High-Precision Pump Based on Shape Memory Alloys

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Abstract. The paper designs a high-precision pump driven by SMA spring, analyzing the performances of Shape Memory Alloy (SMA) spring via different experiments and comparing the output performances of springs of different models and specifications in different currents. The result of study provides suggestion and foundation for other SMA system designing and manufacturing.

Introduction

Nowadays, the main strain research on micropumps is that of the film pump which pumps liquid by changing the inner volume through the movements of the driving film[1]. According to the ways of driving, there are thermo-driving, electromagnetic driving, static driving, ultrasonic driving and piezoelectric driving, etc[1,2]. Even though the film pumps are able to pump the liquid well, they are difficult to be widely applied due to their lower precision in flow control and higher difficulty in designing and manufacturing.

As a material with new functions, SMA is featured by its large output, high response frequency and low voltage requirement[3,4]. SMA spring is adopted here as the driving power for the high-precision pump which controls the input current signals, controls precisely the flow of the current and makes up for the drawbacks in film pumps. The paper designs a mini-structured pump with SMA spring and then analyzes the performances of the spring via different experiments.

The Structure Design of High-Precision Pump with SMA Spring

The structure of high-precision pump with SMA spring, as shown in Figure 1, comprises the driving source (SMA spring), operating device (septum), working device (pump cavity), the input pump and output pump. When the current is added upon the spring, the temperature of the spring rises until it reaches the transformation point where the spring is stretched long; when the current is cut off, the spring returns to its initial length. In such way, the SMA spring moves by its stretching and contracting along the guide post, which triggers the up-and-down movement of the septum, changes the cavity volume and pumps liquid.

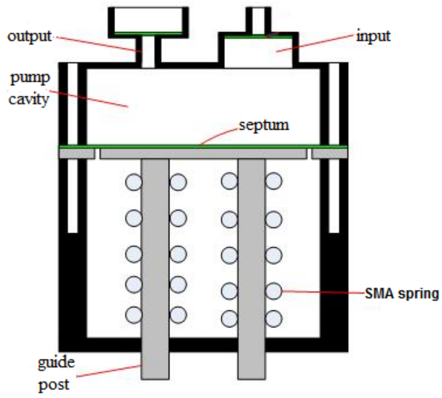


Fig.1, Schematic structure of a shape memory alloy spring pump

As the driving source, SMA spring is the core of the structure. Researches and tests should be conducted to find out its performances and select proper spring accordingly.

Experiments and Analysis on the Performances of SMA Spring

NiTi alloy series is the best shape memory alloy which is most widely adopted. Therefore, NiTi alloy is the material adopted by SMA spring[5,6]. To the given NiTi alloy under heat treatment, the equation is given below. τ is the shearing stress, γ is shearing strain, T is the temperature.

$$\tau(\gamma,\mathrm{T})=\tau(0,\mathrm{T}_0)+[\mathrm{A}\gamma+B(\mathrm{T}-\mathrm{T}_0)]\sum_{i=0}^{\infty}C_i\gamma^i \tag{1}$$

In the following equation[7], P is the load of the helical spring, D is displacement, T is the temperature.

$$p(\delta,\mathrm{T})=\frac{\pi d^3}{8D}\{\tau(0,\mathrm{T}_0)+[\mathrm{A}\frac{\delta d}{n\pi D^2}+\mathrm{B}(\mathrm{T}-\mathrm{T}_0)]\sum_{i=0}^{\infty}C_i\delta^i(\frac{d}{n\pi D^2})^i\} \tag{2}$$

According to reference [7], SMA spring design needs parameters of load P, deformation displacement δ, spring diameter D, material diameter d, coil number n, shearing stress τ, shearing strain γ and temperature T. Because the relations among τ、γ、T can be demonstrated in mathematical model, if two of the five parameters as well as the temperature T are set, the other three parameters can be calculated out according to equations and the relation curve of τ、γ、T. Therefore, the optimal design will be achieved if the constraint condition of $\frac{D}{d^3}=\frac{\pi\tau}{8KP}$ is satisfied.

