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Optimize by Experimental Optimization Techniques on the Structure of Corrugated Bionic Needle[1]

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Abstract: From the view of bionic, optimizing and engineering the corrugated bionic needle with polynomial regression. The results showed that; the width of the ripple with quadratic effect plays a major role in reducing resistance; the impact of non-smooth structure's spacing could be ignored; when the width of the ripple is 1.75mm and the spacing is 1.00mm, the effect of reducing the resistance was the best.
Key Words: Bionics; Polynomial regression; Mechanism of resistance reduction

1. INTRODUCTION

Injection is a usual induction therapy, however, the pain it brings to sufferer is fearful. The recent surveys showed that 20% young person and 8% adults are afraid of injection (GU, 2008). Therefore, it is important to investigate some painless injection technique. The current painless injection techniques include non-needle injection, micro needle injection, resistance reduction injection and rapid injection (QI &LI, 2009). The complicated process and higher costs are disadvantage to the technique.

From the view of bionic, imitating the structure of insect's sucking mouthparts to create a bionic needle. This can be achieved with minimal cost and has significant effect. Some experiments show that, reducing the resistance can reduce the pain response of organisms (WANG, 2008). On the basis of different resistance of a series of needle, optimizing the structure of corrugated bionic needle, for researching the mechanism of resistance reduction, will provide useful data.

2. EXPERIMENTAL METHODS

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The bionic needle based on the non-smooth structure of insect mouthparts including corrugated, serrated, concave are combination at there structures. The corrugated needle has positive effect on resistance reduction. The depth of corrugated needle was 0.05 mm, moving distance was 15mm, as shown as fig.1.

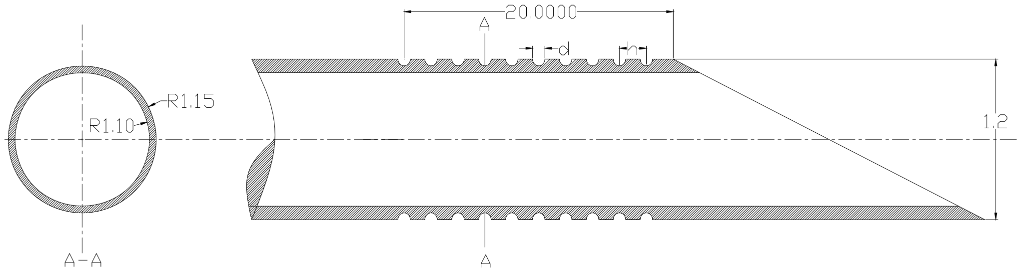
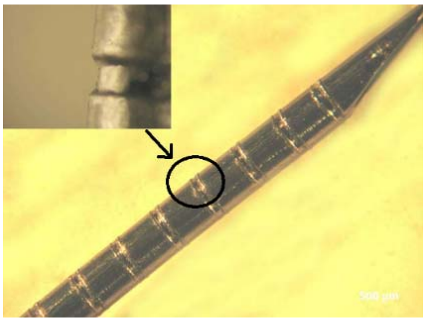


Fig. 1: Operation drawing of bionic needle



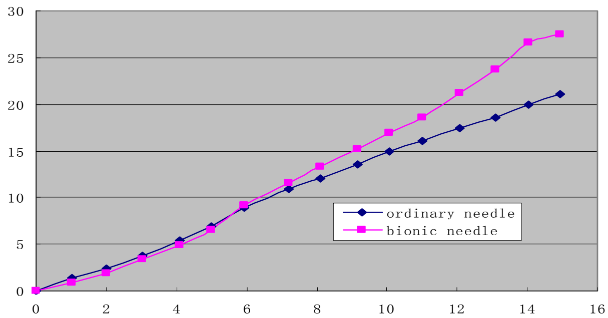


Fig. 2: Non-smooth shape **Fig. 3: Resistance-moving distance curve**

The experimental medium is body simulation silica gel, instead of pork, avoided experimental error made by the uneven texture of pork. Puncture resistance determination machine was used to determine the resistance of bionic needle, as shown in fig. 3. Compared with ordinary needle, the resistance reduction effect of bionic needle is better (Looney & Blick, 1996).

