An Innovation Proposal Employing Lead Screw Mechanism for Office Chair Height Adjustment

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Abstract. Currently, existing office chairs contain reclining and height adjustment capabilities but often require intensive manual adjustment or lack full customization. The motivation behind this concept was to create an office chair that maintains its utility while integrating more advanced mechanical designs to increase adjustability. The motorized seat height adjustment that implements a lead screw mechanism eliminates the need to manually crank a lever or apply pressure to the chair seat, which is common in chairs using a pneumatic cylinder. In this paper, a feasible innovation employing a lead screw mechanism for an office chair height change system is proposed. Firstly, the general background of current office chair height adjustment designs and drawbacks are discussed. Secondly, an overview of the modeling of the overall chair assembly and functions of the height change system's parts is presented. Finally, analytical calculations are analyzed, and finite element analysis is conducted using SolidWorks to assess the nominal shear, nominal stresses, and static displacement of the lead screw. The result of this paper proves the feasibility of the implementation of the lead screw mechanism in office chairs.

Keywords: Machine design, Lead screw, Height adjustment, Office chair.

1. Introduction

Office workers often work from 71% to 80% of the time while seated, or more than 6 hours a day [1]. With adequate support to the body, sitting requires 20% less energy to carry out the same task as standing [2]. Moreover, it is important to note that discomfort or, perhaps worse, musculoskeletal injuries may arise from fitting the body to the chair rather than the other way around. Since everyone has a different height and if the height of the desk is fixed, the height of the seat needs to adjust to a specific position that satisfies everyone's needs. In addition, extended periods spent seated at an inadequate workspace have been associated with muscular injuries such as pain and tenseness. As a result, the ability to adjust the height, depth, and tilting angle of the seat, as well as the lumbar support and backrest recline, are all crucial for adjusting the chair to fit the body to avoid muscular discomfort and injuries [3]. This paper will focus on the overall design of the chair's height-changing functions. Currently, most office chairs' height adjustment systems use a pneumatic cylinder to create a force to hold a person's body weight. The principle behind the pneumatic cylinder is that it utilizes compressed air or other kinds of gas to transfer and store energy [4]. To prevent safety issues, office chairs often have a sealed compartment within the pneumatic cylinder filled with nitrogen of over 90% purity. Potential energy is stored by the compressed gas inside the chamber. Lever action opens a valve, which causes pressurized gas to expand and push the piston and rod higher, producing linear motion. It is true that using a pneumatic cylinder to adjust a chair's height is cheap, easy to operate, and refining structure; however, the lead screw mechanism has the advantage that it can enhance height adjustment precision, stability, durability, and possibly customization, aligning with the specific ergonomic or functional requirements of the workspace. This new modified office chair will be beneficial for professionals who need chairs that stay securely in place at a specific height to maintain an ergonomic posture while performing a delicate task and individuals with physical disabilities that difficult to adjust height through their hands by using a pneumatic cylinder.

