Design of Determination System of Machine-made Cigar Density based on Microwave Technology

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Abstract. In this study, a determination system for machine-made cigars density based on microwave technology was designed and implemented. Leveraging the penetrability of microwaves, this system can rapidly and non-destructively measure the density of cigars, effectively overcoming the limitations of traditional weighing methods in terms of measurement speed and accuracy. Through density determination tests on Great Wall (Mini Vanilla) cigars, the accuracy and reliability of the system were verified, with an average error of only 1.49 mg/cm^3 .This system not only meets the determination requirements during the production process of machine-made cigars, improving product quality, but also provides the possibility for tracing the determination data. It is of great significance for enhancing the production efficiency and quality control in the cigar manufacturing industry.

Keywords: Microwave technology; Machine-made cigars; Density determination.

1. Introduction

In recent years, with the rapid development of the tobacco industry, the demand for cigars in the domestic consumer market has been increasing steadily, mading it difficult for traditional hand-rolled cigars to meet the market demand. Against this backdrop, machine-made cigars have quickly become a new favorite in the consumer market due to their high production efficiency, ease of large-scale production, and moderate prices [1]. A machine-made cigar is composed of three parts: the core, the wrapper, and the binder, and is rolled by machines [2]. However, influenced by factors such as the vein distribution in the filler and wrapper, the density distribution uniformity of machine - made cigars is poorer than that of ordinary cigarettes. This makes it more likely to produce cigars that are either extremely light or overweight, affecting the consistency of product quality. Currently, the density determination of machine-made cigars mainly relies on the weighing method, which is by measuring the weight and volume of cigars and calculating their average density based on the density formula. The method not only takes a long time but also fails to meet the demands of rapid measuring and large-scale production [3,4]. Therefore, developing an efficient and accurate cigar density determination system is of great significance for improving the quality control of cigar products.

As a non-contact, rapid and accurate determination method, microwave technology has been widely applied in the tobacco industry in recent years, and a series of determination standards have been formulated, such as YC/T 476-2013 "Determination of Cigarette Cut tobacco Density -Microwave Metho". These standards not only provide specifications for the application of microwave technology in the tobacco industry, but also inject new impetus into the development of the industry. This paper aims to design a density determination system for machine-made cigars based on microwave technology, which can achieve rapid and non-destructive determination of density of machine-made cigars. Thus, it will effectively improve the quality control level of cigar products and promote the sustainable and healthy development of the tobacco industry.

2. System composition

The determination system for machine-made cigars mainly consists of components such as an automatic blanking device, an automatic injection system, a microwave determination module, a data acquisition device, a PC control system, a motor drive unit, a sorting mechanism and a sample collection box. The overall architecture is shown in Figure 1.

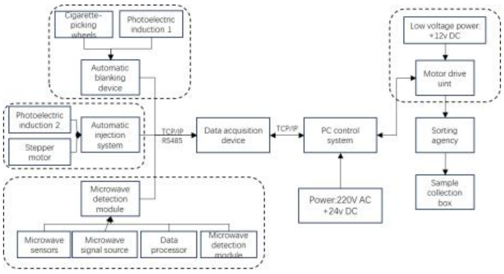


Figure. 1 The framework of the determination system for cigar density

2.1 Automatic blanking and sampling system

The automatic feeding device and sampling system are mainly used for measuring the density of batch cigar samples. Considering the risk that the cigar core of burning end might fall off, the determination system is designed to place and feed the cigars horizontally. The structural design is shown in Figure 2. During the feeding process, the horizontally placed cigar is dropped by the rotation of the cigarette-picking wheels, photoelectric sensor 1 is triggered and transmits a signal to the automatic sampling system. Photoelectric sensor 2 is located at the center of the sample introduction guide rail. Once the sigar lands on the guide rail and triggers this photoelectric signal, the stepper motor promptly starts the sample procedure and pushes the cigar into the microwave sensor, thereby the data acquisition procedure and the subsequent determination procedure. In order to ensure the stability and security of the system, the main control equipment of PC is supplied by 220V AC power, and the stepped motor is supplied by + 24V DC power.

