Design Strategies for a Drinking Cup to Accommodate Hand Tremor

A THESIS PRESENTED

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Abstract

Hand tremor is an involuntary muscle movement, trembling, or shaking of the hands. Caused by either essential tremor (ET) or Parkinson's disease, tremors often affect daily activities including feeding, drinking, typing, and writing. To reveal the design strategies to diminish effects of hand tremor in handheld devices, and in particular a drinking cup in this research, an experimental framework based on vibrations and dynamics has been developed with inspiration from the well-known gyroscopic boat stabilizers, i.e. Schlick stabilizers, in which a high speed rotating disk has been used as a source of angular momentum, producing a resistive gyroscopic torque when an input torque caused by ocean waves acts on the boat. Using a rotating gimbal, this resistive torque can be converted to a useful stabilizing torque which is in the opposite direction of incoming disturbance torques, whether induced from ocean waves or hand tremor. The prototype was built and its preliminary testing was completed, and further results include mathematical modeling and simulations, to demonstrate the validity of the approach taken. In short, it can be stated that when the gyro-disk in the drinking cup is spinning at high speeds, one feels the dampening effects of the resistive torque on the hand. However, human-subjects experiments need to be conducted for future work to validate the efficacy of the device.

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Introduction

Definition of Tremor

Tremors are rhythmic oscillations of a part of the body. It often involves the hands, which is then called hand tremor but it can also be present in the head, mouth, voice, or foot. When in the hands it can be in one, or both [2].

Different Types of Tremor

When people notice a tremor the first thing they think of is Parkinson's. While Parkinson's is a common cause of tremor it is not the only cause. The other common cause is the so-called essential tremor (ET). Probably a poor choice of names, an essential tremor is one that has no known cause. Its character is exactly opposite of the typical Parkinsonian tremor. With essential tremor the hands are quiet when not doing any activity, and then begin to shake when an activity is performed such as writing, eating, or holding something like a tray or plate [4]. Occasionally, Parkinson’s related tremor can also be present during manual activities.

Medical Treatment Approaches

An estimated 10 million Americans are suffering from hand tremors [2]. The cause of essential tremor is unknown, and although there is presently no cure, there are treatment options such as medication and surgery to manage its symptoms. Medications such as primidone and propranolol are first-line therapies for tremor symptom reduction [3]. These medications along with other sedatives and antiseizure medications can be effective but can produce side effects such as fatigue, depression, low blood pressure and gait instability. Hand tremor is slowly progressive throughout life and appears to develop or worsen late in life, increasing the likelihood of medication-related adverse effects. It is estimated that some 25-55% of patients may have tremor that is refractory to medications [4]. In cases where tremor does not respond to medical therapy and is disabling, deep-brain stimulation (DBS) surgery is often recommended to reduce tremor. High frequency electrical stimulation of the thalamic nucleus can alleviate tremor to a significant degree, but DBS lead placement carries a 1% risk of brain hemorrhage, and an approximately 5% risk of hardware infection or malfunction [5].

Problem Definition and Different Engineering Approaches

Problem definition

Caused by either essential tremor (ET) or Parkinson’s disease, hand tremors often affect daily activities including feeding, drinking, typing, and writing. The combined direct and indirect cost of Parkinson’s disease alone, including treatment, social security payments and lost income from inability to work, is estimated to be nearly $25 billion per year in the United States [6].

The objective of this study is to design and build a prototype handheld device that can compensate undesirable hand oscillations of people with hand tremor in order to help patients with tremor perform their daily-life tasks. For this proof-of-concept, the device will be designed and implemented for a liquid-filled cup, to improve precision and reduce spillage during drinking and pouring motions. With this line of thinking a non-invasive, user-friendly and portable device design is presented here with the hope to significantly improve function in patients with hand tremor.

Engineering Approaches to the Problem

As mentioned before, medication and deep brain stimulation can be effective in treating hand tremor but at the same time they can have side effects such as fatigue, depression, low blood pressure, gait instability and brain hemorrhage [3].

On the other hand, rehabilitation strategies have been ineffective for this condition as has been the case for other neurological disorders involving the basal ganglia, which produce conditions characterized by involuntary movements that are difficult to suppress. Despite considerable knowledge of human tremor kinematics, technological aids are not widely available, perhaps due to the general impracticality or obtrusiveness of these devices. In our clinical experience, ungainly prostheses or technological aids tend not to be adopted by patients due to costs of the device and intrusion into their daily life, though these devices can demonstrate some preliminary clinical effectiveness.

For example, in one invention, a rotating disk is firmly held against the backside of the human hand to reduce or eliminate the effect of naturally occurring tremors such as essential tremor or other tremor [7]. The device can be seen in the figure below.

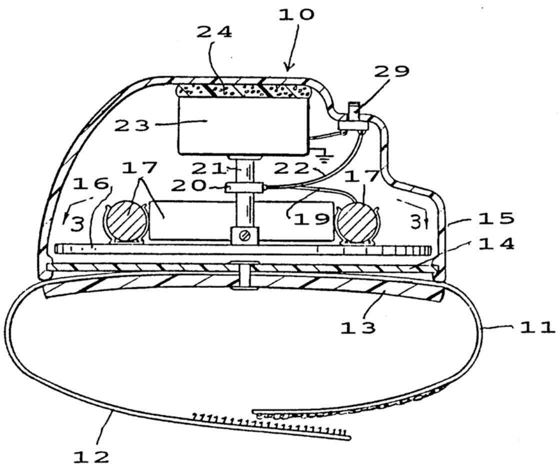

Figure 1 Handheld stablizier device proposed by William D. Hall [7]

This device, although effective might not be comfortable to be worn by some patients. Besides, the constant rotation of flywheel consumes a lot of energy resulting in regular need for the change of batteries.

In an alternative version of this invention, the batteries are removed from the system and instead, the energy for the rotation of the disk comes from an external source. In this version, which can be seen below, whenever the flywheel slows down and needs to be speeded up again, the top end of the axis of rotation should be manually attached to the external source, which is constantly rotating. This task is usually done with the help of the other hand. In addition to the fact that the exposed high-speed rotating parts are not safe, the mechanical couplings need to be replaced regularly as they get worn.

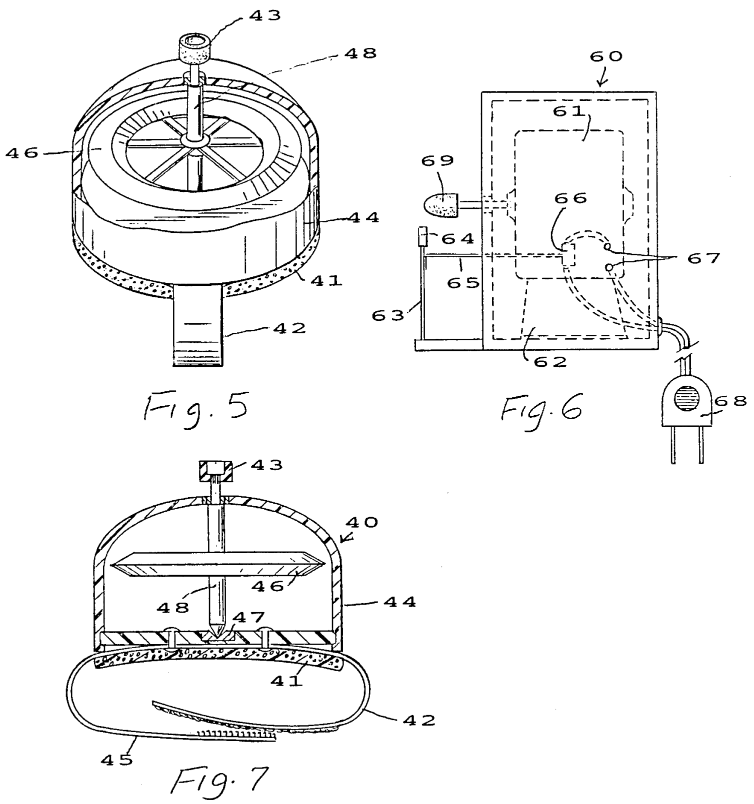

Figure 2 Battery less version of the device invented by William D. Hall **[7]**

Several similar inventions have tried to use the gyroscopic effect in order to compensate hand tremors. For instance, this effect was used as a cardiac stabilizer, providing more precision in open-heart surgery [8], [9]. These devices might be useful for surgical operations and clinical application however, they are not likely to be used in daily life by patients because these devices are designed for surgeons who may have very different hand tremor characteristics, and these devices can be in general heavy and bulky.

