性能可靠和低成本等优点。

**关键词:**卷缩率测试仪;ARM;Petri 网;建模

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Textured yarns are formed by deforming ordinary filament yarn and have the characteristic of greater flexibility which is caused by the crimp of the textured yarns. The crimp property of deformed yarns is directly related to the properties of textured yarns and the characteristics of textile products. The crimp contraction tester is used to measure the physical indexes of the tensile properties, such as crimp contraction, crimp modulus and crimp stability of the textured yarn<sup>[1]</sup>, and print out the test data after mathematical statistics. The existing crimp contraction testers mostly adopt the bidirectional control structure, in which a single-chip microcomputer controls the specific test procedure and an industrial computer sets the system parameters and processes the test data, and thus the cost is high. With the development of embedded technology, the use of a single ARM processor can effectively meet the control function of the crimp contraction tester. However, the test procedure is complex because there are many concurrent actions such as key and pulse signal detection, serial port communication, and motor drive when the system is running. Problems such as resource conflicts and deadlocks may occur when the control is improper. In order to improve the reliability of control, it is necessary to use a formal modeling method.

Petri net is an important modeling and analysis tool, which can describe and analyze system characteristics such as concurrency, conflict, asynchrony and competition. It has been widely used in many fields such as manufacturing and embedded systems. In [2], hybrid Petri net was used as a high-level abstraction modeling tool and combined with the object-oriented paradigm for the modeling of embedded control systems. In view of the strong nonlinearity and large inertia of temperature control of the conventional electric heating furnace in industrial production, the idea of hybrid control system was applied in [3]. An electric heating furnace temperature control system based on Petri nets was designed to realize the rapidity and stability of temperature control. In [4], the timed Petri net was used to model the control system of the automatic medical test analyzer, which solved the problems of conflict and deadlock in the control system. In [5-8], based on the place-transition Petri net, an input-output place-transition Petri net (IOPT) for digital controller modeling was proposed and a set of tools, including graphical editor, state space analyzer, and conflict resolution, automatic code generator, and emulator were developed, which supports the complete system development process from specification to implementation. In [9] and [10], in view of the traditional PLC programming method can not meet the requirements of complex industrial control such as coordination control and competition control, the building method of Petri net control model and the conversion from Petri net model to ladder diagram are introduced. By using these programming methods, procedure press-charge detonator machine and cylinder line control system is respectively implemented.

For ordinary Petri net model, the data types are not rich enough and the described algorithm is

simple. Self-modifying net is a kind of high level Petri net, which differs from P/T system in that it has the arc weight controlled by the places. So in self-modifying net, the system parameters can be more clearly affected by the system state. The self-modifying net system is nonlinear and therefore has a stronger system modeling capability<sup>[11]</sup>. In this paper, a novel control system for crimp contraction tester based on the ARM chip AT91SAM7S64 is designed by following the test method of crimp contraction properties of textured filament yarns. The generalized synchronous self-modifying Petri net system proposed in [12] is used to achieve control system modeling and analysis.

## 1 Test Principle and Hardware Design

The test principle of the crimp contraction tester is to hang a number of skein samples on the hooks of a cylindrical sample holder and to crimp them in the hot air in the oven, and then place the sample holder in the drawer of the crimp contraction tester. According to the test standard, the stretch length of the skein is measured under different load conditions. After the stretching of each sample is completed, the crimp contraction performance indexes of the skein sample are calculated according to the recorded data and stored, and then proceed the next test until all the samples are tested. The structure of the crimp contraction tester is shown in Fig.1.

