IFERP
connecting engineers... developing research

ISSN (Online) 2456-1290

International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)

Vol 11, Issue 4, April 2024

Design and Development of Passive Knee Exoskeleton

[1] Yunus Dalal, [2] Vignesh Arumugam, [3] Krish Solanki, [4] Divyesh Panchal, [5] Kalpesh Patel

[1] Assistant Professor, St. Francis Institute of Technology, Mumbai, Maharashtra, India
[2] [3] [4] [5] Student- St. Francis Institute of Technology, Mumbai, Maharashtra, India
Corresponding Author Email: [1] yunusdalal@sfit.ac.in, [2] vignesharumugam78@student.sfit.ac.in,
[3] krishsolanki66@student.sfit.ac.in, [4] panchaldivyesh17@student.sfit.ac.in, [5] kalpeshpatel@student.sfit.ac.in

---

Abstract— ***Knee joints are crucial for daily activities like standing and walking. However, many people suffer from knee impairments such as muscle weakness, pain, paralysis, and gait disorders due to various reasons like stroke, spinal cord injury, post-polio, injury, osteoarthritis, and other diseases. These impairments significantly affect the quality of life of such patients as they are unable to perform daily activities like normal individuals. Therefore, devices that can help such patients regain the ability to walk with a natural gait are desirable. These devices are designed to improve the physical and mental health of the affected individuals. Passive exoskeletons are not motorized and are often used for ergonomic support, to prevent repetitive stress injuries, or to help hold tools or equipment. The design of the device comprises of springs that work in parallel with the muscles of the quadriceps femoris. The springs store mechanical energy during knee flexion (the negative work phase) and release that energy during the subsequent knee extension (the positive work phase), augmenting the muscles. However, due to the high costs of the exoskeleton, people cannot buy this exoskeleton. However, for cost efficiency and to reduce the pain in the knees of old age people who also carry regular life weights this passive knee exoskeleton will help.***

Index Terms— ***Osteoarthritis, to improve the physical and mental health, Reduce the pain in the knees of old age people.***

I. INTRODUCTION

The ability to work is a widely accepted indicator of mobility and independence. Unfortunately, a significant proportion of the population experiences a decline in mobility due to aging or chronic health conditions. As a result, there is a pressing need to develop systems that can prevent or mitigate the likelihood of knee pain. The human knee joint plays a pivotal role in performing daily life activities, such as standing and walking. However, many patients worldwide suffer from knee impairments such as muscle weakness, pain, paralysis, and gait disorder, which a stroke, spinal cord injury, post-polio injury, osteoarthritis, and other diseases can cause. These patients cannot perform daily activities like normal people, significantly affecting their quality of life.

To address this issue, developing devices that can help individuals with knee dysfunction regain the ability to walk with a natural gait is desirable. Such devices are designed to improve these patients' physical and mental health. Over the past decade, wearable medical devices, such as exoskeleton and active orthoses, utilizing robotic technologies have been developed for patients with walking disabilities. Passive knee exoskeleton are a common conservative treatment option for reducing pain and improving function in people with musculoskeletal injuries and diseases like knee osteoarthritis. They can also enhance the wearer's strength, endurance, and speed by providing most of the energy required to perform task.

Given the prevalence of knee impairments and their significant impact on patients' quality of life, the development of devices that can help them regain their mobility is a critical area of research. The advent of wearable medical devices, such as exoskeleton and active orthoses, provides a promising solution for patients with walking disabilities. By utilizing robotic technologies, these devices can provide patients with the support they need to perform daily activities and regain their independence.

Table 1: Statistics [1]

Facts	Statistics
In 2019, worldwide population with osteoarthritis	About 528 million (an increase of 113% since 1990)
Percentage of people with osteoarthritis older than 55 years	73%
Percentage of people with osteoarthritis who are female	60%
Most frequently affected joint for osteoarthritis	Knee (prevalence of 365 million)
Other frequently affected joints	Hip & Hand
People with osteoarthritis experiencing moderate or severe severity levels	344 million (could benefit from rehabilitation)
Factors contributing to the increase in osteoarthritis prevalence	Aging populations, increasing obesity, and injury
Osteoarthritis as consequence of aging	Not an evitable consequence of aging