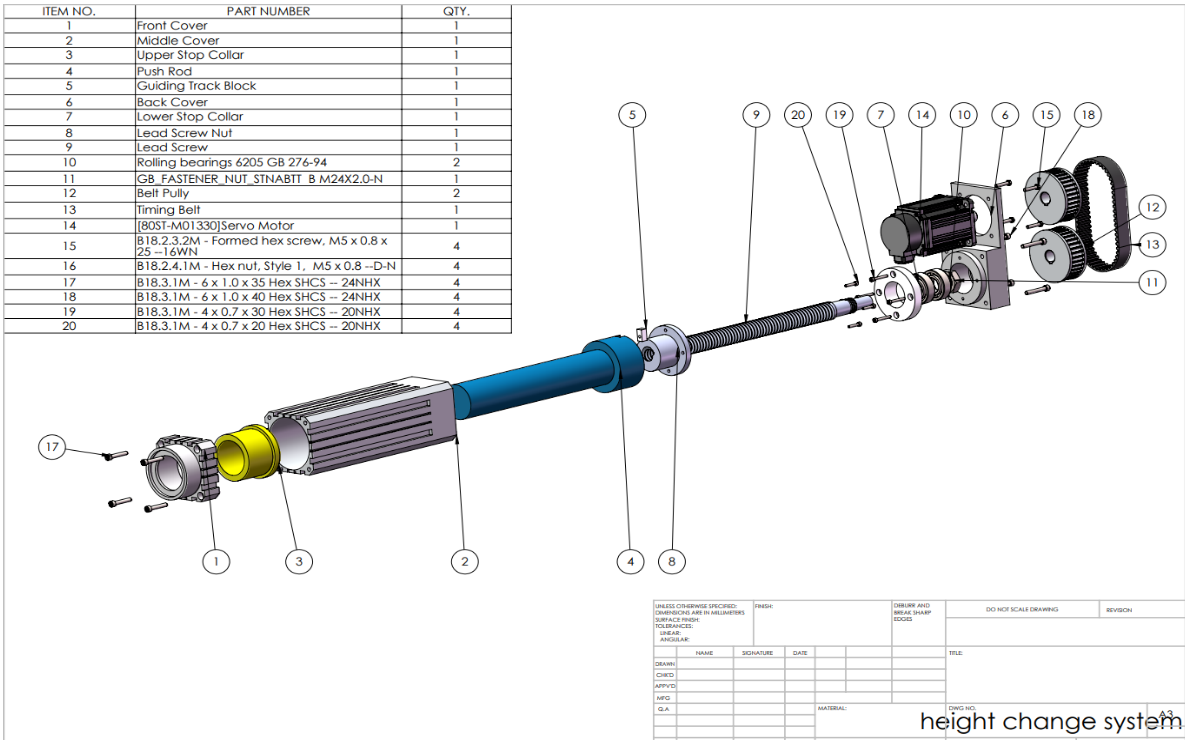
2. Methodology

2.1. The overview of the assembly of the modified office chair

Figure 1. Overall assembly. (Photo/Picture credit: Original)

As shown in Fig. 1, The chair seat and backrest are designed as two separate components, connected by the tilting mechanism. The legs of the chair are affixed to the outer shell of the height change system. Previous renditions of the chair featured a more pronounced shell for the system but that was removed in favor of a sleeker design. The main component of the height change system is a lead screw. A lead screw is a mechanical component that converts rotational motion into linear motion. It comprises a threaded cylindrical shaft and a matching threaded nut. When the screw rotates, the nut moves along its length, resulting in linear motion. Lead screws find extensive application in computer numerical control (CNC) machines, 3D printers, robotics, and other equipment requiring precise linear motion. They are preferred for their simplicity, reliability, and cost-effectiveness compared to alternative linear motion mechanisms. The lead screw studied in this project is part of the Seat Height Adjustment Mechanism that can lift the push rod up to a certain height. It is necessary to perform a stress analysis of the lead screw because it can experience various forces during the operation process [5].

2.1.1 The Function of each component of the height change system



ITEM NO.	PART NUMBER	QTY.
1	Front Cover	1
2	Middle Cover	1
3	Upper Stop Collar	1
4	Push Rod	1
5	Guiding Track Block	1
6	Back Cover	1
7	Lower Stop Collar	1
8	Lead Screw Nut	1
9	Lead Screw	1
10	Rolling bearings 6205 GB 276-94	2
11	GB_FASTENER_NUT_STNABTT B M24X2.0-N	1
12	Belt Pully	2
13	Timing Belt	1
14	[80ST-M01330]Servo Motor	1
15	B18.2.3.2M - Formed hex screw, M5 x 0.8 x 25 --16WN	4
16	B18.2.4.1M - Hex nut, Style 1, M5 x 0.8 --D-N	4
17	B18.3.1M - 6 x 1.0 x 35 Hex SHCS -- 24NHX	4
18	B18.3.1M - 6 x 1.0 x 40 Hex SHCS -- 24NHX	4
19	B18.3.1M - 4 x 0.7 x 30 Hex SHCS -- 20NHX	4
20	B18.3.1M - 4 x 0.7 x 20 Hex SHCS -- 20NHX	4

Figure 2. Mechanical drawing and bill of materials for height change system model inspired by [6]. (Photo/Picture credit: Original)

