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THE FLOW CONTROL METHOD OF FOAMED BITUMEN

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ABSTRACT

Being advantageous for saving energy, protecting the environment and being economical, the foamed bitumen can be widely used in large sized road repairing projects. However, being meta-stable may make it hard to control and measure the flow of foamed bitumen during the foaming process. In order to achieve a stable flow rate of foamed bitumen, this paper proposes that an indirect method should be adopted to control the flow rate of foamed bitumen. Based on the conical annular gap flow adjustment theory, it converts the traditional bitumen sprayer and designs a new flow control method of bitumen, which has been proved by the bitumen flow control test. It can effectively improve the flow control stability of bitumen. The outlet pressure method is used to control the foaming water flow, which has been verified. The method is able to control the foaming water flow in a stable manner. According to what has been researched, setting up the engineering flow control equation of bitumen and foam may prove that when its fitting degree may be over 0.99 and its probability more than 0.05, the control equation is effective.

Keywords: Bitumen foaming, New driving device, Flow control, Structure parameters.

1. INTRODUCTION

Being advantageous for saving energy, protecting the environment and being economical, the foamed bitumen can be widely used in building, repairing and maintaining roads, which also attracts considerable attention in road construction. Although China made the national highway bitumen pavement recycling technical specifications (JTG F41-2008) [1-2] in 2008, the foamed bitumen regeneration technical construction is completely dependant on imported equipment, making road construction and equipment maintenance under the control of non-Chinese entities. Our road field makes a strong appeal for developing a foamed bitumen device of independent intellectual property rights with a research emphasis on how to ensure the quality and stability of the foamed bitumen flow.

In recent years, researchers have been studying how to control the foamed bitumen quality. Wang Anling made a sensitivity analysis of factors affecting bitumen foaming and set a foamed bitumen control equation [3-5] aiming to achieve a high-quality foamed bitumen. Cheng Haiying analyzed the design rule of bitumen foaming cores based on bitumen foaming natures [1,6]. Ruckel used the bitumen foaming testing machine to study the most appropriate test conditions for bitumen foaming [6-10]. However, there is still not any relevant reference about the flow control method of foamed bitumen. In fact, various construction crafts require various foamed bitumen flows, and if the precision and stability of the foamed bitumen flows cannot meet the construction requirements it also will not be able to guarantee the quality of the road construction. However, the bitumen foaming process is complex because the original bitumen is a highly viscous non-newtonian fluid [11-12] and after being foamed, the foamed bitumen is meta-stable, which makes it difficult to accurately control the foamed bitumen flow. How to accurately control the foamed bitumen flow has become an urgent task in recent projects.

This paper adopts an indirect flow method of foamed bitumen. Based on the traditional bitumen spout control device, this paper combines the conical annular gap flow adjustment theory to improve the traditional bitumen spout control device. It uses the self-developed foamed bitumen testing machine as seen in Figure 1 to make the flow control experiments of bitumen and foaming water, and to verify the indirect effect of controlling the foamed bitumen flow.

Figure 1. Bitumen foaming testing machine

2. BITUMEN FOAMING PROCESS DESCRIPTION

Under a certain pressure, hot bitumen (150-170℃) and foaming water at room temperature are injected into the foam chamber, in which both contact and transfer the heat. Therefore, when the bitumen temperature drops slightly, the foaming water rapidly elevates in temperature and makes a phase change, making a large amount of water vapor, and leading to high pressure in the internal chamber. Under the high pressure, the water vapor is forced into the bitumen continuous phase and wrapped by the bitumen film, forming a tenuous foamed bitumen. In the chamber pressure, the tenuous foamed bitumen is forced out of the foam chamber, while in atmospheric pressure the tenuous foamed bitumen has pressure differences inside and outside where its internal pressure is much higher than its external pressure. The rapid expansion of the inner gas of the tenuous foamed bitumen forms a meta-stable foamed bitumen [3-8]. In the course of mixing, the foamed bitumen creates gas. Finally the foamed bitumen flow is mainly determined by the original bitumen flow.

3. THE INTRODUCTION OF BITUMEN FLOW CONTROL METHOD

In road machinery, there are two main bitumen flow methods [13-17].The first, according to the set value of bitumen, it weighs with a load cell, and then makes a one-time injection of the weighed bitumen, which is often used to measure and control bitumen by forcible intermittent mixing stations [9]. The second is by changing the frequency of frequency converters to adjust the bitumen pump driving motor speed, allowing the bitumen flow to be controlled. This is often used by distributors to adjust the bitumen flow, thus the control precision of bitumen flow may be improved by fitting the test data of the bitumen pump speed and flow rate [10].

