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Design of an Integrated Machine for Washing and Packaging Leafy Vegetables

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Abstract: To address current issues in the leafy vegetable processing industry such as high reliance on manual labor, low efficiency, and difficulties in maintaining hygiene standards, this study designed and developed an intelligent integrated leafy vegetable cleansing and packaging machine. This equipment incorporates functions including root removal, yellow leaf elimination, washing, dewatering, and packaging. Based on a modular design concept, it achieves fully automated operation throughout the leafy vegetable processing workflow through the integration of precision mechanical structures and an intelligent control system. The equipment is adaptable to various common leafy vegetable varieties, demonstrating good versatility. It is constructed using food-grade stainless steel and silicone materials, meeting food safety and hygiene standards. The machine is simple and convenient to operate with low maintenance costs. This research outcome not only addresses the industry pain point of low automation in leafy vegetable processing, significantly reducing labor costs and work intensity, but also provides the agricultural product processing industry with an efficient, environmentally friendly, and safe intelligent solution. It holds significant practical value and broad application prospects.

1 Introduction

In recent years, the rapid development of fresh food e-commerce and the prepared vegetable dishes market has continuously heightened consumer demands for the efficiency and hygiene standards of agricultural product processing. As an indispensable category of vegetables in daily life, leafy vegetables have seen sustained growth in market demand. However, the traditional manual handling methods, characterized by low efficiency and high hygiene risks, have become a bottleneck constraining the industry's large-scale development [1]. As the world's largest producer and consumer of vegetables, China possesses a massive scale of vegetable processing. Nevertheless, the leafy vegetable handling segment remains heavily reliant on manual labor, facing challenges such as rising labor costs and low operational standardization [2].

In developed countries such as Japan, Germany, and the United States, fully automated vegetable processing equipment technology is relatively mature, capable of achieving efficient cleaning,

precise sorting, and automatic packaging. The processing efficiency can reach several hundred kilograms per hour, demonstrating a high level of automation [3]. For instance, Japan employs ultrasonic cleaning and ozone disinfection technologies, while Germany relies on multi-sensor collaboration and machine vision systems to achieve high-precision sorting, with a cleanliness rate exceeding 98%. However, foreign equipment is expensive (often over 300,000 RMB per unit), imposes strict requirements on vegetable varieties and sizes, and frequently necessitates a constant temperature environment or pre-treatment. These factors make it difficult to adapt to the realities of China's market, which is dominated by small and medium-sized enterprises, involves multiple vegetable varieties, and requires direct processing of fresh produce. Consequently, such equipment exhibits poor compatibility and cost-effectiveness in this context [4].

2 Scheme Design

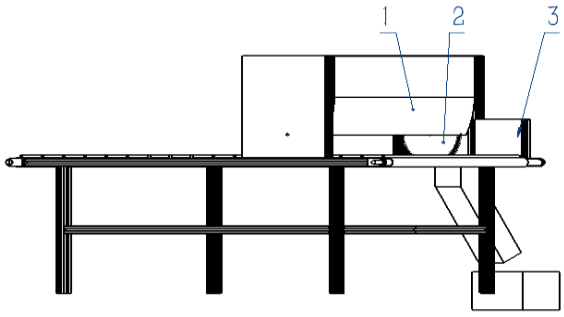
2.1 Overall Scheme Design

This product integrates multiple functional modules, including root removal, yellow leaf elimination, washing, dewatering, and packaging. By combining bubble washing technology with an adaptive mechanical structure [5], it achieves efficient and precise processing for a variety of leafy vegetables, significantly enhancing the automation level and hygiene standards of agricultural product processing [6]. Featuring a compact structure and controllable costs, the equipment is not only suitable for large-scale processing enterprises but also caters to the practical needs of small and medium-sized vegetable processors and the catering industry. It can substantially reduce labor costs and operational risks while improving product quality consistency [7].

This product mainly includes Root Removal system, Yellow Leaf Removal system, Washing system, Dewatering system, Packaging system.

