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A Vibration absorber for absorbing tremors in wrist

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Abstract

In this article, a classic spring damper vibration absorber is designed to reduce the tremor vibration amplitude in patients suffering from tremorous diseases. The absorber is developed as a wristlet placed at the patient's wrist. It can only move perpendicular to the patient's elbow and only supports movement in the flexion and extension directions. The patient's forearm and hand are modeled as two links, Also elbow and wrist are modeled as two frictionless rotational joints which are connected to two pairs of rotational spring-dampers.The absorber is modeled as a mass, spring and a viscous damper connected perpendicular to the elbow. With the help of Euler-Lagrange equations, the system's model is developed, which is solved via MATLAB's ode-15s suite. The tuning of the system is done via genetic algorithm and finally, The simulation results are presented which indicate a 87% and 80% decrease in the wrist and elbow's steady-state amplitude by using the absorber.

Keywords: Parkinson's disease; Passive absorber; Tremor.

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1. Introduction

Tremor affects millions of people around the world. Parkinson disease's (PD) [1] or Essential Tremor (ET) are the most common causes of involuntary limb movements. There are two categories of involuntary movements: rest tremors [2] and action tremors. These movements are more common in patients suffering from PD and ET [3]. PD generates tremors between 3 and 5 Hz, while ET produces tremors between 4 and 12 Hz [3]. Many patients with PD or ET struggle with simple daily tasks such as eating, writing, and buttoning a coat due to the tremors they experience.

There are many studies in the literature that have worked on mitigating the tremors in patients. These devices can be categorized into active, semi-active, and passive devices. In a study conducted by Zhou et al., a device comprised of a sensing glove and an actuating box was developed. The device was capable of exerting force on multiple outputs with only one DC motor. According to the experimental results, voluntary hand movements show a 12.4% Root Mean Square Error (RMSE) [4]. In semi-active devices, passive elements have been used for tremor absorption; however, active components (e.g., sensors and actuators) have improved their performance. In 2005 Loureiro et al. utilized viscous damping to reduce tremor amplitude. By using magnetic devices, the device could adapt to different tremor schemes using MR Fluids [5]. Case et al. also used MR fluids inside three cylinders. According to the simulation results, the first and second harmonics of tremor were suppressed, respectively, by 28.7 + 2.2 dB and 11.8 + 4.8 dB [6]. Yi et al. used an MR fluid damper in their study. They developed a device comprised of a single cylinder containing MR fluid that is connected to fingers via two links and a spherical hinge. Using this device, simulated tremor can be reduced in amplitude by 60.39% and in angular velocity by 55.07%, respectively [7]. Zahedi et al. incorporated MR fluids in a device dedicated to tremor reduction of the wrist in 3 degrees of freedom. There was a significant reduction in acceleration and angular velocity of wrist movements as a result of this device [8]. A passive wearable device is the most cost-effective and simplest way to suppress hand tremors non-invasively. Low-cost bracelets that reduce hand tremors were developed by Yousef et al. In this device, multiple slots are used to suppress multiple frequencies between 3 and 8 Hz. The device was found to decrease tremor amplitude by 98.2% when analyzed with finite element analysis [9]. An inflatable passive orthosis developed by Fromme et al. reduces unintentional vibrations using textile-based materials. A dorsal movement of the wrist bends the air-filled structure, counteracting the unintentional movements that cause tremors. By varying its air pressure, the device can be customized for different tremor schemes and 74% to 82% of tremor power was reduced by the soft orthosis for ADL based on experimental results [10]. Different controllers were proposed for tremor reduction based on wrist FE movement by Gebai et al. Basically, these devices consist of mass, damper, and springs attached to the arm of the patient and indicate that passive absorbers can be used for tremor reduction [11].

In this work, we have developed a passive vibration absorber for patients struggling with Flexion and Extension (FE) tremors. This device consists of a mass, a viscous damper, and a spring. Section 2 derives the governing equations of a dynamical model for the absorber which is connected to patient's wrist, and Section 3 represents the simulation results. Finally, the paper concludes with Section 4.

2. Dynamic modelling

To analyze the tremor response of the absorber developed in this paper, we used a multi-DOF planar system.

