Analysis on the Influence Factors of Fiber Tension in Fiber Placement

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Abstract: A simple experiment platform of fiber placement is designed in this paper, which is mainly composed by uncoiling unit, driving unit and placement unit. Fiber is driven by the driving unit to the placement unit from uncoiling unit. The relations about fiber tension and its influence factor are analyzed. The first factor is the speed ratio of driving unit and placement unit. The second factor is the number of driving wheels. Two conclusions are got. The first one is that the speed ratio is not an important influence on fiber tension. The second one is that the driving unit with more wheels provides greater driving force for fiber. The experiments verify the conclusions.

Key Words: Fiber Placement, Driving Wheel, Fiber Tension, Uncoiling

1 INTRODUCTION

In recent years, with the development of military industry, the research on carbon fiber and its composites is more and more widely [1]. As a new material and high-tech product, carbon fiber is a popular material whether in the military fields or in the civilian fields. It has some excellent properties such as high specific strength, high specific modulus, and high temperature resistant and corrosion resistance. It can be used as structural materials bearing load and playing a role as functional materials. So, it is used widely in many fields such as aviation, aerospace, automotive, environmental engineering and chemical industry. Generally, carbon fiber is made into some components such as aircraft wing, car hood and sports device. The prototyping technology of carbon fiber composites are widely developed [2], especially the technology of fiber placement [3-8]. The system of fiber placement is realized by an automated fiber placement machine. This system includes feeding subsystem and placement subsystem. In placement subsystem, multiple sets of fiber are heated and softened. Then, these fibers are placed on the mandrel by a multi degrees placement head (as the tool of a manipulator). In feeding subsystem, the fiber is wound on the uncoiling unit, and is sent to the placement subsystem by the driving unit. The driving unit provides friction for fiber through multiple driving wheels. These wheels' speeds are same but are different from the speed of the placement wheel. It is necessary to analyze the influence factors of fiber tension in the process of fiber placement.

The rest in this paper is arranged as follows. The configuration of fiber placement system is introduced in section 2. In section3, the relation between the fiber tension and the speed ratio of the driving unit and the placement unit is analyzed. Meanwhile, the relation between the fiber tension and the number of driving wheels is also analyzed. The experiments are provided in section 4 to verify the theory analysis. The conclusion is given in section 5.

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2 FIBER PLACEMENT'S CONFIGURATION

Figure 1 shows the sketch of fiber transform experiment platform for fiber placement system. The experiment system consists of uncoiling unit, driving unit, tension sensor, placement unit, PLC and host computer. The uncoiling unit includes fiber wheel and backing paper wheel. A magnetic particle clutch is set on the fiber wheel to restrain the rotational inertia. Fiber is set on the fiber wheel. Backing paper of the fiber is recovered by the backing paper wheel. The uncoiling unit is not equipped motor to provide driving force. It is driven by the tension of the fiber between the driving unit and the fiber wheel. The fiber speed and tension is not influenced by the deflection roller because it is approximately smooth. The driving unit includes multiple wheels. These wheels are driven by a servo motor through a synchronous belt. The placement wheel is driven by another servo motor. The two servo motors and the magnetic particle clutch are controlled by the PLC. The tension sensor's value is read by the PLC. The PLC communicates with the host computer. The fiber in the fiber wheel is connected to the placement wheel through the guide roll, multiple driving wheels and the tension sensor. The fiber is driven by the friction of multiple driving wheels and the tension provided by the placement wheel. When the machine is not work, the fiber and the driving wheel are not contact and the placement wheel does not rotate. Moreover, the fiber without driving force does not move. When the machine is working, the fiber and driving wheels are contact and the placement wheel rotates. The fiber's speed is less than the speed of multiple driving wheels. So, driving wheels provide sliding friction for the fiber. The uncoiling unit is driven by the tension of the fiber between the driving unit and the fiber wheel. So the fiber is moved.