However, the relations among the stress, strain and temperature of the SMA material are not linear. Compared with ordinary spring, SMA spring enjoys the following features. First, it is not only a passively-driven spring, but also is able to output displacement and power during its circular changes in temperature. Second, in the complex non-linear relations among stress, strain and temperature, SMA material is sensitive to other components and heat treatment. Third, SMA spring works only in temperature changing area; both the stress and strain have hysteresis effects[1]. All these above bring difficulties in the designing and shaping which are usually achieved by experience without foreseeing its performances.

The paper studies the output performances of different SMA springs and builds a test platform as shown in Figure 2. This platform, including a PC controlling machine, a dynamometer and a stabilized power supply, tests and analyzes the response speed of the same spring driven by different currents and the response speed of different springs driven by the same current.

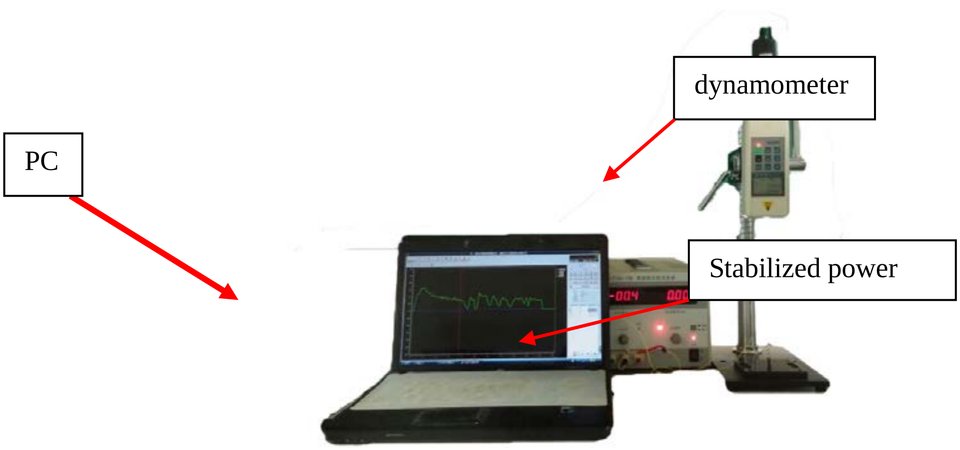


Fig 2. Performance test platform for the Shape memory alloy spring

Table 1 shows the parameters adapted to the three spring models in the experiments:

Table 1, Spring model and parameters

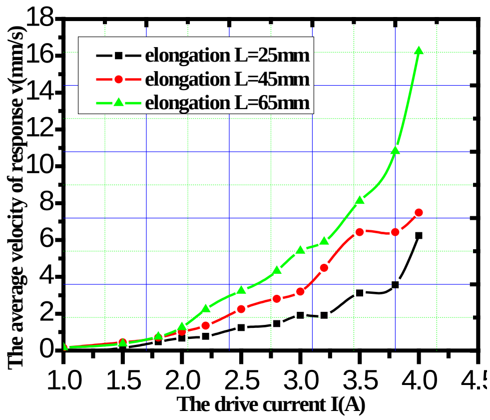
	Initial length（mm）	Spring diameter（mm）	Spring wire diameter（mm）	Stretching temperature（C）	Shrinkage temperature（C）
Spring 1	14	10	0.9	35	60
Spring 2	13	5	0.5	30	53
Spring 3	12	3	0.6	40	60

As shown in Figure 3, the SMA spring, which is already stretched by external force, is fixed at the lower end of the dynamometer and then is added to a driving current from the stabilized voltage supply. A response force is produced when the temperature of the spring reaches to its shrinkage point. Then the spring goes back to its normal state. The dynamometer conveys the data collected from the process to the relevant software in PC controlling machine and a graph of relations between time and force is formed.