2.2 Root Removal System

This product, through innovative design, achieves efficient root removal for leafy vegetables of various sizes [7]. The root removal system of this product consists of limit baffles, a circular cutting blade, and a vegetable pressing curtain，as shown in Figure 1. A conveyor belt is fixedly installed on the machine body. The front end of the conveyor belt is equipped with a feeding inlet, the limit baffles are installed on both sides of the conveyor belt, the circular cutting blade is installed below the middle section of the conveyor belt, and the vegetable pressing curtain is installed above the circular cutting blade. The position of the limit baffles can be adjusted according to different leafy vegetable varieties and sizes to accommodate vegetables of varying dimensions entering the equipment [8].



1-Limit Baffle; 2-Circular Cutting Blade; 3-Vegetable Pressing Curtain;

Figure 1: Root Removal System

The root removal device adopts a precision cutting design:

1) Circular Cutting Blade:

Similar to a saw blade, the circular cutting blade features a smaller tooth profile angle and a greater number of teeth, ensuring cutting precision. It is fixedly mounted on a drive shaft, which is installed on the machine body via bearings. One end of the drive shaft is connected to a cutting motor, which is securely mounted on the machine body. By optimizing the blade parameters and rotational speed, cutting efficiency is significantly enhanced [9]. The circular cutting blade makes precise contact with the root of the leafy vegetables, achieving one-time root removal.

2) Vegetable Pressing Curtain:

Shaped similarly to a circular arc, the vegetable pressing curtain is positioned in front of and above the circular cutting blade, gently pressing down on the leafy vegetables ahead of the blade. It is made of flexible material, which ensures effective fixation of the vegetables while avoiding damage to the leaves [3]. Through an elastic adjustment mechanism, it can adapt to leafy vegetables of varying thicknesses, maintaining stable positioning during the cutting process.

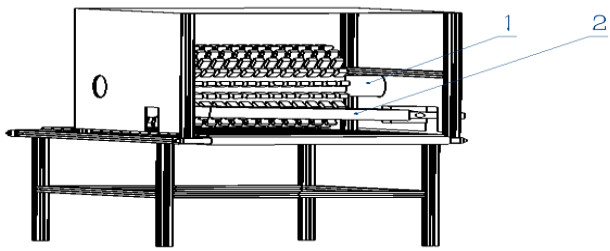
2.3 Yellow Leaf Removal System

This product employs an innovative yellow leaf removal device, comprising a flexible brush and a beater, as shown in Figure 2. The described flexible brush and beater structures work in coordination to achieve efficient removal of yellow leaves from the surface of leafy vegetables.

The flexible brush includes a rotating shaft and silicone soft brushes. Multiple rows of silicone soft brushes are alternately arranged and fixedly mounted on the rotating shaft. The rotating shaft is mounted on the machine body via bearings, with one end connected to a brushing motor, which is fixedly installed on the machine body.

The beater includes a beating arm, flexible protrusions, and a beating motor. The flexible protrusions are evenly distributed on the beating arm. The beating arm is connected to the beating motor via a crankshaft, and the beating motor is fixedly installed on the machine body [10].

This system dynamically removes yellow leaves and impurities from the surface of the leafy vegetables, ensuring cleanliness and laying a foundation for the subsequent washing stage [7].



1-Flexible Brush; 2-Beater;

Figure 2: Yellow Leaf Removal System

(1) Flexible Brush:

The high-precision silicone soft brushes feature a mace-like design, rotating at a moderate speed to gently brush the surface of the leafy vegetables [3]. Since yellow leaves are brittle while green leaves are tough, the flexible brush only damages the yellow leaves, effectively removing them without harming the green ones.

(2) Beater:

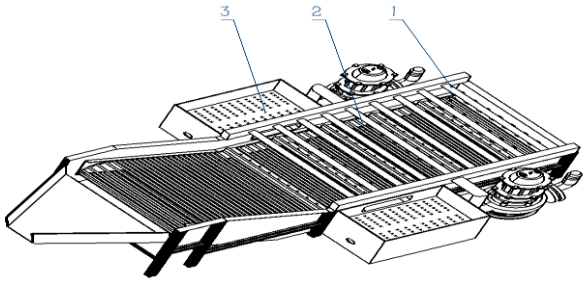
Utilizing a beating arm with flexible protrusions, it performs periodic beating actions to further dislodge stubbornly attached yellow leaves. The beating intensity is adjustable, ensuring effective removal while preventing mechanical damage to the vegetables [11].

2.4 Washing System

The washing system of this leafy vegetable cleansing and packaging machine integrates bubble washing and high-pressure spraying, achieving fully automated deep cleaning and impurity removal throughout the entire leafy vegetable processing workflow [12].

