ELECTROMAGNETIC KNEE HARVESTER

Arun Das P[1], Christo Jose[2], Alsaf P N[3], Prof. Dr. Babu Paul[4]

[1,2,3] Students, Department of Electrical and Electronics Engineering, Mar Athanasius College of Engineering Kothamangalam, Kerala, India
[4]Professor, Department of Electrical and Electronics Engineering, Mar Athanasius College of Engineering Kothamangalam, Kerala, India

---***---

Abstract - *Bio-mechanical energy harvesting is becoming a thrust area for research. When undertaking any physical activity, the human body generates a significant amount of biomechanical energy, which can be collected by means of a portable energy harvester. This energy can be used to power neurostimulators, drug pumps and other implantable devices like motorized prosthetic limbs. It can also be used to power devices like mobile phones, mp3 players etc. Here, a knee-mounted energy harvester with enhanced efficiency and safety is proposed and developed to convert mechanical energy into electricity during human motion. This device can change the bi-directional knee movement during running or walking into uni-directional rotation for an electromagnetic generator using a specially designed transmission system. Without the constraint of induced impact on the human body, this device can harvest biomechanical energy from both knee flexion and extension, improving the harvesting efficiency over previous single-direction energy harvesters. A highly compact and light prototype is developed taking into consideration human kinematics which is promising for portable electronic devices.*

Key Words: Knee-mounted; bio-mechanical; energy harvester; bi-directional; safety; efficiency

1. INTRODUCTION

Our society has become increasingly dependent on portable electronic devices [1] like mobile phones to laptop computers. As energy per unit mass in batteries used to exclusively power these devices are limited, there is a trade-off between device power consumption, battery weight and duration of operation. Consider an example where a typical mobile phone consumes 0.9 W power requiring a 18 g Li-ion battery for 3 hours of talk time [2], a typical laptop computer requires a 720 g Li-ion battery to satisfy its 28 W electrical power needs, lasting less than 4 hours [3]. But, this variation is particularly severe in the design of powered prosthetic limbs which should be performing their sophisticated task over a full day of typical use while being light weight. There are devices which operate for more than 36 hours from a single charge of a battery that weighs about 230 g battery consuming an average power consumption of less than 1 W [4]. Substantial development must be made on operating time and performance of a portable device, by developing an alternative to the current battery technology [1].

Human power is an attractive energy source. Food is converted to positive mechanical work by our muscle with peak efficiency of approximately 25%, comparable to that of IC engines [5]. The average energy density of food is 35-100 times higher than batteries. Moreover, during one day of activity a person uses approximately 10.7MJ of energy. To store this amount of energy using batteries, a bank of approximately 20Kg is required [6]. It is not surprising that many inventions have focused on converting human mechanical power into electrical power due to these attractive properties.

Biomechanical energy can be harvested in several ways. Shenck and Paradiso harvested energy from heel strike [7] by developing an energy scavenging shoes with piezoelectric materials. Floors that scavenge human kinetic energy when people walk across them were also investigated [8, 9]. Rome et al utilized a backpack with a suspended load to convert the kinetic energy of the load to electrical energy [10]. Ylli et al developed and compared two inductive energy harvesters from swing and shock excitations of the foot [11]. From these studies, it seems very encouraging to harvest energy from the rotational motion of the knee joints, as the power is obtained from the negative work done by the muscles [12]. This negative work can be effectively harvested with minimum extra metabolic power input [13].

Knee-mounted energy harvesters have been investigated over the past few years. Piezoelectric and electromagnetic transductions where some of energy conversion techniques studied. Electromagnetic transducers are preferred due to their compactness, cost-effectiveness and high efficiency [14–16]. Power output as high as a few watts, which is enough for many portable devices could be harvested efficiently from rotational motion at lower frequencies, with reasonable generator size.

