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ダブルコイル機構を用いたリニアアクチュエータ

野間　春生　　柳田　康幸　　鉄谷　信二
ATRメディア情報科学研究所
〒619-0288　京都府京阪奈学研都市光台2-2-2
E-mail: {noma,yanagida,tetsutani}@atr.co.jp

あらまし 二重螺旋構造に巻いたコイル間の静電気力を利用したリニアアクチュエータの開発を進めている。提案するアクチュエータはコイル２個を同軸に巻き込んだものであり、コイルをコンデンサーの電極として機能させることで、極間に静電気による吸引力を発生させる。この静電気力とコイルのバネとしての機械的弾性力のバランスによって巻き方向にリニア駆動可能なアクチュエータとして実現することを目指している。この構造により柔軟なリニアアクチュエータの開発が期待される。本稿では、アクチュエータ自体の実現性を検証するために、電気的、および、機械的なモデルを検討した。試作コイルによる実験では機構全体の振動現象が観測されたが、十分な伸縮効果は観測されなかった。また、モデルにスケールファクターを導入し、本提案が有効に機能するスケールについて検討を加えた。

キーワード リニアアクチュエータ、バーチャルリアリティ、静電気力

Development of the New Linear Actuator Using Double Coil Structure

Haruo NOMA　　Yasuyuki YANAGIDA　and　Nobuji TETSUTANI
ATR Media Information Science Laboratories
2-2-2 Hikari-dai, Keihanna, Science City, 619-0288, Japan
E-mail: {noma, yanagida, tetsutani}@atr.co.jp

Abstract Double-coil actuators are based on the concept of electromagnetic field-induced deformation between two compliant electrodes. With the coil configuration, the double-coil actuators can be bended easily, which make them applicable to use as the wearable actuators. Both electrical and mechanical characteristic of the proposed actuators were investigated by using the simplified simulation model in order to find the relationship between the applied voltage to the double-coil actuator and the force and strain response conducted inside the coil. In experiment, even the experimental results were not as same as the expected results obtained from simulation model, but some strain response can be observed. Further investigation on the scale and mechanical characteristic of the coil should be made to find out the suitable scale for the real application.

Keyword: Linear actuator, Virtual reality, Electrostatic attraction

1. Introduction

During the past few years, various types of actuator were developed to satisfy the demand of the particular application such as the muscle-like actuators for small robots [Kornbluh et al. 1995]. The double-coil wearable actuators, in particular, are a type of flexible linear actuators that has demonstrated the strain response in a short response time. This unique performance combined with other factors such as low cost, and simple operational characteristic suggests many potential applications.

First, the basic background and proposed model of the double-coil actuators were introduced in chapter 2. The simplified electrical and mechanical model of the proposed actuators using in the simulation were discussed, respectively. Next, the shrinkage in distance of double-coil due to the electromechanical force was calculated. Then, the experimental results were explained in chapter 3, and followed by the simulation results for the relationship between the applied voltage and the force and strain response in chapter 4. Finally, the conclusion and discussion was stated in chapter 5.

2. Model of a double coil actuator

2.1 Basic Background

The double-coil actuators operate on the simple principle as shown in Fig.1. When a voltage is applied across the compliant electrodes, the electromagnetic force (F_e), as shown in equation (1), is generated and results in shrinkage in separation between two electrodes. When apply the voltage across the two compliant electrodes, the electromagnetic force generated is described by the following equation

$$F_e = \frac{\varepsilon_0 A V^2}{2d^2} \qquad (1)$$

Where,

$_0$: Permittivity of air (Farad/m)
A: Area of Compliant electrode (m^2)
d: Distance between two electrodes (m)
V: Applied Voltage (Volt)

2.2 Electrical Model

In order to simplify the simulation model, we considered the electrical and mechanical characteristic of the double-coil actuator separately.

The simplified electrical model used in the simulation was shown in Fig. 2.

The derived total electrical force ($F_{e(tot)}$) conducted inside the double-coil actuator based on the above model is:

$$F_{e(tot)} = \frac{\varepsilon_0 (2N-1) A V^2}{2d^2} \qquad (2)$$

Where,

A: Area of 1 turn coil (m^2)
N: Number of turn of each coil

2.3 Mechanical Model

The simplified mechanical model using in the simulation was shown in Fig.3.

The total spring constant of the double-coil actuator ($k_{(tot)}$) from the mechanical simplified model is:

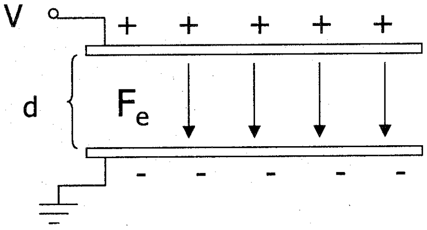


Fig. 1. Electromagnetic force (F_e) conducting

$$k_{(tot)} = \frac{2k}{N} \qquad (3)$$

Where,

k: equivalent spring constant of each turn for each coil (N/m)
N: Number of turn of each coil

The derived total electrical force ($F_{m(tot)}$) conducted inside the double-coil actuator based on the above model is:

$$F_{m(tot)} = k_{(tot)} \Delta x \qquad (4)$$

Where,

Δx: shrinkage distance of the double-coil (m)

2.4 Shrinkage Distance of Double-Coil Actuator

In order to investigate the shrinkage distance of the double-coil actuator, both electrical and mechanic characteristic of the coil must be considered. The simplified model of double-coil, which considers both electrical and mechanical force is shown in Fig.4.

