Investigation into Effect of Output Position and Applied Voltage on the Output Force Performance of the Electric Actuator

Z J Wang¹, G Zhao¹, H J Wang¹, H H Zhao² and J J Yang¹

¹Harbin Engineering University, College of mechanical and electrical engineering, Institute of Intelligent Manufacturing and Robots, 150001 Harbin, China
²Department of Decision Science, School of Business, Macau University of Science and Technology, Macau, China
Email: wangzhijie@hrbeu.edu.cn

Abstract. Electric actuator is a kind of intelligent material for artificial muscles, which has the advantages of low driving voltage, large strain, good biocompatibility, good flexibility, low price, wide application prospect and high academic value. In this work, the influence of different DC voltage and different output position on the output force performance of the electric actuator was studied. The experimental results showed that the performance of the electric actuator was better when the DC voltage was 5V. At this time, the output force was 1.31mN, the output force density was 10mN/g, the response speed was 0.032mN/s, and the strain was 1.29%. When the output position was 20mm, the output force and the response speed of the electric actuator were reached the maximum, which were 3.3mN and 0.063mN/s, respectively, and the corresponding output force density was 25.19mN/g.

1. Introduction
Along with the development of bionics and the new intelligent materials, artificial muscle comes into being [1]. Electro active polymer (EAP) is a new type of artificial muscle, which has the advantages of simple structure, low driving voltage, large deformation, low energy consumption, fast response and so on, and has become a hot research topic at home and abroad of intelligent materials in recent years. Compared with the shape memory alloy and piezoelectric ceramics, the structure of the EAP is more simple and compact with faster response speed, and the deformation capacity is 1-2 order of magnitude higher than them as well [2]. EAP is divided into two types: electronic and ionic. Electronic EAP can produce the induced displacement directly under DC electric field, but it requires a relatively high voltage, even up to the breakdown voltage of the material [3, 4]. Ionic EAP (electric actuator) is composed of two electrodes and an electrolyte layer, which can produce large bending deformation at low voltage, because of its low price, handy manufacture, good flexibility, light weight and many other advantages [5,6], it has a wide application prospect in the fields of robot [7], micro sensor [8], artificial muscle [9], and it has been applied in the field of active micro catheter, moving lens and so on. At present, the research on ion-type electric actuator is mainly focused on conductive polymer, polymer gel and ionic polymer metal composites (IPMC) [10]. However, the response speed of the conductive polymer and polymer gel is slow, and it is difficult to apply in the engineering due to its slow ion diffusion [11]. IPMC is much better than conductive polymer and polymer gel in response speed and strain. Whereas, the large stress resistance of its metal electrode, easy to lose water, low life
and the small output force limit its application. With the development of carbon nanotubes, chitosan and other research, which exist new potentials for ionic EAP. However, one of the most important reasons for limiting the application of ion type electric actuator is that its output force scale is small to mill newton level, so it is urgent to improve its output force performance. The research of output force performance of ionic electric actuator belongs to the frontier discipline of intelligent material, and has a considerable research value.

2. **The preparation of the electric actuator**

The preparation processes of electric actuator include three steps, namely, the preparation of the electrolyte membrane, the preparation of the electrode film and the hot press assembly, and the exact process preparation process is reproduced below.

2.1 **The preparation of the electrolyte membrane**

0.6g chitosan and 20ml 2% (volume fraction) acetic acid solution were measured out and put into a beaker, heated and stirred in a 60℃ water bath, until the chitosan was dissolved sufficiently. Then the stir was continued and added 0.3g glycerol until the glycerol and until chitosan solution mixed evenly. The above solution was poured into a glass mold and placed in an ultrasonic cleaner for 30 min to remove the bubbles. Then put the mold in a vacuum oven for 4 hours. The temperature of the oven was 80℃ and the vacuum degree was 0.

2.2 **The preparation of the electrode membrane**

10 mL 2% (volume fraction) acetic acid solution and 0.06g chitosan were measured into a beaker, heated and stirred in a 60℃ water bath, until the chitosan was dissolved sufficiently. Add 2.5 mL Multi walled carbon nanotubes aqueous dispersions with a mass fraction of 10%, continue stirring for 10 minutes to make sure the solution was well blended. Then the solution was poured into a glass mold and dried in a vacuum oven for 6h, the vacuum degree was 0 and the drying temperature was 80℃.