3. THE RESULTS AND ANALYSIS OF THE EXPERIMENTATION

In this paper, we used multiple orthogonal polynomial regression design to process the experimental data, considered the interaction of two factors. The orthogonal polynomial regression equation is:

$$\hat{y} = b_0 + b_{11}\, x_1(z_1) + b_{21}\, x_2(z_1) + b_{12}\, x_1(z_2) + b_{22}\, x_2(z_2) + b^{(11)}_{12}\, x_1(z_1)x_1(z_2) \qquad (1)$$

and:

$$x_1(z_1) = 2\varphi_1(z_1) = 2\left(\frac{z_1 - \overline{z_1}}{\Delta_1}\right) = 20\,(z_1 - 0.25)$$

$$x_2(z_1) = \varphi_2(z_1) = \left(\frac{z_1 - \overline{z_1}}{\Delta_1}\right)^2 - \frac{N^2 - 1}{12} = 100\,(z_1 - 0.25)^2 - \frac{5}{3} \qquad (2)$$

$$x_1(z_2) = \varphi_1(z_2) = \frac{z_2 - \overline{z_2}}{\Delta_2} = 4\,(z_2 - 1.5)$$

$$x_2(z_2) = 3\varphi_2(z_2) = 3\left[\left(\frac{z_2 - \overline{z_2}}{\Delta_2}\right)^2 - \frac{N^2 - 1}{12}\right] = 48(z_2 - 1.5)^2 - 20$$

Design and results of orthogonal polynomial regression are shown as table 1, in it:

Table 1: Multinomial orthogonal regression design

NO.	z_1	z_2	b_0	$x_1(z_1)$	$x_2(z_1)$	$x_1(z_2)$	$x_2(z_2)$	$x_1(z_1)x_1(z_2)$	y	y^2
1	0.1	0.5	1	-3	1.00	-4	28	12	19.05	363.03
2	0.1	0.75	1	-3	1.00	-3	7	9	13.85	191.91
3	0.1	1	1	-3	1.00	-2	-8	6	16.22	263.09
4	0.1	1.25	1	-3	1.00	-1	-17	3	12.63	159.43
5	0.1	1.5	1	-3	1.00	0	-20	0	16.70	278.72
6	0.1	1.75	1	-3	1.00	1	-17	-3	22.45	503.85
7	0.1	2	1	-3	1.00	2	-8	-6	14.93	222.90
8	0.1	2.25	1	-3	1.00	3	7	-9	12.93	167.18
9	0.1	2.5	1	-3	1.00	4	28	-12	15.46	239.01
10	0.2	0.5	1	-1	-1.00	-4	28	4	11.08	122.77
11	0.2	0.75	1	-1	-1.00	-3	7	3	7.17	51.36
12	0.2	1	1	-1	-1.00	-2	-8	2	7.53	56.70
13	0.2	1.25	1	-1	-1.00	-1	-17	1	8.08	65.23
14	0.2	1.5	1	-1	-1.00	0	-20	0	19.26	370.95
15	0.2	1.75	1	-1	-1.00	1	-17	-1	16.48	271.43
16	0.2	2	1	-1	-1.00	2	-8	-2	16.27	264.82
17	0.2	2.25	1	-1	-1.00	3	7	-3	8.26	68.15
18	0.2	2.5	1	-1	-1.00	4	28	-4	18.71	350.19
19	0.3	0.5	1	1	-1.00	-4	28	-4	17.39	302.50
20	0.3	0.75	1	1	-1.00	-3	7	-3	7.57	57.38
21	0.3	1	1	1	-1.00	-2	-8	-2	17.54	307.65
22	0.3	1.25	1	1	-1.00	-1	-17	-1	15.82	250.27
23	0.3	1.5	1	1	-1.00	0	-20	0	7.57	57.38
24	0.3	1.75	1	1	-1.00	1	-17	1	3.97	15.74
25	0.3	2	1	1	-1.00	2	-8	2	7.19	51.73
26	0.3	2.25	1	1	-1.00	3	7	3	14.15	200.22
27	0.3	2.5	1	1	-1.00	4	28	4	8.42	70.90
28	0.4	0.5	1	3	1.00	-4	28	-12	12.39	153.43
29	0.4	0.75	1	3	1.00	-3	7	-9	10.78	116.10
30	0.4	1	1	3	1.00	-2	-8	-6	10.14	102.77
31	0.4	1.25	1	3	1.00	-1	-17	-3	12.58	158.26
32	0.4	1.5	1	3	1.00	0	-20	0	8.51	72.34
33	0.4	1.75	1	3	1.00	1	-17	3	15.48	239.48
34	0.4	2	1	3	1.00	2	-8	6	5.22	27.25
35	0.4	2.25	1	3	1.00	3	7	9	11.74	137.75
36	0.4	2.5	1	3	1.00	4	28	12	8.05	64.76
	D_j		36	180	36	240	11088	1200	451.54	6396.63
	B_j		451.54	-161.25	26.62	-20.34	72.59	-142.92		
	b_j		12.54	-0.90	0.74	-0.08	0.01	-0.12		
	S_j			144.46	19.68	1.72	0.48	17.02		
	F_j			48.37	6.59	0.58	0.16	5.70		
	α_j			0.01	0.01			0.01		