For equilibrium equation under stable condition:

$$F_e = F_m \qquad (5)$$

$$\frac{\varepsilon_0 (2N-1) A V^2}{2d^2} = k_{(tot)} \Delta x \qquad (6)$$

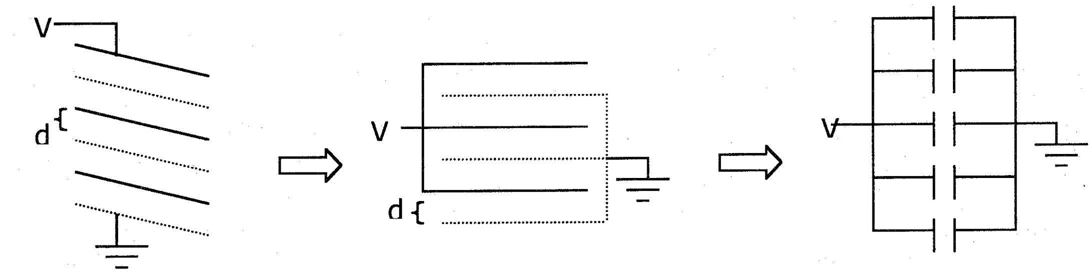
Here, we supposed that shrinkage distance (Δx) is enough smaller than coil length (Nd).Then, the shrinkage distance of the double-coil actuator (Δx) is:

$$\Delta x = \frac{\varepsilon_0 (2N-1) A V^2}{2 k_{(tot)} d^2} \qquad (7)$$

3. Experimental Results

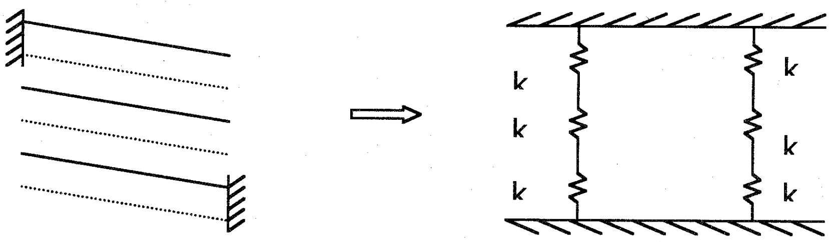
In order to verify the simulation model, we performed the experiment using the following configuration.

-Width of the coil: 4 mm.
-Number of turn (N): 35 turns
-Area (A) : $4.0212 \times 10^{-4}\ m^{-2}$
-Separation (d) : 1 mm.
-Spring Constant (k) : 58.96 N/m



(a) Physical Model (b) Physical Simplified Model (c) Electrical Simplified Model

Fig. 2. Electrical simplified model of double-coil wearable actuator

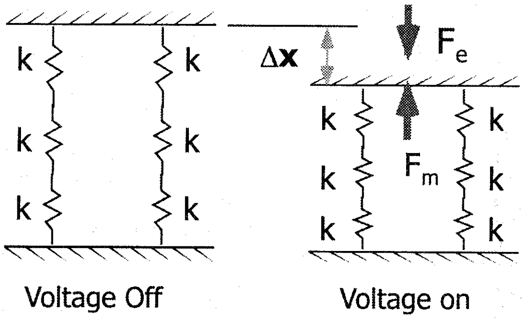


each spring constant "k" represents one of 1 turn of each coil.

(a) Physical Model

(b) Mechanical Simplified Model

Fig. 3. Electrical simplified model of double-coil actuator



a) The simplified model
When the applied voltage is off

b) The simplified model with electrical
and mechanical force when voltage is on

Fig.4 The shrinkage distance (Δx) of double-coil actuator caused by the resultance force among electrical and mechanical force.

-Applied Voltage (V): 0-8 kVolts

According to the above configuration, the expected shrinkage calculated by using the proposed simulation model is 0.0131 m. Anyway in the real experiment, we cannot obtain the shrinkage as much as we expected. When we applied high voltage to the experimental coils, the double-coil moves suddenly. Even we held the high voltage for a while, the coil still shaking and not stable enough to measure the shrinkage.

