Intelligent Control Based on Case-based Reasoning for Outlet Tobacco Moisture Percentage of Loosening Resurgence Machine*

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Abstract—Tobacco loosening and resurgence process has strong nonlinearity and large delay-time ratio, and it is difficult to describe the process via accurate mathematical models. Thus, it is difficult to control the outlet tobacco moisture percentage (OTMP) for loosening and resurgence machine by operators. To solve these problems, combining the expert knowledge and operation experience, an intelligent control method based on case-based reasoning (CBR) is presented for loosening and resurgence machine. The intelligent control method is applied in a certain cigarette plant which shows that the OTMP is controlled in the scope of target value and water consumption is reduced.

Keywords—tobacco loosening and resurgence process, outlet tobacco moisture percentage (OTMP), case-based reasoning (CBR), intelligent control

I. INTRODUCTION

As an appropriate facility in the tobacco loosening and resurgence process, loosening resurgence machine is one of the most important facilities in primary processing line of cigarette plants. It is very commonly used in China. The function of loosening resurgence machine is to increase the temperature and moisture percentage of dried tobacco, to improve toughness and resistance to processing of dried tobacco, and to loosen dried tobacco after cut [1]. The OTMP is the most important controlled target in the tobacco loosening and resurgence process. If OTMP is unstable, not only the moisture content of tobacco dried and expanded but also the quality of cigarette will be influenced [2]. The control precision of OTMP is high, thus the permissible scope of the OTMP is very narrow. However, the OTMP is intractable due to the intrinsic nonlinearity and large delay-time ratio in the loosening and resurgence process. Also, it is hard to describe the tobacco loosening and resurgence process by accurate mathematical models. To control the OTMP in its target value scope, the modeling and controlling are integrated, based on CBR [3], an intelligent control method is developed by two layers structure. The proposed method has been applied in the tobacco loosening and resurgence process.

This paper is organized as follows. Section 2 introduces the tobacco loosening and resurgence process. The intelligent control method is addressed in section 3. Section 4 gives application results of the presented method. A conclusion is presented in section 5.

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II. TOBACCO LOOSENING AND RESURGENCE PROCESS

The tobacco loosening and resurgence process is shown in Fig.1 (see the Appendix.1). After the package of dried tobacco is removed, the dried tobacco block is cut into several sub-blocks which have equal size and weight. Then the tobacco sub-blocks are sent into microwave loosening machine. After that, the tobacco is sent into the loosening and resurgence machine by the vibrating conveyor. The tobacco is kepting rolled by the interactions with the deflectors and rake nails in the roller of the loosening and resurgence machine. Hence, tobacco has a spiral forward movement by tobacco gravitation, roller obliquity and roller rotation. Meanwhile, the water and saturated steam come into the roller by mixing nozzle. Also, the hot circulation air comes into the roller. The tobacco keeps absorbing heat and moisture through contacting with steam, water and the circulation air. As a result, the temperature and moisture of tobacco increase. At the outlet of the roller, the outlet tobacco is collected for reservation by the vibrating conveyor. Most of the vapor which is not absorbed by tobacco is drawn from the roller by a circulation fan, then is heated by steam entering the heat exchanger. The vapor and steam forming circulation air come into the roller for heating and humidifying the inlet tobacco.

The OTMP is adjusted by water flow which is ejected by mixing nozzle. Actually, in Chinese cigarette plants, operators manually figure out the set point of water flow utilizing their experience to control the OTMP. Recently, there are two ways for operators to figure out the set point of water flow. One is figuring out the set point of water flow directly; the other is figuring out the set point of water modified coefficient (WMC), then using (1) in program logic controller (PLC) program to calculate the set point of water flow. Many operators would like to adopt the latter. In (1), $F$ is the set point of water flow; $K$ is the set point of WMC; $L$ is the inlet tobacco flow; $\beta_{\text{out}}$ is the OTMP; and $\beta_{\text{in}}$ is the inlet tobacco moisture percentage (ITMP). However, owing to the working conditions and inlet tobacco character change frequently, operators usually cannot figure out proper set point in time. Consequently, the OTMP becomes volatile so that it is difficult to reach the target value scope.