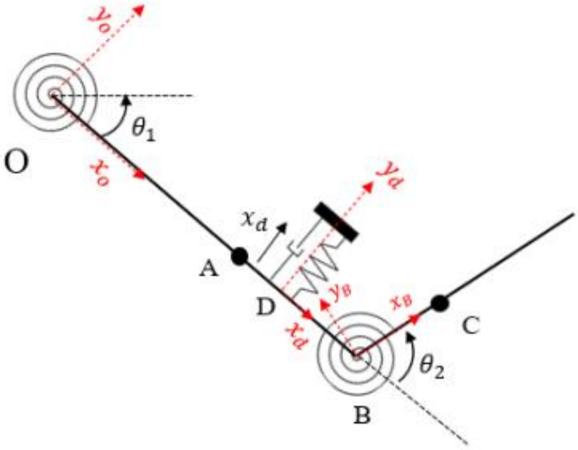


Figure 1. Representation of the model's scheme.

Fig. 1 represents the dynamic model of the system where θ_1 and θ_2 are the rotation angles of elbow and wrist joints in the FE direction. Also, the absorber is connected to the elbow at D. m_1, m_2 and m_d are the concentrated masses of the forearm, hand, and the absorber at their respective center of masses. The kinetic and potential energy of the entire system can be calculated as follows:

$$\begin{aligned} T = {} & \frac{I_{C1}}{2}(\dot{\theta}_1)^2 + \frac{I_{C2}}{2}(\dot{\theta}_1 + \dot{\theta}_2)^2 + \frac{m_1}{2}(l_{c1}\dot{\theta}_1)^2 + \frac{m_d}{2}\left(\left(\dot{\theta}_1\sqrt{x_d{}^2 + l_d{}^2}\right)^2 + \dot{x_d}{}^2 + 2\dot{\theta}_1\dot{x_d}l_d\right) \\ & + \frac{m_2}{2}\left((l_1 \times \dot{\theta}_1)^2 + \left(l_{c2}(\dot{\theta}_2 + \dot{\theta}_1)\right)^2 + 2l_1l_{c2}\dot{\theta}_1(\dot{\theta}_2 + \dot{\theta}_1)cos(\theta_2)\right) \end{aligned} \tag{1}$$

$$\begin{aligned} U = {} & m_1gl_{c1} \times sin(\theta_1) + \frac{1}{2}k_{t1}\theta_1{}^2 + \frac{1}{2}k_dx_d{}^2 + \frac{1}{2}k_{t2}\theta_2{}^2 + m_dg(l_d \times sin(\theta_1) + x_dcos(\theta_1)) \\ & + m_2(l_1sin(\theta_1) + l_{c2}sin(\theta_1 + \theta_2)) \end{aligned} \tag{2}$$

where $k_{t1}$and k_{t2} are the passive rotational stiffness of the elbow and wrist joints, respectively. Also k_d is the effective stiffness of the viscous absorber. Reyligh's dissipation factor is calculated below:

$$\mathfrak{R} = \frac{1}{2}c_1\dot{\theta}_1{}^2 + \frac{1}{2}c_d\dot{x_d}{}^2 + \frac{1}{2}c_2\dot{\theta}_2{}^2 \tag{3}$$

where l_1, l_d, l_{c1} and l_{c2} are forearm length ($\overrightarrow{OB}$), distance of absorber from elbow joint ($\overrightarrow{OD}$), distance of forearm and hand's center of mass from elbow ($\overrightarrow{OA}$) and wrist ($\overrightarrow{BC}$) joints, respectively. Using Euler Lagrange formulation, the dynamic equation of the system can be acquired as follows:

$$\begin{aligned} & gl_{c1}m_1\cos(\theta_1) + gl_1m_2\cos(\theta_1) + gl_dm_d\cos(\theta_1) + gl_{c2}m_2\cos(\theta_1 + \theta_2) + k_{t1}\theta_1 \\ & \quad - 2l_1l_{c2}m_2\sin(\theta_2)\,\dot{\theta}_1\dot{\theta}_2 - 2l_1l_{c2}m_2\sin(\theta_2)\,\dot{\theta}_2{}^2 - m_dx_d\left(gsin(\theta_1) - 2\dot{\theta}_1\dot{x_d}\right) \\ & \quad + I_{C1}\ddot{\theta}_1 + I_{C2}\ddot{\theta}_1 + l_{c1}{}^2m_1\ddot{\theta}_1 + l_1{}^2m_2\ddot{\theta}_1 + l_{c2}{}^2m_2\ddot{\theta}_1 + l_d{}^2m_d\ddot{\theta}_1 + +x_d{}^2m_d\ddot{\theta}_1 \\ & \quad + I_{C2}\ddot{\theta}_1 + l_{c2}{}^2m_2\ddot{\theta}_2 + l_1l_{c2}m_2\cos(\theta_2)\,\ddot{\theta}_2 + I_dm_d\ddot{x_d} \\ & \quad = T_{voluntary1} + T_{voluntary2} + \mathcal{F}_{SMA} - c_1\dot{\theta}_1 \end{aligned} \tag{4}$$

