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► To cite this version:

L Colas, K Giraud-Esclasse, R Temporelli. Mechanical performances of DREEVEN, a novel motorization unit for custom knee orthosis. 48eme Congrès annuel de la Société de Biomécanique, Oct 2023, Grenoble, France. hal-04227858

HAL Id: hal-04227858

<https://hal.science/hal-04227858>

Submitted on 4 Oct 2023

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Mechanical performances of DREEVEN, a novel motorization unit for custom knee orthosis

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1. Introduction

In Europe and the United States, 75 million people suffer from walking disorders: stroke, osteoarthritis, arthritis, sarcopenia, poliomyelitis, cerebral palsy, multiple sclerosis, myopathies, etc. These motor disorders cause increased muscle and/or joint weakness. To reduce the progressive loss of locomotor faculties caused by these pathologies, the health authorities recommend a regular and adapted physical activity: walking. To improve the daily life of people with walking disabilities, restore their mobility and extend their walking perimeter, focusing on the knee joint, REEV develops the DREEVEN solution [Temporelli, 2022], a motorization unit for custom knee orthosis.

If many assistive lower limb orthosis are already available on the market [Dollar, 2008], the motorized ones are serial (not custom) exoskeletons which is a problem considering that most people needing motor assistance require custom orthosis. In addition, as presented in [Bernhardt, 2006], patients tend to think that actual serial exoskeletons don't cover all desired use cases, are unwieldy and the mass/volume is not well accommodated on the human body. For these reasons existing serial exoskeletons are not suitable and unattractive for a daily use. In addition, they are expensive; hence, they are mostly bought by dedicated rehabilitation centres. Thus, people lack access to the daily assistive rehabilitation/help they require today.

The DREEVEN solution presented in this article is based on an unobtrusive electrohydraulic transmission which can be integrated on any custom orthosis thanks to its specific mechanical interface designed to fit the morphology of the patient. The solution consists in a motorized hydraulic emitter-receptor cylinder derived from [Temporelli, 2019]. Two hydraulic hoses link the emitter part (the power unit) and the receptor part (transmission mechanism at lower limb level). This principle allows to relocate and spread the mass and volume of the power unit to an appropriate area of the human body (e.g. close to the center of mass for a better body balance) and allows designing a light and slim transmission mechanism at lower limb level. The design of the mechanical transmission also allows to transmit eccentric and concentric torque to the knee, therefore assisting the patient during the entire gait cycle. For these reasons,

the DREEVEN solution allows to power custom knee orthosis with an adequate assistive torque and an adequate bandwidth on the knee in various use cases whilst being slimmer and lighter than other marketed systems.

Here, we present the mechanical architecture of the DREEVEN solution and the experimental investigation of its mechanical performances: torque capacities and bandwidth.

2. Methods

2.1 Dimensioning and target performances

Understanding the kinematics and kinetics of the lower limbs during the different daily activities is fundamental for developing a robotic orthosis. We established a typical profile of a 80kg patient with a healthy gait and focused our attention on walking, ascending/descending stairs and sit-to-stand/stand-to-sit movements. Grounding our calculation on the dataset presented in [Reznick, 2021], we defined our requirements as follows: we aim to assist 30% of the knee torque developed by a 80kg user (approximation of the mean weight of men in Europe) during a 1-second sit-to-stand movement lasting. The worst load case occurs at the 110° knee flexion where a 110Nm knee torque is required. Considering the 30% assistance objective that was based on an estimation of the best power-mass ratio respecting the allocated esthetic volume envelope, and the targeted speed, the system was designed to be able to produce a **33Nm** torque at a **0,5Hz** frequency.

2.2 Mechanical design

As previously stated, existing exoskeletons tend to be heavy, bulky, expensive and lack power or use cases coverage. We aim to overcome these drawbacks with our design. After consideration of existing exoskeletons mechanical designs [Shi, 2019], we designed a novel mechanical transmission for lower limb exoskeleton inspired by the electromechanical clutch actuator presented in [Temporelli, 2019]. The presented design relies on an hydraulic transmission functioning as described in Figure 1.