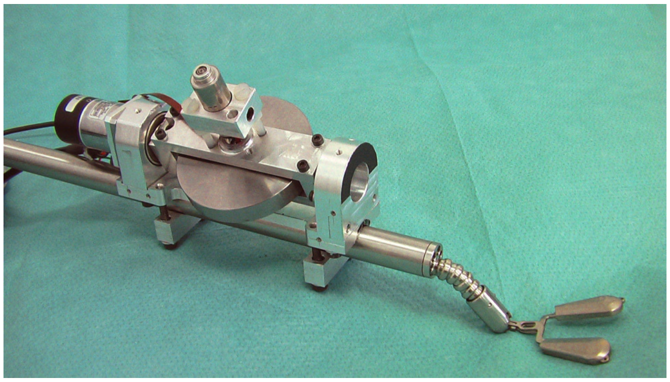

Figure 3 Active cardiac stabilizer invented by Gagne et. al. [8]

Furthermore, suppression of involuntary tremors of hand has always been a challenge for camera and camera stabilizer designers. Several people have proposed different solutions to minimize the unwanted shakings while recording with a camera and thus improving the quality of recorded movie.

Some inventors have recommended the use of a large counterweight mounted at a significant distance from the center of mass of the camera [10]. In this design the camera gets installed on top the counterweight and is connected to the handle through a revolute joint. The concept behind using the counterweight is to increase the overall rotational moment of inertia of the whole body, which will always hold the camera in the vertical position and then the tremors of hand are neutralized via the revolute joint.

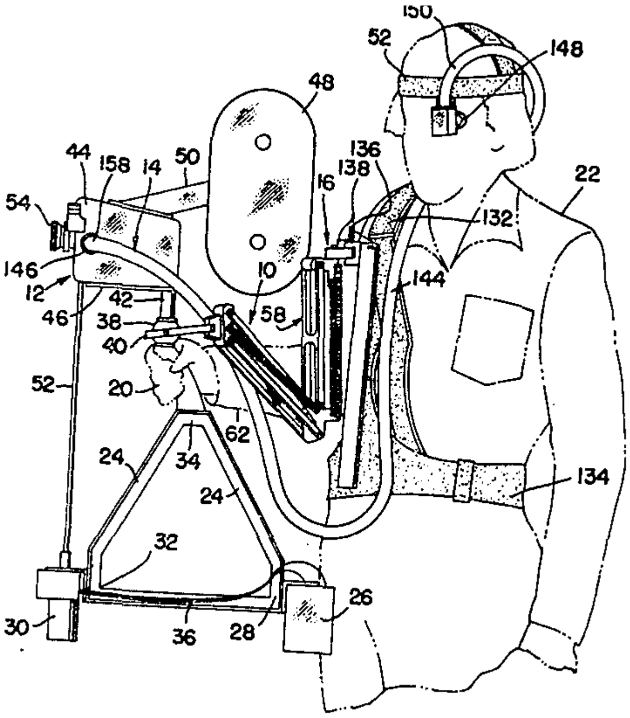

Figure 4 Steadycam device proposed by Brown [10]

This idea is very simple and inexpensive; however it is large, heavy, puts a strain on the operator, requires a long setup time and limits the camera movement. Also, it prevents any rotation with respect to the horizontal plane, which might not be favorable sometimes. In this design, the orientation of the camera should be manually handled using another handle, which is attached directly to the camera itself.

Also, as explained briefly above, a high-speed flywheel can be attached to a camcorder, handheld camera, spotting scope, or binocular to stabilize it in two or more axes. Kenyon Labs produce KS-2, KS-4, KS-6, KS-8 and KS-12 sealed dual counter-rotating brass or tungsten flywheels (“gyros”) that are spun by brushless motors at about 22,000 RPM in a bulky “hermetically sealed helium-filled housing” in an apparent effort to reduce high drag, heat dissipation and power consumption.

Figure 5 Kenyon Lab’s KS6 camera stabilizer (taken from www.ken-lab.com)

One “gyro” mounted to the camera in line with the lens will resist the motion in both pitch and yaw. Three “gyros” can be attached to the camera in three perpendicular directions to stabilize motion in more than two axes. The higher the moment of inertia of the flywheel and the higher the spin speed is, the more stabilization effect we will have.

This idea, although much similar to what will be proposed as a solution in this research, has some disadvantages. Kenyon Labs’ camera stabilizer units require 26 continuous watts of power for 4 to 7 minutes to spin up, weigh up to 5 pounds or more, are up to 6 inches long, and are relatively expensive.

In another research, electro mechanical motors are used to generate a motion in the opposite direction of the incoming tremors, in order to neutralize their effect [11].

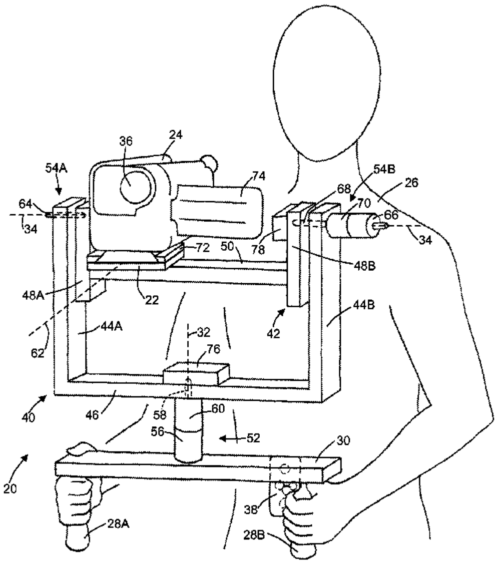

Figure 6 Handheld platform stabilizer [11]

In this invention, two servomotors are used in two perpendicular directions that are mainly the incoming tremors can be parallel with. For each one of those axes, an accelerometer is also attached to the body. The way that the whole mechanism works is that, the sensors measure the amplitude of the incoming noises from the user's hand and then the produced signal is scaled up by a predefined scaling rate, and then the result is sent to the electro motors as a command signal, making them produce an instantaneous motion at the opposite direction of the incoming noise, resulting in neutralizing their effect and isolating the camera from the un-wanted vibrations coming from the hand.

This idea is very effective in stabilizing the camera if two conditions are satisfied. First, the controller that receives the signals coming from the sensors, and generates the signals that go into the motors, should be quick enough to produce the noise-cancelling motion at the right time. Otherwise it will not be effective. Second, the sensors ideally should be attached at the intersection of the two axes of rotation, but in two perpendicular directions. Otherwise, they will have overlaps in measuring the incoming noises and the motors will therefore not produce the favorable counter-direction motions.

However, the main disadvantage of this idea is that it is relatively expensive and can be bulky. Besides, the motors and sensors need to be connected constantly to a power source to operate. This also brings in the issue of incoming cables to the system, which might restrict the range of the area that it can be moved.

Overall these technologies although partially effective, can be impractical and not fully functional for the specific application we have here at hand. They are either expensive preventing their broad utilization, or not applicable for everyday tasks and for those requiring accommodation for their fine motor skills. In addition, it is desired the envisioned device should be non-invasive and preferably not recognizable in public, in order to prevent patients face any social embarrassment.

Proposed Solution and Approach

Overview of Proposed Solution

The objective of this thesis is to design and build a prototype handheld device/implement (HI) that can compensate undesirable hand oscillations of people with hand tremor.

The proposed HI will be designed in a way to provide stabilization to the hand, with the expectation that it will improve task performance regardless of how vibrations emanate and propagate to the hand. This line of engineering design can later on be expanded towards focusing on task performance as measured by clinical cup holding/pouring tests. Also, while our efforts in this study will be focused on a stabilizing cup (HI) that aids in drinking and pouring, if successful the methodology could be applied generally. The fundamental idea behind this effort is to use a strategically placed small and light-weight gyroscope or *flywheel*, in a compact and ergonomic manner, around the cup to be utilized by a patient. That is, we plan to use a flywheel as stabilizing actuator.

Engineering details of the proposed solution

Before an engineering solution can be proposed for this solution, a mathematical model for the tremors needs to be developed. Previous studies have shown that tremors caused due to Parkinson’s have a frequency of 4 to 6 Hz and the ones caused due to ET have a frequency of 4 to 10 Hz [12] .