During walking, knee joints behaves like that of an inverted pendulum, in which the direction of angular motion is opposite during the flexion and extension phases over one gait cycle [17]. Safety is also a major issue for human assistive devices. The inertia of the torque transmission system may pose a danger to the knee joint. The generator may continue to rotate even after the motion of the knee joint has stopped, and may induce torque to the wearer if the force transmission from the reverse direction cannot be blocked. Besides, for energy harvesting systems with EM generators, the latter can also operate as active motors if power supplied, resulting in serious injury to the leg. Previous researches have not addressed the safety issue from the mechanical point of view. To improve efficiency and safety of bio-mechanical energy harvesters, we propose a novel knee-mounted energy harvester that can convert mechanical power from the knee joints into electricity during walking. This device can change the bi-directional rotational input from the knee into uni-directional rotation for an electromagnetic generator, using a specially designed transmission system. Efficiency of energy harvesting is improved, as all negative work during gait cycles can be harvested. At 1.5 m s−1 walking speed, our prototype can harvest an average power of 3.5W, which is enough for most portable devices in both daily and medical applications [18].

2. DEVICE WORKING PRINCIPLE

The electromagnetic knee harvester is a dynamic system which can convert biomechanical energy to electrical energy. Figure 1 shows schematic of proposed system. It basically consists of electromagnetic generator, energy harvester, knee brace and harvesting circuit. Figure 2 shows internal structure of the biomechanical energy harvester. Considering the distinct functions of muscle, we distinguish between two general methods of harvesting energy: parasitic and mutualistic. For parasitic energy harvesting, the electricity is harvested at the expense of metabolic energy of the user.

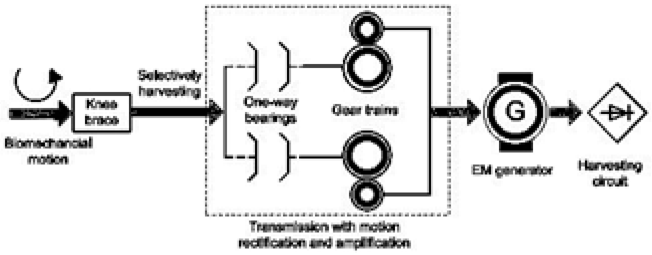

Fig -1: Schematic of the electromagnetic knee harvester

In this method, the energy is harvested during the periods when muscles normally perform positive work, causing muscles to perform more positive work than they would otherwise. On the other hand, mutualistic energy harvesting is accomplished by selectively harvesting energy at times and in locations when muscles normally decelerate the body.