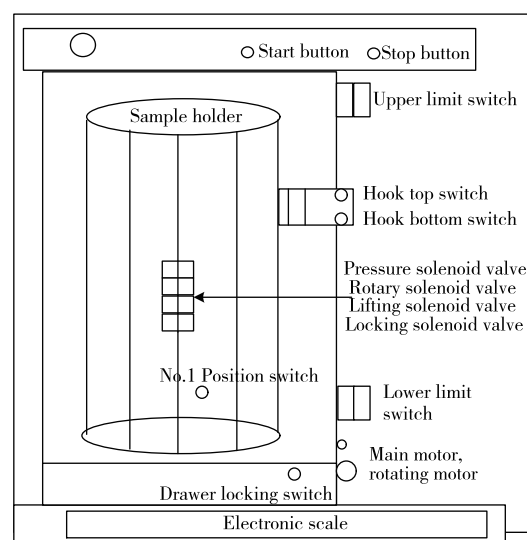


Fig.1 Structure of crimp contraction tester

The hardware components of the control system for crimp contraction tester include the following modules:

1) Sample holder rotation module. The skein samples to be tested at different positions on the sample holder must be rotated by the rotating motor to control the sample holder to reach the specific test location before starting the test. This module uses a single-phase permanent magnet synchronous motor as rotating motor, which is controlled by a relay to start and stop.

2) Tension driving module. There is a row of hooks at the upper and lower ends of the sample holder. The upper hooks are fixed on the frame of the sample holder, but the lower hooks are not. Skein samples hang between the upper and lower hooks. AC servo motor is used as the main motor, which is controlled by AC servo driver. The system main controller provides the PWM signal and the direction signal to the AC servo driver. The frequency of the PWM signal is proportional to the speed of the motor. The rotating of the main motor will control the movement of chains, driving the press block to move up and down. When the press block moves downwards, the press block cylinder protrudes and forces the hook down.

3) Force measurement module. The force is measured by using an electronic scale. The cylinder mechanism lifts the sample holder and makes it force on the electronic scale, with which the main controller communicates via RS232. The tension on the skein will be reflected on the electronic scale.

4) Length measurement module. The main controller measures the number of pulses issued by the motor encoder and calculates the length of the skein extension according to the electronic gear ratio of the motor driver.

5) Human-machine interface module. It is made up of a touch screen and a printer. The touch screen uses Inter-Integrated Circuit interface to realize the setting of system parameters and the display of test data. The USB printer realizes the printing of data report after each test.

6) Main controller. The AT91SAM7S64, an industrial-grade microcontroller is used as the main controller. The microcontroller is fast and powerful, which has a 64 kB high-speed Flash, 16 kB of RAM, and a rich set of resources such as a PWM controller, USART, and USB device interface to meet control requirements.

The detailed hardware block diagram of the control system is shown in Fig.2.

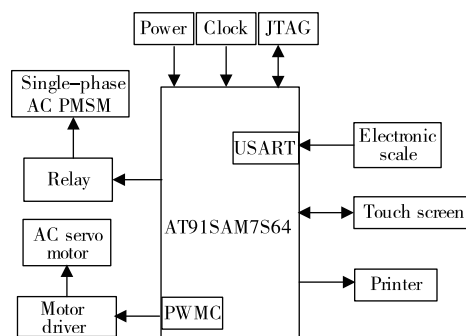


Fig.2 Block diagram of control system

## 2 Petri Net Modeling and Analysis

### 2.1 Generalized Synchronous Self-Modifying Net

Definition 1: A generalized self-modifying net is a tuple.

$$\Sigma = (P, T; F, K, W, M)$$

In which,  $P$  is a finite set of places;  $T$  is a finite set of transition;  $F$  is a finite set of arcs, such that  $F \subseteq (P \times T) \cup (T \times P)$ .

$K = \{K_L, K_H\}$  is a capacity function of  $\Sigma$ , where  $K_L$  is an lower bound capacity function and  $K_H$  is an upper bound capacity function.  $\forall p \in P$ , the capacity of  $p$  can be expressed as  $[K_L(p), K_H(p)]$ . When  $K_L(p)$  and  $K_H(p)$  are infinite, the closed interval of capacity turns into open interval.

$W: F \rightarrow \mathbf{R} \cup \text{Exp}(P)$  is a weight function, where  $\mathbf{R}$  is a real number set and  $\text{Exp}(P)$  is a set of function expressions with elements in  $P$  as variables.

