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STATISTICAL CONTROL OF DEFECT FREQUENCY IN KNITWEAR PRODUCTION USING A U-CONTROL CHART

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Abstract. The paper proposes a statistical process control model for knitting production based on data collected by an intelligent monitoring system. Since the sample size varies from shift to shift, a u-chart is justified for monitoring defect frequency, and its limits (UCL = 8.6; LCL = 1.0 events/100 m) are calculated. Pareto analysis showed that 80.4 % of defects belong to three classes. A regression relationship between yarn tension and defect frequency ($R^2 = 0.89$) was used to justify the target value of the control chart, T ≈ 23 cN; the process capability index Cpk increased from 0.74 to 1.21.

Keywords: statistical process control, u-chart, control limits, Pareto analysis, yarn tension, process capability, Cpk, knitting

Introduction

Statistical process control (SPC) is one of the key methodological tools of a quality management system; it is based on separating the natural (random) variation of a process from variation due to special, assignable causes [1]. In conventional quality control, knitted fabric is inspected by sampling at the final stage, so defect information is obtained late and in small amounts. This does not allow control charts to be maintained in real time.

AI-based monitoring systems record every defect event together with its time, class and the parameters of the process mode [2, 3]. Such a data array provides an empirical basis for the full application of SPC methods. However, in knitwear production the questions of selecting the type of control chart and linking its limits to process parameters have not been studied sufficiently.

The aim of the paper is to develop a control chart for the knitwear production process based on intelligent monitoring data and to substantiate its target value from a technological standpoint.

Object and Methods of the Study

The study was carried out over three months on circular knitting machines at the pilot production site of a knitwear enterprise; a total of 1,842 defect events were recorded. The study used the theory of Shewhart control charts, the Western Electric rules, Pareto analysis, regression analysis and process capability indices [1, 4].

The type of control chart depends on the type of data. $\bar{X}$–R or $\bar{X}$–s charts are used for continuous variables, while for counts of events a c-chart (with a constant sample size) or a u-chart (with a variable sample size) is applied. Since the length of fabric produced per shift in knitwear production varies, the u-chart is the most suitable tool for monitoring defect frequency. Defect frequency is normalised per unit of product:

$$\lambda = N_n \cdot 100 / L_m, \quad (1)$$

where λ is the defect frequency, events/100 m; N_n is the number of recorded defects; L_m is the length of fabric produced during this period, m.

The control limits of the u-chart are calculated on the basis of the Poisson distribution:

$$\bar{u} = \Sigma N_n / \Sigma L_m, \quad (2)$$

$$UCL = \bar{u} + 3\sqrt{(\bar{u} / \bar{n})}, \quad LCL = \max(0; \bar{u} - 3\sqrt{(\bar{u} / \bar{n})}), \quad (3)$$

where $\bar{u}$ is the average defect frequency in the base period; $\bar{n}$ is the average sample size (in units of 100 m). Unlike the simple three-sigma rule, these expressions take into account the actual production volume of each shift.

The Western Electric rules were applied to detect an out-of-control process: one point outside the control limits; nine consecutive points on one side of the centre line; six consecutive points steadily increasing or decreasing.

Results and Discussion

Pareto analysis. To determine the relative weight of the defect types, the cumulative share was calculated:

$$C_i = (\Sigma_{j \le i} n_j) / (\Sigma n_m) \cdot 100\ \%. \quad (4)$$

According to the analysis, 80.4 % of defects belong to three types – dropped stitches (33.2 %), stripes (27.1 %) and holes (20.1 %) (Fig. 1). Uneven density and knots / yarn irregularity accounted for 11.4 % and 8.2 %, respectively. In line with the Pareto principle, it is advisable to concentrate quality management efforts on these three classes and to set the control chart limits primarily for them.

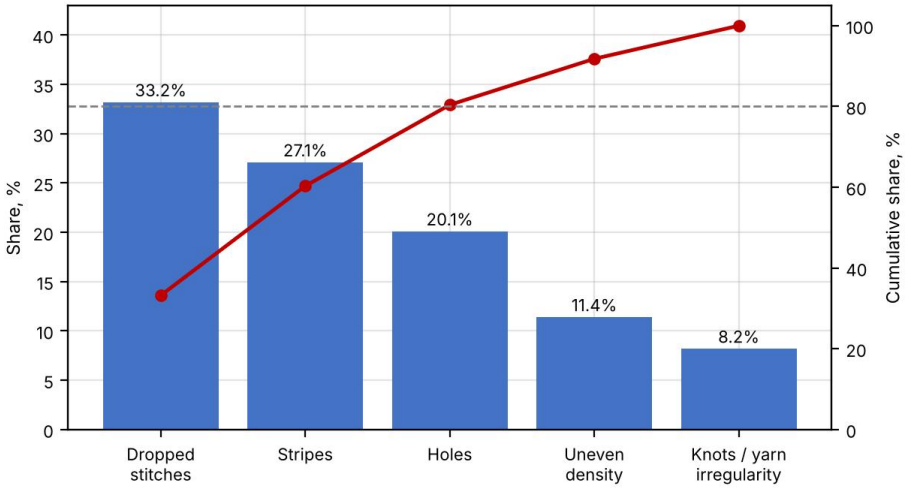


Fig. 1. Pareto chart of defect types

Substantiation of the target value of the control chart. To give the control chart limits a physical basis, the relationship between yarn tension T and defect frequency was studied by the least-squares method, and the following empirical model was obtained:

$$\lambda = 0.19T + 6.0 \cdot \exp[-(T - 17)/2.2] + 0.021(n - 25) + 0.0018(n - 25)^2 - 3.56, \quad (5)$$

where T is the yarn tension, cN; n is the rotational speed of the needle cylinder, rpm. The coefficient of determination is $R^2 = 0.89$.