The system is divided in two parts: the emitter (the power unit installed in a bag pack close to the center of mass) and the receptor unit (the transmission mechanism installed on a lower limb custom orthosis). At the emitter level, the motor drives in rotation a ball screw that pushes the ball nut solidary to two pistons using mechanical blades, therefore opening and closing the emitter cylinders. The small chamber of each emitter cylinder is connected to the small chamber of a receptor cylinder that gets opened or closed by the oil transport, and the pistons in their travels pull on a cable therefore resulting in the rotation of the knee pivot. As the receptor is fixed on a thigh orthosis and the knee pivot is linked to a calf orthosis,

the motor rotation leads to a torque being transmitted to the knee, therefore assisting the patient's gait.

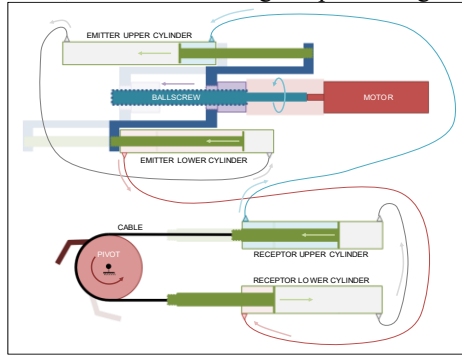


Figure 1 : Mechanical architecture of DREEVEN

The 'Results and Discussion' section describes the test procedure that allowed us to validate the defined mechanical objectives.

3. Results and discussion

In order to evaluate its mechanical performances, the first prototype of the DREEVEN solution was placed on a test bench. A high stiffness spring was attached to it with a cable, creating a return force when the pivot rotated.

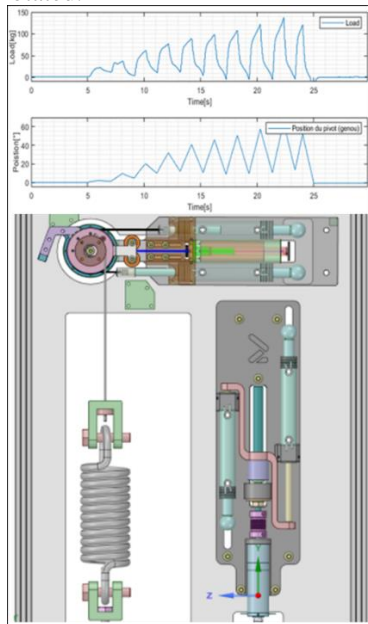


Figure 2 : DREEVEN on its test bench and step loaded cycle test results

A simple back and forth open-loop control was applied with 3 different reference shapes (steps, ramp and sweep sinusoid).

The test bench and experimental results of the 1Hz loaded step test are presented in Figure 2. The DREEVEN developed a **34.06 Nm** torque on the pivot and its response was fast enough to sustain a chirp up to **1 Hz**, therefore confirming the system's capacity to reach the desired bandwidth and torque, thus whilst keeping the mass and volume of the mechanical

assembly to 2170cm³ and 1,5kg in the backpack and 1461cm³ and 1,1kg on the leg. These performances can be compared to [Sanchez, 2019] and classify DREEVEN as a light exoskeleton for its application and encourages us to follow our development of differentiating features by implementing a novel robust and adaptive control law.

4. Conclusions

We present DREEVEN, a novel concept overcoming the drawbacks of the lower-limb assistive exoskeletons present on the market in order to bring a novel assistive solution to the patients. The electro-hydraulic transmission divided in a power unit placed in a backpack and a receptor mechanism interfaced with a custom leg orthosis allows a better mass spreading and power density. An experimental validation phase allowed us to test the mechanical performances of the system, confirming its ability to assist 30% of the knee torque developed by a 80kg patient during a 1 second long sit-to-stand movement.

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Keywords: exoskeleton, biomechanics, control, mechatronics, medical robotics

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