$M: P \rightarrow \mathbf{R}$  is the marking function.  $M_0$  is the initial marking.

Definition 2 (firing condition and result of a transition):

The weight of an arc under marking  $M$  is defined as:  $\forall (x, y) \in (P \times T) \cup (T \times P)$ ,

$$W_M(x, y) = \begin{cases} W(x, y) & W(x, y) \notin \text{Exp}(P), \\ e_M & W(x, y) = e, e \in \text{Exp}(P). \end{cases} \quad (1)$$

By using  $M(p_i)$  to replace  $p_i \in P (i = 1, 2, \dots)$  in the expression  $e$  and evaluate it,  $e_M$ , the result of expression  $e$ , can be obtained.

The firing conditions for transition  $t$  under marking  $M$  are as follows:

$$\forall s \in {}^*t: (M(p) - W_M(p, t)) \in [k_L(p), k_H(p)] \text{ and } \forall s \in t^*: (M(p) + W_M(t, p)) \in [k_L(p), k_H(p)]. \quad (2)$$

In(2),  ${}^*t$  and  $t^*$  is the preset and postset of transition  $t$ .

If transition  $t$  can be firable under  $\mathbf{M}$ ,  $\mathbf{M}$  is changed to its successor  $\mathbf{M}'$  after firing of  $t$ .  $\mathbf{M}'$  is defined as follows

$$\mathbf{M}'(p) = \begin{cases} \mathbf{M}(p) - \mathbf{W}_M(p, t) & p \in \cdot t - t \cdot \\ \mathbf{M}(p) + \mathbf{W}_M(t, p) & p \in t \cdot - \cdot t \\ \mathbf{M}(p) - \mathbf{W}_M(p, t) + \mathbf{W}_M(t, p) & p \in \cdot t \cap t \cdot \\ \mathbf{M}(p) & p \notin \cdot t \end{cases} \quad (3)$$

Definition 3: A generalized synchronous self-modifying net (GSSN) is a triple  $(\Sigma, E, G)$ , where  $\Sigma = (P, T; F, K, \mathbf{W}, \mathbf{M}_0)$  is a generalized self-modifying net;  $E$  is a set of external events;  $G: T \rightarrow E \cup \{e\}$  is an event function in which  $e$  is the always occurring event.

In a GSSN, the firing of a transition will occur if the transition is enabled and its associated event occurs. The state equation of the GSSN can be written in the form of state equation of the self-modifying net system as follows [13]

$$\mathbf{M}' = \mathbf{M}_0 + \rightarrow \mathbf{C} \cdot \mathbf{U} \quad (4)$$

In which the matrix operator “ $\rightarrow$ ” represents replacement plus,  $\mathbf{C}$  is the association matrix of  $\Sigma$  and  $\mathbf{U}$  is the matrix representation of concurrent step sequences of  $\Sigma$ .

Fig.3(a) is a GSSN model. Fig.3(b) shows the timing of  $X_1$ ,  $X_2$  as well as the evolution of the markings.

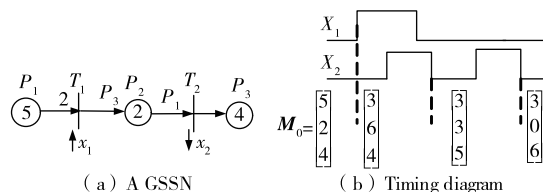


Fig.3 A generalized synchronous self-modifying net system example

According to the equation (4), the markings in Fig.3(a) are calculated as follows

$$\mathbf{M} = \begin{bmatrix} 5 \\ 2 \\ 4 \end{bmatrix} \rightarrow \begin{bmatrix} -2 & 0 \\ P_3 & -P_1 \\ 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 1 \end{bmatrix} = \begin{bmatrix} 5 \\ 2 \\ 4 \end{bmatrix} \rightarrow \begin{bmatrix} -2 & 0 & 0 \\ P_3 & -P_1 & -P_1 \\ 0 & 1 & 1 \end{bmatrix} = \begin{bmatrix} 3 \\ 0 \\ 6 \end{bmatrix}$$

## 2.2 Petri Net Modeling and Analysis of Test Procedure

According to the test method for crimp contraction properties of textured filament yarns, a GSSN system model for the test process of the control system of the crimp contraction tester was established in Fig.4.