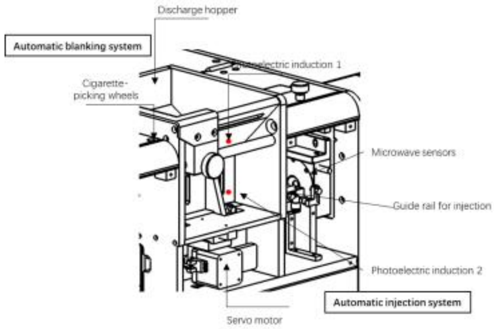
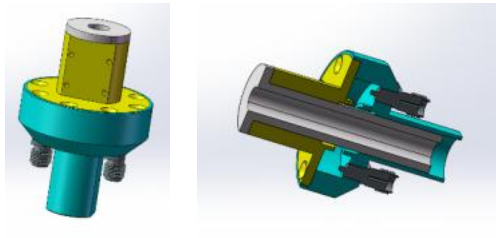


Figure. 2 Structure diagram of automatic feeding and sampling device

2.2 Microwave module

The microwave module mainly consists of four parts: a microwave sensor, a microwave source, a detection module and a data processor. According to the principle of the perturbation method, the basis for accurate measurement by the microwave sensor is to obtain precise resonant frequency shift and half-power bandwidth shfit. Since machine-made cigar is similar in shape to ordinary cigaretts and their density distribution is linear, a mircowave sensor is designed in this paper using a cylindrical waveguide cavity with the TM010 mode. Firstly, the cylindrical resonant cavity has a high quality factor, a strong structure, and is easy to machining with high precision. Secondly, because the microwave electric field distribution in the TM010 mode is strong in the center and weak at the edges, the horizontally entered cigar samples pass exactly through the center of the microwave resonant cavity, which can effectively improve the determination resolution [5] . Figure 3 shows the cylindrical microwave sensor designed in this paper. Its central aperture has a diameter of 20 mm, which is fit for all the machine-made cigars. In addition, a measurement window with a width of 3 mm is designed at the center of the cavity for determinating the density of the cigars passing through the sensor.



(a) shape structure (b) sectional drawing

Figure. 3 microwave sensor structure

The microwave source, an important module for generating microwave signals, consists of two parts: a frequency synthesizer circuit and a power amplifier circuit[6]. In this paper, the ADF4350BCPZ chip is adopted for design. This chip can provide a microwave signal ranging from 137.5 MHz to 4,400 MHz, covering the frequency output range of 2,000 MHz to 3,000 MHz required in this system. The signal amplifier circuit is mainly developed with the GALI-5+ amplifier. The system detection module is designed based on the AD5519 chip, which is developed by ADI Company. It is a product with high-precision, true RMS power detection functions. It has features such as high bandwidth, dual detection channels, and a high-speed detection response of 6 ns / 8 ns, which can meet the high dynamic detection requirements within the frequency range of 2 GHz to 3 GHz.

The data processor is the core component of the microwave determination module. It is implemented based on an embedded system and is responsible for functions such as issuing work instructions for the microwave system, hardware configuration, data collection, preprocessing, and data uploading. In this paper, the "ARM + FPGA" collaborative processing architecture is adopted for the design and development of the data processor. In this architecture, the ARM part is mainly responsible for the configuration of the microwave hardware system, resource scheduling, data preprocessing, and communication tasks with the upper computer; The FPGA is in charge of controlling the high-speed ADC, performing functions such as data collection, data packing, and system timin. The ARM is implemented using the STM32F4 series single-chip microcomputer from ST Company. With a main frequency of 168 MHz, it can provide a performance of 210 DMIPS/566 CoreMark. This single-chip microcomputer is equipped with an independent floating-point unit (FPU) module, which is suitable for signal processing, and also has multiple communication interfaces such as SPI and UART. The FPGA selects the Artix-7 series from Xilinx Company. This series of FPGA has the characteristics of low power consumption, small size, and strong expansion capabilities, which can meet the diverse data aquisition requirements.