Regarding the amplitude of the tremors unfortunately there is no precise information. As a safe estimation for the amplitude, it is assumed that the magnitude of the tremors is 20 degrees or $\frac{\pi}{9}$ at most. Keeping the above mentioned assumptions in mind, the hand tremors around each axis can be mathematically modeled as a sinusoidal motion with an amplitude and frequency of respectively $\frac{\pi}{9}$ rad and 10Hz:

$$\theta = \left(\frac{\pi}{9}\right)\sin(20\pi t)$$

With this assumption, the angular speed and acceleration along with their maximum amounts will be as below:

$$\theta = \left(\frac{\pi}{9}\right)\sin(20\pi t)$$

$$\frac{d\theta}{dt} = \left(\frac{\pi}{9}\right).(20\pi).\cos(20\pi t)$$

$$\frac{d^2\theta}{dt^2} = -\left(\frac{\pi}{9}\right).(20\pi)^2.\sin(20\pi t)$$

Maximum Speed: 22rad/sec or 210 RPM
Maximum Acceleration: 1378 rad/s^2
Moment of Inertia of a cup filled with water with a radius and height of 10cm: 0.000729 Kg.m^2
Maximum Torque: 0.000729.1378=1 N.m

As explained above, it is assumed that the cup is a cylinder with 10cm in diameter and 10cm in height with almost 0.5Kg mass. As it can be seen, the torque needed to rotate the cup with the aforementioned angle profile will be almost 1 N.m. In this calculation, and in the rest of the thesis, we ignore the fact that the liquid in the cup moves and causes additional oscillations, leaving consideration of this for future work.

In this section, the mechanical concept of producing gyroscopic effect will be explained:

Angular Momentum

According to Newton's second law every rotating disk has an angular momentum which can be obtained from the equation below [13]:

$$L_z = I\omega$$

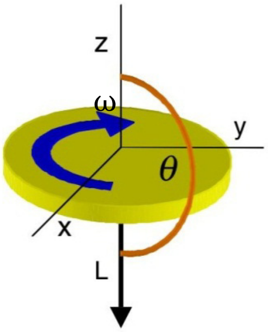

Figure 7 Angular momentum in a rotating disk [13]

where I is the moment of inertia of the disk, which in turn can be calculated as follows:

$$I_z = \frac{mr^2}{2} = \frac{1}{2}\rho\pi r^4 h$$

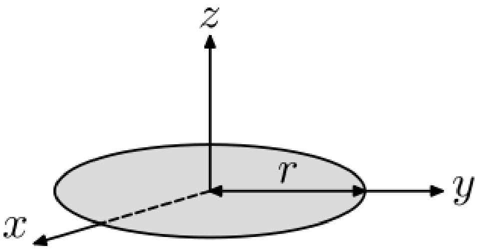

Figure 8 Moment of Inertia of a disk with respect to its main axis [13]

where the density of material is ρ, r is the radius of the disk and h is the thickness of the disk. As it can be seen, the moment of inertia and therefore the magnitude of angular momentum of a disk is directly related to the 4th order of radius and linearly related to the thickness of disk.

A rotating disk shows gyroscopic effect. It means that if an input moment is applied to it along an axis other than the spin axis, it will do a precession motion around the third axis [14].

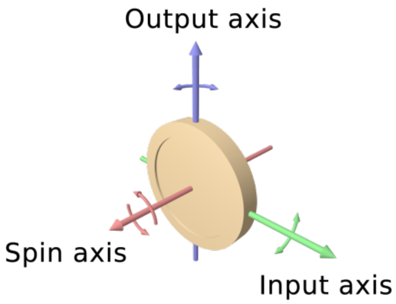

Figure 9 Spin, Input and Output axes in a gyroscope [14]

An input torque along the spin axis will not produce any gyroscopic effect.

Implementation of gyroscopic effect for stabilization

A flywheel (i.e. rotating disk) attached in a gimbal is usually called a gyroscope. A gyroscope may be attached to some other gimbals in order to increase its degrees of freedom [15]. Picture below illustrates a 2-gimbaled gyroscope which enables it to rotate in 2 directions:

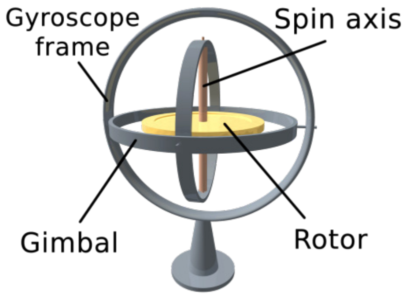

Figure 10 Degree-of-freedom gyroscope [14]

Several inventors have tried to take advantage of gyroscopic effect for stabilization purposes through different designs. The form of the design highly depends on the application of the gyroscope.

Schlick stabilizer

Otto Schlick introduced Schlick stabilizer in 1906 [16], which has been widely used, for stabilization of ships and small boats. It is a very smart design that uses a gimbal to convert the direction of the output moment of the gyroscope in a way that it is useful for stabilization of the vessel.

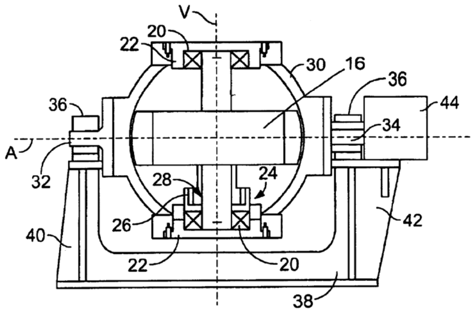

Figure 11 Schick Stabilizer [16]

It mainly consists of a flywheel (16), a gimbal (30) which holds the spin axis of the flywheel at (20). The gimbal is attached to the body of the ship through revolute joints (32), (34). Having been installed in either of the orientations illustrated below, Schlick stabilizer damps roll motion in the boats, which is caused by waves [17].

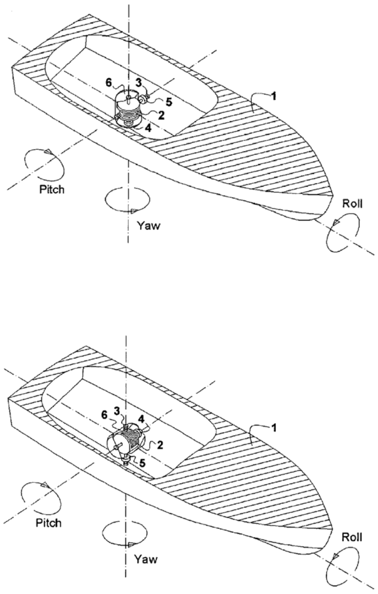

Figure 12 Different orientations of Schlick stabilzer [17]

The basic concept of this stabilizer is explained here in brief; the input destabilizing moment coming from sea waves tends to rotate the boat and therefore the gyrostabilizer along roll axis. This moment causes the gyroscope to produce a moment along pitch axis due to gyroscopic effect but since the gyroscope is free to rotate around pitch axis, it rotates either toward the front of the ship or the end of the ship depending on the direction of the input roll moment. The pitch motion of the flywheel in combination with the angular momentum of the flywheel again produces another gyroscopic output moment along roll axis and in the opposite direction of the input destabilizing moment coming from waves. This output moment opposes the input moment coming from waves helping the ship to stay stable around roll axis. The magnitude of this output moment mainly depends on the rate of the input roll motion, damping in the gimbals revolute joints, moment of inertia of flywheel and the speed of flywheel.

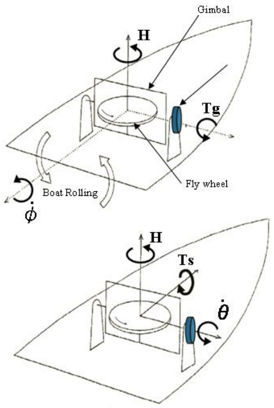

Figure 13 Moments produced in Schlick stabilizer [17]

It’s noteworthy mentioning that a boat is only vulnerable to instability along roll axis. since instability along pitch axis is not a concern due to its geometric shape. Therefore, the task of the stabilizer is to stabilize the boat along roll axis and that is why it is called “anti-roll gyro stabilizer”.

The mathematical process in which the stabilizing torques i.e. T_s is produced, is as below [15]:

$$T_g = H \times \dot{\phi}$$

$$I\ddot{\theta} = T_g - C\dot{\theta}$$

$$T_s = H \times \dot{\theta}$$

Equation 1 Governing equations of Schlick stabilizer

Proposed Solution and the Experimental Prototype

In the case of a cup, destabilizing oscillations might be along all three axes with different amplitudes. Unfortunately there is no precise information about the pattern of hand oscillations. But there is a possibility that if we control the oscillations around one axis in a hand, oscillations around the other two axes might also be controlled. We think this may be the case since limbs associated in the oscillations of hand are not necessarily independent systems and they might have mechanical interactions with each other.