The washing system comprises a washing tank, an exhaust pipe, an air pump, a spray water pipe, a water pump, and a circulation tank. The washing tank is fixedly installed on the machine body. The exhaust pipe is installed at the bottom of the washing tank and connected to the air pump. The spray water pipe is installed in the upper part of the washing tank and connected to the water pump. The circulation tank is connected to the overflow outlet of the washing tank.

Through modular collaborative operation [2], the system ensures efficient and thorough washing of the leafy vegetables, providing a standardized operational foundation for the subsequent dewatering and packaging stages, thereby significantly enhancing processing efficiency and finished product quality. The overall structure is shown in Figure 3.



1-Exhaust Pipe; 2-Spray Water Pipe; 3-Circulation Tank;

Figure 3: Washing System

(1) Bubble Washing:

A large volume of fine bubbles is released into the washing tank through the exhaust pipe. As these bubbles rise, they fully contact the surface of the leafy vegetables, creating a vigorous stirring effect [12]. The bursting effect of the bubbles effectively removes mud, pesticide residues, and fine impurities from the vegetable surfaces, achieving remarkable cleaning results.

(2) High-Pressure Spraying:

The spray water pipe employs a multi-nozzle design to jet high-pressure water streams at the leafy vegetables from different angles [9]. The water pressure is adjustable, ensuring effective cleaning while preventing damage to the leaves. The combined action of high-pressure water and bubble washing achieves comprehensive, deep cleaning.

(3) Water Circulation System:

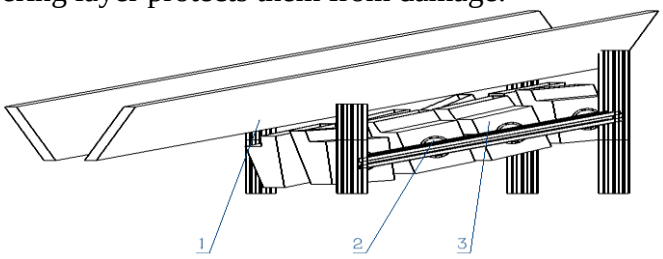
The wash water flows into the circulation tank through the overflow outlet. After filtration, it can be reused, conserving water and reducing environmental pollution [6].

2.5 Dewatering System

The dewatering system of this product consists of a V-shaped channel, a blower, and a ventilation duct working in coordination, as shown in Figure 4 [11].

The V-shaped channel includes inclined side plates and a flexible covering layer. Two inclined side plates are symmetrically installed to form the V-shaped structure, with the flexible covering layer attached to their surfaces. The blower comprises a motor, an impeller, and a protective cover. The impeller is mounted on the motor shaft, enclosed by the protective cover, and the blower is fixedly installed inside the machine body. The ventilation duct connects to the blower's outlet, with its air outlet directed toward the bottom of the V-shaped channel.

This setup efficiently removes surface moisture from leafy vegetables through an automated process, balancing high efficiency with protective care [4]. The washed vegetables are conveyed by a belt into the V-shaped channel. Its inclined design allows the vegetables to slide down naturally, while the flexible covering layer protects them from damage.



1-V-shaped Channel; 2-Blower; 3-Ventilation Duct;

Figure 4: Dewatering System

(1) V-shaped Channel Design:

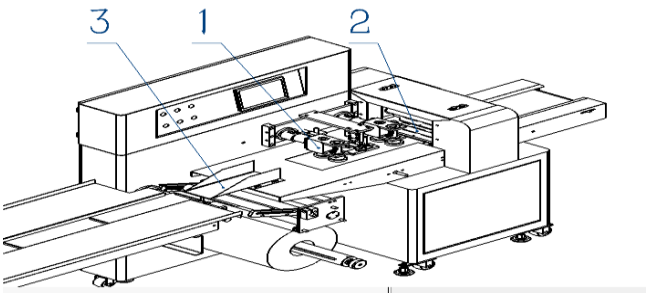
The inwardly tapered V-shaped structure gradually gathers the leafy vegetables as they slide down, facilitating concentrated water removal [3]. The flexible covering layer is made of food-grade silicone, which ensures smooth sliding of the vegetables while preventing friction damage.

