

Summary of Master's thesis

(Session July 2021)**"Design and modeling of a novel pneumatic passive upper limb exoskeleton based on McKibben artificial muscle"**Candidate: Stefania Magnetti Gisolo

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The upper extremity is one of the most complex part of human body, consisting of four articulations: the glenohumeral, sternoclavicular, acromioclavicular and scapulothoracic [1]. The glenohumeral joint is commonly referred as shoulder joint. When the upper limb is lifted, the contraction of shoulder complex muscles must balance the torque due to gravity of the arm's segments. Yet, in industrial environment, overhead working tasks could require the user to keep his arms in elevated position for a long time, also holding a load or a tool in hand [2]. Thus, to reduce the effort on shoulder complex muscles, a supportive device is needed, as a wearable equipment interacting with human. Therefore, the aim of this paper is to submit a new passive upper limb exoskeleton for partially compensating the gravitational torque while lifting the arm, working on a McKibben pneumatic artificial muscle (PAM), as passive actuator, that, once pressurized, is able to exert a high force-to-weight ratio, by contraction [3]. The commercial PAM employed is the Festo DMSP-20-200N RMCM [4].

At first, the original design of the proposed exoskeleton is described, and then a possible improvement is suggested, which consists of joining a shoulder pad, fixed to the exoskeleton, meant to improve the PAM exerted torque characteristic with respect to the gravitational torque (Figure 1).

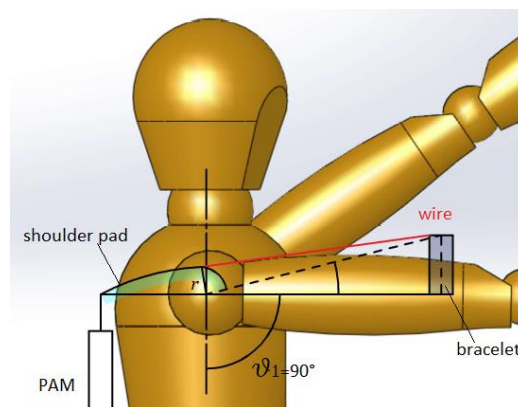


Figure 1 Simplified scheme of the novel design by joining the shoulder pad: ϑ_1 is the elevation angle of the upper arm with respect to vertical direction, r the variable radius of the shoulder pad profile that matches the lever arm of the PAM force only at $\vartheta_1 = 90^\circ$.

To do so, a graphic method is implemented for designing the profile, and Figure 2 shows the comparison between the compensation of torque realized without the shoulder pad (dotted lines) and employing the shoulder pad (solid lines). As shown, by employing the shoulder pad a reduction of the difference between the torque due to gravity and the one generated by the PAM, is accomplished, reducing the effort that shoulder muscles should exert to work out of equilibrium (the point in which the torques exerted by the PAM match the torque due to gravity).

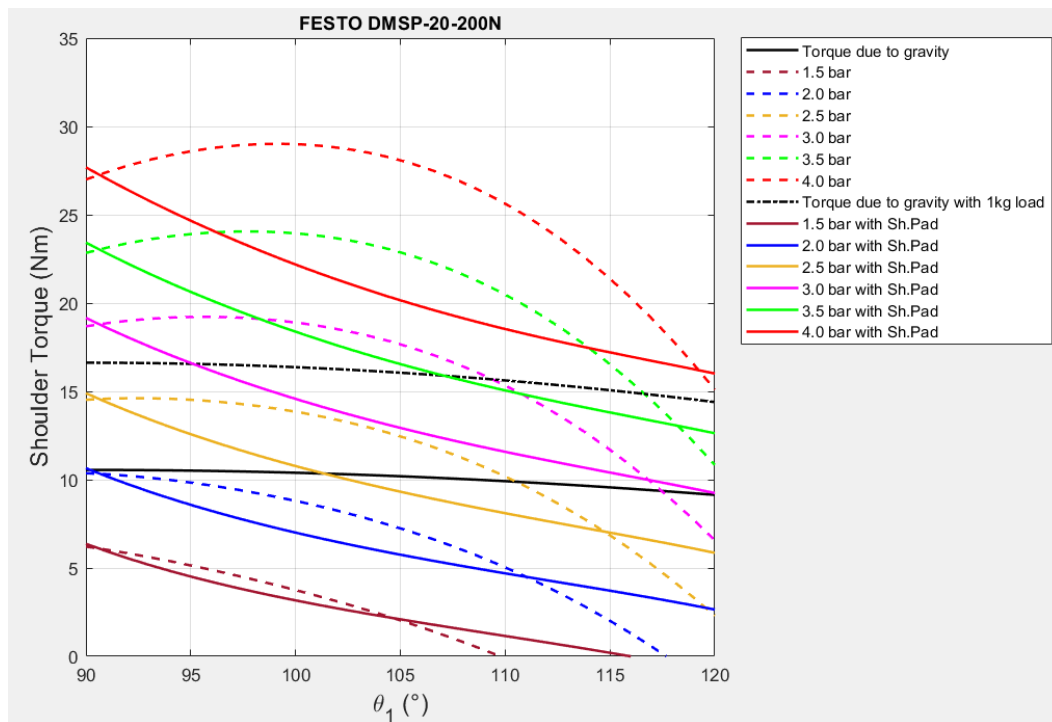


Figure 2 Shoulder torques due to gravity, without and with 1kg load in hand (dash-dotted line), with torques generated by the pneumatic muscle without (dotted line) and by employing the shoulder pad designed (solid line), at different supply pressures, with elevation angle of forearm $\theta_2 = 0^\circ$.

Then, a mounting solution is suggested, working out the CAD model, by employing a 2-DOF universal joint, centered in the assumed shoulder joint, to allow the movement of the arm. A particular mounting of the PAM is proposed, by using a sheath to reverse the direction of the wire, from the shoulder pad to the free end of the PAM, that is hung by its fixed end upwards. Besides some solutions are proposed for the exoskeleton to be fitted to different users.

So, the results of FEM analysis are carried out with two different CAD finite element modeling software (SolidWorks and Altair Hypermesh), by choosing the materials in order to make the exoskeleton as light as possible and check the elastic static failure of materials. Finally, the overall weight of the structure is estimated as 6.17 kg.

References

1. Engin, A.E.: On the Biomechanics of the Shoulder Complex. J. Biomechanics, vol.13, pp. 575-590 (1980).
2. Theurel, J., Desbrosses, k., Roux, T., Savescu, A.: Physiological consequences of using an upper limb exoskeleton during manual handling tasks. Applied Ergonomics 67, pp. 211-217 (2018).
3. Tondu, B.: Modelling of the McKibben artificial muscle: a review. J. Intell. Mater. Syst. Struct. 23, pp. 225-253 (2012).
4. https://www.festo.com/cat/en-us_us/data/doc_enus/PDF/US/DMSP-MAS_ENUS.PDF.