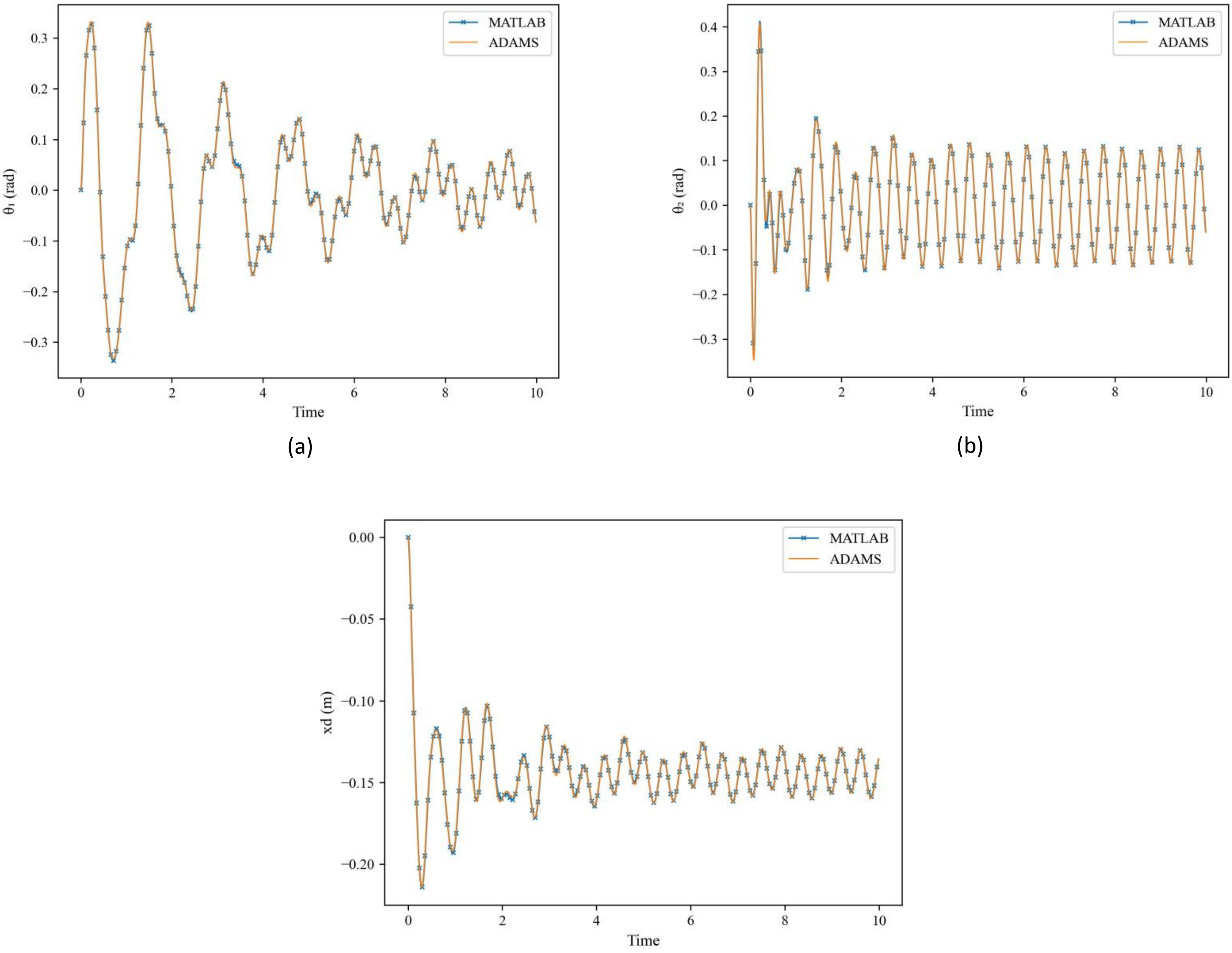
$$\begin{aligned} & gl_{c2}m_2\cos(\theta_1 + \theta_2) + k_{t2}\theta_2 + l_1l_{c2}m_2\sin(\theta_2)\,\dot{\theta}_1{}^2 + I_{C2}\ddot{\theta}_1 + l_1l_{c2}m_2\cos(\theta_2)\,\ddot{\theta}_1 + I_{C2}\ddot{\theta}_2 \\ & \quad + l_{c2}{}^2m_2\ddot{\theta}_2 = T_{voluntary2} - c_2\dot{\theta}_2 \end{aligned} \tag{5}$$