The meaning of each place, transition, and signal in the model are shown in Table 1. The model can be divided into the following three steps.

1) Sample holder rotating to the test position

At the ready state of each test, after the start button is pressed, transition  $T_1$  fires, indicating the locking solenoid is opened and waiting for the drawer arriving at position. When the drawer locking switch is closed, transition  $T_2$  will fire, which drives the rotation motor to make the sample holder rotating. When the close signal of No.1 position switch is generated, a token enters into the place  $P_4$ , indicating that the skein to be tested are in

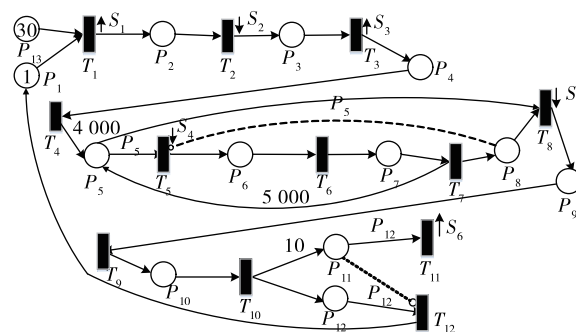


Fig.4 Petri net model of test procedure

place.

### 2) Press block moving to the lower hook position

When transition  $T_4$  fires, the main motor is started to rotate at a high speed with the chain, which drives the pressure block to move up until the upper limit position. When transition  $T_5$  fires, the main motor stops, and opens the pressure solenoid valve to control the pressure block cylinder to stretch. At this time, the main motor is restarted at a high speed. When the switch signal of the bottom hook is received, a specified load is forced to the skein. In this process, the place  $P_5$  represents the operating state of the main motor, and its token represents the motor speed. The arc  $(P_5, T_5)$  and arc  $(P_5, T_8)$  are controlled arcs, whose weight value equals the token of  $P_5$ . When  $T_5$  or  $T_8$  fires, the token will be removed from  $P_5$ , indicating that the motor stops running.

### 3) Test process

When place  $P_9$  gets a token, the skein is started to add force and the formal testing starts. At this time, transition  $T_9$  fires and the PID adjustment process are performed until the skein is subjected to the specified load. When place  $P_{10}$  has a token, transition  $T_{10}$  fires, indicating that the timer starts timing and starts to load the skein with the specified force for a specified time. The weight of arc  $(T_{10}, P_{11})$  and  $(T_{10}, P_{12})$  represents the force holding time and a single timing cycle respectively. Each time when overflow signal of the timer arrives, transition  $T_{11}$  is enabled and the timer interrupt number is counted. If the fixed time has arrived, the token of place  $P_{11}$  is reset to zero, and the current test process is completed by enabling the fire of transition  $T_{12}$  by inhibitor arc  $(P_{11}, T_{12})$ . The number of samples is represent by the tokens of place  $P_{13}$ , which do not equal to zero will start next test procedure.