The traditional bitumen flow control driving device is shown in Figure 2, where the cylinder piston rod is fixedly connected to the conical valve stem. With air taken in from the upper cylinder chamber, the conical valve stem moves downward and the bitumen spout closes. With air taken in from the lower cylinder chamber, the conical valve stem moves upward and the bitumen spout opens. If the bitumen flow is accurately controlled, the bitumen spout cross-sectional area must be effectively adjusted. The device shown in Figure 2 can only open or close the bitumen spout, but it cannot effectively adjust the cross-sectional area of the bitumen spout. Therefore, the bitumen spout must be improved to affect the foamed bitumen flow.

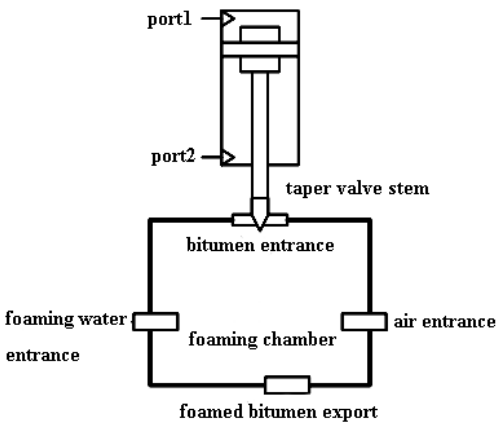


Figure 2. Traditional driving device

The conical annular gap flow [18-19] is:

$$q = C_d A_T \sqrt{\frac{2}{\rho}\Delta p} \tag{1}$$

In the formula:

A_T —through-flow cross-sectional area of the nozzle(m^2);

C_d —orifice discharging coefficient;

ρ —flow density(kg/m^3);

Δp —pressure difference between inlet and outlet (Pa).

The through-flow cross-sectional area is:

$$A_T = \pi x \sin\alpha (d - \frac{x \sin 2\alpha}{2}) \tag{2}$$

In the formula:

α —half cone angle of the value cone (°);

d —inlet diameter (m);

x —the valve opening degree (m).

From the formula above, the flow through the annular gap is related to the fluid density, pressure difference between the inlet and the outlet, and the opening degree of its valve core. Therefore, based on the conical annular gap flow control theory, the driving device of bitumen nozzles is designed to adjust the bitumen flow, but due to the fact that the pressure difference is affected by the coupled field in the foaming chamber, it is difficult to calculate the accurate flow from formulas (1) and (2). To predict its bitumen flow, the fitting method of experimental data may be used later.

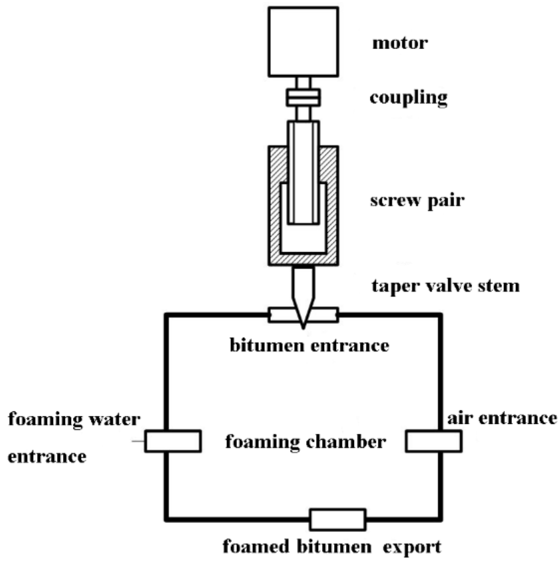


Figure 3. New driving device

A schematic diagram of the new driving device is shown in Figure 3, while the new driving device consists of a stepping motor, coupling and sliding screw pair, and a cone stem. When the cone stem is fixedly connected with the ball screw nut, the stepper motor may drive and displace the cone stem, which can be rectified by adjusting the stepping motor pulses. This also changes the effective cross-sectional area of the bitumen spout, and then realizes the infinitely variable control of bitumen flow. Figure 4 is the photo of a real new driving device.