$x_j(z_j)$ —— code space of the jth Factor;
$x_i(z_i)x_j(z_j)$ —— interaction between two factors;
y —— W ' -W ;
W —— The work done by resistance with bionic needle;
W ' —— The work done by resistance with common needle;
b_j —— Regression coefficient;
S_j —— Deviation sum of squares of factors and their interactions;
F_j —— F test of regression coefficient;
α_j —— Significance level.

The work did by resistance is:

$$W = \int_0^l F\,dx \qquad (3)$$

And W is work, F is resistance, l is moving distance.

The repeated experiments of center is shown as table 2:

Table 2: The repeated experiments of center

NO.	z_1	z_2	y
1	0.25	1.5	12.74
2	0.25	1.5	13.92
3	0.25	1.5	16.64
4	0.25	1.5	13.3

$$S_e = \sum_{i_0=1}^{4} y_{i_0}^2 - \frac{1}{4}\left(\sum_{i_0=1}^{4} y_{i_0}\right)^2 = 8.96$$

$$f_e = 3$$

$$S_{回} = S_{x_1(z_1)} + S_{x_2(z_1)} + S_{x_1(z_1)x_2(z_2)} = 181.16$$

$$f_{回} = 3$$

$$S = \sum_{i=1}^{36} y_j^2 - \frac{1}{36}\left(\sum_{i=1}^{36} y_j\right)^2 \ 733.05$$

$$f = 35$$

$$S_R = S - S_{回} = 551.89$$

$$f_R = f - f_{回} = 32$$

$$F_{回} = \frac{S_{回}/f_{回}}{S_R/f_R} = 2.06 > F_{0.10}(f_{回}, f_R) = 2.05$$

$$\hat{y}_0 = b_0 + b_{11}\ x_1(z_1) + b_{21}\ x_2(z_1) + b_{12}^{(11)}\ x_1(z_1)x_1(z_2) = 12.54\text{-}0.9\text{+}0.43\text{+}0.48\text{=}12.55$$

$$\overline{y_0} = \sum_{i_0=1}^{4} y_{i_0} / 4 = 14.15$$

Lack of fit test is:

$$F_{lf} = \frac{(\hat{y}_0 - \overline{y_0})^2}{S_e / f_e} = 0.86$$

So the regression equation is:

$$\hat{y} = 12.54 - 0.9\, x_1(z_1) + 0.74\, x_2(z_1) - 0.12\, x_1(z_1) x_1(z_2) \quad (4)$$

It is perfect, its significance level is 0.01, and the confidence is 90%. We can get polynomial regression equation by combining equation 3 and equation 4:

$$\hat{y} = 12.54 - 0.9\, x_1 + 0.74\, x_1^2 - 0.12\, x_1\, x_2 \quad (5)$$

Combining equation 2 and 5：

$$y = 74z_1^2 - 40.18z_1 + 2.4z_2 - 9.6z_1 z_2 + 16.83 \quad (6)$$

Equation 6 reflected the relationship between non-smooth structure and resistance reduction. One of the most influential factors is width of ripple, which has quadratic effects. After ignoring the impact of non-smooth structure's spacing, the interaction of two factors is influential, as shown as fig.4. When width of corrugation is 0.4mm, the effect is not significant. With the increasing in width, the effect gets obvious. According to GB 18457-2001[5], considering the rigid conditions, the results is: width 1.00mm, spacing 0.50mm.This bionic needle reduce acting43.02×10^{-3} J, the result was consistent with the data processing.