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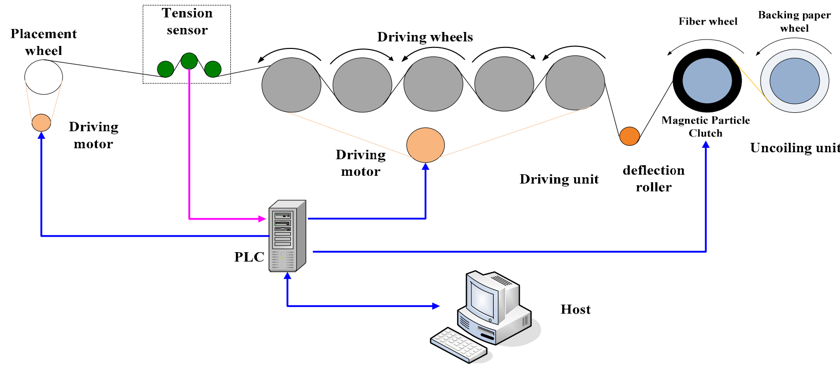


Fig 1. The sketch of fiber transform experiment platform for fiber placement system

3 THE THEORETICAL ANALYSIS

As figure 2 shows, when the number of driving wheels N is five, driving wheels are marked as S_1, S_2, S_3, S_4 and S_5. V is the speed of the fiber between the placement wheel and S_1. V_i(i=1,2,3,4) is the speed of the fiber between S_i and $S_{(i+1)}$.V_5 is the speed of the fiber between S_5 and the deflection roller. V_6 is the speed of the fiber between the deflection roller and the fiber wheel.V_5 is approximately equal to V_6 because the deflection roller is nearly smooth. V_s is the speed of five driving wheels. V_s/V is the ratio of V_s and V.

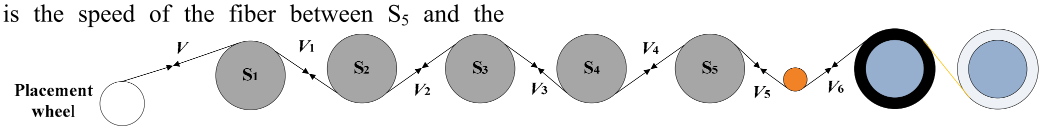


Fig 2. The mark of the speed and the driving unit

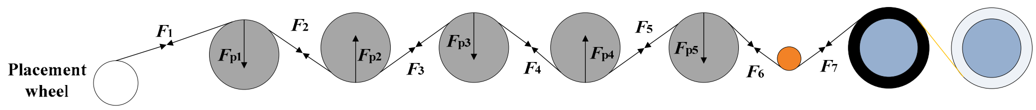


Fig 3.The mark of the force

As figure 3 shows, F_1 is the tension on fiber between the placement wheel and S_1. F_i (i=2, 3, 4, 5) is the tension on the fiber between $S_{(i-1)}$ and S_i. F_6 is the tension on fiber between S_5 and the deflection roller. F_7 is the tension on fiber between the deflection roller and the fiber wheel. F_7 is approximately equal to F_6. F_{pi} (i=1, 2, 3, 4, 5) is the fiber pressure on S_i.

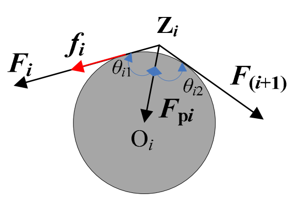


Fig 4. The force diagram of the driving wheel S_i

When the fibers are placed, V is greater than zero. The fiber is contacted with the driving wheel and F_1 is greater than zero. Figure 4 is the force diagram for the driving wheel S_i. F_i is the fiber tension before S_i. $F_{(i+1)}$ is the fiber tension after S_i. Z_i is the pressure equivalent point of the fiber to the driving wheel S_i. O_i is the center of S_i. Z_iO_i is the line between point Z_i and point O_i. θ_{i1} is the angle between F_i and the line of Z_iO_i. θ_{i2} is the angle between $F_{(i+1)}$ and the line of Z_iO_i. So, formula (1), (2) and (3) can be got as follows.

