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Development of Rotary-Brake Design in Motorized Upper Limb Prosthetics

Wirawat Sirisopha, Jackrit Suthakorn*

Department of Biomedical Engineering, Mahidol University, Nakorn Pathom, 73170
*Corresponding Author: egjst@mahidol.ac.th

Abstract

The technology on upper-limb prosthesis has been consequently improved to serve the patients' general needs for their living and life style. The needs include: (1) the need to re-gain their living abilities closed to normal people; (2) the need of prosthesis with cosmetic function (generally, a passive mechanism) and; (3) the need of prosthesis with a high-performance for sport activities [1]. Currently, the research on motorized upper-limb prosthesis has recently gained a momentum to improve the patients' even better living ability. However, a significant problem, which slows down the development, is the high-energy consumption on the motorized prosthesis, especially, at the elbow joint. This drawback is occurred when the amputee desires to move and hold their arms at a specific position while holding an object. The energy is drained during elbow's locking state as much as or greater than the moving state. The high-energy consumption problem would affect the prosthesis design at the power storage section. Therefore, this requires increasing the weight and cost. Our study introduces an approach to integrate a specific break/crutch onto the motorized joints of upper-limb prosthesis. However, such specific break/crutch is different in function, output-torque, material, weight and dimensions to the current availability in the industrial lines. Our study has found a suitably designed clutch system that reduces energy consumption but gives an appropriate output torque. Our study is also design a new crutch mechanism of non-backdrivable that provides two-directional rotation, called "2D Rotational Sprag Clutch," previously presented the conceptual design in [2]. The design and prototyping development of 2D Rotating Sprag Clutch is presenting in the paper. The initial test is also discussed, and has shown the good results.

Keywords: Non-backdrivable mechanism, Sprag clutch, Motorized Upper limb prosthetics, Elbow locking

1. Introduction

The technology of motorized upper limb prosthetics has been continually improved to reach the highest functions and activities to serve the user for their living and life style. The products of motorized upper limb prosthetics have been developed and commercialized by many companies such as Otto Bock, Touch bionics, Boston, etc. The generations of upper limb prosthetics are starting from the uses of simple Bowden cable as a pulley and harness system to control arm movement which has changed little over few years and also still in use today [3]. This pulley system is called the non-powered system. For powered system, there have been developed to use pneumatic hand as a second generation which patented in Germany in 1915 and generally use during 1950s. After World War II, the first myoelectric prosthesis, the third generation, has been developed and widely known as a vacuum tube amplifier control. Myoelectric prosthesis is the prosthesis which uses electromyography (EMG) signals to control the movements of prosthesis such as elbow flexion/extension, wrist rotation, or grasping hand. IBM and other companies had developed to solve the problems of non-portable, no battery operated and large by using gear shift mechanism to obtain high gripping force from electric motor which can be seen as a principle in current Otto Bock Hand [4]. Finally, the myoelectric controlled system had developed and use until now with portable batteries and small electric motors. The commercial myoelectric upper limb prosthesis had been developed over 70 years with many interesting applications for example the Vaduz hand and the electric powered hand from Army Medical and Biomechanical research Laboratory. The Vaduz hand was created a hand controlled by the muscles of prehension by using the gear shifting mechanism to obtain high gripping force from electric motor as similar to a principle in current Otto Bock hands which seen during the early post-war period. The electric powered hand is using a slip detector in the thumb to grip the objects at the fingertips when the object tries to slip out and also automatically increase the gripping force to hold the objects on the hand until the slippage stopped.

The mechanism of motorized upper limb prosthesis can separated to two parts of preparation and prosthetic part. The preparations of the amputee start with the discussion of the amputee, surgeon, and physical therapist to discuss of what will happen after surgery. The amputee will need an exercise to increase the muscle strength and flexibility for preparing after surgery and amputation. The prosthetic part is start with the nerve innervation from the surgeon by renovated the nerves that controlled arm or hand movement from amputee's shoulder to the chest muscle. The electrodes will place on the amputee's chest muscle and in the socket of harness of upper limb prosthesis to make a connection between amputee and prosthesis. Next step is about how the prosthesis compatible with user such as size and shape of prosthetics, how to learn to use the prosthesis. Therefore, the amputee needs to be training from the therapist to improve the strength as well as teaching them how to use the prosthesis for daily activities.