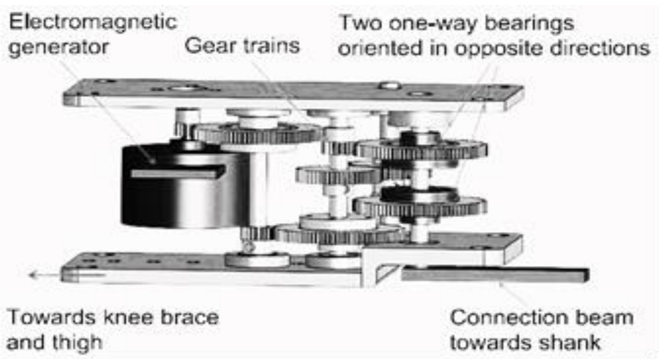

Fig -2: Internal structure of the electromagnetic knee harvester

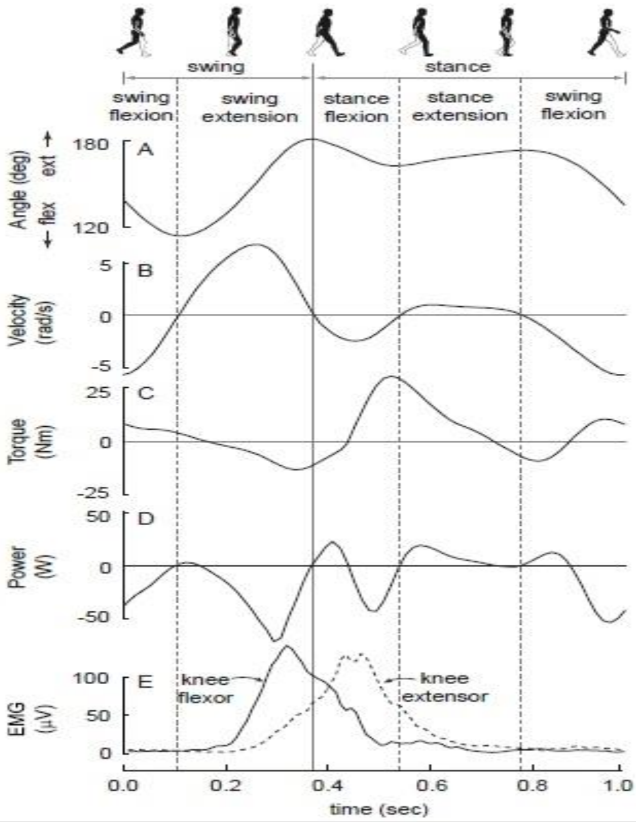

Fig -3: Typical knee joint mechanics and muscle activity during walking (subject mass=58kg; speed=1,3m/s; step frequency=1.8Hz. Data from [19,20]. A) Knee joint angle where 180 degrees is full extension. B) Knee joint angular velocity is motion in the extension direction. C) Knee joint torque with the convention that extensor muscle torques are positive. D)Knee joint power. E) Rectified and filtered electromyograms(EMG) from one knee flexor muscle (solid line) and one knee extensor muscle (dashed line).

Typical knee joint mechanics and muscle activity during walking is shown in Figure 3 [19,20]. Rather than braking entirely with muscles, a generator would perform some of the required negative work converting the mechanical energy of the body into electrical power. Spur gear train to range the equipment. The low angular velocity and high torque of the knee motion are transmitted and converted into high angular velocity and low torque at the generator by gear trains. The shaft connector is rotate the gear train to speed up the rotational speed to generate the current in efficiently. The roller clutch to lock the one directional rotational. Wearer's thigh is fitted with knee brace in which the generator is fixed, and the input torque is transmitted through a connection beam that is fixed on the shaft.

3. DEVICE DESIGN

The energy harvester must be adaptable with the kinematics of lower limb. The requirements of range of motion must cover the range of the knee joint for normal walking, with an extra safety margin. The energy harvester made has a knee flexion angle of 120° range, which is enough to avoid any constraints to the normal motion of leg. There are four main challenges for designing a device to harvest energy from the motion of the knee joint in biomechanics of walking. The first one was to find an effective mechanism for converting biomechanical power into electrical power. This generator had to be worn on the leg, so it needed to be small and lightweight. The second challenge was to design and develop a mechanism for converting the intermittent, bi-directional and time varying knee joint power efficiently into suitable form. The third one was to optimize parameters of the system to maximize the electrical power generated without adversely affecting the walking motion.

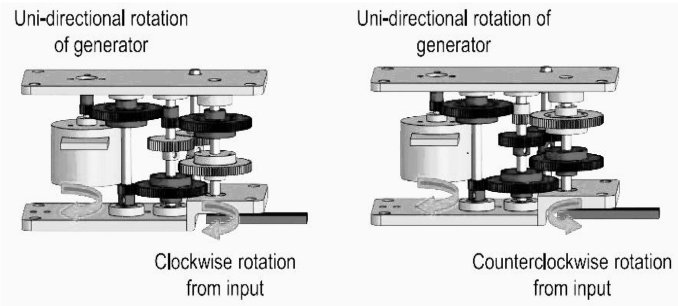

Fig-4: Torque transmission mechanism by which bi-directional knee input is converted into uni-directional rotation for generator

Only a certain amount of knee mechanical power is available at any point in the walking cycle. Attempt to harvest too much power will hinder the motion of user. To harvest energy from both the flexion and extension movement of our limb, a transmission system, which has the functions of motion rectification as well as amplification is developed. It converts the bi-directional input torque from the knee into uni-directional rotation at the electromagnetic generator. Figure 4, shows the torque transmission route with principle of the motion rectification. It has two one-way bearings mounted at the input shaft, oriented in opposite directions. These bearings can selectively transmit the input torque from different rotating directions through two different gear trains. There are different gear numbers for the two gear trains. The one-way bearings and gear trains will work together to unify the rotation direction at the generator. As a result, the efficiency of energy harvesting is improved.

