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## Fabrication of Thin McKibben Artificial Muscles with Various Design Parameters and Their Experimental Evaluations

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### 1. Overview

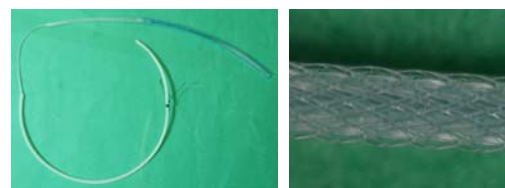
Thin McKibben type artificial muscles which have various design parameters have been fabricated and tested. Their contraction force, contraction ratio and diameter change have been measured and the relationship between their characteristics and design parameters has been made clear.

The McKibben artificial muscles are known as one of the light weight and the high output force soft actuators. The McKibben artificial muscle usually consists of a rubber tube, a sleeve which is made with knitted fibers and terminals which plug both ends of the rubber tube. The rubber tube expands in the radial direction by applying pressure in the rubber tube, and it leads into the contraction force/displacement in the axial direction by changing the knitting angle. Although the theoretical contraction force can be calculated by the Schulte's formula[1], it has no consideration about the hardness of the rubber tube and the number of the sleeve's fiber. In this research, various kinds of the McKibben artificial muscles were fabricated actually and evaluation experiments were conducted in order to clarify the change of the contraction force, the contraction ratio and the diameter of the thin McKibben artificial muscles when the hardness of the rubber tube, knitted angle of fibers and the number of the sleeve's fiber were changed.

Two types of silicone rubber tube, 30 and 40 in durometer A hardness, were used for the McKibben artificial muscle. The outer diameter is 1.3[mm], and the inner diameter is 0.9[mm]. The circumference of this rubber tube was covered with the sleeve. One end was bound with the thread, and the tube for air supply was attached to the other end. The fiber material was Tetoron monofilament with 0.12[mm] in diameters. Table 1 shows the design parameters of the knitting angle and the number of the sleeve's fiber of the prototypes. A fabricated McKibben artificial muscle is shown in Fig.1. The natural length of this artificial muscle is 150[mm].

The measurement experiments of the contraction force and the contraction ratio were conducted with increasing air pressure from 0.0[MPa] to 0.5[MPa] with the increments of 0.1[MPa]. The contraction forces with each air pressure were measured by the force gauge while the McKibben artificial muscle is fixed by natural length. Fig.2 shows the equipment for measurement of the contraction force.

From the experiments, it is found that the hardness of the rubber tube does not affect the characteristic of the McKibben artificial muscle so much. Moreover, it is clarified that the McKibben artificial muscles tends to explode with few number of the sleeve's fiber. The max contraction force was 18.13[N] at 0.5[MPa] with No.11 actuator. The max contraction ratio was 34[%] at 0.5[MPa] with No.9 actuator. the thin McKibben type artificial muscles which have various design parameters were fabricated. Additionally, the contraction force, the contraction ratio and the diameter of the McKibben artificial muscles were measured and the characteristics were clarified experimentally.



(a) Overview (b) Close-up  
Fig.1 The fabricated McKibben artificial muscle



Fig.2 Experimental equipment

Table 1 Design parameters and experimental result

No.	Hardness [Durometer A]	Angle [deg]	Fiber number	Max force [N]	Max contraction ratio[%]
No.1	40	30	32	4.06	17.3
No.2	40	20	32	7.86	25.3
No.3	40	18	24	10.05	30
No.4	30	30	32	4.17	18
No.5	30	20	32	8.61	28
No.6	30	20	24	7.67	32
No.7	30	20	16	5.11	13
No.8	30	18	32	15.77	32
No.9	30	18	24	10.71	34
No.10	30	18	16	7.93	10.7
No.11	30	17	32	18.13	31.3
No.12	30	17	24	7.89	30.7
No.13	30	17	16	4.47	6.7

### 2. References

- [1] Schulte, H. F., "The Characteristics of the McKibben Artificial Muscle," The Application of External Power in Prosthetics and Orthotics, (1961) pp. 94-115.