2.3 Composition of the sorting system

To prevent the defective cigar products that are overweight or underweight during the production process and ensure the consistency of the products, the sorting system shown in Figure 6 was designed in this study. After passing through the microwave detection module, the machine-made cigars enters the sorting system. The cigars are judged and processed by the upper computer PC system. Subsequently, the sorting motor is used to guide the qualified and unqualified products into the sample collection boxes below respectively, thus achieving the consistency of cigar product density and quality control.

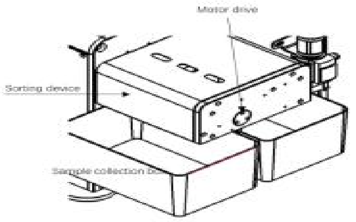


Figure. 4 Structure diagram of sorting system

3. Control system

3.1 Analysis of sampling direction and speed

The direction and speed of cigar sampling play a crucial role in the resolution and accuracy of density determination. When a cigar is introduced vertically or at an inclined angle, on the one hand, a special sample clamping device must be designed, which may cause the sample to be damaged under the action of the fixture. On the other hand, during the measurement process, the sample is affected by the gravitational acceleration in the vertical direction, making it difficult to ensure that it passes through the measurement window of microwave sensor at a constant speed, resulting in inconsistencies data resolution. In view of this, this paper designs an automated sampling system that samples in the horizontal direction to ensure the precision and stability of the determination.

In this study, the density determination was carried out on the same Great Wall (Mini Original Flavor) cigar (with a length of 98 mm, a circumference of 26 mm, and an actual density of 310.89 mg/cm3). The same experimental parameters were adopted to comparatively verify the influence of different speeds on the density results. Figures 7 to 10 show the density distribution of cigars at different speeds. The corresponding density results are listed in Table 1. It can be seen from the table that differences in the resolution of density data, which in turn causes deviations in the density determination values. Among them, when the speed was set at 52 mm/s, the difference between the measured density values and the true value was the most significant, reaching 30.98 mg/cm3; while when the speed was set at 62 mm/s, the density deviation is the smallest, only -1.62 mg/cm3. Further observation reveals that as the sampling speed increases, the density deviation shows an upward trend. Therefore, when performing density determination on cigar samples, the system advances at a speed of 62 mm/s to obtain more accurate measurement results.