II. LITERATURE REVIEW

Van Dijk and colleagues (2011) proposed a for designing by utilizing the phase of a task energy is stored during work on a joint and returned during work done by a joint. This same methodology was employed by Etenzi et al. (2020) in the creation of a passive knee-ankle exoskeleton that focuses on storing and returning energy during specific phases of the gait cycle. Sawicki and Ferris (2008) characterized the mechanics and energetics of gait when using unpowered ankle exoskeletons, and this understanding has influenced ankle exoskeleton designs in subsequent literature. Collins et al. (2015) and Nasiri et al. (2018) demonstrated that ankle designs aimed at optimal stiffness can reduce metabolic cost during gait and running. Witte et al. (2020) investigated the effects of powered and unpowered exoskeletons on human running. Additionally, Yandell et al. (2019) designed passive ankle exoskeletons for widespread use.

When performing a squat ascent, the rectus femoris functions as both a hip flexor and knee extensor. Furthermore, this effect is more evident when the trunk is upright, as observed by Escamilla (2001). Although the stance and foot placement do not impact muscle activation at the knee during a squat, they do affect knee kinetics, as shown by Almosnino et al. (2013) and Lorenzetti et al. (2018). Therefore, an ideal device to assist with reducing muscle activation should not significantly influence the user's preferred stance and foot-loading profiles. As a solution, a passive, unpowered exoskeleton called Spring-Exo was proposed by the researchers. Spring-Exo is specifically designed to aid knee extension and reduce rectus femoris activation during squat ascent. By utilizing the power profile illustrated in Figure 1, Spring-Exo can store energy during descent and release it during ascent. With the help of the spring providing joint torque during ascent, the user's effort and muscle activation during ascent can be minimized.

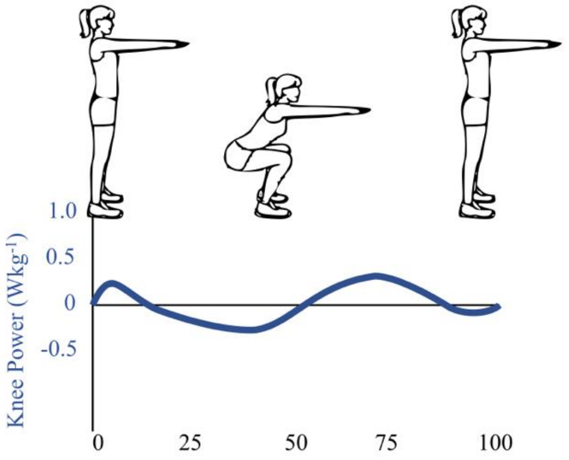


Fig. 1: Squat% [2]

Passive exoskeletons leverage human biomechanics to improve task efficiency (Carrozza et al., 2017). The advantage of passive wearables lies in their discreteness, enabling them to be used in everyday life without inconveniencing the wearer (Carrozza et al., 2017). These characteristics make them well-suited for industrial settings were reducing effort and joint strain, particularly in lifting tasks, is desirable. The power and moment profiles of the knee joint during a lifting task, as characterized by Hwang et al. (2009), exhibit distinct phases of work performed on or by the knee joint, as depicted in Figure 1 [2].

Fig.1 Based on Hwang et al. (2009), the power profiles of the knee joint during a typical squat motion are displayed. The squat cycle is indicated by the upright positions at the beginning (0%) and end (100%). The midpoint of the squat cycle (50\%) represents the lowest point of the squat. The power profile of the knee demonstrates a clear transition from negative to positive power before and after the 50% mark. The descent phase of the squat generates negative power due to the assistance of gravity, which can be stored as elastic energy in a spring. This stored energy can then be released during the ascent phase to aid in knee extension. This concept forms the basis of the Spring-Exo design utilized in the study presented in this research paper [2].

Commercial passive exoskeletons typically assist in maintaining specific postures for extended amounts of time, such as the Chairless Chair (Noone, Deizisau, Germany) for long-standing tasks, the ShoulderX (US Bionics, Berkeley, CA), the Paexo (Ottobock, Duderstadt, Germany) for raised arm tasks, and the ZeroG (Eksobionics, Richmond, VA) for tool carrying. These exoskeletons provide support in a static position but cannot support the dynamic task of lifting during squatting.