When amputee using the prosthesis and want to move their prosthesis's arm to the desired position or want to hold their arm to hold objects, the power is the main components which control some of these movements. The prosthesis needs power to control the movement which led the system needs more energy storage. Therefore, the power limitation and the energy consumption of the prosthetics will be the problem of this study. Another problem which can be a side effect of energy storage is weight and cost increase. To solve these problems, our study has found a suitably designed clutch system that reduces energy consumption but gives an appropriate output torque. Our study is also design a new crutch mechanism of non-backdrivable that provides two-directional rotation, called "2D Rotating Sprag Clutch". The design and prototyping development of the 2D Rotating Sprag Clutch is presenting in this paper. The initial test is also discussed, and has shown the good results.

2. Previous Works

The previous works in this study is including two sections. First part is described in brake selections which compare general specification of commercial brake/clutch. Second part is described in interesting commercial upper limb prosthetic products.

2.1 Brake/Clutch Selections

The brake/clutch selection to use in this study has been review in previous works [2]. The clutch is review by compare the specification in strong and weak points of each commercial brake/clutch. The comparison shows the strong and weak points of band brake, particle brake, wrap-spring clutch, roller clutch, and sprag clutch. Band brake is simple and cheap but wear is occurred during working. Particle brake is freely spun when energizing coils. Wrap spring clutch is low cost and no slip when rotate backward but torque density is underestimate which is equal to 0.00623 Nm/g. Roller clutch is simple design, freely spin in one direction and lock in opposite direction, and give a good torque density of 0.15 Nm/g. Sprag clutch is low cost, simple design, and give maximum torque density better than other one-way type clutch which is equal to 2.467 Nm/g. From the brake/clutch selections shown above, it seems that the sprag clutch is the most suitably clutch to use in the study because it shows the best torque density. In this study is focusing on torque density which can describe as the study required a good torque but less weight. The torque density is the ratio of torque divided by weight of the component. Therefore, the good torque density means the clutch is small and lightweight but gives a good torque which is appropriate to the objective of this study.

2.2. Interesting Upper limb Prosthetics

In both on-going research and commercial products, there are many works which are motorized upper limb prosthetics. The interesting examples are described below.

(a) Utah Artificial arm [5,6] developed by the Motion Control comes with many features such as high-speed movement, good responsive control of an elbow, and more natural movement in simultaneous elbow and hand control. The Utah arm can drive an elbow up to 22 desired positions by using DC motor and can hold loads up to 22.7 kilogram (50 pounds) but the weak point is consumed lots of energy and heavy because of the external batteries.

(b) Boston Digital arm [7, 8], the first Myoelectric controlled elbow, manufactured by Liberating Technologies (LTI) with a platform for controlling various devices such as hands, grippers, wrist rotators, and shoulder lock actuators. This arm is use sprag type clutch as a motor to drive the arm in both flexion/extension direction and can be locked in every position as soon as the motor not powered.

(c) Otto Bock Dynamic arm [9] which developed to use with transhumeral and shoulder disarticulation amputees is lower battery weights and faster than other elbows prosthesis because the use of a variable gear mechanism.

(d) Touch Bionics I-limb hand [1,10], the first commercial available bionic hand which looks and acts like a real human hand, is the multi-articulating finger which each finger can be automatically locked into desired position when pressing finger against a firm surface which controlled by patient's limb muscle signal through separated motor.

3. Materials and Method

3.1 Sprag clutch structure and mechanism

The structure of a general sprag clutch is consists of four main parts which are inner and outer race, sprags, energizing spring, and retainer.

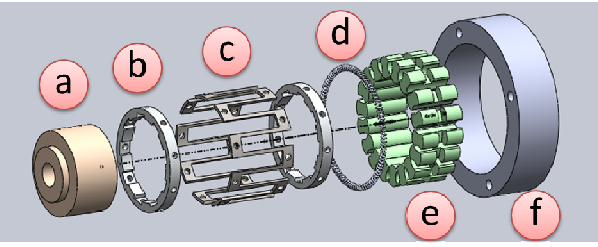

Fig.1 Structure of sprag clutch consists of inner race (a), cage lock (b), cage (c), spring (d), sprags (e), and outer race (f)