$$F = \frac{KL(\beta_{\text{out}} - \beta_{\text{in}})}{1 - \beta_{\text{out}}}$$ (1)
### III. INTELLIGENT CONTROL METHOD FOR OTMP

The intelligent control method of the OTMP is consisted of two layers [4-6]: the intelligent setting layer includes a pre-setting model based on CBR and a feedback compensator based on expert rules, and the loop control layer contains a water flow controller. The overall structure is showed in Fig.2 (see the Appendix.1).

The pre-setting model in intelligent setting layer gives the pre-set point of the WMC according to the target value, entrance tobacco character, and climate. Then, the pre-set point and the compensating value are added as the set point of the WMC, and compensating value is calculated by the feedback compensator. After that, the set point of the water flow is obtained through equation (1). At last, on the loop control layer, the water flow controller guarantees that the actual water flow can track its set point by using PID control algorithm [9-14].

#### A. Intelligent setting layer

**Pre-setting model based CBR**

Combing the CBR with the expert experience, the pre-setting model gives the pre-set point of WMC for the control loop of water flow. The pre-setting model has five steps: case production, case retrieval, case reuse, case revision and case retain.

Case production: Generally, a typical case includes two components: case description(C) and case solution(Y). Because the WMC set point changes along time, the value of stored time to a case is different. The latter the case produces, the more valuable the case is. Besides case description and case solution, stored time of the case (T) is also included. Therefore, a case can be denoted by a vector form: Case=(C, Y, T).

According to expert experience, the OTMP has not only nonlinearity with WMC $y^* (t)$, but is also influenced by boundary conditions $\Omega$ reflecting climate and inlet tobacco character such as the season, the trademark of cigarette, the production stage, the ITMP and the flow of the inlet tobacco. Thereby, any case in the case-base of the tobacco loosening and resurgence process consists of target value of the OTMP $G^*$, previous set point of WMC $y^* (t-1)$, output of control loop of water flow $y(t)$, boundary conditions $\Omega$, pre-set point of WMC $\bar{y}(t)$ and stored time T. So, case description is $C = \{G^*, y^* (t-1), y(t), \Omega, \bar{y}(t)\}$, and case solution is $Y = \{\bar{y}(t)\}$. The case of the tobacco loosening and resurgence process is shown in Table 1.

<table>
<thead>
<tr>
<th>Case description (C)</th>
<th>Case solution (Y)</th>
<th>Stored time</th>
</tr>
</thead>
<tbody>
<tr>
<td>$G^*$</td>
<td>$y^* (t-1)$</td>
<td>$\bar{y}(t)$</td>
</tr>
<tr>
<td>$c_1$</td>
<td>$c_2$</td>
<td>$c_3$</td>
</tr>
<tr>
<td>$c_4$</td>
<td>$c_5$</td>
<td>$c_6$</td>
</tr>
<tr>
<td>$c_7$</td>
<td>$c_8$</td>
<td>$\bar{y}(t)$</td>
</tr>
<tr>
<td>$\Omega$</td>
<td></td>
<td>T</td>
</tr>
</tbody>
</table>

The case description is expressed as $C = \{c_i\}_{i=1,2,...,8}$, where $c_i$ denotes a description feature of a working condition. In this case, $c_1$ stands for target value of the OTMP, $c_2$ is the previous set point of WMC, $c_3$ is the output of control loop of water flow, $c_4$ represents the ITMP, $c_5$ is the flow of the inlet tobacco, $c_6$ is the season, $c_7$ corresponds to the trademark of cigarette, and $c_8$ is the production stage. The case solution $\bar{y}(t)$ is pre-set point of WMC, and T is the stored time of the case.