(2) Hot-air Dewatering:

The airflow generated by the blower is directed through the ventilation duct toward the root ends of the leafy vegetables. This upward-flowing air current effectively removes surface moisture [11]. Both temperature and wind speed are adjustable, ensuring dewatering effectiveness while preventing heat damage to the vegetables.

2.6 Packaging System

The packaging device consists of a bag former, a heater, and a cutter, as shown in Figure 5 [9]. The bag former includes a forming plate and vertical plates. Two vertical plates are vertically mounted on both sides of the forming plate, creating a U-shaped channel. The heater comprises a heating block and a temperature control unit. The heating block is installed along the packaging film path, and the temperature control unit is connected to it. The cutter includes a serrated blade and a cutting drive mechanism. The serrated blade is installed at the packaging film output end, and the cutting drive mechanism is connected to the blade. This setup completes the packaging and sealing of leafy vegetables through an automated process, ensuring both packaging quality and efficiency [13].



1-Heater; 2-Cutter; 3-Bag Former;

Figure 5: Packaging System

(1) Bag Forming:

The packaging film passes through the U-shaped channel of the bag former to form the initial

shape of the bag, while the leafy vegetables are fed into the bag from above [9]. The size of the bag former is adjustable to accommodate different packaging specifications.

(2) Heat Sealing:

The heater performs heat-sealing on the packaging film. Precise temperature control ensures a secure seal without damaging the film. The temperature control system monitors the heat in real-time to maintain consistent sealing quality.

(3) Cutting and Separation:

The serrated blade cuts and separates the continuous packaging film into individual packaged units [9]. The cutting speed is synchronized with the packaging speed to ensure accurate cutting positions.

2.7 Selection of Partial Power Equipment

2.7.1 Air Pump Selection

The selection of an air pump is primarily based on three aspects: air volume (Q), air pressure (P1), and power (P2). Refer to Table 1 for the air pump selection.

Table 1: Air Pump Selection

Parameter	Calculated Value	Selected Value	Remarks
V	0.84 m^3(Assumption)	0.84 m^3 (Assumption)	Effective Volume of Washing Tank (m^3)
f	60 (Assumption)	60 (Assumption)	Bubble Renewal Frequency (time/h)
h	0.35 (Assumption)	0.35 (Assumption)	Water Depth (m)
Q	60.48 m^3/h	80 m^3/h	
P1	5.15 kPa	8 kPa	
P2	0.21 kW	0.75 kW	

Air Volume (Q) Calculation

$$Q = V \times f \times K1 \quad (1)$$

K_1 is the safety factor, typically taken as 1.2. From Table 1, V=0.84 and f=60. Substituting these into Equation (1) yields Q=60.48 m^3/h. For practical application, an air pump with an air volume of 80 m^3/h is selected.

Air Pressure (P_1) Calculation

$$P1 = \rho \times g \times h \times K2 \quad (2)$$

K_2 is the resistance coefficient, generally taken as 1.5. ρ=1000 (where ρ is the density of water), g=9.8 (where g is the gravitational acceleration). From Table 1, h=0.35. Substituting these into Equation (2) yields P_1=5145 Pa. For practical application, an air pump with an air pressure of 8 kPa is selected.

Power (P_2) Calculation

$$P2 = \frac{(Q \times P1)}{(\eta \times 3600)} \quad (3)$$

η is the efficiency of the air pump, typically ranging from 0.6 to 0.7. From Table 1, Q=80, P_1=8000, and η=0.65. Substituting these into Equation (3) yields P_2=205.13 W. For practical application, an air pump with a power rating of 0.75 kW is selected.

2.7.2 Water Pump Selection

The selection of a water pump is primarily based on three aspects: flow rate (Q), head (H), and power (P). Refer to Table 2 for the High-Pressure Spray Pump Selection

Table 2: Spray Pump Selection

Parameter	Calculated Value	Selected Value	Remarks
Flow Rate(Q)	2.4 m³/h	3 m³/h	
Head(H)	40 m	45 m	
Power (P)	0.53 kW	0.75 kW	
V	0.84 m³ (Assumption)	0.84 m³ (Assumption)	Effective Volume of Washing Tank (m³)
q1	0.2 m³/h (Assumption)	0.2 m³/h (Assumption)	Flow Rate per Nozzle (m³/h)
H1	0.3 MPa	0.3 MPa	Operating Pressure

Flow Rate (Q) Calculation

$$Q = q1 \times N \tag{4}$$

N is the number of nozzles, N = 12. From Table 2, q_1 = 0.2. Substituting these into Equation (4) yields Q = 0.24 m³/h. For practical application, a pump with a flow rate of 0.3 m³/h is selected.