The sprags which placed between inner and outer race (see in fig.1e) are used to transmit torque during an engagement of clutch. The different shapes or materials of the sprags make the different results of engagement and usage function. Generally, the material of sprag is heat-treated high-carbon chromium steel, which will make the sprags more hardness. The energizing spring (see in fig.1d) used to prevent the clutch from backlash during the operations and to hold the sprags in a contact position with inner and outer races to become engaging. The materials is generally use as stainless steel or special alloy. The inner and outer race (see in fig.1a and 1f) are used to arrange the sprag into the line for uniform torque transmission. The retainer or cage (see in fig.1c) is generally made by heat-treated carbon steel plate that served in three usage purposes. First, it used to prevent the sprags from moving out of a proper position in two opposite directions. Second, they separate the sprags out around the races to provide a uniform stress distribution and to decrease the friction that comes from sprag contacting points, and (3) they insure the sprags to get engaging or disengaging and make the sprags get faster engagement.

The sprag clutch mechanism is generally rotates in one direction and lock in the opposite direction when running under loads. However when turning the clutch in the locked direction or in opposite direction of the initial rotation, the friction force and contact force from each sprag will make each sprag lock together.

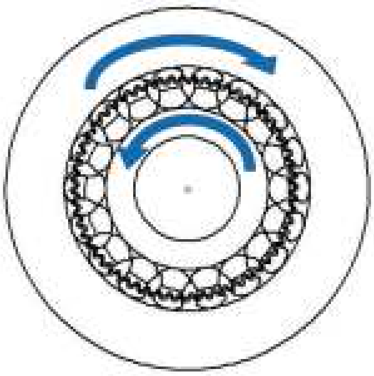

Fig.2 General mechanism of sprag clutch

The general mechanism can describe by the illustrated of fig.2. When the inner race attempts to rotate in counterclockwise direction, the outer race will turn freely in clockwise direction by the contacting of sprags. On the other hand, the outer race will locked by sprags engagement when the inner race attempts to rotate in clockwise direction.

3.2 Required mechanism

This paper is concentrate to use non-backdrivable mechanism which is a mechanism of passive movement [11,12]. The non-backdrivable mechanism is starts when the inner race attempts to rotate in either clockwise or counterclockwise directions that will let the outer race to turn freely in both directions by the sprag engagement. In the other way, the inner race was grounded which the outer race will not move in both directions. In passive movement, it means the sprag clutch will lock/unlock the clutch directions by their own mechanism as illustrated in fig.3.

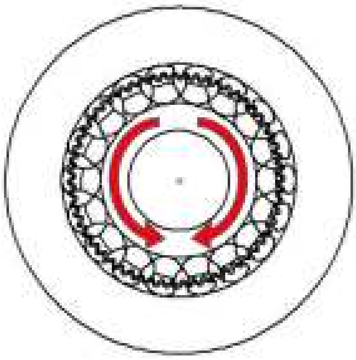

Fig. 3 Required sprag clutch mechanism

4. Experiment and Results

The design experiment can separated to two parts such as simulation and rapid prototype part. The simulation part will show the possibility of designed sprag clutch in displacement and rapid prototype will prove the simulation section.

4.1 Simulation

Due to previous work [2], the simulation of designed sprag clutch had shown the good results of two-directional rotation after applied torque to rotate inner and outer race in different four steps of rotations. To see the real movement of design sprag clutch, the rapid prototype is the good choice to make a fast and cheap model.

4.2 Rapid Prototype

The rapid prototype has been made from the designed components of sprag clutch which exclude the sprag's retainer. The sprag's retainer is build up by machining technology instead of using rapid prototype because the rapid prototype technology cannot be made the very small component like the retainer. Fig. 4 and 5 will show the complete part of rapid prototype of design I which consist of (1) sprags, (2) inner race, (3) outer race, (4) aluminum retainer, and (5) retainer lock.