Figure 4. New driving device

4. THE FLOW CONTROL TEST OF BITUMEN AND FOAMING WATER

4.1 A bitumen flow control test in the traditional driving device

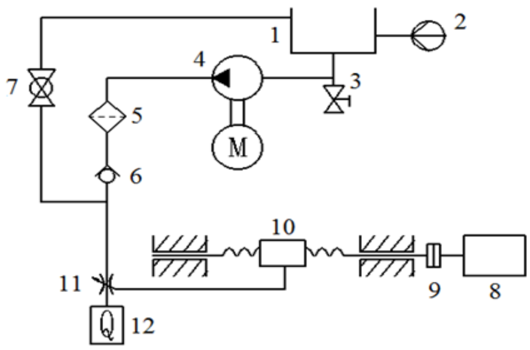
The traditional bitumen flow control driving device is shown as Figure 2, where its cone stem is compatible with its bitumen entrance, controlling the air flow through Port 1 and Port 2, moving its cylinder piston rod up and down, and opening and closing its bitumen entrance. Because it is difficult to accurately control the air flow, the effective area of bitumen entrance cannot be appropriately adjusted, which makes it difficult to adjust the bitumen flow. When the traditional bitumen spout driving device is used, the motor speed of the bituminous pumps may be controlled to adjust the bitumen flow, though it is difficult to adjust the effective cross section of the bitumen entrance. The motor speed is adjusted by frequency converter, so after the frequency is set to 39.68Hz and 44.33Hz, the two parallel tests can be done separately. The tests use No. 70# bitumen, which is heated at a temperature of 155℃±5℃ with its bitumen entrance being a standard size and its cone angle 60°; 1/8VP9002S303 foaming water is sprayed with its water pressure at 0.3Mpa and its air pressure at 0.4Mpa. The experiment data are shown in Table 1.

Table 1. Control experiment data of bitumen quality and flow in the traditional driving device

Parallel test groups	Motor frequency (Hz)	The group testing numbers	Mass flow (g/s)	Average value (g/s)	Standard deviation (g/s)	Variation coefficient
1	39.68	1	169	181.5	10.17	0.056
		2	181.5			
		3	193.9			
2	44.33	1	248.5	222.0	25.31	0.114
		2	229.5			
		3	187.9			

By the bitumen mass flow tests, it has been found that there are large deviations of mass flow data under similar control conditions. Table 1 lists the bitumen flow data tested in the two frequencies, from which the standard deviations of bitumen mass flow test data are 10.17 and 25.31 when the motor frequencies are at 39.68Hz and 44.33Hz. However, their variation coefficients are 0.056 and 0.114. To avoid the effect of an unequal mass flow of bitumen in the traditional control method and new control method, the variation coefficient is adopted to judge the experiment data. The variation coefficient describes the standard deviation of bitumen mass flow compared with its average change rate, measuring the variation degree of bitumen mass flow. Through the absolute value of variation coefficients, the dispersion degree of test data may be obtained. When the value is larger, the more the dispersion degree will be, while when the value is smaller, the worse the dispersion will be. The control stability of bitumen mass flow may be described by its variation coefficient.

4.2 A bitumen flow control test in the new driving device



1. Bitumen tank 2. Temperature Sensor 3. Screwed Valve
4. Bitumen Pump 5. Filter 6. One-way valve
7. Electric Ball Valve 8. Stepper Motor 9. Coupling
10. Sliding Screw Pair 11. Bitumen Spout Adjusting Valve\
12. Foaming Chamber

Figure 5. The bitumen systematic design theory in the new driving device

The bitumen systematic design theory of bitumen foam testing machine is shown in Figure 5. The displacement of its cone stem is controlled by the input pulse of its stepper motor. When there is zero clearance between the cone stem and bitumen spout, its bitumen spout adjusting valve 11 is closed. Under this condition, the bitumen tank 1 is heated, and the electric ball valve 7 opens. The temperature sensor 2 transmits in real time the bitumen measured to the control system. After the bitumen temperature reaches 140℃, the bitumen pump 4 is turned on and the bitumen heats circularly in the pipe, with the heating elements set out of the pipe. When the bitumen heating temperature reaches the preset value of 155℃, the electric ball valve 7 is closed, and the stepper motor moves as its pulse sets. The bitumen spout adjusting valve 11 is then opened and the bitumen is injected into the foaming chamber 12.