Head (H) Calculation

$$H = H1 + H2 + H3 + H4 \tag{5}$$

H_1, converted to a water column height, is 30 m. H_2 and H_3 are both loss values, taken as 3 m and 2 m respectively. H_4 is the safety margin, set at 5 m. Substituting these into Equation (5) yields H = 40 m. For practical application, a pump with a head of 45 m is selected.

Power (P) Calculation

$$P = \frac{(Q \times H \times \rho \times g)}{(\eta \times 3600)} \tag{6}$$

η is the pump efficiency, typically ranging from 0.65 to 0.75; here η = 0.7. From Table 2, Q = 3, H = 45, ρ = 1000, g = 9.8. Substituting these into Equation (6) yields P = 525 W. For practical application, a pump with a power rating of 0.75 kW is selected.

2.7.3 Circular Cutting Blade Motor Selection

The motor selection is primarily based on three aspects: torque (T), speed (n), and power (P). Refer to Table 3 for the motor selection parameters.

Table 3: Motor Selection

Parameter	Calculated Value	Selected Value	Remarks
Torque(T)	9.8 N·m	9.8 N·m	
Speed (n)	1450 r/min (Rated Value)	1450 r/min (Rated Value)	
Power (P)	0.94 kW	1.5 kW	
F	200 N (Assumption)	200 N (Assumption)	Cutting Force (N)
v	2.93 m/s	2.93 m/s	Cutting Linear Velocity (m/s)

Power (P) Calculation

$$P = F \times \frac{V}{\eta} \times K \times 1000 \tag{7}$$

η is the efficiency, typically ranging from 0.7 to 0.85. K is the safety factor, usually taken as 1.3. From Table 3, F = 200, V = 2.93, and K = 1.3. Substituting these into Equation (7) yields P = 940 W. For practical application, a motor with a power rating of 1.5 kW is selected.

Torque (T) Calculation

$$T = 9550 \times \frac{P}{n} \tag{8}$$

From Table 3, P = 1500 and n = 1450. Substituting these into Equation (8) yields T = 9.8 N·m.

2.8 Structural Strength Analysis

Structural strength analysis is conducted on key components to ensure the safe and reliable operation of the equipment [14]. Taking the circular cutting blade shaft as an example, it bears torque and radial loads during operation; its strength and stiffness are verified via finite element analysis. Analysis results from Figure 6 indicate that the maximum stress is far below the yield strength of the material, with a sufficient safety factor, which can meet the requirements of long-term operation.

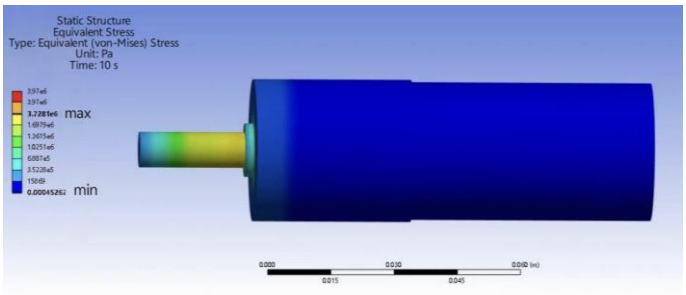


Figure 6: Static Analysis of the Circular Cutting Blade Motor Shaft

3. Product Features and Advantages

Compared to existing technologies, the distinctive feature of this product lies in the coordinated interaction of the feeding inlet, limit baffle, circular cutting blade, vegetable pressing curtain, flexible brush, beater, washing tank, exhaust pipe, spray water pipe, V-shaped channel, blower, bag former, heater, cutter, and drive system. This integration creates a structural form that combines root removal, yellow leaf removal, washing, dewatering, and packaging into a single unit [1]. It achieves fully automated operation throughout the entire process [1], reduces manual intervention, ensures precise operation, significantly saves time costs, and makes the processing workflow efficient and smooth. It is particularly well-suited for continuous, large-scale leafy vegetable processing operations [2]. The specific advantages are as follows:

Full-process Automation: This product utilizes adjustable limit baffles to accommodate leafy vegetables of different sizes. Precise root removal is achieved through a high-precision circular cutting blade, while the vegetable pressing curtain ensures stable positioning of the vegetables during cutting, resulting in a highly efficient root removal process [8].