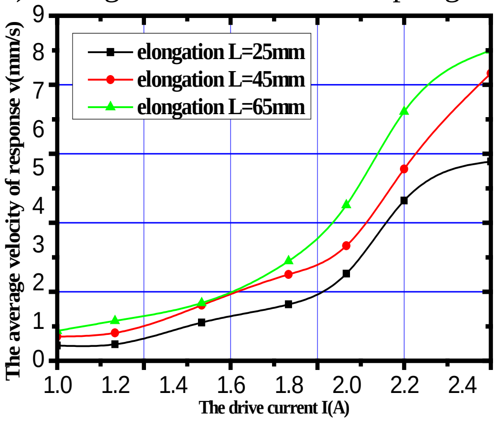
(a） dynamometer （b） initial spring (c) stretched spring

Fig 3,The gauge and shape memory alloy spring

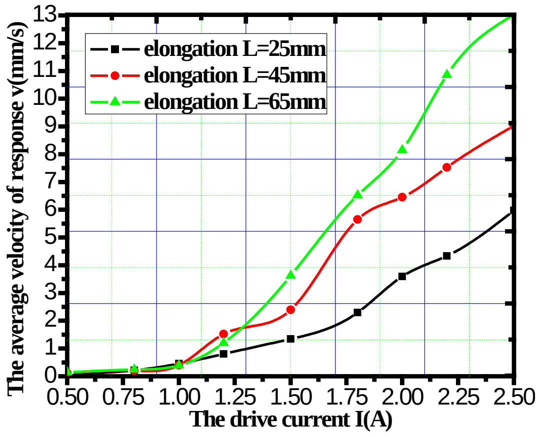
Figure 4 and Figure 5 show the response rate of three spring models driven by different currents and of the same spring model with different initial length driven by current.



a) average back rate curve of spring 1



b) average back rate curve of spring 2



c) Average back rate curve of spring 3

Fig 4, Drive current and average speed response to relationship graph

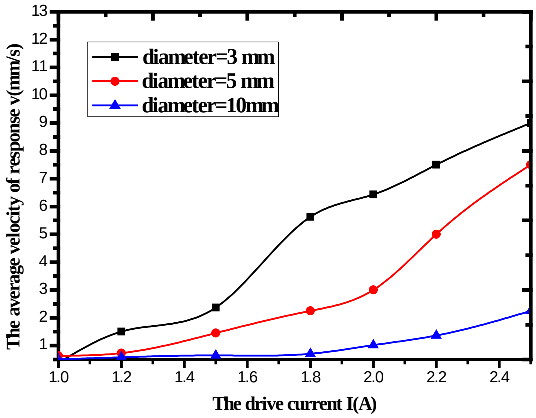


Fig 5, Relationship between the different types of springs and the average response rate of the drive current

According to the figures above, we can conclude that:

As the increase of the drive current, the response rate of the same SMA spring is low at the beginning and rapidly accelerates when the current reaches 1A.

The longer initial length the spring has, the stronger response force it generates but longer initial response time it needs.

At the same initial length, the longer the diameter of the spring is, the more drive current is needed; driven by the same current, smaller springs need shorter response time and gain larger average response rate.

According to the experimental data and the comparison of the figures, it is concluded that No. 3 spring gains larger response rate under comparatively weaker current. However, the diameter of this spring is too short and will bring troubles to the installation of the structure. Therefore, various factors should be taken into consideration when a spring is to be chosen.

Conclusion

The paper aims to design a high-precision pump with SMA spring. The pump adapts a spring with two-ways memory effect, which is simple in structure and easy for operation. In order to research SMA spring and text its performances, experiments and analysis are conducted. According to the results, we find that the diameter and initial length of the spring have comparatively large influence on the output performances. Therefore, in order to gain large response force and pumping output, a proper spring should be chosen in designing and producing the devices.

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