III. METHODOLOGY

The predictions for knee forces during walking vary significantly due to different methods, solution algorithms, and modeling assumptions utilized. Isokinetic knee extension in open kinetic chain activities has been extensively researched due to its relatively simple modeling compared to the complexity involved in modeling walking. The earliest studies simplified the prediction of forces during walking by grouping muscles with similar functions, showing average peak forces of three times the body weight. Other studies, also grouping muscles with similar functions, indicated peak forces ranging from 1.7 to 2.4 times body weight. By using an objective function that minimizes total forces and moments, peak force predictions have approached seven times body weight, addressing the redundancy issue. Tibiofemoral contact forces during level walking, influenced by the minimized quantities, varied from 4 to 6 times body weight [3].

The forces endured by the knee during walking vary significantly among individuals and are impacted by factors like age, body weight, walking speed, and overall health. In older adults, additional factors like joint health, muscle strength, and walking patterns can further influence knee forces variability.

Studies suggest that the average vertical ground reaction force during walking ranges from 1 to 1.5 times body weight. For example, in the case of an older individual weighing 70 kilograms (154 pounds), the force exerted on each leg while walking could range from 70 to 105 kilograms (154 to 231 pounds) on average [4].

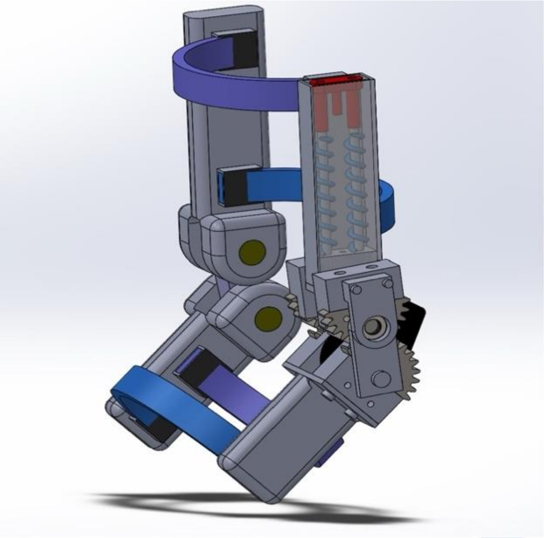


Fig. 2: Solidworks Design

A. Calculations

1. *Spring Design*

$$Walking\ Force = 850\ N$$

$$\therefore W = \frac{850}{4} = 212.5\ N \cdots \tag{1}$$

For 50CrV23,

$$\left.\begin{aligned} \tau &= 750\ Mpa \\ G &= 80 \times 10^3 N/mm^2 \\ c(SpringIndex) &= 6 \end{aligned}\right\} \tag{2}$$

$$\text{Shear Stress Factor}(K_s) = 1 + \frac{1}{2c} = 1 + \frac{1}{2(6)}$$

$$\therefore K_s = 1.08 \tag{3}$$

a) *Resultant Shear Stress*

$$\tau = \frac{8WD}{\pi d^2}$$

From (1), (2) & (3),

$$\therefore d(wire\ diameter) = 2.16 \cong 2mm \tag{4}$$

$$\because c = \frac{D}{d}$$

$$\therefore D = c \times d = 6 \times 2 = 12mm \tag{5}$$

$$\delta = \frac{8PD^3n}{Gd^4} \cdots \tag{6}$$

$$Lf(Free\ body\ Lenght) = 120mm$$

$$Lf = Ls + \delta + 0.158\delta \tag{7}$$

$$Ls = n \times d \tag{8}$$

Substituting (6) & (8) in (7) we get,

$$\therefore n = 25.6 \cong 26$$

$$\therefore Ls(SolingLength) = n \times d = 26 \times 2 = 52mm$$

b) *Pitch Spring*

$$p = \frac{Lf}{n - 1} = 4.8mm$$

2. *Buckling of column*

D = 8 mm

L = 170 mm

$$I_{min} = \frac{\pi}{4} \times D^4 = 201.06\ mm^4$$

F.O.S = 6

To find → P_{safe}

$$Le = \frac{L}{2} = \frac{170}{2} = 85mm$$

$$PE = \frac{\pi^2 EI_{min}}{(Le)^2} \rightarrow Euler'sCripplingLoad$$

$$\therefore PE = 54931\ \text{N}$$

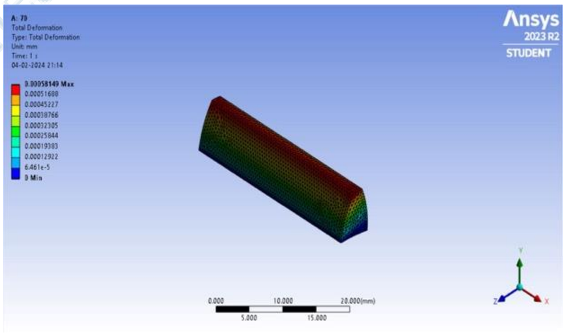
$$\therefore P_{safe} = \frac{PE}{F.O.S} = \frac{54.9 \times 10^3}{6}$$