As shown in Fig. 2, the height adjustment system is constructed utilizing an Acme thread lead screw (9), lead screw nut (8), and a Stepper motor (14). The lead screw nut (8), which engages with the screw, typically serves as the linearly moving component, while the screw acts as the rotating element powered by the Stepper motor (14). The Stepper motor is interconnected with a belt pulley (12) via a timing belt (13), facilitating a synchronized operational flow. This belt pulley is affixed to the lead screw, serving as the primary actuating component responsible for the screw's displacement. The motor, belt pulley, and lead screw are securely fastened by a back cover (6), providing structural integrity and stability. Two roller bearings (10) are strategically positioned around the lead screw and belt pulley, minimizing frictional forces and supporting smooth rotational motion. The lead screw is encompassed by a push rod (4), which effectively transfers the applied force to the seat bottom, enabling precise height regulation. Stops (3) and (7) are strategically positioned at the extremities of the screw, preventing excessive extension and ensuring the maintenance of controlled movement limits.

2.1.2 Material selection of key component

Table 1 illustrates the material selection for the lead screw and lead screw nut. AISI 4030 is selected as the material for the lead screw. AISI 4030 falls within the AISI-SAE 4000 series as an alloy steel variant. Its composition includes notable proportions of chromium (from 0.25% up to 18%) and molybdenum (0.04% up to 0.75%), attributing to its robustness and durability. AISI 4030 is commonly employed in scenarios that require high strength, resilience, and resistance to wear. Since the lead screw needs to take a big amount of force, AISI 4030 is a perfect choice between strength and cost [7].

Table 1. AISI 4030 Steel Characteristics

Lead Screw Material	Mass Density	Yield Strength	Young's Modulus	Poisson's Ratio	Shear Modulus
AISI 4030 Steel	7850kg/m^2	$4.6\times10^8\text{N/m}^2$	$2.05\times10^{11}\text{N/m}^2$	0.285	$8\times10^{10}\text{N.m}^2$

2.2. Stepper motor selection to satisfy the desired load through torque calculation

Figure 3. CAD Model for Lead Screw. (Photo/Picture credit: Original)

Table 2. Lead Screw Characteristics

Major Diameter (d_m)	Minor Diameter (d_r)	Threaded Length	Thread Type	Pitch	Total Length	Engagement Length	Lead (Single start thread)
30mm	25.5mm	300mm	Acme	6mm	450mm	150mm	6mm

Fig.3 illustrates the CAD model of the Lead screw. The desired load is determined by the maximum operation load which is equal to 150 kilograms, and it equals 1470 in Newtons. For the Acme thread lead screw, according to Meruva et al. [5], the torque required to raise, T_r, or to lower T_l is given by

$$T_r = \frac{Fd_m}{2}\left(\frac{l+\pi f d_m sec(\alpha)}{\pi f d_m - f l sec(\alpha)}\right) \tag{1}$$

$$T_l = \frac{Fd_m}{2}\left(\frac{\pi f d_m sec(\alpha) - l}{\pi f d_m + f l sec(\alpha)}\right) \tag{2}$$

Where F is the desired load, d_m is major diameter, l is pitch length, α half of the total flank angle, and f is coefficient of friction. In this case, according to Table 2, F=1470N, d_m=30mm, $\alpha = 14.5^{\circ}$ and l=6mm. The typical coefficient of lubricated lead screw nut materials at room temperature is between 0.1 and 0.18, in this case, f is assumed to be the midpoint between 0.1 and 0.18, which equals 0.14. After calculation, T_r=35.11 Nm and T_l=11.96 Nm.

From Equations (1) and (2) it can be obtained that the required torque to raise and lower the maximum load are 35.11 N-m and 11.96 Nm respectively. SOYO 130BYG350 37 N-m stepper motor is selected to achieve the desired load. Moreover, Meruva et al. [5] state that one significant advantage of a lead screw is its ability to be self-locking when the lowering torque is positive. To achieve self-locking, the following conditions must be met:

$$\pi f d_m (13.20) > l \text{ (6mm)} \tag{3}$$

From Equation (2) the lowering torque equals 11.96 N-m and is greater than zero, and according to Equation (3), the self-locking condition is met as well. As a result, the lead screw nut can stop at a certain height when zero torque is provided.