$$x_d\left(k_d - m_d\dot{\theta}_1{}^2\right) + m_d\left(gcos(\theta_1) + l_d\ddot{\theta}_1 + \ddot{x_d}\right) = -c_d\dot{x_d} \tag{6}$$

where $T_{voluntary1}$ and $T_{voluntary2}$ are the torques of elbow and wrist. These torques are the sum of postural torques exerted to joints and the torques generated by tremor. The excitation force is taken to be a harmonic force rotating elbow joint with an amplitude of 1 N/m

Except for passive stiffness and damping of joints, all structural variables in the model are derived from experiments conducted by Leva [12]. This study adopts the formulation proposed by Fromica et al. [13] and determines that flexion of the wrist is 1.05 Nm/rad and extension is 1.3125 Nm/rad. Also, using a linear regression of experiments conducted by Endo et al. [13] k_{t2} is found to be 2.19Nm/rad and 2.62Nm/rad for flexion and extension of the elbow joint. c_1 and c_2 also are determined by the works of Popescu et al.[14] and Milner et al. [15]. Here, we take passive damping of wrist and elbow (i.e. c_1 and c_2) to be 0.104 Nms/rad and 0.088 Nms/rad for elbow flexion and extension, and 0.017 Nms/rad for both flexion and extension of the wrist.

As insurance of the model's validity, the developed dynamic system is also modeled in the ADAMS software, and the time responses of both systems are cross-checked. The results depicted in Fig. 2 represent a time response for a system with absorber mass, stiffness, and damping of 1.5 kg, 100 N/m, and 1 Ns/m, respectively.



(a)

(b)

(c)