Intelligent Yellow Leaf Removal: The product employs a combined design of a flexible brush and a beater to remove yellow leaves. By leveraging the difference in physical properties between yellow and green leaves, it effectively removes yellow leaves without damaging the green ones, thereby improving the quality of the leafy vegetables [4].

Deep Cleaning Technology: Through the synergistic action of bubble washing and high-pressure spraying, the product achieves deep cleaning of leafy vegetables. It effectively removes surface mud, pesticide residues, and fine impurities, ensuring the food safety of the leafy vegetables [12].

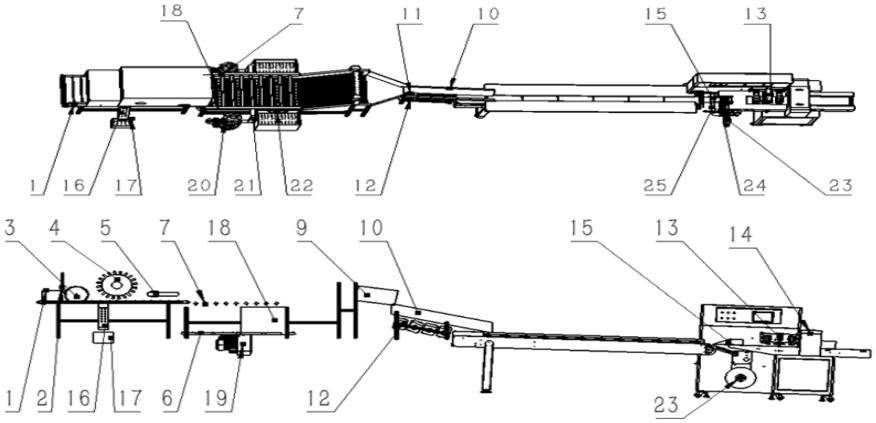
Efficient Dewatering System: The product features a combined design of a V-shaped channel and hot-air dewatering, which rapidly removes surface moisture from the leafy vegetables. This prevents spoilage caused by excessive moisture after packaging and extends the shelf life [11].

Automated Packaging: The packaging system of this product realizes full automation from bag forming and sealing to cutting. It offers high packaging efficiency and excellent seal quality, capable of meeting packaging requirements for different specifications [13].

Optimized Structural Design: The mechanical structure of this product is simple, easy to maintain and clean. It adopts a modular design, offers comprehensive functionality, and has a high safety factor [14]. It simultaneously addresses multiple challenges in leafy vegetable processing, enhancing work efficiency and saving costs [1].

4. Conclusion

Through a highly integrated modular design (with the overall structure shown in Figure7), this product has successfully developed an intelligent integrated leafy vegetable cleansing and packaging machine that combines the functions of root removal, yellow leaf removal, washing, dewatering, and packaging. It precisely meets the market's urgent demand for high-efficiency, integrated processing equipment. Furthermore, the product innovatively incorporates automatically adjustable limit baffles, a flexible yellow leaf removal device, and a continuous conveying system. This enables flexible adaptation to leafy vegetables of different sizes and varieties, effectively enhancing processing efficiency and the level of automation while reducing labor costs and operational complexity. It provides a comprehensive and reliable solution for the agricultural product processing industry.



1-Limit Baffle; 2-Circular Cutting Blade; 3-Vegetable Pressing Curtain; 4-Flexible Brush; 5-Beater; 6-Exhaust Pipe; 7-Spray Water Pipe; 8-Circulation Tank; 9-Vegetable Guide Channel; 10-V-shaped Channel; 11-Blower; 12-Ventilation Duct; 13-Heater; 14-Cutter; 15-Bag Former; 16-Root Guide Channel; 17-Root Collection Box; 18-Washing Tank; 19-Air Pump; 20-Water Pump; 21-Main Water Pipe; 22-Overflow Outlet; 23-Film Support Roller; 24-Horizontal Roller 1; 25-HorizontalRoller 2

Figure 7: Overall Structure

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