2.3 **Hot pressing assembly**

The electrode membrane and the electrolyte membrane were cut into a size of 35mm×5mm. The hot-pressing temperature of the hot press was set at 20℃ and hot-pressing pressure was 0N, and the hot pressing time is 20min, then a biological gel electric actuator was obtained.

3. **Force output analysis of electric actuator**

3.1 **Influence of different DC voltage on output force performance of electric actuator**

The prepared electric actuator was measured with different applied DC voltage using the output force measuring device, the measurement position was 30 mm, the measurement time was 150 s, and 300 data points were collected. In order to observe the trend of the change better, the polynomial fitting of the output force of the electric actuator with time was obtained by polynomial fitting of the data points with Origin, as shown in figure 1 (a). Using output displacement measuring device, the output displacement under different DC voltage was obtained. The measurement time was 90s, and 300 data points were collected. In order to observe the trend of the change better, the polynomial fitting of the displacement of the electric actuator with time was obtained by polynomial fitting of the data points with Origin, as shown in figure 1 (b).
Figure 1. The fitting curves of the actuation performance of the electric actuator with different DC voltage: a) output force, b) output displacement.

According to figure 1(a), with the increase of DC voltage applied at both sides of the electric actuator, the output force of the electric actuator increased as well. When the DC voltage applied at both sides of the electric actuator was less than 3V, the curves of the output force of the electric actuator with time showed poor stability, especially in the former 40s. It can be seen from figure 1(b) that the output displacement of the actuator increased with the increase of DC voltage applied at both sides of the actuator. In addition, the stability of the output displacement was increased when the applied voltage was greater than 3V in the front 40s.

The variation of the output force performance of the electric actuator with different DC voltage applied at both sides was obtained by processing and calculating the data in figure 1. The output force, response speed, the output force density and strain of the electric actuator with different applied DC voltage were obtained, as shown in table 1. In order to analyze the effect of DC voltage applied at the both sides of the electric actuator on its performance directly, the output force and response speed of the electric actuator varies with different DC voltage were plotted by Origin, as shown in figure 2 (a), and the output force density and strain of the actuator with different applied DC voltage were plotted, as shown in figure 2(b).

Table 1. The output force, response speed, the output force density and strain of the electric actuator with different applied DC voltage.

| DC voltage(V) | Output force density (mN/g) | Strain (%) | Output force (mN) | Response speed (mN/s) |
|---------------|----------------------------|------------|-------------------|----------------------|
| 1             | 0                          | 0.11       | 0                 | 0                    |
| 2             | 2.82                       | 0.18       | 0.37              | 0.005                |
| 3             | 3.74                       | 0.71       | 0.49              | 0.004                |
| 4             | 5.42                       | 0.97       | 0.71              | 0.012                |
| 4             | 10                         | 1.29       | 1.31              | 0.032                |
Figure 2. Influence of DC voltages on output force performance of electric actuator.

It can be seen from figure 2(a) that the output force of the electric actuator increased with the increase of the applied DC voltage. When the applied DC voltage was less than 2V, the output force of the electric actuator was very small, basically no force output. When the applied DC voltage is greater than 3V, the output force of the electric actuator has a large increase. When the voltage was 5V, the output force of electric actuator reached the maximum of 1.31mN. The response speed of the electric actuator increased with the increase of the applied DC voltage. When the applied DC voltage was greater than 3 V, the response speed became lager, and when the applied DC voltage was 5V, the response speed reached the maximum of 0.032mN/s.

Through the analysis of figure 2(b), the output force density of the electric actuator increased with the increase of the applied DC voltage. Since the mass did not change, the variation law was the same as the change of the output force. When the applied DC voltage was 5V, the output force density of the electric actuator reached the maximum of 10mN/g. The strain of the electric actuator was gradually increased with the increase of the applied DC voltage. When the DC voltage was 3V, the strain of the electric actuator was 0.71%. When the DC voltage was 5V, the strain of the electric actuator was 1.29%.

3.2 Influence of Different Output Position on Output Force Performance of Electric actuator

The prepared electric actuator was measured at a different output position using the output force measuring device, the applied voltage was 5V, the measurement time was 150 s, and 300 data points were collected. In order to observe the trend of the change better, the polynomial fitting of the output force of the electric actuator with time was obtained by polynomial fitting of the data points with Origin, as shown in figure 4(a). According to the variation trend of the output force performance curve, the front 40s of the output force of the electric actuator approximately increased linearly. And the output force response speed of the electric actuator was obtained by linear fitting its output force of the front 40s, as shown in figure 3(b).
Figure 3. The output force performance of the electric actuator varies with time at different output positions: a) output force, b) response speed.