With this line of thinking a simple system resembling the Schlick stabilizer was made at Complex Dynamic Systems and Control Laboratory at Northeastern University, which is depicted below:

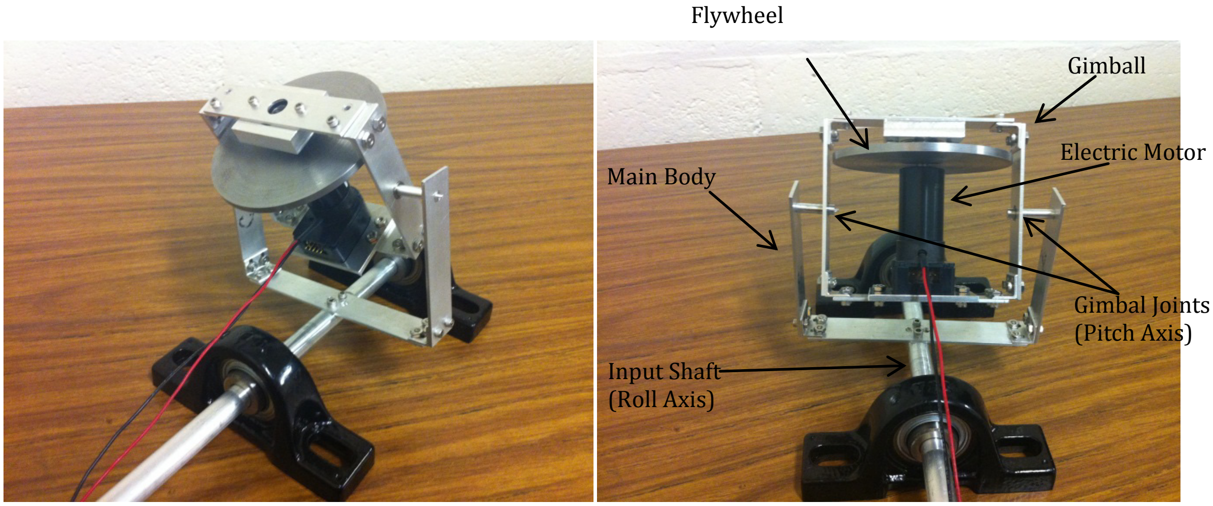

Figure 14 Schlick stabilzer prototype made at Northeastern University

A thin disk made of steel is being used as the flywheel that will be the source of gyroscopic effect. A DC motor is attached directly to the bottom of the flywheel through a shaft, and rotates the disk with a constant speed, once the input motor voltage is set.

The motor-flywheel couple is mounted to a frame made from aluminum, which is shown as the “Gimbal” in the picture, at two points; Motor is mounted directly to the frame using a bucket shaped holder. The top end of the disk however, is push-fitted inside a bearing, which is not visible in the picture. The bearing is also mounted to the gimbal through the box shaped aluminum part that can be seen on the left picture. The gimbal is attached to the main body through two revolute joints, and it’s free to rotate around the pitch axis. The main body, which resembles the object that is desired to be stabilized (e.g. boat, cup, etc.), is attached to a shaft, through which external destabilizing noises will be transmitted to the system. The main body is made up of three thin aluminum bars, which are orthogonally attached together to form a frame. Also the input shaft is attached to the two bigger bearings, which are the means by which the whole system sits on the ground.

The sample disk used in this device is 6cm in diameter and 2mm in thickness and the DC motor attached to it rotates with a speed of 7500 RPM. The motor used in this prototype is made by Faulhaber, and its series code is 2342012 CR. The electro-mechanical details of the motor as well as the data sheet for the bearings can also be found in appendix.

When the flywheel is rotating at speeds around 7,000 RPM, it is observed that the gyroscopic effect produced by the flywheel opposes the input oscillations that are applied to the system by rolling the input shaft, thereby reducing the transmitted oscillations to the main body and thus helping stabilize the main body. The strength of the opposing moment generated by the flywheel is correlated to the mass moment of inertia of the disk (related to the material and geometric properties of the flywheel) and the rotation speed.

Simulations

Model Development

Below is a schematic view from schlock stabilizer [15]:

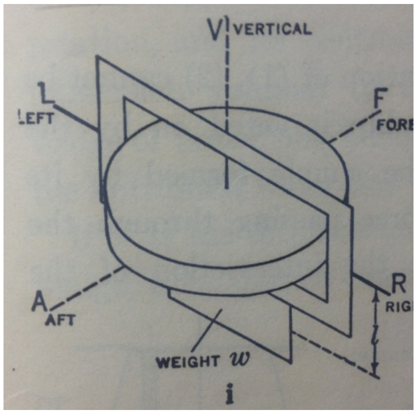

Figure 15 Schlick Stabilzer [15]

If we write the equations of motion for Schlick stabilizer shown in picture above, we will have:

$$J\ddot{\theta} + K\dot{\theta} + Wh\theta + N\dot{\varphi} = P\sin pt$$
$$A\ddot{\varphi} + k\dot{\varphi} + wl\varphi - N\theta = 0$$

Equation 2 Eauations of motion of Schlick stabilizer

where theta is the roll angle, phi is the gimbal angle, A is the moment of inertia of rotor, I is the moment of inertia of the boat, J is the summation of I and A, K is roll damping, k is the gimbal damping ratio, Wh represents the buoyancy effect, N is the angular moment of the rotor, w is the eccentric mass, l is the length of eccentricity, and Psin(pt) is the moment applied by waves. If we solve the equations above for phi, we will end up having:

$$
\begin{gathered}
\mathrm{JA}\frac{d^4\theta}{dt^4}+(\mathrm{Jk}+\mathrm{KA})\frac{d^3\theta}{dt^3}+(\mathrm{J}\omega\mathrm{l}+\mathrm{Kk}+\mathrm{WhA}+\mathrm{N}^2)\frac{d^2\theta}{dt^2}\\
+(\mathrm{K}\omega\mathrm{l}+\mathrm{Whk})\frac{d\theta}{dt}+\mathrm{Wh}\omega\mathrm{l}\,\theta\\
=\mathrm{NPp}\cos(\mathrm{pt})
\end{gathered}
$$

Equation 3 Simplified equation of motion of Schlick stabilizer

It needs to be mentioned that since we do not have roll damping and buoyancy effect in a cup, the terms containing Wh and K in the equation above will be zeroed-out in our case. If we develop the Simulink model for the equations of motion mentioned above we will have:

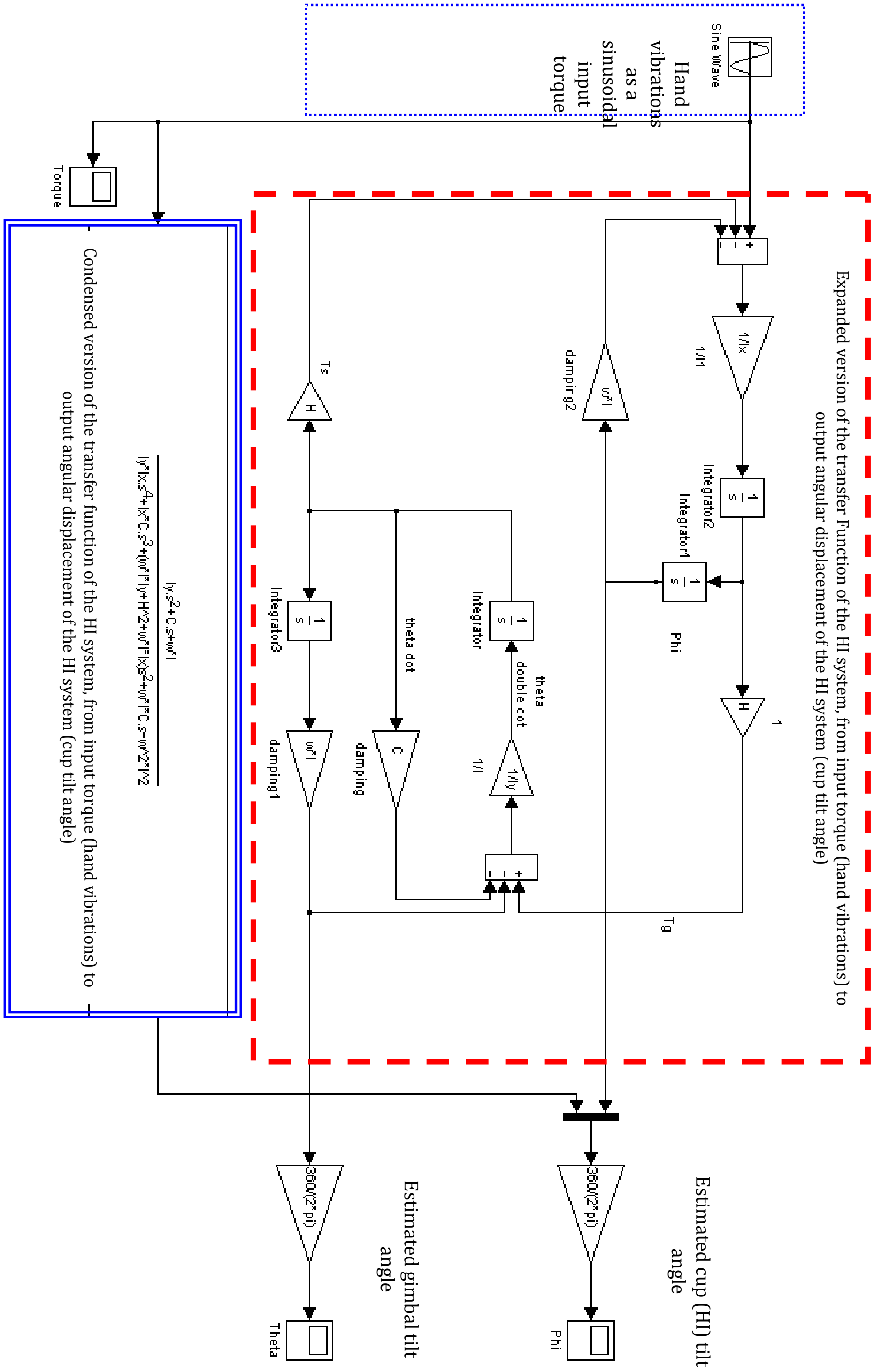

Figure 16 Simulation Diagram of the HI system was built in Simulink/MatLab Software