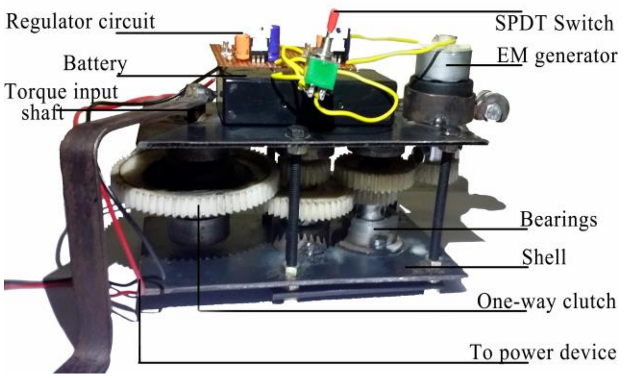

Fig -5: Hardware implementation (prototype) of the electromagnetic knee harvester

Figure 5, shows photo of the assembled prototype. The energy harvester enclosed between two plates consists of bearings to reduce friction. A PMDC generator is selected for energy conversion which is compact and has high conversion efficiency. The gears used are plastic gears which are light and has high mechanical strength. Three stage gears are used for power transmission during swing phase and during stance four stage gears are used in the gait cycles. A knee brace is used to interface the system to user's thigh as shown in Figure 6. The generator output which is varying dc is fed to an 8V voltage regulator 7808 whose output charges the 6V chargeable battery. Diodes are introduced to provide safety, to avoid motoring action of generator back from the battery as shown in Figure 7. An SPDT switch is provided for supplying power to load from battery through a 5V voltage regulator 7805 when required.

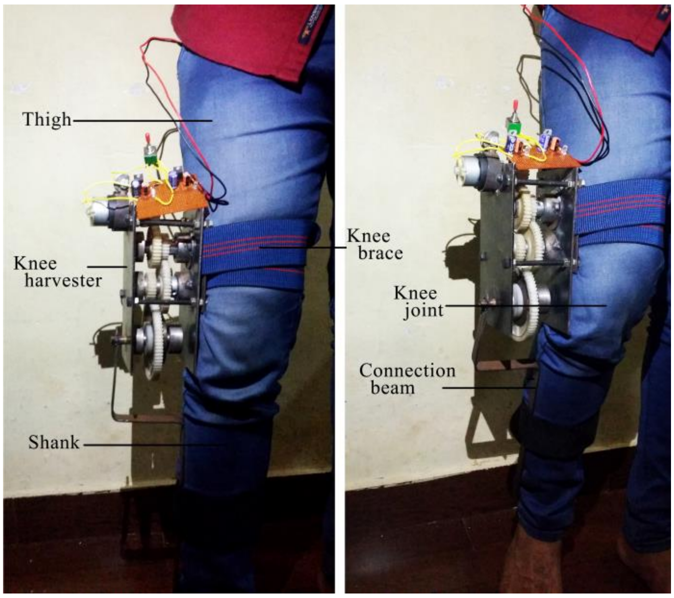

Fig-6: Photos of knee harvester mounted on human lower extremity

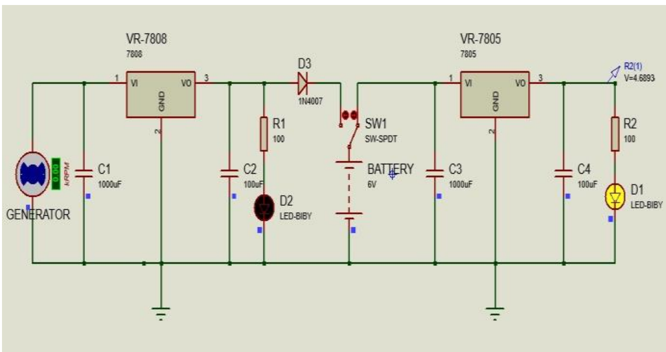

Fig-7: Circuit for charging battery from the knee harvester and supplying to load.