$$F_{pi} = F_i \cos\theta_{i1} + F_{(i+1)}\cos\theta_{i2} \tag{1}$$

$$f_i = \rho F_{pi} \tag{2}$$

$$F_{(i+1)} = f_i + F_i \tag{3}$$

Where ρ is friction factor of driving wheels and f_i is the friction of S_i to fiber. F_{pi} is the pressure of fiber to S_i. Formula (4) can be deduced based on formula (1), (2) and (3).

$$F_{(i+1)} = k_i F_i \tag{4}$$

Where $k_i = (1+\rho\cos\theta_{i1})/(1-\rho\cos\theta_{i2})$

It is obvious that

$$k_i > 1$$

So, F_7 is got as formula (5).

$$F_7 = k_1k_2k_3k_4k_5F_1 \tag{5}$$

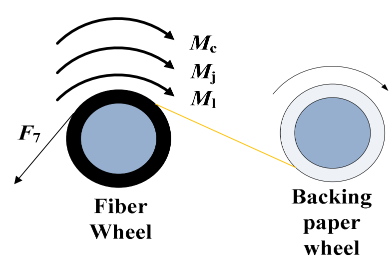


Fig 5. The force diagram of the uncoiling unit

Figure 5 shows the force diagram of the uncoiling unit. F_7 provides driving force for fiber wheel and. The fiber wheel provides driving force for the backing paper wheel through the synchronous belt. On the other hand, the magnetic particle clutch provides drag force for the fiber wheel. Two gears' radiuses of the synchronous belt's two ends are different.

Formula (6) is the ration between the line speed V and the angular speed ω.

$$V = R\omega \tag{6}$$

So, the forces of the fiber wheel can be expressed by formula (7).

$$F_7 R(t) = M_1 + M_c + M_j \tag{7}$$

Where
$$M_j = J_s \mathrm{d}\frac{V_6}{R(t)}$$

$$M_c = J_c \mathrm{d}\frac{V_6 R_{gs}}{R(t) R_{cs}}$$

The gear's radius on the fiber wheel is R_{gs} and the gear's radius on the backing paper wheel is R_{gc}. The radius of the fiber wheel is R_s and the radius of the backing paper wheel is R_c. J_s is the rotational inertia of the fiber wheel. J_c is the rotational inertia of the backing paper wheel. $R(t)$ is the real time radius of the fiber rotation on the fiber wheel and it's a variable value. The torque of the fiber wheel is M_j. The torque of the backing paper wheel is M_c. The torque of the magnetic particle clutch is M_l.

Formula (8) can be deduced based on the formula (6) and (7).

$$k_1 k_2 k_3 k_4 k_5 F_1 R(t) = M_1 + J_c \mathrm{d}\frac{V_6 R_{gs}}{R(t) R_{cs}} + J_s \mathrm{d}\frac{V_6}{R(t)} \tag{8}$$

So, F_1 can be got as formula (9).

$$F_1 = \frac{M_1 + J_c \mathrm{d}\frac{V_6 R_{gs}}{R(t) R_{cs}} + \mathrm{J}_s \mathrm{d}\frac{V_6}{R(t)}}{k_1 k_2 k_3 k_4 k_5 R(t)} \tag{9}$$

When N=3, Formula (10) can be got as follow.