**Table 1** Meaning of places, transitions and signals

Element	Meaning	Element	Meaning	Element	Meaning
$P_1$	Testing ready	$T_1$	Open locked solenoid valve	$S_1$	Start button
$P_2$	Waiting close of drawers	$T_2$	Open relay	$S_2$	Locking switch
$P_3$	Rotating motor operation	$T_3$	Disconnect relay	$S_3$	No.1 position switch
$P_4$	Skein in place	$T_4$	Output PWM signal	$S_4$	Upper limit switch
$P_5$	AC servo motor operation	$T_5$	Stop PWM output	$S_5$	Hook bottom switch
$P_6$	AC servo motor stop	$T_6$	Open pressure solenoid valve	$S_6$	Timing interrupt signal
$P_7$	Press block Protruding	$T_7$	Reverse output PWM signal		
$P_8$	High speed running down	$T_8$	Calculate tare weight		
$P_9$	Adding force to skein	$T_9$	Adjust PID		
$P_{10}$	Reaching specified force	$T_{10}$	Start timer		
$P_{11}$	Keeping force	$T_{11}$	Process timer interruption		
$P_{12}$	Periodic timing	$T_{12}$	Complete current test		
$P_{13}$	Sample numbers				

According to the test method for crimp contraction properties of textured filament yarns, in the test procedure, at different times, the test sample needs to be loaded with different force and maintained the corresponding time, and then the stretch length of the sample is measured. The detailed description is as follows:

### 1) When the press block moves down to the lower hook, the sample is loaded until it bears the

force of 0.2 cN/dtex, and then it is held for 10 seconds and the length value  $L_g$  of the sample is measured.

2) The sample is unloaded and keeps this state for 10 minutes, and then the length value  $L_z$  is measured.

3) The sample is loaded again until it bears the force of 0.01 cN/dtex for 10 seconds, and then it is held for 10 seconds and the length value  $L_f$  of the sample is measured.

4) Change the load to the specific force for 10 seconds, and then unload the force. After 20 minutes, the length value  $L_b$  is measured. Based on the parameters measured, the crimp contraction and other performance index can be calculated. The model in Fig.4 describes the process of applying one load test to the sample.

By using the modeling tool for GSSN, the model of Fig.4 is simulated and analyzed. The reachable tree can be obtained under the initial markings  $M_0$ . The model reached a target markings (1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0) after a series of transitions fired, which showed the test process has completed correctly and indicated that all transitions are live and there is no conflict between input signals at the same time.

### 3 Test Results

In the design of the control system of the new crimp contraction tester, the control process is modeled and analyzed by Petri net, which ensures the reliable operation of multiple concurrent actions such as motor control, force loading, PID adjustment and switch signal detection in the system. Compared with the traditional design process, the proposed Petri-net based method effectively reduces the workload of system development and debugging. The designed new crimp contraction tester has been actually tested and complies with various performance requirements specified in the test method for crimp contraction properties of textured filament yarns. During the test procedure, the touch screen displays the measured length of each sample during the stretching process and the calculated results, such as crimp contraction, crimp stability etc., as shown in Fig.5. At present, the instrument has been used in a number of chemical fiber enterprises and textile enterprises.

	$L_g$ /mm	$L_z$ /mm	$L_b$ /mm	CC /%	CS /%
1	999.20	644.02	651.52	35.55	97.89
2	999.62	636.62	644.44	36.31	97.85
3	995.98	629.78	637.32	36.77	97.94
4	1003.90	643.62	651.04	35.89	97.94
5	998.52	646.16	654.62	35.29	97.60
6	1002.00	630.42	636.62	37.08	98.33
7	997.40	629.18	636.84	36.92	97.92
8	999.02	623.62	630.90	37.58	98.06
9	1005.00	703.98	709.82	29.95	98.06
10	1009.94	713.16	718.68	29.39	98.14

Fig.5 Display of test results

### 4 Conclusion

Through a thorough understanding of the test method for crimp contraction properties of textured filament yarns, Petri net modeling and analysis of the control system is carried out based on the GSSN system, using its characteristics of transitions associated with external events and controlled arcs. The practical application results of the designed crimp contraction tester show that it can meet the needs of various types of textile enterprises and chemical fiber enterprises, saving the cost for those enterprises. The Petri net model designed in this paper is only used to analyze the design flow to ensure the reliability of the system test under complex conditions. If the controlled system adopts a PLC

as the main controller, an existing conversion method from Petri net to PLC ladder diagram can be integrated to realize the automatic conversion from the GSSN system model to the PLC code, thereby completely implementing a model-based design flow.

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