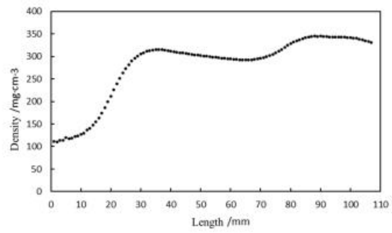


Figure. 5 52mm/s density distribution curve

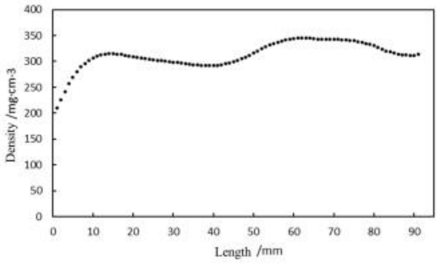


Figure. 6 62mm/s density distribution curve

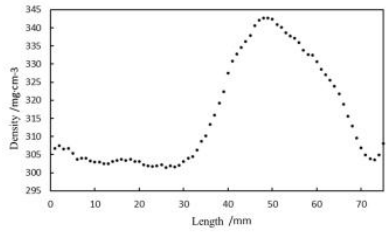


Figure. 7 66mm/s density distribution curve

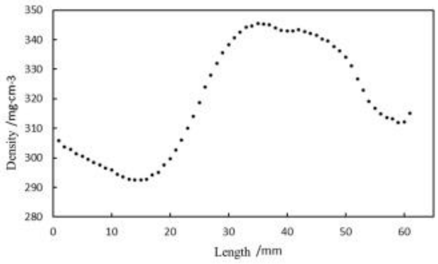


Figure. 8 70mm/s density distribution curve

3.2 Software system

The control software executed on upper computer is developed by C# language and consists of seven functional modules: equipment self-inspection, communication, measurement controlling, algorithm implementation, data query, parameters setting and log recording. These moduls are integrated into a control system by the main program.

The self-inspection module is responsible for diagnosing the equipment hardware and the main workflow. It interacts with the modules such as PLC through RS485 via single-step instructions to ensure the correct execution of each action command, such as sample injection, push rod forward, push rod backward, and qualified sorting operations.

The communication module uses the TCP/IP protocol to communicate with the microwave module, PLC, and other modules, ensuring the correct timing and stability of data transmission. As a crucial component of the control system, the measurement module allows users to create brands with the circumference, length and other parameters of the products. Users can also select the production machine number, production shift information, and set the number of batches and sorting conditions. Furthermore, a database of cigar density measurement results is constructed in the "one-brand-one-number" mode.

The algorithm implementation module is the core module of the system. It integrates multiple algorithms and screening methods. Based on the raw data acquired by the ADC and preset screening conditions, it calculates and statistically processes the density data to obtain the final measuring results.

The data query module enables users to query and analyze historical data, including basic query and advanced query functions with multi-criteria filtering. The basic query can quickly retrieve all the data of a certain day without the need to input additional query conditions. The advanced query offers a lot of filtering options, such as brand, machine number, batch number, and date, etc.

The parameters setting module allows users to configure the basic information of the control system, such as product brand, machine number, production batches, etc., as well as perform settings like user switching and model correction.

The log recording module can capture exceptions during the operation of the softwave system and record detailed logs, which are saved as text files. When the device fails, log analysis helps to quickly locate and resolve problems, provides records for subsequent optimization and improvement of the system.

4. Algorithm design and verfication

4.1 Algorithm design

In the density determination system of machine-made cigars, the determination algorithm is the core part of this system. As depicted in Figure 11, it presents the determination principle diagram. When there is no filler or the sample under test in the microwave electromagnetic field, the material within the cavity is primarily air, and the resonant cavity is in a balanced state, with its frequency f0 and half-power bandwidth w0 remaining constant. Since that the width of the measurement window is merely 3 millimeters, when a cigar passes through the microwave resonant cavity, it induces a tiny volume perturbation to the resonant cavity. Simultaneously, the material changes from air to the cigar, leading to the detuning of the resonant cavity and thereby causing the inherent frequency f0 to decrease to fs and the half-power bandwidth w0 to increase to ws. By the determination of the variations in the aforementioned microwave parameters, in combination with the existing standard density measuring methods, a determination model is established and the density measurement of cigars is achieved [7－9].

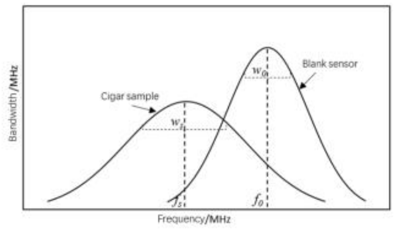


Figure. 9 Schematic diagram of microwave determination

Considering the possible temperature variation in the production process, the density determination formula of formula (1) is designed by introducing the sample temperature T to compensate the density determination. Through this formula, the impact of temperature differences on the density determination results can be effectively corrected, ensuring the accuracy and reliability of the determination.