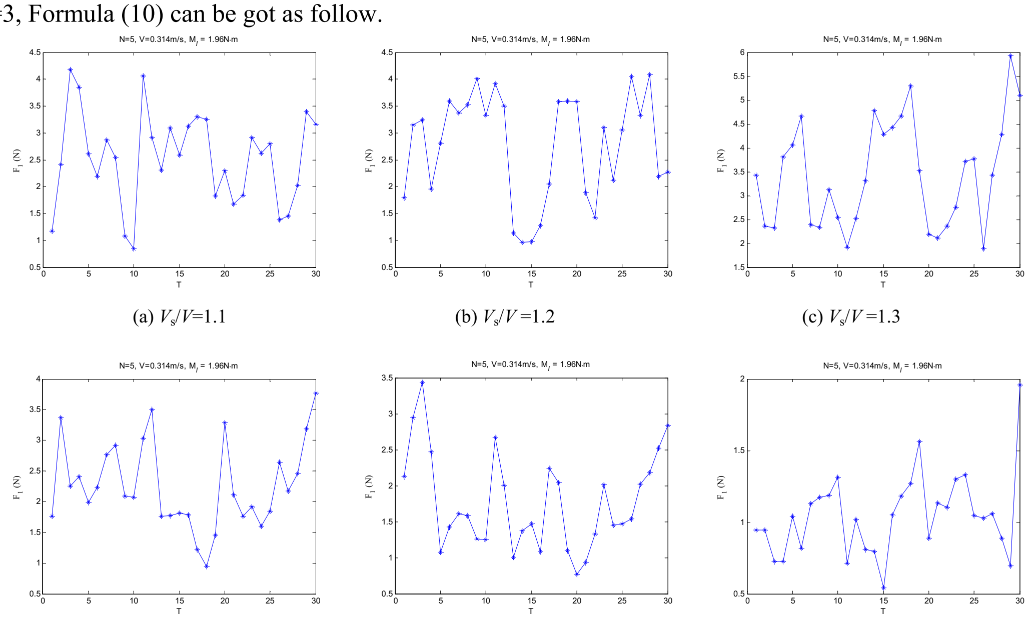
$$F_1 = \frac{M_1 + J_c \mathrm{d}\frac{V_6 R_{gs}}{R(t) R_{cs}} + J_s \mathrm{d}\frac{V_6}{R(t)}}{k_1 k_2 k_3 R(t)} \tag{10}$$

As the formula (9) and (10) show, F_1 is not related to V_s/V. But V_s must greater than V. Besides, N is an important factor on F_1. F_1 is less when N is greater. So, when F_1 is fixed, the driving force for the fiber is greater when N is greater.