2.3. Analytical calculations for lead screw parameter

2.3.1 Torsional Shear stress calculation

Eggert [8] states that the torsional shear stress is given by

$$\tau = \frac{Td_r}{J} \tag{4}$$

Where T is the torque applied to the lead screw, d_r is the threaded radius of the lead screw, and J is the polar moment of inertia of the lead screw. In this case, T was picked to 35.11 N-m since the design is using SOYO 130BYG350 37 Nm stepper motor. After expanding J, Torsional shear stress is then equal to,

$$\tau = \frac{16T}{\pi d_{\mathrm{r}}{}^3} \tag{5}$$

2.3.2 Axial stress calculation

The axial stress is given by

$$A_{axial} = \frac{4Fa}{\pi\, d_{\mathrm{r}}{}^2} \tag{6}$$

Where A_{axial} is axial stress, Fa is applied load which equals to 1470N.

2.3.3 Maximum von Mises stress calculation

Eggert [8] states that the maximum von Mises stress is given by

$$A' = \sqrt{A_{axial}{}^2 + 3\tau^2} \tag{7}$$

Where A' is von Mises stress, and τ is torsional shear stress. Then rearrange the equation and substitute Equation (3) with Equations (1) and (2), the result is that,

$$A' = \sqrt{\left(\frac{4Fa}{\pi\, d_{\mathrm{r}}{}^2}\right)^2 + 3\left(\frac{4Fa}{\pi\, d_{\mathrm{r}}{}^2}\right)^2} \tag{8}$$

After plugging all known values, von Mises stress is equal to 18.88 MPa.

3. Results and Discussion

3.1. FEA analysis of the lead screw

3.1.1 Static analysis using boundary conditions

Finite element analysis was performed on the Lead screw using static forces to measure critical stress points and deflection. Specifically for the height change system, it is important to ensure that the lead screw was able to operate under loading without buckling. Fig. 5 illustrates a lead screw with threaded FEA analysis, depicting four boundary conditions related to the overall model. These conditions define how the model interacts with its surroundings and how external forces or constraints affect its behavior. The following four boundary conditions are given:

1) An axial maximum load of 1470 N is applied.
2) A torque of 35.11Nm is provided by the SOYO 130BYG350 stepper motor.
3) The lower end of the lead screw is fixed.
4) A bearing condition is applied to the lower end of the lead screw to simulate the behavior of bearing supports.

3.1.2 Finite element simulation results

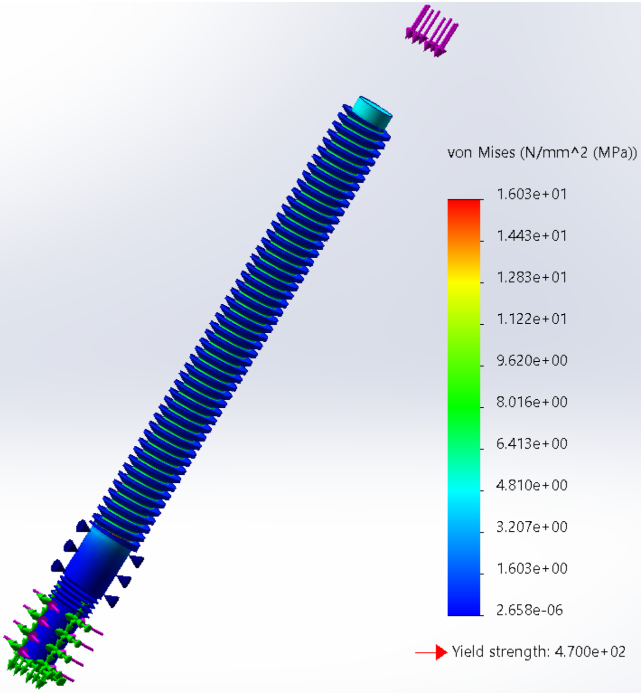


Figure 4. Lead screw FEA analysis Von Mises stress. (Photo/Picture credit: Original)