Inspired from the very basics of the mathematical and physical description of the gyro-gimbal system, which were discussed above, we built a simulation study, in which we simulate shaking of the handheld device described above. Here, we assumed that the amount of torque being applied by hand to the portable part is realistic, but the tilt angle is not very large, and remains not more than 20 degrees.

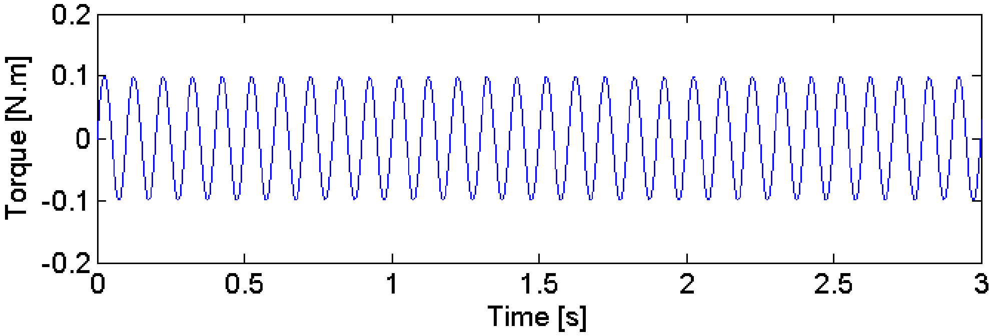

Figure 17 Input sine wave function torque

The transfer function corresponding to those set of formula is derived and is embedded in Simulink model. This was done so that the accuracy of the Simulink model could be verified.

Stability Analysis

In order to investigate the stability of the system, Routh-Hurwitz stability criterion was applied. Equation below shows the transfer function in detail:

$$\frac{Iy\,s^2 + C\,s + w\,l}{Ix\,Iy\,s^4 + Ix\,C\,s^3 + (w\,l\,Iy + H^2 + Ix\,w\,l)\,s^2 + w\,l\,C\,s + w^2\,l^2}$$

Equation 4 Transfer function representing Schlick stabilizer

Where C is the damping in gimbal joints.

Applying Routh-Hurwitz criterion to the denominator of the transfer function we will have:

$$\begin{bmatrix} Ix\,Iy & w\,l\,Iy+H^2+Ix\,w\,l & w^2\,l^2 & s^4 \\ Ix\,C & w\,l\,C & 0 & s^3 \\ H^2+Ix\,w\,l & w^2\,l^2 & 0 & s^2 \\ w\,l\,C-\dfrac{Ix\,C\,w^2\,l^2}{H^2+Ix\,w\,l} & 0 & 0 & s \\ w^2\,l^2 & 0 & 0 & 1 \end{bmatrix}$$

Figure 18 Routh Hurwitz table array

According to Routh-Hurwitz criterion, in order to have a stable system, all the elements of the table in the first column, marked by the red box, should have sign agreement. It is obvious that the first and third elements are always positive, so the other elements should also be positive for stability. For the second element to be positive, we should have a nonzero damping coefficient.

Regarding the last element of the table, it can be concluded that the offset of the center of mass of the disk from the gimbal rotation axis i.e. theta axis, should be non-zero.

For the third fourth element, it can be seen that in order to have a positive magnitude the following term should be positive:

$$w\,l\,C\,H^2$$

Equation 5 Expansion of third element of Routh Hurwitz table which again indicates that both L and C should be nonzero and positive.

Simulation Results

With the set up simulation, we can apply the aforementioned torque on the handheld device, and assuming that the gyro-disk in the portable part is spinning at different speed and the motion of the liquid in the cup is ignored, we can investigate how much the arising resistive torque slows down the hand tilt motion. We present these simulation results, where the tilt angle of the cup in degrees is plotted with respect to time, as predicted from the simulation diagram in Figure 18. In Figure 18, three curves are presented. The first one is in blue color corresponding to "no motion" of the gyro-disk system (i.e., zero RPM), where we see that without gyro-disk spinning, as the hand vibrates, so does the HI system within ± 20 degrees. In the second case, the gyro-disk is set to spin at 2,500 RPM, and the tilt angle of HI is plotted with red, where we see that tilt angle dampens out and reduces to oscillations within a few degrees, in the matter of 5-6 seconds. In the third case, if we set the gyro-disk speed at 5,000 RPM, within 2-3 seconds, we would expect to find significant reduction in HI tilt angle (green), which is within ± 2 degrees.

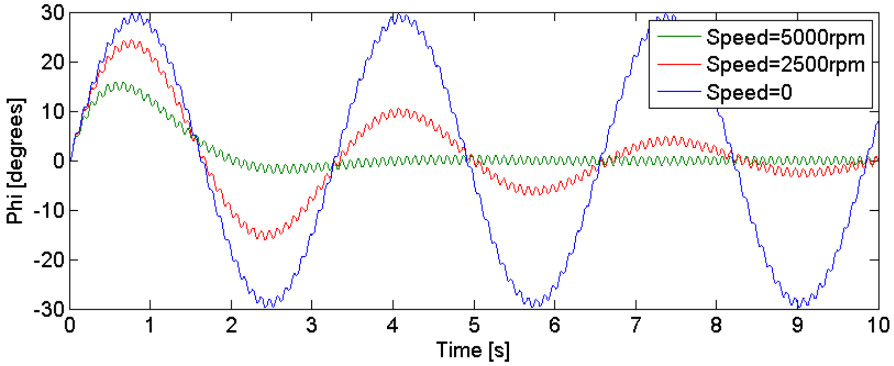

Figure 19 Expected HI tilt angle in degrees, obtained from the simulation

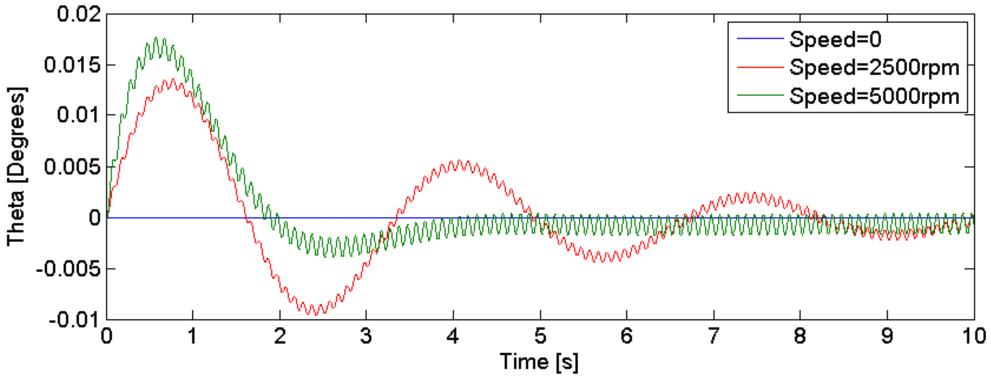

Figure 20 Expected gimbal tilt angle in degrees, obtained from the simulation

Also, in order to investigate the effect of damping on the stabilization, three different simulations were performed with all the other conditions kept constant. Graph below shows the effect of damping on the tilt angle of HI.