4 EXPERIMENT

4.1. Relation Between F_1 and V_s/V

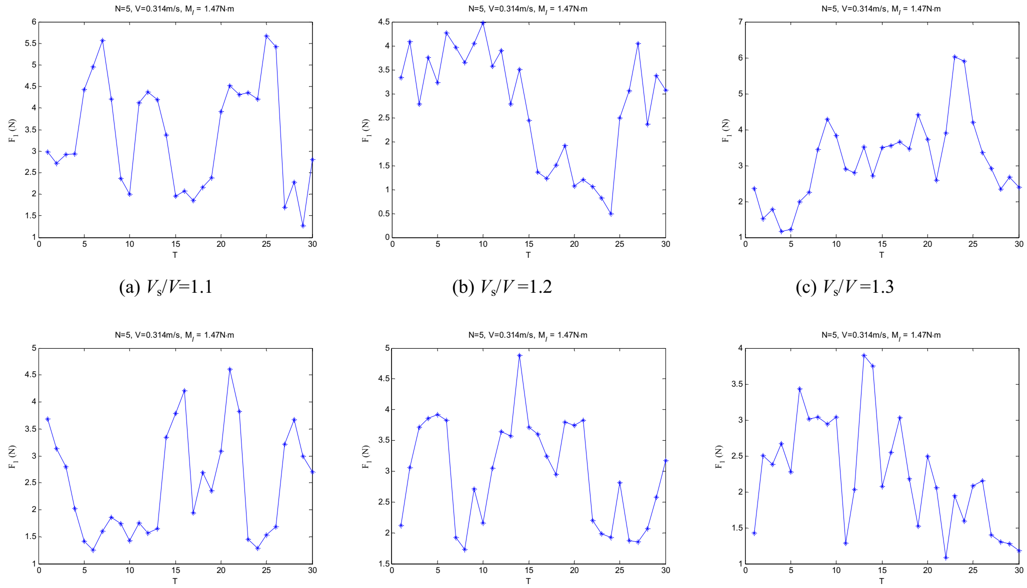
First experiment is carried out to test and verify the relation between F_1 and V_s/V based on the experiment platform of the figure 1 shows. In this experiment, N=5. M_l is 1.96 N·m. V is 0.314m/s. The ratio of V_s/V is fixed on 1.1, 1.2, 1.3, 1.4, 1.5 and 1.7 respectively. Six groups' values of F_1 are sampled after the ratio of V_s/V is stable. Every group includes thirty values of F_1. Mean filter is used in tension sensor and mean filter number is 20. The sampling frequency is 400 Hz. The changing curves of F_1 are shown in figure 6 when the ratio of V_s/V is set 1.1, 1.2, 1.3, 1.4, 1.5 and 1.7 respectively. The x axis is thirty time series. M_l is set on 1.47 N·m and other parameters are not changed. Then, a same experiment is carried out. The changing curves of F_1 are shown in figure 7. M_l is set on 0.98 N·m. The changing curves of F_1 are shown in figure 8. As figure 6, 7 and 8 shown, no matter how value of M_l is, the tension is change random between the periods of thirty time series. F_1 is main influenced by $R(t)$ based on Formula (6) because M_c, J_1, R_0, R_1, J_0, k_1, k_2, k_3, k_4, k_5 are all invariant. $R(t)$ variant without regularity. So, F_1 change without regularity when V_s/V is set on different values. F_1 is not related to V_s/V. It is consistent with the result of formula (9).



(a) V_s/V=1.1 (b) V_s/V=1.2 (c) V_s/V=1.3

(d) V_s/V=1.4 (e) V_s/V=1.5 (f) V_s/V=1.7

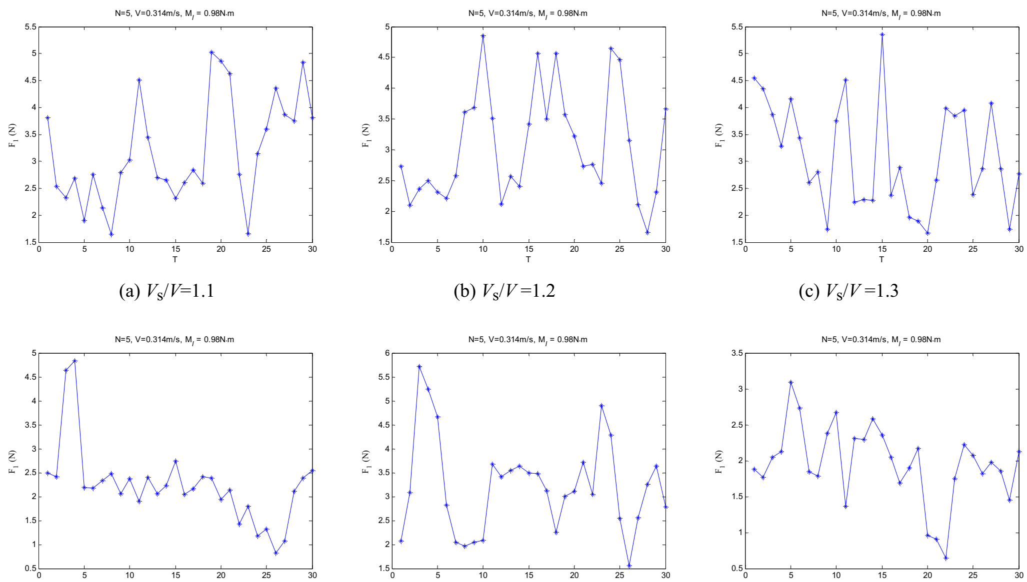
Fig 6. The changing curves of F_1 when M_l=1.96 N·m