Table 2. Calibration experiment data of bitumen quality and flow in the new driving device

Parallel test groups	Pulse number (p)	The group testing numbers	Mass flow (g/s)	Average value (g/s)	Standard deviation (g/s)	Variation coefficient
1	200	1	175.3	174.7	1.96	0.01
		2	176.7			
		3	172.0			
2	300	1	199.3	193.1	4.91	0.03
		2	192.7			
		3	187.3			
3	400	1	210.7	204	4.71	0.02
		2	200.7			
		3	200.7			

To test the bitumen flow control accuracy in the new driving device, the bitumen flow of bitumen foaming testing machine has been demarcated in Figure 1. The tests select No. 70# bitumen, which is heated at a temperature of 155℃±5℃. In this temperature range, the bitumen viscosity changes to a lesser degree and the temperature impact on the flow may be ignored. When the pulses of the stepper motors are respectively set at 200p, 300p and 400p, the three parallel tests may be made to test the bitumen mass flow, the test data of which are shown in Table 2.

Table 2 shows the standard deviations in the three groups of bitumen mass flow calibration tests as being less than or equal to 4.91g/s. This means that when the bitumen temperature changes within a certain range, fluctuating within 10℃, the deviation of the bitumen mass flow will be very small, which the bitumen quality is sprayed within per unit time as long as there is a certain input pulse of the stepper motor. By analyzing Tables 1 and 2, the variation coefficient of bitumen quality in Table 1 is more than that of bitumen quality in Table 2, showing that the new driving device used may control the bitumen flow in a more stable manner than the traditional driving device. Therefore, if the input pulse of its stepper motor is controlled, the bitumen mass flow can be effectively controlled.

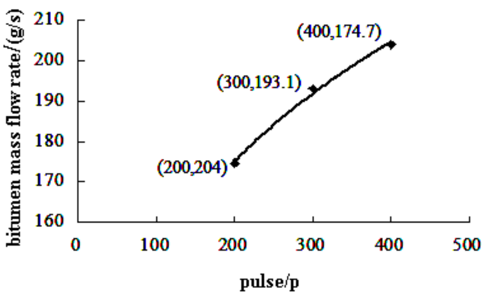


Figure 6. Change curve of bitumen flow and stepper motor pulse number

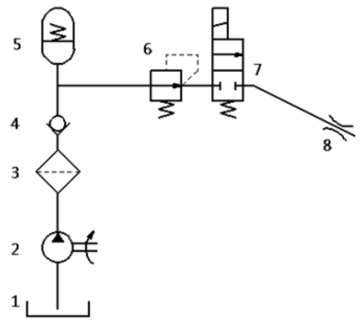
Based on analyzing Table 2, the bitumen quality and the pulse number of its stepper motor may be fitted in a nonlinear manner, which is fitted as seen in Figure 6.

The curve function is $y=53.019x^{0.2255}$ and $R^2=0.9949$. The statistical probability value is P=0.035. In the formula, y represents the bitumen quality and x is the pulse number of the stepper motor.

From the fitting function within a certain range, a nonlinear fitting may describe the relationship between the bitumen quality and the motor pulse number in the new bitumen flow driving device, in which R^2 is the trend line fitting indicator. When the trend line R^2 is close to 1, its statistical probability value P will be less than 0.05, showing that when its confidence probability is 95%, the application of the fitting functions are reliable.

4.3 The foaming water flow control theory and experiment

In theory, when the foamed bitumen is produced, its flow is the sum of a bitumen flow and foaming water flow. However, if the bitumen is foamed, it must be at a certain temperature between 150-170℃, which may vaporize the foaming water. Generally, after the foamed bitumen declines to the original bitumen, the foaming water will not be present. Therefore, the foaming water does not affect the foamed bitumen flow. At a certain bitumen temperature, the foamed bitumen flow is mainly determined by the bitumen flow, but the high quality foamed bitumen can only be achieved by accurately controlling the foaming water flow and the bitumen flow.



1. Water Tank 2. Water Pump 3. Filter 4. One-way Valve 5. Accumulator 6. Pressure Reducing Valve 7. Solenoid Valve 8. Water Nozzle

Figure 7. Foaming control theory

The foaming water flow control theory is shown in Figure 7. Water pump 2 allows the forming water in water tank 1 to go through filter 3 and the one-way valve 4 to accumulator 5, while the foaming water flow can be adjusted by controlling the outlet pressure of pressure reducing valve 6.

The foaming water flow control test is conducted in four parallel test groups, in which the foaming water nozzle pressures are 0.2MPa, 0.3MPa, 0.4MPa and 0.5MPa.

Table 3 shows the test data of the foaming water flow which shows that the foaming water quality standard deviations sprayed in the four parallel tests are less than 0.53g/s. This means that when a certain spout entrance pressure of foaming water is set, the deviation of foaming water mass flow may be smaller and is relatively stable.