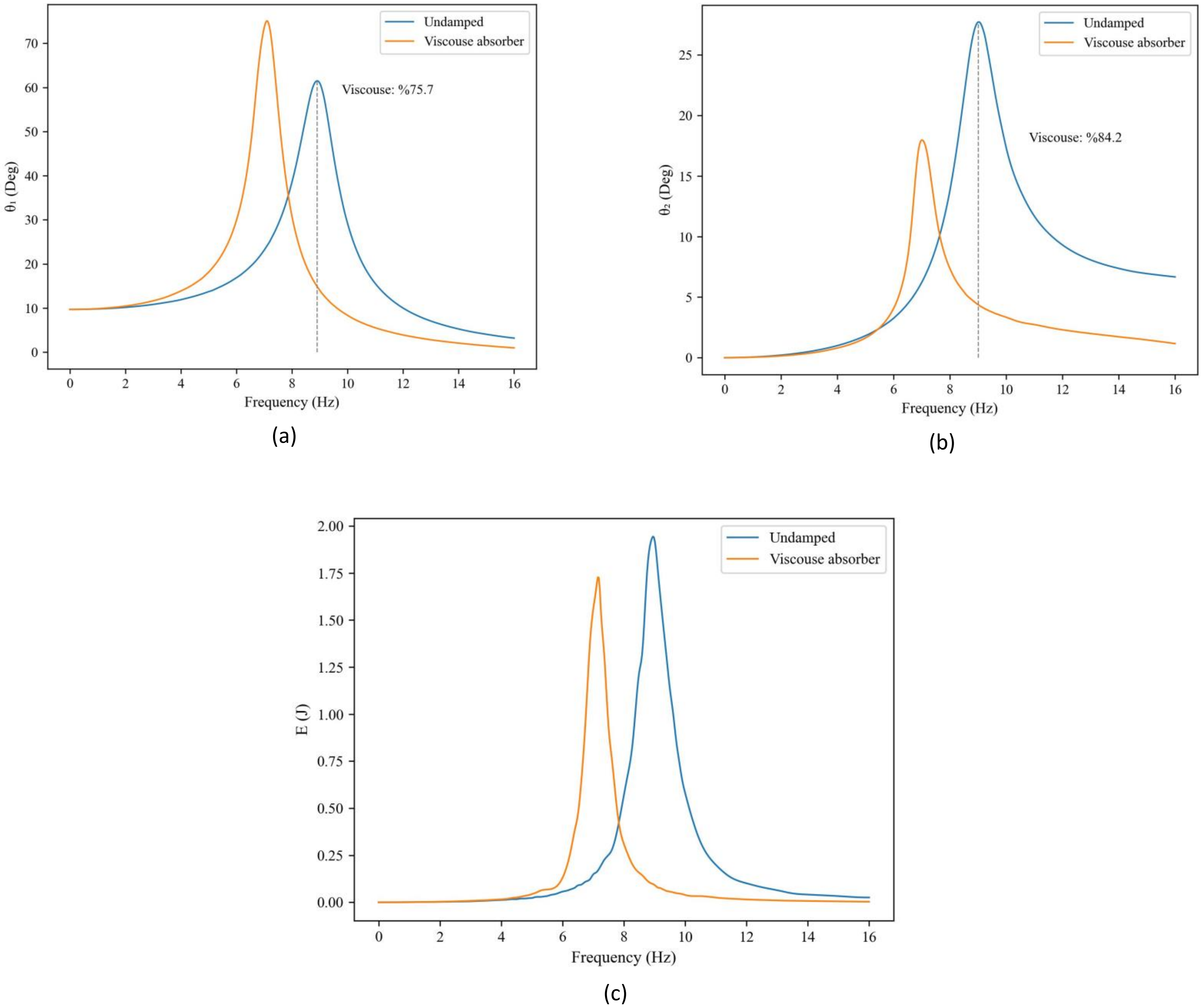
Figure 2. The time response of the developed models for a) elbow, b) wrist and c) absorber elongation in ADAMS and MATLAB.

As it can be seen, the developed system model has less than 0.2% error with ADAMS's results which calls for sufficient accuracy of Eqs. 4-6

3. Results

We have optimized the developed absorber by using the genetic algorithm to minimize the area under the wrist's frequency response. Via this process, the absorber's mass, stiffness, damping, and distance from the elbow are found to be 0.1020 kg, 378 N/m, 16.431 Ns/m, and 0.17 m, respectively. Using these parameters the frequency responses of the system can be acquired, which are depicted in Fig. 3.

It can be seen that the developed damper can reduce the resonance vibration amplitude in the elbow and wrist of the patients to a maximum extent of 75.7% and 84.2%, respectively. The absorber increases the maximum vibration amplitude of the elbow as it reduces the maximum amplitude of the wrist. Also by analysing frequency response of elbow and wrist, we can see that the developed absorber is not suitable to use in every frequency, meaning that in certain frequencies, the absorber can cause an increase in the vibration amplitude, so the patient is better off not using the absorber. The frequency at which the absorber starts to reduce the vibration amplitude is roughly 7.2 Hz for both elbow and wrist. Referring to Fig. 3-c, it can be inferred that the kinetic energy of the entire system can be reduced to roughly 99.9% at its resonance frequency. Also, despite the absorber having an extra mass relative to the undamped system, it can reduce the maximum kinetic energy of the entire system as well. But, it is imperative to note that the absorber starts to reduce the system’s kinetic energy at 7.2 Hz. For frequencies smaller than that, the undamped model has less kinetic energy than the damped one. This means the more the vibration frequency, the better the absorber can cooperate in absorbing the tremor energy. It can be inferred that this device is more suitable for patients with advanced tremors.



(a)

(b)

(c)

Figure 3. The frequency response of the developed system. a) Frequency response of the elbow, b) Frequency response of the wrist, c) Kinetic energy of the systems in various excitation frequencies.

4. Conclusion

The developed absorber can significantly reduce the overall involuntary vibration amplitude in the elbow and wrist of the patients. However, it is essential to note that this device is not always beneficial for the patient, and at some frequencies, the device can even worsen the tremor amplitude. This frequency is roughly 7.2 Hz for the elbow and 7.5 Hz for the wrist, and if the patient's vibration is lower than these frequencies, he shouldn't use the device.

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