(a) V_s/V=1.1 (b) V_s/V=1.2 (c) V_s/V=1.3

(d) V_s/V=1.4 (e) V_s/V=1.5 (f) V_s/V=1.7

Fig 7. The changing curves of F_1 when M_j=1.47 N·m



(a) V_s/V=1.1 (b) V_s/V=1.2 (c) V_s/V=1.3

(d) V_s/V=1.4 (e) V_s/V=1.5 (f) V_s/V=1.7

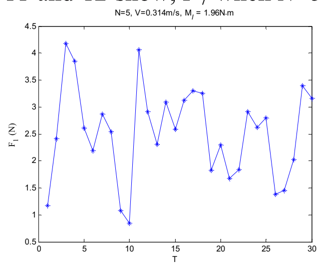
Fig 8. The changing curves of F_1 when M_j=0.98 N·m

4.2. Relation Between *N* and the Driving Force

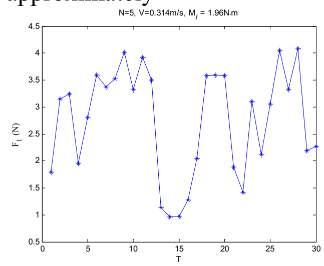
Second experiment is carried out to test the driving force when N is settled on five and three respectively. V is set on 0.314m/s. M_j is set on 1.96 N·m. Firstly, N=5. Three groups' values of F_1 are sampled when V_s/V is set on 1.1, 1.2 and 1.3 respectively. The sampling frequency is 400 Hz. And the three groups' values are shown in figure 9. In contrast, N is three. Three groups' values of F_1 are sampled when V_s/V is set on 1.1, 1.2 and 1.3. And the three groups' values are shown in figure 9. Next, V is set on 0.471m/s. V_s/V is set on 1.2, 1.3 and 1.4 respectively. N=5. Three groups' values are sampled and shown in figure 10. In contrast, N=3. Three groups' values are sampled and shown in figure 10. As figure 9 and 10 show, F_1 is bigger when N=3. It is consistent with the result of formula (9) and (10).

4.3. Relation Between F_7 and *N*

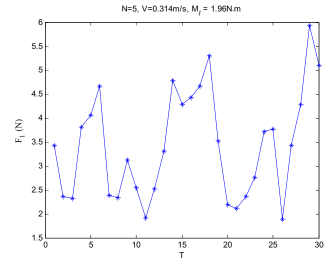
The third experiment is carried out to test the tension change on fiber when sensor is set on position between the driving unit and the uncoiling unit. Firstly, M_l is set on 1.96 N·m. V is set on 0.314m/s. N=5. Three groups' values of F_7 are sampled when V_s/V is set on 1.1, 1.2 and 1.3 respectively. The three groups' values of F_7 are shown in figure 11. N is changed to three. Three groups' values of F_7 are sampled when V_s/V is set on 1.1, 1.2 and 1.3 respectively. The three groups' values of F_7 are shown in figure 11. Secondly, V is set on 0.157m/s. N=5. Three groups of F_7 are sampled when the ratio of V_s/V is set on 1.1, 1.2 and 1.3 respectively and shown in figure 12. N=3. Three groups' values of F_7 are sampled when the ratio of V_s/V is set on 1.1, 1.2 and 1.3 respectively and shown in figure 12. As figure 11 and 12 show, F_7 when N=5 is approximately equal to F_7 when N=3. Experiment 2 shows that F_1 when N=3 are greater than F_1 when N=5. It is consistent with the result of formula (6).