$$P_{safe} = 6268.5\ N$$

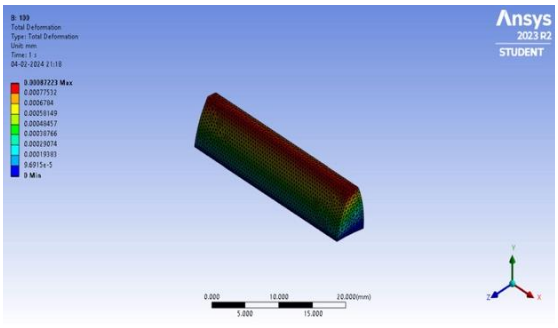
IV. RESULTS

A. Analysis Of Gear Tooth

1) *Total Deformation*

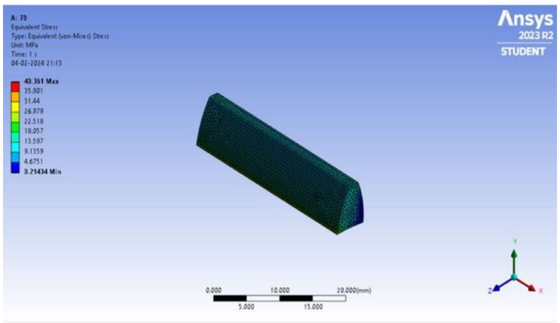


a) 70kg

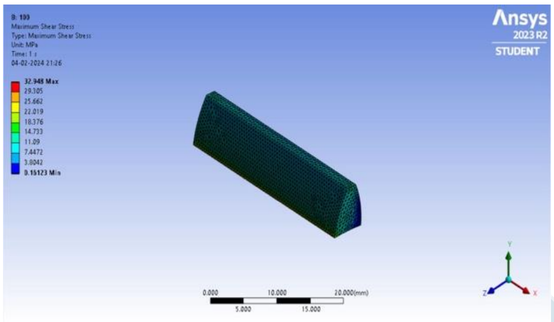


b) 100kg

2) *Equivalent Stress*

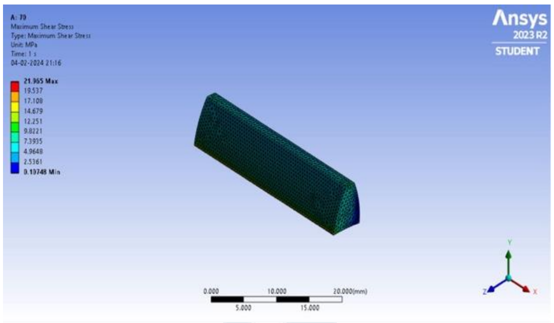


a) 70kg

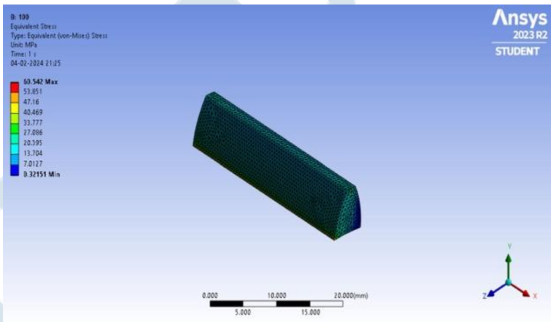


b) 100kg

3) *Maximum Shear Stress*



a) 70kg

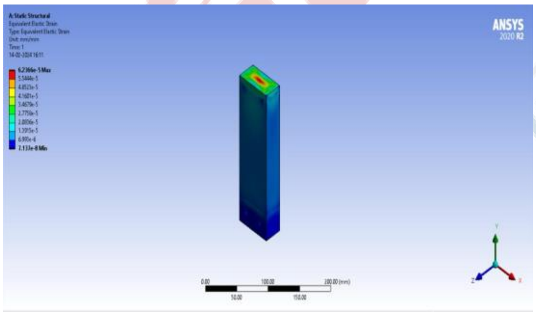


b) 100kg

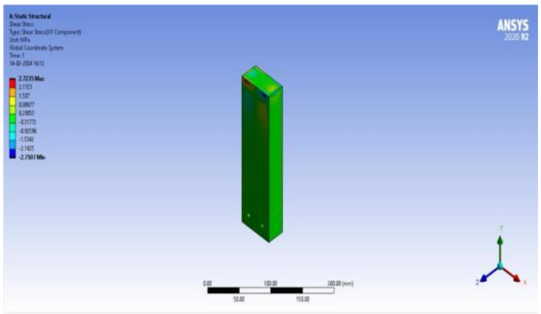
Table 2: Analysis of Gear Tooth

	70kg			100kg		
	Maximum	Minimum	Average	Maximum	Minimum	Average
Total Deformation	5.81e-004mm	0 mm	2.25e-004mm	8.72e-004mm	0mm	3.33e-004mm
Equivalent Stress	40.361 mpa	0.214 mpa	8.7 mpa	60.542 mpa	0.321 mpa	13.08 mpa
Maximum Shear Stress	21.96 mpa	0.107 mpa	4.89 mpa	32.94 mpa	0.161 mpa	7.34 mpa

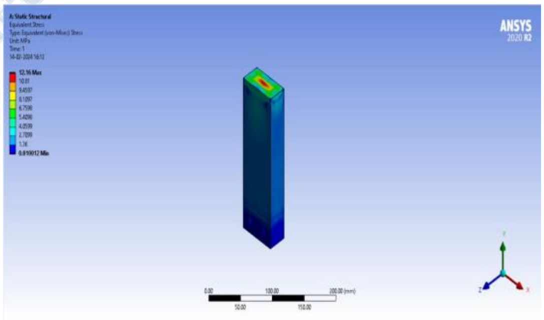
B. Analysis Of Frame



a) Equivalent Elastic Strain



b) Shear Stress



b) Shear Stress

Table 3: Analysis of Frame

	Maximum	Minimum	Average
Equivalent Elastic Strain	6.2366e-005 mm/mm	7.137e-008 mm/mm	3.2045e-006 mm/mm
Shear stress	2.7235 Mpa	-2.7507 Mpa	-4.354e-004 Mpa
Equivalent (von-Mises) Stress	12.16 Mpa	1.0012e-002 Mpa	0.59911 Mpa

V. CONCLUSION

Our research has demonstrated the successful design, fabrication, and evaluation of a passive exoskeleton prototype aimed at enhancing human performance and reducing the risk of musculoskeletal injuries in various applications.

In this project, we present a meticulously engineered design featuring a passive knee actuation system. Our innovative approach incorporates precision-crafted half gears and a sophisticated cam mechanism, augmented by resilient springs and a Bowden cable. The intricate interplay of these components facilitates seamless actuation, empowering users with enhanced mobility and comfort.