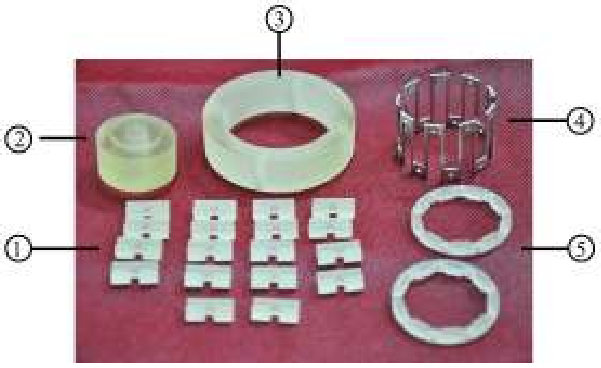

Fig. 4 Rapid prototype components of designed sprag clutch

Fig.5 Rapid prototype of designed sprag clutch

The steps of part assembly is starting by arranged (1) into (4) one by one with appropriate position; then locking (4) by (5) side by side with the screws and nuts; put (2) and (3) axially in to the complete inner part assemble of (1), (4), and (5). The complete assembled part has been tested manually by hand to see the rough mechanical movement. The result is shows that the sprag clutch can moved in both directions but cannot be locked when moving the outer race and grounded inner race.

5. Conclusion and Future work

The simulation of designed sprag clutch shows the good result of two-directional rotation with non-backdrivable mechanism when applied 1Nm torque to both inner and outer race. Therefore, the rapid prototype has been made to prove and see the real displacement. The result from rapid prototype doesn't show good results of two-directional rotation because the reasons of materials and the friction coefficient of two contacting surface. The main parameters in this study are the shape of the sprags and type of material that it uses. Therefore, the materials and the sprag's shape should be considered as a future work which is on the process of literature review.

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7. References

[1] M. Fairley (2009), *State-of-the-Art Upper-Limb Prosthetics Technology*, The O&P EDGE, pp. 24-32, URL: http://www.oandp.com/articles/2009-10_ 01.asp

[2] W. Sirisopha and J. Suthakorn (2011). A Study of Rotary-Brake Design for Utilizing in Motorized Upper Limb Prosthesis, paper presented in *2011 International Conference on Computer Control and Automation*, Jeju Island, South Korea, pp. 129-133.

[3] H. H. Sears. (1992), Special Considerations: Trends in Upper-Extremity Prosthetics Development, *Atlas of Limb Prosthetics: Surgical, Prosthetic, and Rehabilitation Principles*, 2nd Edition, Rosemont, IL.

[4] R. F. Weir and J. W. Sensinger (2003), *The Design of Artificial Arms and Hands for Prosthetic Applications in Biomedical*

Engineering and Design Handbook: Volume 2: Applications, 2nd Edition, ISBN: 0-07149-839-7, McGraw Hill, pp. 537-598.
[5] E. Iversen, H. H. Sears, and S. C. Jacobsen (2005), Applications of control: Artificial arms evolve from robots, or vice versa?, *IEEE Control Systems Magazine*, vol. 25, pp. 16-20.
[6] S. C. Jacobsen, D. F. Knutti, R. T. Johnson, and H. H. Sears (1982), Development of the Utah artificial arm, *IEEE Transactions on Biomedical Engineering*, vol. 29, pp. 249-269.
[7] Boston Digital Arm™ System, URL: http://www.liberatingtech.com/products/LTI_Boston_Arm_Systems.asp.
[8] C. Toledo, L. Leija, R. Munoz, A. Vera, and A. Ramirez (2009), Upper limb prostheses for amputations above elbow: A review, *Health Care Exchanges*, Pan American, pp. 104-108.
[9] R. J. Sobotka, The Use of Myoelectric Control in Upper Extremity Prostheses, URL:http://www.ballertop.com/myoelectric_contcon.asp
[10] C. Connolly (2008), Prosthetic hands from Touch Bionics, *Industrial Robot*, vol. 35, pp. 290-293.
[11]M. Hild, T. Siedel, T. Geppert, S. Jeschke, H. Liu, and D. Schilberg (2011), Design of a Passive, Bidirectional Overrunning Clutch for Rotary Joints of Autonomous Robots, paper presented in *Intelligent Robotics and Applications*. vol. 7101: Springer Berlin, Heidelberg, pp. 397-405.
[12] M. Controzzi, C. Cipriani, and M. C. Carrozza (2010), Miniaturized non-back-drivable mechanism for robotic applications, *Mechanism and Machine Theory*, vol. 45, pp. 1395-1406, doi 10.1016/j.mechmachtheory.2010.05.008.