With the foaming water quality *y* being the ordinate and the entrance pressure of its foaming water nozzle *x* being the abscissa, Table 3 portrays a nonlinear fitting of foaming water average value and its fitting curve is shown in Figure 8. Where it can be seen that the fitting functions are $m=106.57n^{0.7978}$ and $R^2=0.9941$, while its statistical probability value is P=0.0064. In the formula, m represents the foaming water quality and n the entrance pressure of foaming water nozzle.

Table 3. Calibration experiment data of foaming quality and flow

Parallel test groups	Pressure (MPa)	The testing group numbers	Mass flow (g/s)	Average value (g/s)	Standard deviation (g/s)
1	0.2	1	28.9	28.96	0.13
		2	28.9		
		3	29.1		
2	0.3	1	42.2	42.20	0
		2	42.2		
		3	42.2		
3	0.4	1	51.1	51.31	0.25
		2	51.1		
		3	51.7		
4	0.5	1	60.0	60.38	0.53
		2	61.1		
		3	60.0		

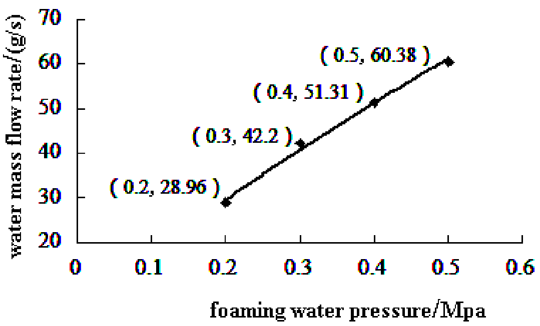


Figure 8. The fitting curve of foaming flow change

The foaming water mass flow can be effectively controlled with engineering applications. According to the nonlinear functions fitted in the experimental data, it can meet their requirements if the relevant coefficients are close to 1. As shown in Figure 7, the fitting curve is used to show the relationship between the quality of the foaming water and the inlet pressure of the foaming water nozzle. When the trend line R^2 is close to 1, its statistical probability P is less than 0.05, showing that the confidence probability is 95% and the fitted nonlinear function can be reliable in applications. Therefore, it can meet the design needs of the foaming water mass flow being precisely controlled in the projects.

5. TO TEST AND VERIFY THE FOAMED BITUMEN

According to the pulse number of its stepper motor set in the new driving device, the amount of foamed water calculated from its oil proportion and the required foaming water pressure, the bitumen foaming test is verified by selecting No. 70# bitumen, setting the test temperature at 160℃, and setting the injection time at 15 seconds.

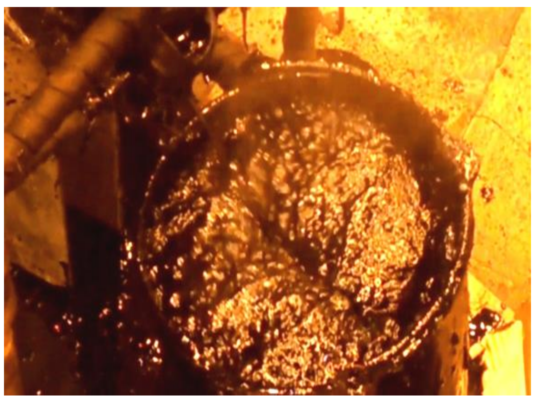


Figure 9. Bitumen foaming

After being tested in the experiments, the expansion rate of the foamed bitumen, shown in Figure 9, may be 13 seconds and its half-life may be 12 seconds. This is better than the national recycling technical specifications of bitumen pavement (JTG F41-2008).

6. CONCLUSIONS

(l) By the bitumen flow control tests, the traditional bitumen flow control method and the new bitumen flow control method are compared and analyzed, and the result shows that the new control method can control the bitumen flow in a more stable manner.

(2) An indirect flow control method of engineering foamed bitumen is proposed. According to the amount of foamed bitumen and the oil proportion of foamed bitumen required in the project, the amount of bitumen and foaming water can be determined as the bitumen flow control equation y=53.019$x^{0.2255}$ is used to obtain the pulse number. In the formula, y represents the bitumen quality and x represents the pulse number of the stepper motor. Then the foaming water control equation m=106.57$n^{0.7978}$ is used to get the inlet pressure of its foaming water nozzle. In the formula, m represents the foaming water quality and n the inlet pressure of the foaming water nozzle. An indirect flow control of foamed bitumen may be realized.

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