4. CONCLUSIONS

A bio-mechanical knee mounted energy harvester with improved efficiency is proposed and developed. The bi-directional knee rotation input is converted to uni-directional motion by a modified gear train mechanism which is fed to an electromagnetic generator. This device can harvest energy from both knee flexion and extension movement thus improving overall efficiency of the system.

A light and compact prototype was developed considering human kinematics. We can harvest an average power of 3.5W at 1.5m/s walking speed, which is enough to power most portable electronic devices. While future versions of this technology may prove useful to the public for powering their portable devices, people whose lives depend on portable power will embrace it more quickly. The systems principles could also be embodied in a fully implanted energy harvester to power neurostimulators, drug pumps and other implantable devices.

5. FUTURE WORKS

Future researches will focus on developing energy harvester with reduced user's effort. The local torque monitoring, oxygen consumption, global gait analysis testing can be done to improve connections between the body and harvester. Controlled energy harvesting scheme can be used to reduce human effort by using sensor-controlled detection method.

REFERENCES

[1]. Starner T, Paradiso JA: Human generated power for mobile electronics. In Low-power electronics design Edited by: Piguet C. Boca Raton: CRC Press; 2005.

[2].Nokia6301datasheet [http://www.nokia.com/A4140021]

[3]. Dell™ Inspiron™ 1525/1526 product information [http://support.dell.com/support/edocs/systems/ins1525/en/index.htm]

[4].OttobockCLeg [http://www.ottobock.com/cps/rde/xbcr/ob_com_en/ifu_647h215_d_gb_f_e_c_leg.pdf]

[5]. Margaria R: Positive and negative work performances and their efficiencies in human locomotion. Int Z Angew Physiol 1968, 25:339-351.

[6]. Starner T: Human-powered wearable computing. IBM Systems Journal 1996, 35:618-629.

[7] Shenck N S and Paradiso J A 2001 Energy scavenging with shoe-mounted piezoelectrics IEEE Micro 21 30–42

[8] http://sustainabledanceclub.com

[9] http://innowattech.co.il

[10] Rome L C, Flynn L, Goldman E M and Yoo T D 2005 Generating electricity while walking with loads Science 309 1725–8

[11] Ylli K, Hoffmann D, Willmann A, Becker P, Folkmer B and Manoli Y 2015 Energy harvesting from human motion: exploiting swing and shock excitations Smart Mater. Struct. 24 025029

[12] Winter D A, Patla A E, Frank J S and Walt S E 1990 Biomechanical walking pattern changes in the fit and healthy elderly Physical Therapy 70 15–22

[13] Niu P, Chapman P, Riemer R and Zhang X 2004 Evaluation of motions and actuation methods for biomechanical energy harvesting Power Electronics Specialists Conf., PESC 04. 2004 IEEE 35th Annual pp 2100–6

[14] Cheng W L, Chen C and Liao W H 2014 Design considerations in medium-power biomechanical energy harvesting circuits IEEE Int. Conf. on Information and Automation pp 783–8

[15] Donelan J M, Li Q, Naing V, Hoffer J A, Weber D J and Kuo A D 2008 Biomechanical energy harvesting: generating electricity during walking with minimal user effort Science 319 807–10

[16] Donelan J M, Kuo A D, Hoffer J A, Li Q and Weber D 2010 Method and apparatus for harvesting biomechanical energy US Patent, No. US7652386B2

[17] Gage W H, Winter D A, Frank J S and Adkin A L 2004 Kinematic and kinetic validity of the inverted pendulum model in quiet standing Gait & Posture 19 124–32

[18] Yun J, Patel S N, Reynolds M S and Abowd G D 2011 Design and performance of an optimal inertial power harvester for human-powered devices IEEE Transactions on Mobile Computing 10 669–83

[19]. Winter DA: Biomechanics and motor control of human movement 2nd edition. New York: Wiley; 1990.

[20]. Hof AL, Elzinga H, Grimmius W, Halbertsma JP: Speed dependence of averaged EMG profiles in walking. Gait & Posture 2002,16:78-86.