Analysis of System Efficiency of Korean Total Artificial Heart

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Introduction

The Korean Total Artificial Heart (TAH) was developed in 1988 at SNU. In 1990's the research through several animal experiments has shown the possibility of a clinical application of TAH. For totally implantable TAH system, the efficiency is very important factor to reduce the volume size of implantable battery. In this paper, the overall system efficiency of TAH including microcontroller, motor driving system, mechanical actuator, and blood sac has been evaluated. Among those parts, the motor driving system has an important meaning on energy consuming. The efficiency of that system has been evaluated in a constant rotation velocity.

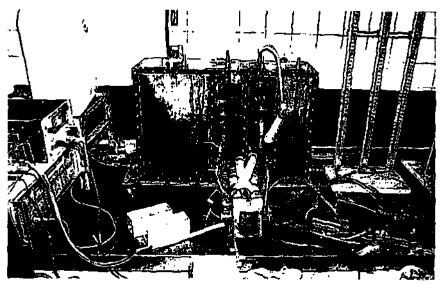
This paper will present a cource for TAH to improve overall system efficiency by analyzing the relations of control parameters with overall system efficiency.

Materials and Methods

Overall system efficiencies were acquired in the various conditions. [Fig. 1] The Korean TAH can control the cardiac output (CO) varying heart rate (HR) and stroke volume (SV) which differents with other TAHs, thus experiments were performed with respect to the velocity (υ) and the stroke angle (SA) of mechanical actuator.

To calculate the electrical input energy and the hydraulic output energy, motor current (Im) and CO[ℓ/min] were averaged through 1 heart beat with the condition of 12V (V_m) of input voltage and 100 mmHg of AoP.

The input energy(E_{in}) is



[Fig. 1] The Mock Circulation Test Device for TAH

$$E_{in} = V_m \times I_m \qquad (1)$$

and the output energy (E_{out}) is

$$E_{out} = CO \times [(AoP - LAP) + (PAP - RAP)] \qquad (2)$$

The overall system efficiency (μ_{sys}) is

$$\mu_{sys} = \frac{CO \times [(AoP - LAP) + (PAP - RAP)] \times 133/60000}{V_m \times I_m} \qquad (3)$$

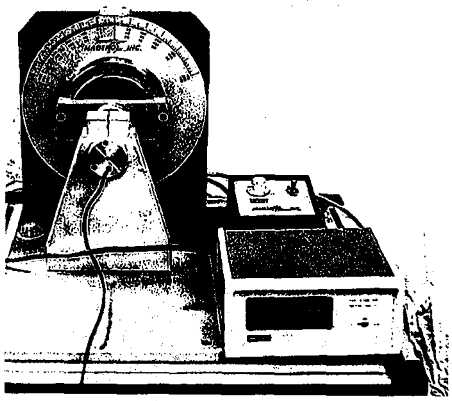
To separate the motor driving system from overall system, we examined a brushless DC motor (Sierracin 566-20A) which is used to drive the Korean TAH. [Fig. 2]

With a constant voltage of 8V, 10V, 12V, the armature current (I) and the rotational speed (N)[rpm] were obtained at various torque (T) from 4 oz-in to 10 oz-in.

The efficiency[μ_m] of the motor according to the operating torque is calculated as follows.

$$\mu_m = (1 - I_o / I)(1 - I / I_s) \\ = (1 - T_f/T)(1 - T/(T_s + T_f)) \quad (4)$$

I_o : noload current
I_s : starting current
T_f : friction torque
T_s : stall torque



[Fig. 2] The Mortor Torque Test Device

Results & Discussion

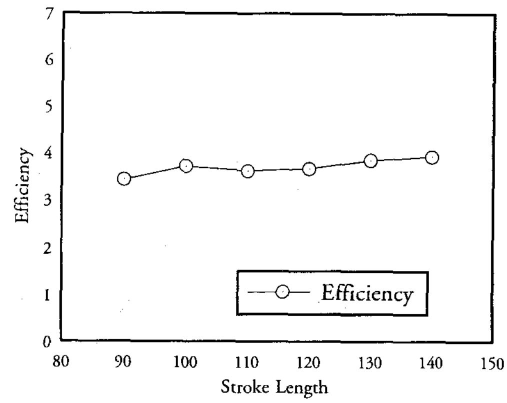
The System Efficiency Test

After analyzing experiment data, the average of overall system efficiency was 3.50% with the standard deviations of 0.26. Figure. 3 and Figure. 4 are the curves of overall system efficiency versus SA and υ. SA, AoP, and PAP are closely related with μ_{sys}. They makes CO and hydraulic work. This means that the E_{out} is the major factor of system efficiency. It can be interpreted from Figure 5. The E_{loss} is larger than the E_{out} and has a large ratio of E_{in} even if there were no load. The E_{loss} of no load condition is occurred by sac deformation, viscous frictions of gear lubricants, variable volume's volume change, and the reversive motion of actuator.