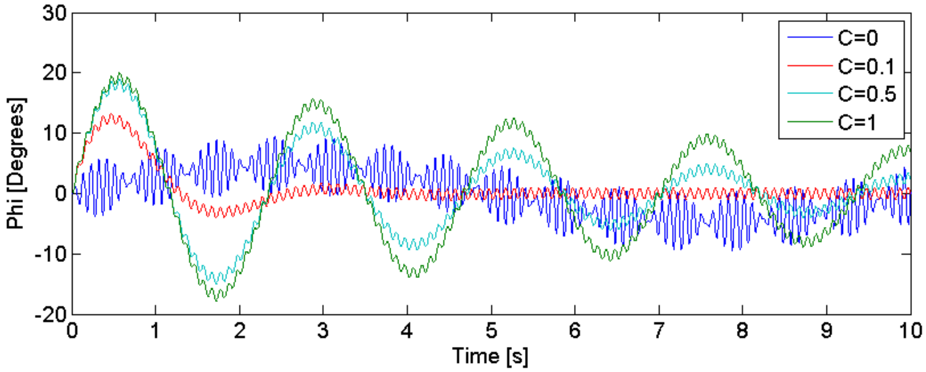

Figure 21 Effect of damping on the tilt angle of HI obtained from simulations

As it can be seen and was also concluded before, the damping ratio should not be absolute zero in order to have stabilizing effect. Also high damping ratios are not favorable either.

One other parameter than can be investigated is the eccentricity of the center of mass of the disk from theta axis (i.e. gimbal rotation axis) or l. As it can be seen below, a zero eccentricity makes the system unstable. It means that the disk should be assembled eccentric and should actually act like a pendulum.

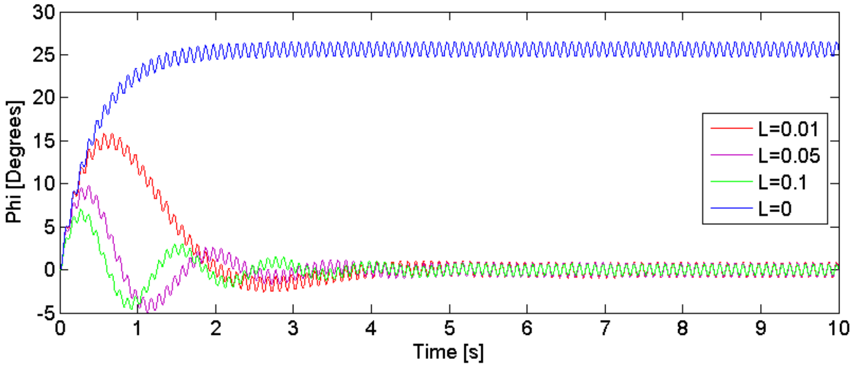

Figure 22 Effect of eccentricity of disk from gimbal tilt axis on the tilt angle of HI

The results of the simulation show that the more the eccentricity is, the more stabilization is achieved. However, this parameter cannot be too large since large travel distances of the disk while swinging, are not favorable.

To summarize, we reveal that, as the speed of the gyro-disk is increased, simulations predict that the portable part of the HI (cup) will tilt much less in angular displacement. Also large amounts of damping ratio on gimbal rotation axis is not favorable as well as zero damping. And the more eccentricity from theta axis we can afford for the disk, the better the stabilization effect will be. Although one would apply the same torque to shake the cup, validating via simulations that, with the physical variables used to design the prototype, we expect to find some improvement in dampening the tilt angle of the portable part.

Final Design

After that the effectiveness of the proposed idea was shown through the prototype, it was anticipated that if an appropriately scaled down version of the system in Figure 14 is attached to / embedded in the bottom of a cup, the gimbal-gyro system can equally be effective, and can suppress hand tremor induced oscillations applied to the cup at least in the roll direction the flywheel is effective. This is indeed a hypothesis and shows the direction of this study, which should be tested via human subjects testing beyond the scope of this thesis.

The scaled down gimbal-gyro system was designed to be strategically attached to a cup, Figure 22. It was envisioned that the gimbal-gyro system would be safely attached underneath the cup but without the electric motor. The nature of the design requires the gimbal joints shown in Figure 14 as attachments to the inner wall of the outer casing, effectively enabling the transmission of gyroscopic stabilizing moment from the gyroscope to the cup.

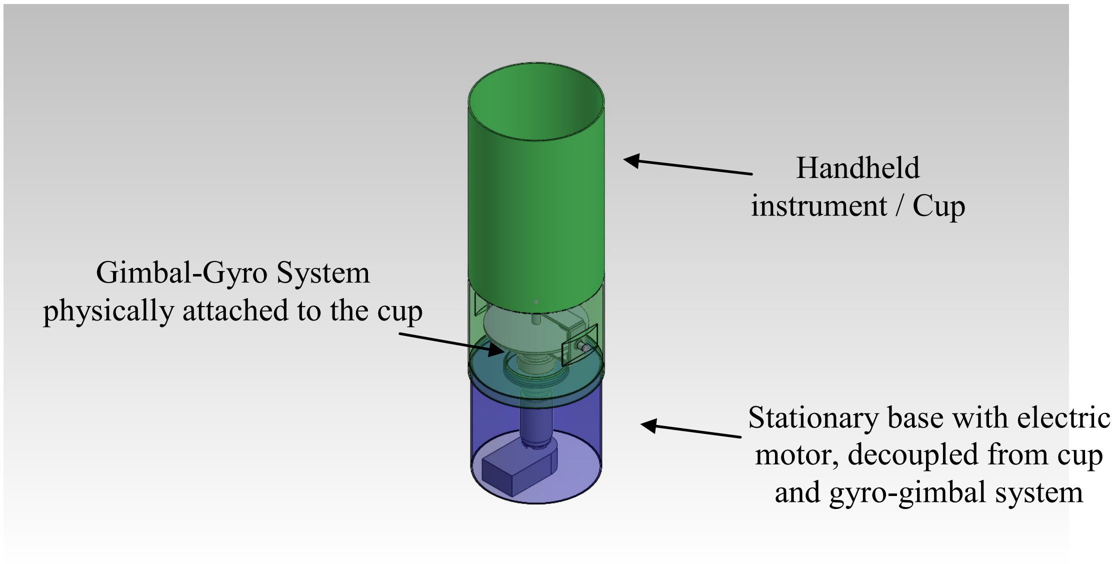

Figure 23 3D model of the final design

To expand the discussion, the part shown in green in Figure 22 is the cup to be stabilized, while the transparent part in green is the gimbal-gyro stabilizer attached physically to the cup. Separate from these components is the base (purple on schematic) in which the electric motor and circuitry is housed. This part is a stationary desktop component, on which the cup-gyro-gimbal system sits. Keeping the stationary part separate from the remaining parts ensure safety as the electric circuitry is kept away from liquids inside the cup, and also makes the overall design lighter since the user only needs to lift the cup as well as the gimbal-gyro system, but not the heavy electric motor.

In our proposed design in Figure 23, since the electric motor is no longer physically attached to the disk, we use two magnetic couplings to accomplish transmission of spinning torque from electric motor to the disk. That is, one of the magnets attached to the electric motor provokes another magnet attached to the disk, thereby transferring spin in a non-contact manner. The technical data of the magnets can be found in appendix.

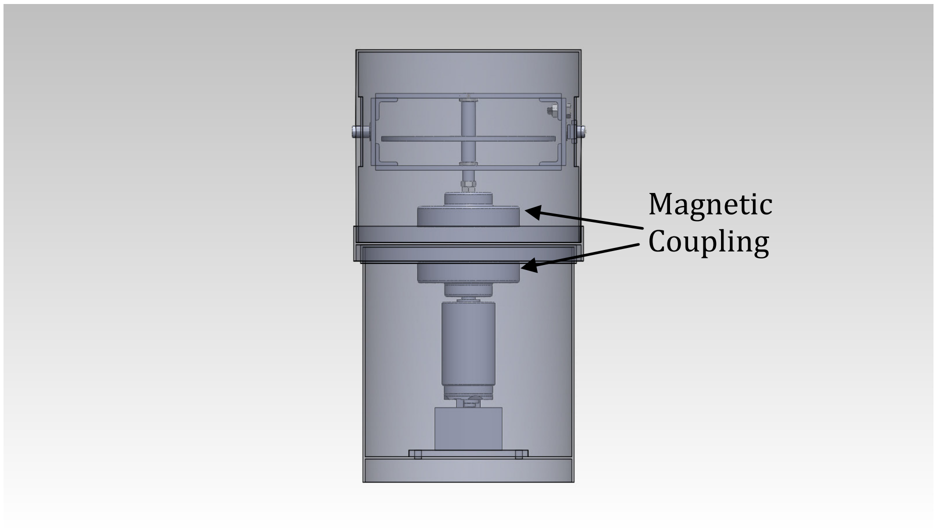

Figure 24 Side view of the 3D model displaying the magnetic couplings

The above configuration enables us most importantly to keep the stationary part decoupled from the stabilizer and the cup. In addition, it doesn't have the wearing problem of mechanical couplings as well as the unpleasant noise that these couplings might have. Also, not using mechanical coupling enables us to have all the mechanical parts in the stabilizer part and the stationary part unexposed and secure. Furthermore, these kinds of magnetic couplings have the advantage that they can tolerate radial eccentricity and axial offset to some extent. With this advantage, there is no more a need for high precision mechanical couplings, which are usually expensive. Also, another advantage of using these couplings is in stopping the flywheel from spinning, once it is put on the stationary part. The reason for the favorability of this fact is that, in order to have a synchronized start of spin for both of the magnets, they should start to spin from the same initial speed. Since the lower magnet, which is attached to the motor, is already steady, the motion of the top magnet will be dampened because of the moment of inertia of the motor, and will provide the favorite conditions for the spin to start.