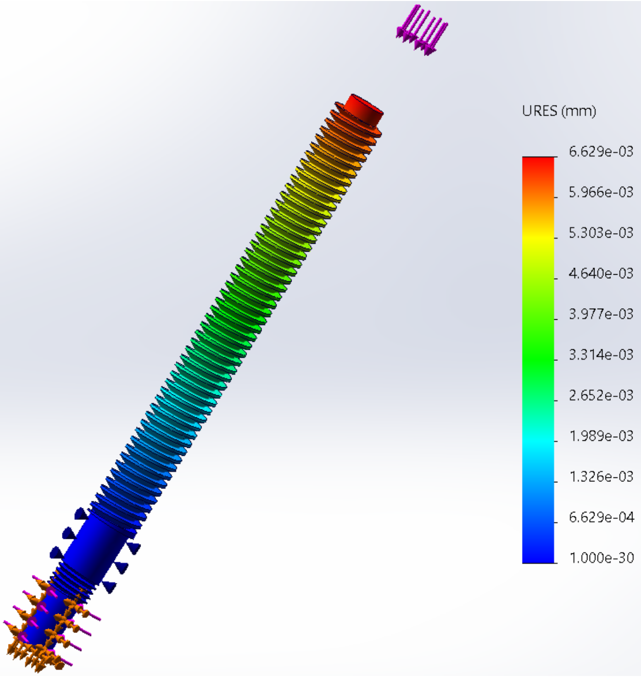


Figure 5. Lead screw FEA analysis static displacement (URES). (Photo/Picture credit: Original)

According to Fig. 4, the yield strength of AISI 4030 equals 470MPa. Since the maximum Von Mises stress is smaller than the yield strength, it means that the material is operating within its elastic region and has not reached permanent deformation. After comparing the results of stresses of the lead screw between analytical calculation and FEA analysis, it is found that the result from analytical calculation is approximately 17.85% higher than FEA analysis. This result concludes that the FEA analysis is approximate and close to the analytical calculation, and the FEA analysis is therefore correct and trustful. From Figs. 4 and 5, the results show that the maximum Von Mises stress is 16.03MPa, and the maximum displacement is $6.629e^{-03}$m. Furthermore, as shown in Fig. 4, the lead screw's threads undergo significant stress, particularly at the thread's root, and the sections at the top of the bearing support must withstand the axial load transferred through the crew. Fig. 5 illustrates that the maximum static displacement occurs at the top of the lead screw due to the axial and torsional stress. Safety factor can be obtained after dividing yield strength over max von Mises stress, which equals 29.32. The result safety factor is bigger than the common high safety factor for a chair between 2 and 4; therefore, the design of the lead screw characteristics parameters is valid. A big amount of future work is needed if this proposal wants to accomplish reality. Future iterations of lead screw parameter design are needed to lower costs while maintaining a stress safety factor of no less than 2 to ensure overall rigidity. Moreover, diameter is the most critical parameter to consider because it is related to factors including load capacity, critical speed, buckling resistance, torsional strength, thread pitch and lead, and efficiency of the lead screw [9]. Therefore, it is important to take thoughtful consideration of all the above factors to design an optimal lead screw diameter value. Furthermore, a magnetic lead screw innovation that translates rotational motions into linear motions via using the magnetic field of permanent magnets may offer a viable substitute for mechanical lead screws. As permanent magnets are positioned on both the nut and the screw, there is no longer any contact between them, making magnetic lead screws more effective than mechanical ones. Friction loss is eliminated by this design. Results from 3-D simulations indicate that a torque input of 4.3N-m may generate 1384N of force in magnetic lead screws [10].

4. Conclusion

The integration of a lead screw mechanism for height adjustment in office chairs presents a promising alternative to conventional pneumatic systems. This research has demonstrated that the lead screw mechanism provides enhanced precision, stability, and durability. Analytical calculations and finite element analysis have validated the feasibility and safety of this mechanism under typical loading conditions. The lead screw design ensures a self-locking feature, enhancing safety and usability, particularly for individuals with physical disabilities and professionals requiring specific ergonomic postures. The analysis confirmed that the lead screw could sustain the necessary loads without risk of buckling or excessive deformation, maintaining a high safety factor well above typical requirements. Future work should focus on optimizing the lead screw parameters to reduce costs while preserving structural integrity and safety. Additionally, exploring advanced materials and alternative designs, such as magnetic lead screws, could further enhance performance and efficiency. In conclusion, the proposed lead screw mechanism offers a feasible and innovative solution for improving office chair adjustability, addressing ergonomic and functional needs effectively. This design holds the potential to significantly enhance user comfort and safety, making it a valuable improvement over the existing height adjustment mechanism.

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