By analysing the variation trend of the curve in figure 3, it can be concluded that the output force of the electric actuator was not always increasing as the output position was closer to the clamping end. When the output position was greater than 20mm from the clamping end, the output performance curve of the electric actuator was relatively stable. In the first 40s, the output force performance curve was the most stable one when the output position was 30mm from the clamping end.

The variation of the output force performance of the electric actuator with the different output position was obtained by processing and calculating the data in figure 3. The output force and response speed of the electric actuator with different output position were obtained, as shown in table 2. In order to analyze the effect of different output position of the electric actuator on its performance directly, the output force and response speed of the electric actuator with different DC voltage were plotted by Origin, as shown in figure 4.

Table 2. The output force and response speed of the electric actuator with different output position.

| Output position (mm) | Output force (mN) | Response speed (mN/s) |
|---------------------|-------------------|-----------------------|
| 15                  | 3.0               | 0.026                 |
| 20                  | 3.3               | 0.063                 |
| 25                  | 2.2               | 0.047                 |
| 30                  | 1.31              | 0.032                 |
| 35                  | 0.81              | 0.018                 |

Figure 4. Influence of output position on output force performance of electric actuator.
By analyzing the data in Figure 5, it was found that the output force of the electric actuator first increased and then decreased as the output position was closer to the clamping end. When the output position was 20mm, the output force of the electric actuator reached the maximum of 3.3mN. As the output position was closer to the clamping end, the response speed of the electric actuator first increased and then decreased, and the decline was relatively large. When the output position was between 20mm and 35mm, the response speed increased linearly, and reached the maximum of 0.063mN/s when the output position is 20mm.

4. Conclusions

The voltage applied on both sides of the electric actuator had a great influence on its output force performance. When the applied DC voltage was less than 2V, the output force of the electric actuator was very small, basically no force output. When the applied DC voltage was 3V, the curves of the output force of the electric actuator with time showed poor stability, especially in the former 40s. When the voltage was 5V, the output force performance of the electric actuator was optimal, the corresponding output force was 1.31mN, the output force density was 10mN/g, the response speed was 0.032mN/s, and the strain was 1.29%. The different output position of the electric actuator had a great influence on its output force performance, too. When the output position was 20mm from the clamping end, the output force and the response speed of the electric actuator were reached the maximum, which were 3.3mN and 0.063mN/s, respectively. At this time, the output force density was 25.19mN/g. In the first 40s, when the output position was 30mm from the clamping end, the output force of the electric actuator was the best.

Acknowledgments

This work was partially funded by the National Natural Science Foundation of China (grant number 51675112 and 51275102); and the Fundamental Research funds for the Central Universities (grant number HEUCFP201730) and the Faculty Research Grants in Macau University of Science and Technology (grant number FRG-17-025-MSB).

References

[1] Wu G, Hu Y and Chen W 2014 Sci. Bull. 23 2240-52
[2] Jiang B and Batra R C 2001 J. Intell. Mater. Syst. Struct. 12 165-82
[3] Lehmann W, Skupin H, Tolksdorf C, Gebhard E, Zentel R, Krüger P, Lösche M and Kremer F 2001 Nature 410 447-50
[4] Huang C, Zhang Q M and Jakli A 2003 Adv. Funct. Mater. 13 525-9
[5] Fukuda K, Sekitani T, Zschieschang U, Klaau H, Kuribara K, Yokota T, Sugino T, Asaka K, Ikeda M and Kuwabara H Adv. Funct. Mater. 21 4019-27
[6] Shankar R, Krishnan A K, Ghosh T K and Spontak R J 2008 Macromolecules 41 6100-9
[7] Bar-Cohen Y 2013 J. Spacecr. Rockets 39 822-7
[8] Zhu S E, Shabani R, Rho J, Kim Y, Hong B H, Ahn J H, Cho H J 2011 Nano lett. 11 977-81
[9] Takashima, Y, Hatanaka S, Otsubo M, Nakahata M, Kakuta T, Hashidzume A, Yamaguchi H and Haradaa Nat. Commun. 3 1270
[10] Gong J P, Kagata G and Osada Y 1999 J. Phys. Chem. B 103 6007-14
[11] Otero T F, Martinez J G and Arias-Pardilla J 2012 Electrochim. Acta 84 112-28