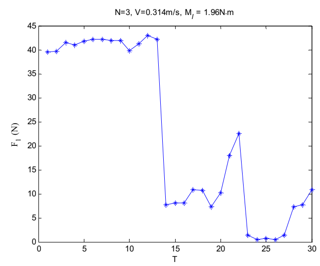
(a) V_s/V=1.1 and N=5



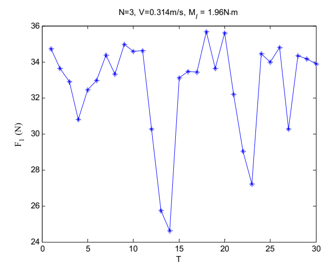
(b) V_s/V =1.2 and N=5



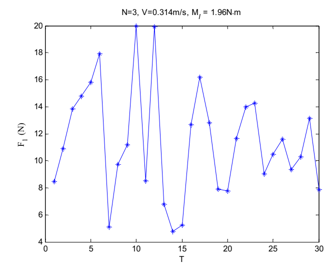
(c) V_s/V =1.3 and N=5



(d) V_s/V=1.1 and N=3

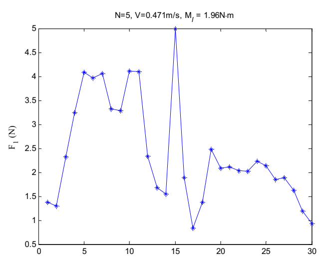


(e) V_s/V =1.2 and N=3

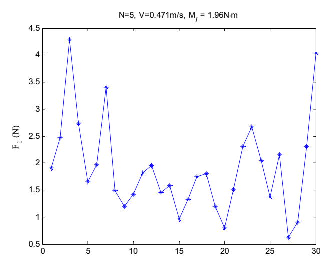


(f) V_s/V =1.3 and N=3

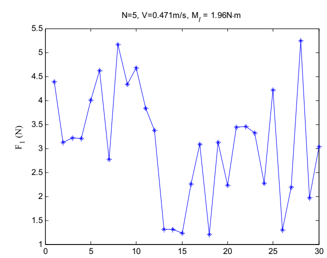
Fig 9. The changing curves of F_1 when V=0.314m/s