It is planned that whenever the cup is placed on the stationary base, a switch will turn on the electric motor which will quickly spin the flywheel up to 7,000 RPM, and the speed, although reducing, provided low friction, will remain effective for up to 15-20 seconds for the user to lift the cup and drink the liquid. After 15-20 seconds the cup needs to be placed on the stationary base again, in order for the flywheel to speed up again.

Using the electrical switch to turn the motor on/off, most importantly energy will be saved. This is due to the fact that the motor does not need to remain rotating while the cup is being used and is not placed on top of the stationary part. Second, provided that an appropriate switching system is used, non-smooth starts and stops of motor that are usually along with a small stroke, can be prevented.

Realization of HI

After drafting of how the final design would look like, as explained in the previous section, the first version of the real model of the Holding Implement (HI) was built. In this prototype, as envisioned in Figure 24, we have a portable and a stationary part, where the motor and magnetic coupling are in the stationary part, and the gyro-gimbal pair and another magnetic coupling are in the portable part. When both parts are on top of each other, an appropriate amount of voltage is applied to the motor, spinning the magnetic coupling. This in turn activates the other magnetic coupling in the portable part, and since this coupling is attached to the gyro system, the gyro disk spins at speeds up to 7000 RPM, creating a resistive torque against tilting it from its original vertical configuration.

As soon as an input voltage actuates the motor, it takes up to 10 seconds for the gyro disk in the portable part to reach its final speed, thus creating the maximal resistive torque. Once the maximum speed is reached, it is anticipated that the user will pick up the portable part, encounter sufficient resistive torque to stabilize his/her hand, and have enough time to take a sip or two before the gyro disk slows down and resistive torque effects fade out. As soon as the portable part is picked up, a switch on the stationary part is deactivated cutting the motor voltage.

When the gyro speed fades out, the user will place the portable part again on top of the stationary part. This will activate the aforementioned switch, feeding voltage to the motor, and accelerating the gyro disk once again, making it ready with sufficient resistive torque for the next round of holding and drinking from the cup.

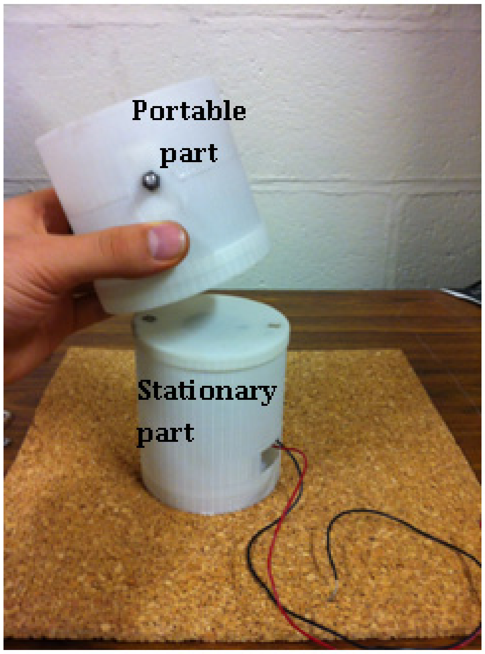

Figure 25 Side view of our Holding Implement (HI) prototype displaying the stationary (on the table) and portable (in hand) parts. This prototype has been produced based on what we envisioned in Figure 3. Notice in the picture on left that we are not displaying the cup that must be attached to the portable part.

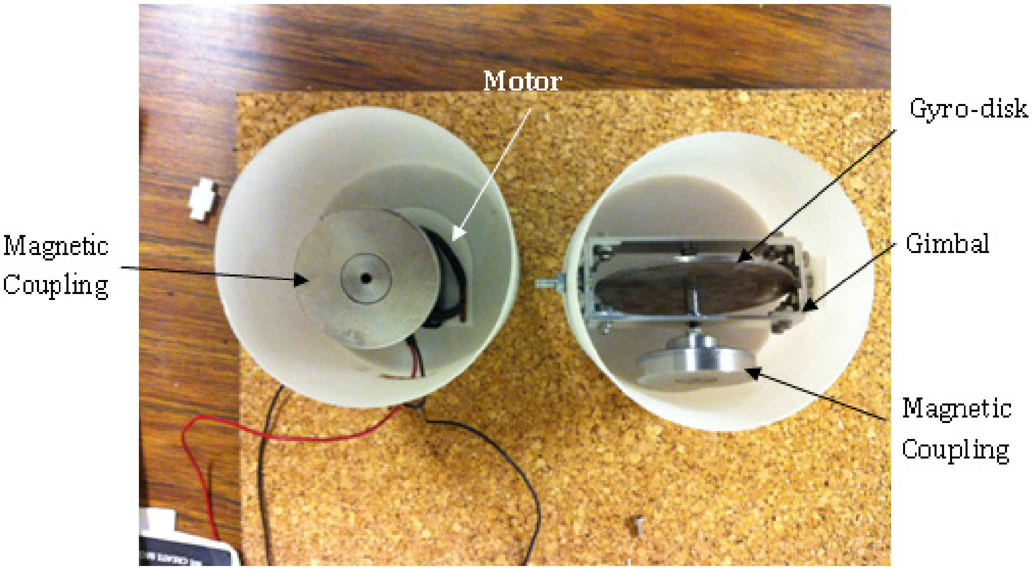

Figure 26 Top view of the stationary and portable parts of the holding implement (HI) without the protective lids, displaying on left the motor and magnetic coupling system (stationary part), and on right the gyro-gimbal pair with another magnetic coupling (portable part). This prototype has been produced based on what we envisioned in Figure 14.

Currently, the prototype shown in Figure 25 is completely functional, and although we do not have experimental results, it can be stated that when the gyro-disk in the portable part is spinning at high speeds, one very well feels the resistive torque on his/her hand.

Conclusion and Next Steps

An experimental framework based on vibrations and dynamics has been developed with inspiration from the well-known gyroscopic boat stabilizers, i.e. Schlick stabilizer. As it produces resistive torques, the device could be effective in attenuating arbitrary hand tremors of people with essential tremor, Parkinson's for oscillation magnitudes not more than 20 degrees and frequency of up to 12Hz. The detailed evaluation of the effectiveness of the device for use by human subjects is yet to be investigated through experiments. Without disclosing any intellectual property, we believe that the proposed framework has the potential to reduce hand tremor of many people with hand tremor related diseases. In case that this idea is confirmed through experiments, due to its simplicity and low cost, it will have the potential to be used in daily life activities. Also, in case that the effectiveness is approved, with some minor changes, the device will have the potential to be used for other applications such as for musical instruments, writing devices, and hand held weapons. This can be as a next step for this study. Another direction that can still be pursued is to make this device more ergonomic and physically smaller.

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Appendix

Permanent Magnet Coupling

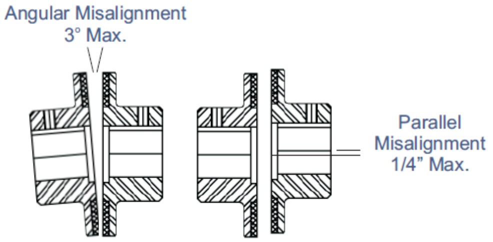
This two piece rare-earth permanent magnet coupling is for contact-free torque transmission through any non-ferrous wall, with the benefit of slipping when the maximum torque is exceeded, protecting mechanical components in the drive line from damage.

Ideally suited to:

- Marine applications removing the need for shaft seals
- Laboratory mixers and vessel agitators
- Driving submerged pumps or compressors
- Driving across vessels where contents must be isolated
- Food processing
- Pharmaceutical industry
- Where a safety slip mechanism is required
- Solar / low power applications requiring extremely efficient torque transmissions
- Rotary indication through barriers

How Disc Couplings Work

Disc couplings consist of opposing discs with powerful rare earth magnets. The torque applied to one disc is transferred through an air gap to the other disc.
Because of the simple flat design, you can have angular misalignment of up to 3° or a parallel misalignment of up to 6mm and still transmit nearly full rotational torque.
Easily isolate drive side components from clean or contained processes.
This is our simplest and most versatile coupling.