The case-base is organized as four layers, as shown in Fig.3 (see the Appendix.1). The first layer comprises four nodes because there are four seasons-spring, summer, autumn and winter-in a year; every node in the second layer corresponds to a specific trademark of cigarette; the third layer involves three nodes representing initial stage, operating stage and finished stage respectively; and cases in the fourth layer reflecting typical working conditions are collected by using the expert experience and data.

Case retrieval: To improve the efficiency of case retrieval, hierarchical retrieval strategy is considered. Suppose that the current problem case is denoted by $M$ and its description is $C_{im} = \{c_i\}_{i=1,2,...,8}$, then retrieve the case-base according to season, trademark and production stage seriatim. As a result, a sub case-base with K cases $L_i$ is got.

The similarity value $SIM(M, M_i)$ between $M$ and the kth case in $L_i$ is calculated by the following equation:

$$SIM(M, M_i) = \sum_{k=1}^{K} \omega_k \cdot sim(c_i, c_{ik})$$

Where $\omega_k$ denotes the weight of each feature, their values depend on experience. $sim(c_i, c_{ik})$ is similarity value between the ith feature of $M$ and of the kth case in $L_i$. It is computed by (3):
\[
\text{sim}(c_i, c_j) = 1 - \frac{|c_i - c_j|}{\max\{c_i, c_j\} - \min\{c_i, c_j\}} \quad (3)
\]

Where \(\max\{c_i\}\) is the maximum of \(c_i\), while \(\min\{c_i\}\) is the minimum of \(c_i\). Retrieve all cases in \(L_i\) whose similarity value to \(M\) is not less than the threshold value \(SIM_t\) given by experience. Suppose the number of these cases is \(R\), and these cases construct a sub case-base containing \(R\) cases \(L_j\). If \(L_j\) is empty, then retrieve the case with the max similarity value to \(M\) called \(Mm\) for case reuse.

Case reuse: If \(L_j\) is not empty, then the case solution of current case is obtained by (4):

\[
\bar{y}_{j}(t) = \frac{\sum_{i=1}^{R} SIM(M, M_i) \times \bar{y}_i}{\sum_{i=1}^{R} SIM(M, M_i)} \quad (4)
\]

Where \(\bar{y}_k\) is the case solution of the \(k\)th case in \(L_j\). Suppose the description of \(Mm\) is \(C_m = \{c_{m,i}\}, i = 1, 2, \ldots, 8\). If \(L_j\) is empty, then revise it according to the following rules:

If \(c_j - c_{m,j} > b_{1j}\), then \(\bar{y}_{j}(t) = \bar{y}_m(t) + d_{1j}\) \(\quad (5)\)

If \(c_j - c_{m,j} < b_{2j}\), then \(\bar{y}_{j}(t) = \bar{y}_m(t) + d_{2j}\) \(\quad (6)\)

Where \(\bar{y}_m(t)\) is the case solution of \(Mm\), \(b_{1j}, b_{2j}\), \(d_{1j}\) and \(d_{2j}\) are given by experience, \(j = 1, 2, \ldots, 5\).

Case revision: Use \(\bar{y}_d(t)\) and (1) to compute the water flow set point and send the set point to the loop control layer, then obtain the resulted OTMP \(G(t)\). Revise the current case solution \(\bar{y}(t) = \bar{y}_d(t) + \Delta y(t)\) according to the following rules:

If \(c_6=m_1\) and \(c_7=m_2\) and \(c_8=m_3\) and \(G_{\text{max}}^* - T2 \leq G(t) \leq G_{\text{min}}^*\) Then \(\Delta y(t) = a_4\) \(\quad (10)\)

If \(c_6=m_1\) and \(c_7=m_2\) and \(c_8=m_3\) and \(G(t) < G_{\text{min}}^* - T2\) Then \(\Delta y(t) = a_4\) \(\quad (11)\)

\(\bar{y}_m(t)\) comes from experience.