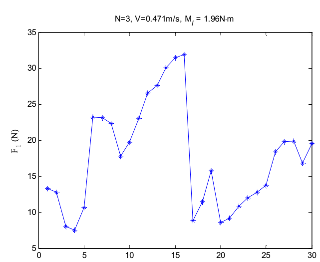
(a) V_s/V=1.2 and N=5



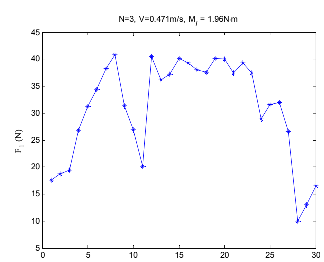
(b) V_s/V =1.3 and N=5



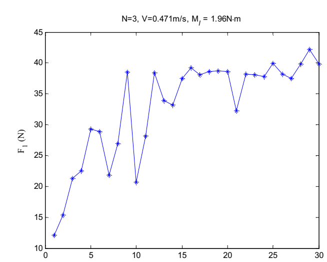
(c) V_s/V =1.4 and N=5



(d) V_s/V=1.2 and N=3

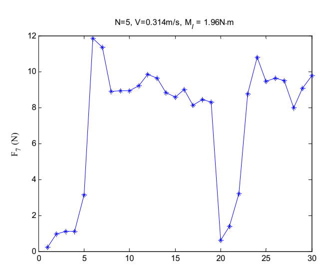


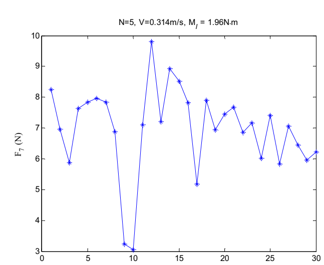
(e) V_s/V =1.3 and N=3

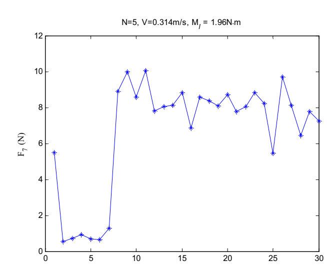


(f) V_s/V =1.4 and N=3

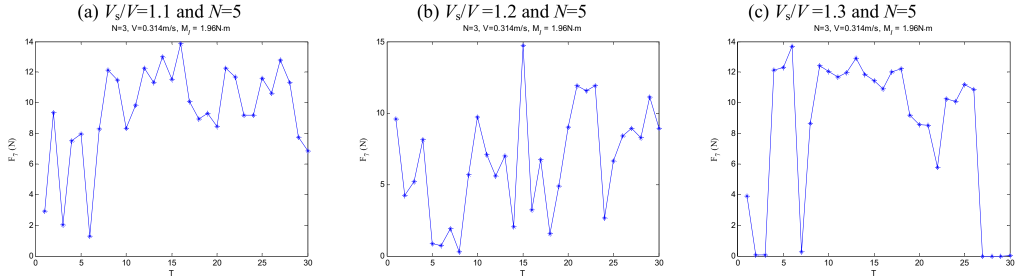
Fig 10. The changing curves of F_1 when V=0.417m/s





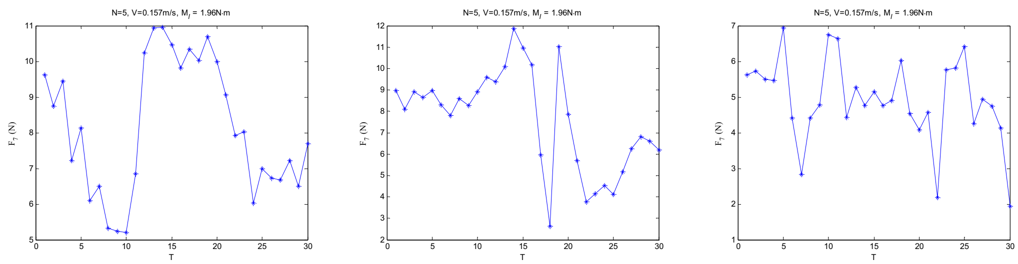


(a) V_s/V=1.1 and N=5 (b) V_s/V=1.2 and N=5 (c) V_s/V=1.3 and N=5

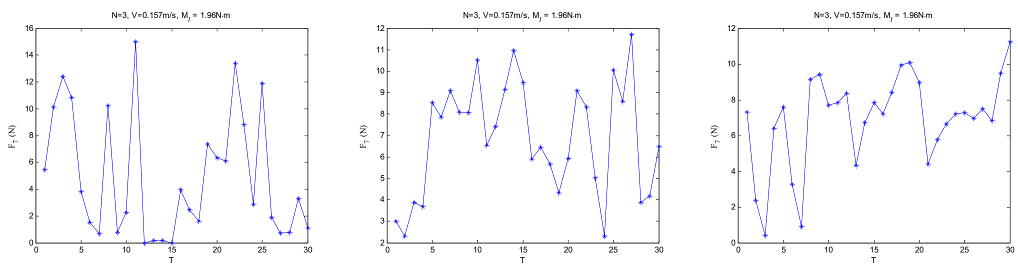


(d) V_s/V=1.1 and N=3 (e) V_s/V=1.2 and N=3 (f) V_s/V=1.3 and N=3

Fig 11. The changing curves of F_7 when V=0.314m/s



(a) V_s/V=1.1 and N=5 (b) V_s/V=1.2 and N=5 (c) V_s/V=1.3 and N=5



(d) V_s/V=1.1 and N=3 (e) V_s/V=1.2 and N=3 (f) V_s/V=1.3 and N=3

Fig 12. The changing curves of F_7 when V=0.157m/s

5 CONCLUSION

The relations about fiber tension and its influence factor is analyzed and confirmed by three experiments. Two conclusions are deduced. Firstly, the relation between the tension and ratio of V_s/V is not obvious. Secondly, the more of the driving wheels, the greater of driving force can be provided. Three experiments confirmed the conclusions.

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