Advantages of Disc type Couplings:

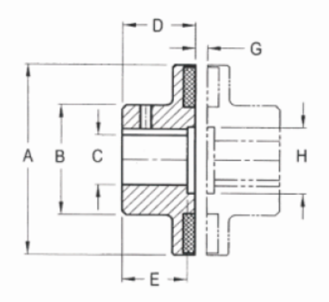
- No wearing parts - wear free transmission of torque
- Synchronous design
- No slip at any speed - protecting mechanical components in the drive-line from damage
- No physical contact between driving and driven parts
- Simplifies containment barrier
- Custom designs available
- Overload protection up to 110%
- Electrical, mechanical and chemical isolation

Technical Data:

Material - 400 Series stainless steel
Magnet (Nickel-Plasted) NdFeB*
Operating temperature - 140°C
*Also available with SmCo magnets rated up to 280°C

Note: Couplings are delivered with an integrated stainless steel cover to protect magnets and allow for clean operation and easy maintenance. The above images show exposed magnets for illustration only.

Permanent Magnet Coupling



P/N	HP @ 1750 rpm	KW @ 1750 rpm	Max Speed	*Weight per hub Kg.	Torque Normal Nm	Torque Peak Nm	A mm	B mm	C Max mm	D mm	E mm	G mm	H mm
PMK20	0.03	0.02	42500	0.05	0.11	0.16	26.92	20.57		16.00	16.00	3.18	N/A
PMK40	0.08	0.06	26000	0.10	0.45	0.56	43.69	20.57	see	14.99	15.00	4.83	N/A
PMK50	0.17	0.13	23000	0.15	0.68	0.90	50.29	28.45	chart	14.99	15.00	4.83	N/A
PMK60	0.25	0.19	19000	0.26	1.02	1.36	59.94	38.10	below	19.05	19.00	4.83	N/A
PMK70	0.45	0.34	15500	0.58	1.69	2.26	72.64	50.80		25.40	25.40	4.83	N/A
PMK90	1	0.75	12000	1.01	4.07	4.52	93.47	69.85	34.93	25.40	25.40	6.35	N/A
PMK110	2	1.49	10500	1.16	8.13	9.04	106.68	69.85	34.93	25.40	25.40	6.35	N/A
PMK130	3	2.24	9000	1.99	12.20	13.56	129.54	76.20	41.28	38.10	31.75	6.35	52.32
PMK150	5	3.73	9200	2.17	20.34	22.60	124.97	69.85	41.28	38.10	31.75	6.35	52.32
PMK170	7.5	5.59	9200	3.14	30.51	33.90	124.97	107.95	53.98	47.50	41.40	6.35	68.33
PMK190	10	7.46	7800	4.07	40.67	45.19	147.07	107.95	60.33	52.58	45.97	6.35	77.72
PMK200	13	9.69	7800	3.23	53.10	61.01	147.07	60.20	38.10	41.66	31.75	6.35	47.75

Notes:
*Weight per hub includes magnets.
Hubs sold separately.
Please refer to recommended bore sizes in the table below, see **Notes** and then **How to Order**.

Bore Code	0000	0125	0188	0197	0236	0250	0313	0315	0375	0394	0433	0472	0500	0551	0625	0709	0748	0750	0875	1000
Bore Size	Solid	1/8″	3/16″	5mm	6mm	1/4″	5/16″	8mm	3/8″	10mm	11mm	12mm	½″	14mm	5/8″	18mm	19mm	3/4″	7/8″	1″
P/N																				
PMK20		X	X	X	X	X	X	X												
PMK40	X		X	X	X	X	X	X	X	X										
PMK50	X				X	X	X	X	X	X	X	X	X							
PMK60	X								X		X	X	X	X	X	X	X	X		
PMK70	X										X	X	X	X	X	X	X	X	X	X

Notes:

PMK20 has one set screw (grub screw), PMK40 and PMK50 have two set screws.
PMK60 and PMK70 have one set screw and keyway (for bores 11mm and larger.)
Keyways start with bores 11mm and larger.
All larger sizes of Permanent Magnet Couplings are supplied as solid bores, with additional costing for boring & keyway machining.
PMK150-PMK200 are manufactured to order. Minimum order quantity 2 hubs (different bores accepted).

How to Order:

P/N for 1 hub + bore code + P/N for the other hub + bore code EG: 1 off PMK20-0000(solid) + 1 off PMK20-0236 (6mm bore)

Please contact TEA Transmissions - **email:** sales@tea.net.au for price and delivery.
CAD files available via our website: **www.tea.net.au**

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New TEA Product - Aug 2010 (updated Oct 2010) pg 2

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Graphite Commutation

16 mNm

For combination with
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22/7, 22F, 23/1, 26/1, 26/1 S, 26A, 30/1, 30/1 S, 38/3
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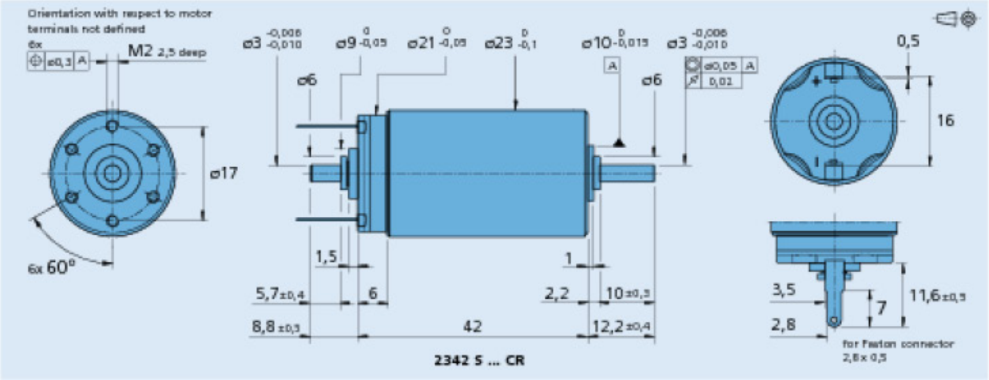
Series 2342 ... CR

		2342 S	006 CR	012 CR	018 CR	024 CR	036 CR	048 CR	
1	Nominal voltage	U_N	6	12	18	24	36	48	V
2	Terminal resistance	R	0,4	1,9	4,1	7,1	15,9	31,2	Ω
3	Output power	$P_{2\,max.}$	20,5	17	18,1	19	19,4	17,7	W
4	Efficiency, max.	$\eta_{max.}$	81	80	81	81	81	81	%
5	No-load speed	n_0	9 000	8 100	8 000	8 500	8 100	8 000	rpm
6	No-load current (with shaft ø 3 mm)	I_0	0,17	0,075	0,048	0,038	0,024	0,017	A
7	Stall torque	M_H	87,2	80	86,5	85,4	91,4	84,4	mNm
8	Friction torque	M_R	0,98	1	0,99	0,99	0,99	0,95	mNm
9	Speed constant	k_n	1 650	713	462	366	231	170	rpm/V
10	Back-EMF constant	k_E	0,604	1,4	2,16	2,73	4,34	5,87	mV/rpm
11	Torque constant	k_M	5,77	13,4	20,7	26,1	41,4	56,1	mNm/A
12	Current constant	k_I	0,173	0,075	0,048	0,038	0,024	0,018	A/mNm
13	Slope of n-M curve	$\Delta n/\Delta M$	103	101	92,5	99,5	88,6	94,8	rpm/mNm
14	Rotor inductance	L	13,5	65	150	265	590	1 050	µH
15	Mechanical time constant	τ_m	6	6	6	6	6	6	ms
16	Rotor inertia	J	5,6	5,7	6,2	5,8	6,5	6	gcm²
17	Angular acceleration	$\alpha_{max.}$	160	140	140	150	140	140	·10³rad/s²
18	Thermal resistance	$R_{th\,1}$ / $R_{th\,2}$	3 / 15						K/W
19	Thermal time constant	τ_{w1} / τ_{w2}	6,5 / 490						s
20	Operating temperature range:								
	– motor		-30 ... +100						°C
	– rotor, max. permissible		+125						°C
21	Shaft bearings		ball bearings, preloaded						
22	Shaft load max.:								
	– with shaft diameter		3						mm
	– radial at 3 000 rpm (3 mm from bearing)		20						N
	– axial at 3 000 rpm		2						N
	– axial at standstill		20						N
23	Shaft play								
	– radial	≤	0,015						mm
	– axial	=	0						mm
24	Housing material		steel, black coated						
25	Weight		88						g
26	Direction of rotation		clockwise, viewed from the front face						
Recommended values - mathematically independent of each other									
27	Speed up to	$n_{e\,max.}$	7 000	7 000	7 000	7 000	7 000	7 000	rpm
28	Torque up to	$M_{e\,max.}$	16	16	16	16	16	16	mNm
29	Current up to (thermal limits)	$I_{e\,max.}$	2,7	1,4	0,95	0,72	0,48	0,35	A



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