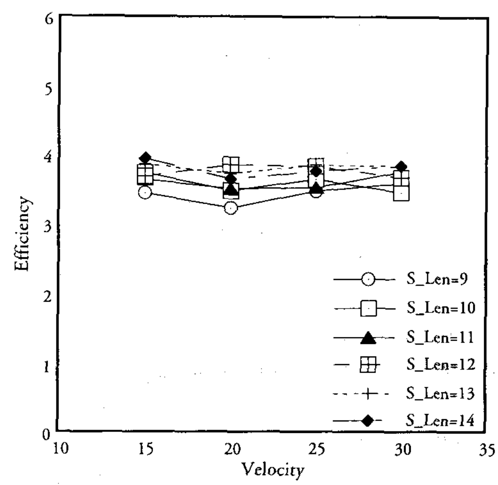
The input energy is adsorbed in the inertia terms of the moving actuator. The reduction of the momentum inertia of moving actuator will elevate the overall system efficiency remarkably.

The Motor Efficiency Test

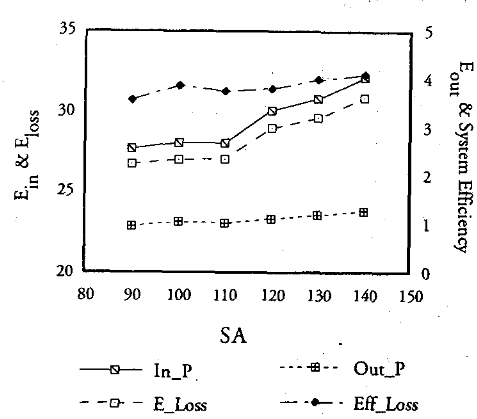
Figure 6 shows the motor efficiencies (μ_m) to various torques. The maximum values of μ_m varies with supplied voltage [Table 1].



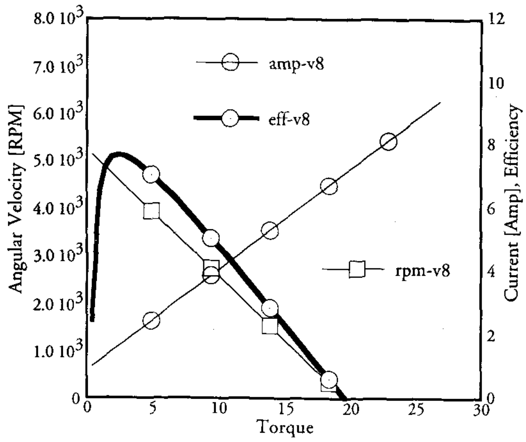
[Fig. 3] The Curve of Efficiency to Stroke Length



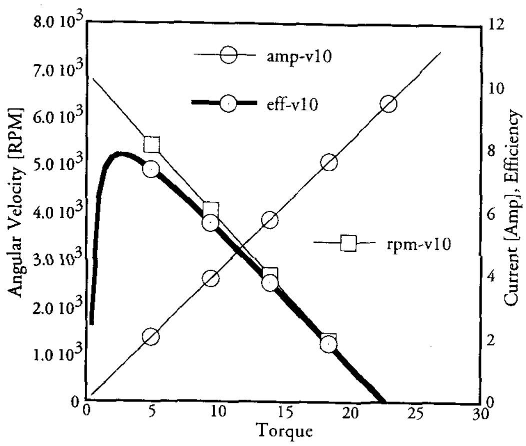
[Fig. 4] The Curve of Efficiency to Velocity



[Fig. 5] The Curves of Input Energy, Output Energy, Loss Energy and System Efficiency



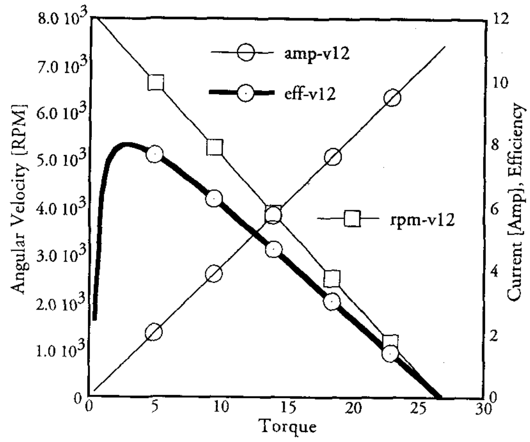
[Fig. 6] The Curve of Torque to Angular Velocity, Current and Efficiency (V=8)



[Fig. 7] The Curve of Torque to Angular Velocity, Current and Efficiency (V=10)

Voltage	Efficiency
8	77
10	78
12	80

[Table. 1] The Max. of the Motor Efficiency vs Voltage



[Fig. 8] The Curves of Torque to Angular Velocity, Current and Efficiency (V=12)

As the motor operates dynamically, the dynamic efficiency of the motor should be evaluated.

To improve the overall system efficiency, there needs the more research on the designs and fabrications of TAH.

References

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