The relationship is non-linear: at low tension the exponential term (instability of loop formation) dominates, while at high tension the linear term (increase in yarn breaks) prevails. As a result, the function has a minimum, observed at $T \approx 23$ cN. This value was adopted as the target value of the control chart. Since the value of 26 cN recommended in the existing process

documentation lies away from the minimum, it is recommended that it be revised from the standpoint of quality management.

Calculation of the control limits. In the base period (the first trial month), the average defect frequency was $\bar{u}$ = 4.8 events/100 m and the average sample size was $\bar{n}$ = 3.0 (in units of 100 m). According to expression (3):

$$UCL = 4.8 + 3\sqrt{(4.8/3.0)} = 8.6; \quad LCL = \max(0; 4.8 - 3.8) = 1.0 \text{ events/100 m.} \qquad (6)$$

After the limits were introduced, all daily values recorded in the second and third trial months remained within the interval [1.0; 8.6], and no warning signal was triggered under the Western Electric rules (Fig. 2). This confirms that the process is in a state of statistical control and that the optimised mode (T ≈ 23 cN) has been maintained consistently.

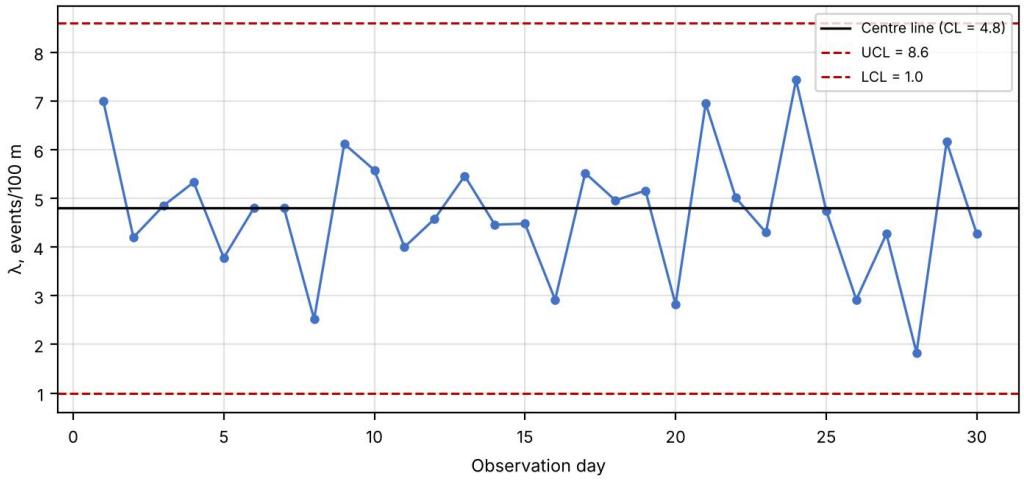


Fig. 2. u-control chart of defect frequency (CL = 4.8; UCL = 8.6; LCL = 1.0 events/100 m)

Table 1

Main parameters of the SPC control chart

Parameter	Symbol	Value
Centre line (average defect frequency)	CL	4.8 events/100 m
Upper control limit	UCL	8.6 events/100 m
Lower control limit	LCL	1.0 events/100 m
Target process parameter (yarn tension)	T*	≈ 23 cN
Defect classes under priority control	—	Dropped stitches, stripes, holes (80.4 %)
Coefficient of determination of the regression model	R^2	0.89

Process capability. Taking into account the process limit Nn ≤ 6 events/100 m set by the enterprise's internal standard, the process capability index was calculated:

$$Cpk = (USL - \mu) / (3\sigma). \qquad (7)$$

Before optimisation, Cpk = 0.74, and after the yarn tension was adjusted to the target value, Cpk = 1.21 (an increase of 63.5 %). This shows that the process moved from an "unsatisfactory" state (Cpk < 1.0) to a "satisfactory" one (Cpk > 1.0). It should be noted that for a discrete indicator such as the number of defects, Cpk is calculated through a normal approximation; therefore, it should be interpreted as an indicator for comparing process states.

According to the methodological guidelines, when the control chart limits are exceeded, the process mode is checked and, if necessary, corrective action is taken. It is recommended to specify this rule as follows: if a point exceeds the UCL, the yarn tension and the condition of the needles are checked and the result is entered in the nonconformity register; if nine consecutive points lie above the centre line, unscheduled maintenance of the needle cylinder and the yarn feeding mechanism is carried out; if a point falls below the LCL, the calibration status of the inspection system is checked, since this may indicate missed defects.

Conclusions

1) It has been substantiated that, because the sample size varies from shift to shift, the u-chart is the most suitable tool for monitoring defect frequency in knitwear production.

2) Pareto analysis showed that 80.4 % of defects belong to three classes (dropped stitches – 33.2 %, stripes – 27.1 %, holes – 20.1 %); control efforts should be directed primarily at these classes.

3) A regression model ($R^2 = 0.89$) describing the effect of yarn tension and needle cylinder speed on defect frequency was obtained, and the target value of the control chart, $T \approx 23$ cN, was substantiated.

4) The limits of the u-chart were calculated as UCL = 8.6 and LCL = 1.0 events/100 m; after implementation, the process remained in a state of statistical control, and Cpk increased from 0.74 to 1.21.

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