Our proposed passive knee exoskeleton design embodies a harmonious fusion of cutting-edge engineering principles and biomechanical expertise. By seamlessly integrating precision components and sophisticated mechanisms, we aim to revolutionize the landscape of assistive technologies, empowering individuals with knee impairments to navigate their world with newfound confidence and ease.

The development of this passive exoskeleton represents a significant advancement in the field of wearable robotics, offering a cost-effective and practical solution for augmenting human capabilities without the need for external power sources.

REFERENCES

[1] "Osteoarthritis." *World Health Organization (WHO)*, 14 July2023,https://www.who.int/news-room/fact-sheets/detail/ osteoarthritis.

[2] R. Hidayah, D. Sui, K. A. Wade, B.-C. Chang, and S. Agrawal, "Passive knee exoskeletons in functional tasks: Biomechanical effects of a springexo coil-spring on squats," *Wearable Technologies*, vol. 2, p. e7, 2021.

[3] D. D. D'Lima, B. J. Fregly, S. Patil, N. Steklov, and C. W. Colwell Jr," Knee joint forces: prediction, measurement, and significance," *Proceedings of the Institution of Mechanical Engineers, Part H: Journal of Engineering in Medicine*, vol. 226, no. 2, pp. 95-102, 2012.

[4] J. Nilsson and A. Thorstensson, "Ground reaction forces at different speeds of human walking and running," *Acta Physiologica Scandinavica*, vol. 136, no. 2, pp. 217–227, 1989.