### TABLE 2 EXPERT RULES FOR COMPENSATING THE PRE-SET POINT

<table>
<thead>
<tr>
<th>Antecedents</th>
<th>Conclusions</th>
</tr>
</thead>
<tbody>
<tr>
<td>If (c_6=n_1) and (c_7=n_2) and (c_8=n_3) and (f_1 \geq \Delta G(t) \geq f_1)</td>
<td>(\Delta \bar{y}(t) = 0)</td>
</tr>
<tr>
<td>If (c_6=n_1) and (c_7=n_2) and (c_8=n_3) and (f_2 \geq \Delta G(t) &gt; f_2)</td>
<td>(\Delta \bar{y}(t) = r_1)</td>
</tr>
<tr>
<td>If (c_6=n_1) and (c_7=n_2) and (c_8=n_3) and (f_3 \geq \Delta G(t) &gt; f_3)</td>
<td>(\Delta \bar{y}(t) = r_3)</td>
</tr>
<tr>
<td>If (c_6=n_1) and (c_7=n_2) and (c_8=n_3) and (-f_1 &gt; \Delta G(t) \geq f_1)</td>
<td>(\Delta \bar{y}(t) = r_2)</td>
</tr>
<tr>
<td>If (c_6=n_1) and (c_7=n_2) and (c_8=n_3) and (-f_2 &gt; \Delta G(t) \geq f_2)</td>
<td>(\Delta \bar{y}(t) = r_4)</td>
</tr>
<tr>
<td>If (c_6=n_1) and (c_7=n_2) and (c_8=n_3) and (-f_3 &gt; \Delta G(t) \geq f_3)</td>
<td>(\Delta \bar{y}(t) = r_5)</td>
</tr>
</tbody>
</table>

Feedback compensator based on expert rules

To overcome the uncertainty and unknown disturbances, a feedback compensator based on expert rules \([7,8]\) is constructed by using experience. Fed in the error \(\Delta G(t)\) between the OTMP target value \(G^*\) and measured value of the OTMP \(G(t)\), the feedback compensator computes the feedback compensating value of WMC \(\Delta \bar{y}(t)\) according to Table 2. Where \(n_1, n_2\) and \(n_3\) are specific symbols for denoting season, trademark and production stage; and \(r_i\) \((i=1,2, \ldots, 6)\), \(f_1, f_2\) and \(f_3\) are got from the expert experience and industrial experiments. At last, the final WMC set point \(y^*(t)\) is

\(y^*(t) = \bar{y}(t) + \Delta \bar{y}(t)\).

### B. The loop control layer

The loop control layer adopts a PID controller as the water flow controller. The parameters of the controller computed by
the Critical Proportion Degree Method [9-14] are Kp=29.38, Ki=1.98, Kd=0.126.

IV. APPLICATION

Take certain trademark cigarette in certain cigarette plant as an example. The target scope of the OTMP is 19±0.5%. The results of operator manual control method and the intelligent control method are shown in Fig.4 and Fig.5, respectively.

As shown in Fig.4 and Fig.5, we can see that the OTMP controlled by operator fluctuates between 18.3% and 19.8%, which exceeds the target value scope; while by the intelligent control method fluctuates between 18.6% and 19.4%, which enters the target value scope. Additionally, the water consumption is about 487.3L in the whole process when controlled by the operator. However, it is about 482.9L when controlled by the intelligent control method. Therefore, the intelligent control method meets precision requirement of OTMP, and reduces water consumption by 0.9%.

V. CONCLUSIONS

Because the OTMP is hard to control, an intelligent control method integrating of expert experience, CBR and PID control is presented. The method can automatically and effectively adjust WMC to deal with the boundary conditions variety in tobacco loosening and resurgence process. The application indicates that the proposed method is succeed in control of the OTMP in its target value scope, reduces water consumption, relieves burden of operators, and improves the level of intelligence of loosening resurgence machine.

REFERENCES

Fig. 1 The tobacco loosening and resurgence process

Fig. 2 Structure of the intelligent control method

1. Target of OTMP
2. Season
3. Trademark
4. Production Stage
5. Inlet Tobacco Flow
6. ITMP
7. Previous Set Point of WMC
8. Output of Control Loop Water Flow

Fig. 3 The layer of case-base