$$D(\Delta f, \Delta w, T) = \left[(k_1 \cdot T + k_2) \cdot \frac{\Delta w}{\Delta f} + k_3 \cdot T + k_4\right] \cdot \Delta f + (k_5 \cdot T + k_6) \cdot \frac{\Delta w}{\Delta f} + k_7 \cdot T + k_8 \quad (1)$$

In the formula: D represents the determination density value of cigars being measured, with the uint of mg/cm3; Δ f denotes the change of microwave resonance frequency after filling the cigar sample, calculated as Δ f = f0 - fs, with the uint of MHz; Δ w indicates the change in the microwave half-power bandwidth after filling the cigar sample, calculated as Δ w = ws - w0, with the uint of MHz; T is the temperature of the sample being measured, with the uint of ° C; k1, k2, k3, k4, k5, k6, k7, k8 are the coefficients of the equation, determined through regression analysis.

4.2 Great Wall (Mini Vanilla) cigar validation

To verify the reliability and accuracy of the aforementioned determination system and algorithm, this study selected the Great Wall (Mini Vanilla) cigar as the verification sample. On-site process technician selected cigar samples with different density gradients based on their experience and calculated the theoretical density value of each sample using the weighing method. After screening, a total of 42 cigar samples were collected, with a density range of 245 mg/cm3 to 337 mg/cm3. The theoretical density values of the above-mentioned cigars samples were matched one-to-one with the measurement values of the microwave density determination system to establish a density determination model for the Great Wall (Mini Vanilla) cigar. The relevant results of the density determination model is shown in Table 1. According to the data in Table 1, it can be seen that the correlation coefficient of the density determination model established based on the above determination algorithm reaches 0.97, the standard deviation is 2.35 mg/cm3, and the average error is 2.52 mg/cm3, indicating a high density determination accuracy.

Table. 1 Density determination model of Great Wall (Mini Vanilla)

Correlation coefficient	Standard deviation/mg·cm^{-3}	Mean error/mg·cm^{-3}	Maximum error/mg·cm^{-3}
0.97	2.35	2.52	5.93

In addition, 10 cigars were selected as independent samples to further verify the density determination model, and the results are shown in Table 2. According to Table 2, the theoretical density distribution calculated by weighing method ranged from 253.77 mg/cm3 to 303.80 mg/cm3, which was smaller than the density range of the model sample, indicating that the selected samples were reasonable and the data were valid. The average error between the weighing method and the measured value of the microwave density measuring system designed in this paper is 1.49 mg/cm3, and the maximum error is 3.09 mg/cm3, which is lower than the precision index of the model. Therefore, the microwave-based density determination system for machine-made cigars designed in this paper can efficiently and accurately measure the density of machine-made cigars, meeting the daily measuring need of the users. At the same time, compared with the traditional weighing method, this system is faster in measuring the density of cigars and does not cause damage to the samples, which can significantly improve production efficiency.

Table. 2 Comparative analysis of density determination in Great Wall (Mini Vanilla)

No.	Weighing method/mg·cm^{-3}	Microwave method/mg·cm^{-3}	Error/mg·cm^{-3}
1	282.81	284.62	-1.81
2	300.28	299.45	0.83
3	301.78	298.95	2.83
4	253.77	254.35	- 0.58
5	294.68	291.59	3.09
6	285.79	286.10	- 0.31
7	303.80	302.16	1.64
8	299.80	297.50	2.30
9	276.61	277.86	-1.25
10	295.97	296.25	- 0.28
Mean	——	——	1.49

5. Conclusions

This paper designs and develops a density determination system for machine-made cigars based on microwave technology, and conducts density detection experiments using Great Wall (Mini Vanilla) cigars. The experimental results show that the average error between the density measurement values of this system and the calculated values obtained by the weighing method is only 1.49 mg/cm3. This determination system can not only achieve rapid, non-destructive and accurate measurement of cigar density, meeting the detection requirements in the daily production of machine-made cigars and thus improving product quality, but also realize the traceability of detection data, providing strong support for quality control in the production process.

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