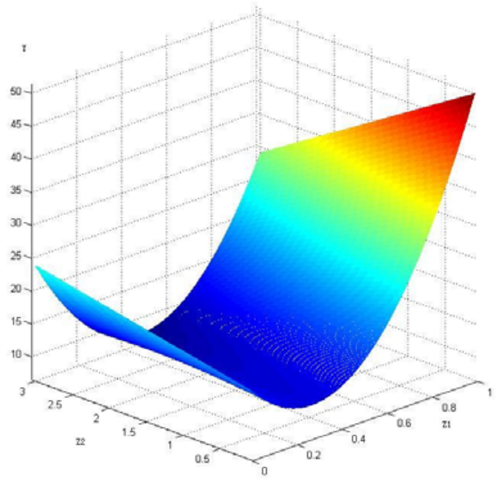


Fig. 4: Optimization Results of non-smooth structure

4. ANALYSIS THE MECHANISM OF THE RESISTANCE REDUCTION

For bionic needle, W is decided by friction factor (YANG, 2003; LI, 1999; SHI, 1995; ZHU, 1995). There is still air stored in the non-smooth structure of the bionic needle. Eddy current appeared with the movement of needle and reduces friction, thereby reducing W by bionic needle. Ordinary needle surface is smooth, and full access to the medium. The friction factor is larger, so W is larger too.

In the Secondary Vortex, there are high-speed band, low speed band, Stable area and eddy area on the interface of fluid and solid (Lee & Lee, 2001; Haecheon et al., 1993). With the non-smooth structure and smooth flow of counter-rotating vortex pair interacting, the secondary vortex comes into being. It reduced vortex strength, impaired production and stability of low-speed. After the air stored in the non-smooth

[5] GB 18457-2001, *Stainless Steel Needle Tubing for Manufacture of Medical Device[S]*.

structure discharged, the original space turn into vacuum, and the water flows into it. This process reduces the friction force.

On the other hand, according to Mohr Coulomb's law, needle with non-smooth surface has smaller contact area, it can reduce W did by friction force[6] (Bacher E & Smith, 1985; YANG & REN, 2003).

5. CONCLUSION

By optimizing the structure of the bionic needle with orthogonal polynomial regression design experiments, the regression equation can be obtained. Compared with ordinary needle, bionic needle has significant ability to reduce resistance. The most prominent factor is the width of ripple, which has quadratic term effects.

One of the resistance reduction mechanism is that eddy current created by the movement of the needle which reduces friction. Another is that non-smooth surfaces reduce area of contact and the needle was to do less work.

REFERENCES

BacherE V, Smith C R. (1985). A combined visualization anemometry study of the turbulent drag reducing mechanisms of triangular micro-groove surface modifications. *American Institute of Aeronautics and Astronautics, Shear Flow Control Conference, Boulder, CO, Mar*:12-14, 11 p. USAF-supported research.

GU Song-tao. (2008). Research on Bionic Injector Based on Insect Piercing-sucking Mouthpart [D], *Jilin University, 6.*

Haecheon.Choi,Parviz.Moin.John.Kim. (1993). Direct numerical simulation of turbulent flow over riblets. *J.Fluid Mech, 255*: 503-539.

LI Cheng-zhi. (1999). *Aerodynamics and Aviation Industry.* Taiyuan: Shanxi Education Press.

Looney W R,Blick E F. (1996). Skin-friction coeffcients of compliant surfaces in turbulent flow. *J.Spacecraft and Rockets, 3(10)*: 1562-1571.

QI Ying-chun, LI Yan. (2009). Current Status of Research on Painless Injection[J]. *Chinese Medical Equipment Journal. 30(9).*

SHI Chao-li. (1995). *History of human flight*. Beijing: China Labor Press.

S.-J.Lee,S.-H. Lee. (2001). Flow field analysis of a turbulent boundary layer over a riblet surface. *Experiment in Fluids, 30*: 153-166.

WANG Jing-chun. (2008). Coupling Bionic Research on Painless Injector Needles Based on Insect Piercing-sucking Mouthpart [D]. *Jilin University.6.*

YANG Xiao-dong. (2002). Analysis of Deformation Mechanism of the Creature Flexibility Elastic and Plastic Models[J]. *Journal of Jilin University(Engineering and Technology Edition). 32(4).*

Yang Xiao-dong Ren Lu-quan. (2003). Types and Mechanisms of Shape Drag Reduction.Yang Xiao-dong Ren Lu-quan.*Transactions of The Chinese Society of Agricultural Machinery, 01.*

ZHU Zi-qiang. (1995). *Aerodynamics in Modern Aircraft Design.* Beijing University of Aeronautics and Astronautics Press.

[6] *Main stages of aircraft development.* Beijing: Aviation Industry Press, 1989.