4. Simulation in different scale

Since we could not obtain the good experimental results by using the double-coil actuator prototype, some of the simulation model considered other scales of the double-coil actuator was constructed. From the derived equation (2);
From

$$F_{e(tot)} = \frac{\varepsilon_0(2N-1)AV^2}{2d^2} \qquad (8)$$

Here we consider s times bigger or smaller configuration than the previous prototype. Area of the coils and gap between the coils are affected and voltage and permittivity are userd same one.

$$F_{e(s)} = \frac{\varepsilon_0(2N-1)(s^2A)V^2}{2(sd)^2} \qquad (9)$$

Where

s: scale factor of the double-coil actuator

So

$$F_{e(s)} = F_e \qquad (10)$$

Or describe in word, the change in scale factor has no effect on the electrical force conducted in the double-coil actuator.

Then relationship between the total electrical force ($F_{e(tot)}$) and the scale factor of the double-coil actuator can be shown in Fig. 5. In Fig. 5, the scale factor 1 indicates the experimental coil. When we consider the large scale from 10-100 times larger in size such as in the construction application, the electrical force applied to the double-coil actuator is so small and not applicable to the large-scale size. But when we consider the small-scale (micro-scale) application such as in cell technology, the electrical force is high compare to its size. So this graph can be indicated that our proposed double-coil actuator maybe applicable in small-scale application.

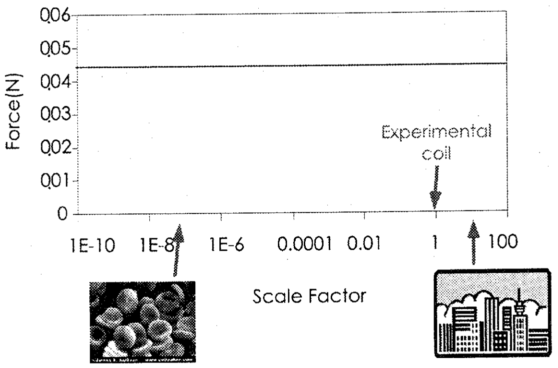


Fig. 5 Relationship between the total electrical force and the scale factor of the double-coil actuator.

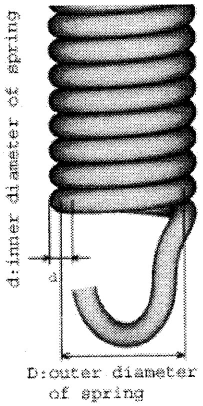


Fig.6 The inner diameter and outer diameter of the coil

The relation between the shrinkage in separation of the two coils (Δx) and the scale factor of the double-coil actuator can be derived as in the following:

From

$$\Delta x = \frac{\varepsilon_0 (2N-1) A V^2}{2 k_{(tot)} d^2} \qquad (11)$$

When the scale factor of the coil changes, the spring constant (k) also changes as follows;

$$k = \frac{G d^4}{8 N D^3} \qquad (12)$$

$$k_s = \frac{G (sd)^4}{8 N (sD)^3} \qquad (13)$$

So,

$$\Delta x_s = \frac{\varepsilon_0 (2N-1)(s^2 A) V^2}{2 (sk)(sd)^2} = \frac{\Delta x}{s} \qquad (14)$$

Where

D: The outer diameter of the coil (m)

d: The inner diameter of the coil (m) as shown in Fig. 6

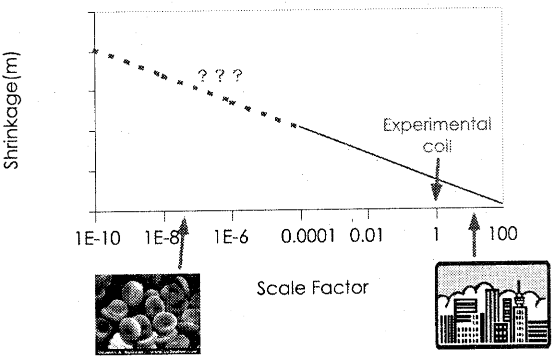


Fig. 7 Rrelationship between the shrinkage (Δx) and the scale factor of the double-coil actuator.

The plot between the shrinkage in separation of the two coils and the scale factor is shown in Fig. 7

From Fig. 7, the shrinkage increases as the scale factor decrease. Anyway due to the limitation of manufacturing and the spring characteristic, in reality, we cannot manufacture the spring in very small size (represent by the dash line region) as we shown in the graph. This graph shows the trend that our proposed double-coil actuator gain some advantage in small scale and may be applicable for the small scale technology.

5. Conclusions and Discussion

In order to investigate the characteristic of the newly proposed double-coil wearable actuator, we constructed the simplify model concerning the electrical characteristic and mechanical characteristic separately. The experiments using some double-coil actuator prototypes were performed to verify the simulation model. During the experiment some vibration but not clear shrink could be observed when we applied the high voltage to the double-coil actuator. This may cause by the inappropriate scale of the actuator prototypes. When consider the characteristic of our proposed actuator by changing scale factor, the simulation results shown that, our new double-coil wearable actuator may be applicable for the small-scale application. Further investigation on the scale and mechanical characteristic of the coil should be made to find out the suitable scale for the real application.

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Reference

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