

Leg Ergometer for Blood Flow Studies

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Abstract

Dr. William Schrage is conducting research studies involving blood flow through the femoral artery during exercise. He needs a device that will allow a subject to do constant work by kicking one leg while he images the femoral artery in that same leg. The goal of this project is to design a device that will fit his needs for his research. Some of his major requirements include passive return of the foot to the normal position after the kick, a constant kick rate, measurable work output, and reliability. Three design alternatives were developed and the advantages and disadvantages of each were weighed and a final design was chosen.

Problem Statement

Dr. William Schrage is researching blood flow through the femoral artery during exercise and needs an ergometer that will allow for a regular kicking motion with a passive return of one leg while providing a constant resistive force against the kick. This device will be used in his research lab as part of his studies. While the subject is kicking, he will be imaging the femoral artery to determine blood flow.

Background

Blood Flow Research

Dr. William Schrage works in the department of kinesiology conducting blood flow research. He will use this design in his experiments to measure blood flow in the femoral artery. The data he obtains will lead to further research on how smaller blood vessels regulate the femoral blood flow. He infuses drugs into the femoral artery to

observe how they are delivered to the microcirculation where they activate the signaling system. There are two main questions to this research. First, what are the neural, metabolic, and vascular signals controlling blood flow at rest and exercise? Second, how do conditions like aging and cardiovascular diseases such as obesity, high blood pressure, and diabetes alter the regulation of blood flow? The wider implications of this research will lead to a better understanding of blood pressure control and how blood flow changes and affects people with obesity and diabetes.

Existing Devices

Previously, the client used a leg ergometer that was designed for similar studies at Mayo Clinic. The previous device was composed of a flywheel off an exercise bike and a car seat for the patient's seat. For the boot, which was connected to the bike pedal by a bar and ball joints, two separate rollerblade boots were used. One was small and intact while the other was larger and had the toe cut out to allow for various foot sizes. An ultrasound probe held by the researcher was used to observe and measure the blood flow, and sensors connected to the resistance system measured wattage and kicking rate. Unfortunately, the device was unreliable. The flywheel would occasionally have a backward spin, resulting in zero resistant force applied when the patient kicked forward. Also, the nylon belt, which was attached to the flywheel, caused friction and produced heat, which altered the length of the nylon belt and the work output by the patient. Both of these factors corrupted the data gained from the sensors.

There are several types of leg ergometers, one example being exercise bikes. Most of them are two-leg cycles which contain a flywheel and a brake system which gives resistant force to the user. However, there are also leg ergometers for medical use,

which look similar to a normal exercise bike. In this case, most of them are one-leg cycles. These devices are useful in measuring heart rate or endurance.

Product Design Specifications

The final product should have a streamlined, compact design that encloses the loose parts as much as possible. This will prevent anything from becoming caught in the moving elements and increase the overall safety of the device. This product should also have a minimum lifespan of five years. To accomplish this, it must be sturdy and built of durable materials that will withstand the patients' weight and the numerous tests it will be used to conduct.

The device should be easily portable, with wheels on the base of the frame, to ensure that it can be moved around the research area as needed. In order to unobtrusively fit in the area, it should be approximately 5' long by 3' wide. The chair of the ergometer should be positioned 3' above the ground and it must recline so it can be positioned at various angles from vertical. Also, the entire device must be adjustable to accommodate test subjects of heights ranging from 5'4" to 6'4".

The ergometer should accommodate a full range of motion for the kicking leg, which will be connected to the device via a boot of some sort on the patient's foot. It should also provide relative comfort and thigh stabilization to the patient throughout the experiment. The leg must be able to fully extend while kicking to 180°, and return to a natural rest position of 90°. The device should also allow for some right-left flexibility to accommodate the different kicking pathway of each patient. In addition to this, the area

where the patient is kicking should be enclosed beyond the full leg extension length to ensure the safety of the other people in the room while testing.

The device must have a resistant force against the upward kicking motion of the leg, but zero force when the leg is falling back to the rest position. This allows for a passive return to the rest position of the leg after kicking. The force on the leg should be adjustable between tests, and the device should be set up for right-leg testing. If possible, the device may be set up to switch from right-leg testing to left-leg testing, but this is not a requirement.

The ergometer must be able to be used at a rate of 30-60 kicks per minute, and it should run at 5-100 W of constant power. This means that the device must be able to be set to a single wattage and to run at that setting for at least 20 minutes without deviating. The kicks per minute and wattage outputs should be read by sensors and then sent to a laptop through an A/D converter. Because an ultrasound will be used to view the arteries in the patient's kicking leg, a platform for the arm of the one holding the sensor could be added to the device to increase the comfort of the researcher. This whole device must be assembled and built for under \$2,000.

Alternative Designs

There are certain aspects of each design alternative that are universal. Every design includes a seat for the patient that reclines and has an adjustable height to accommodate different test subjects. The boot for the foot of the kicking leg will include a base and straps to hold the shoe of the patient in place. The boot will then be connected to the source of resistance, which will have an adjustable force. There will be sensors attached

to the device to measure the wattage and kicking rate of the patient, as well as wheels on the base of the frame to allow for movement of the device.

Gas Spring Shock

The first design chosen employs a gas spring shock as the resistive force against the foot. The gas spring shock

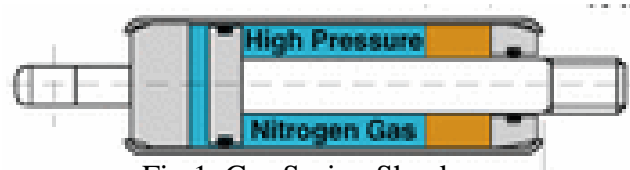


Fig 1. Gas Spring Shock

works by the compression of gasses within a cylinder. When the foot kicks forward, the rod is pulled and the gas compresses (Fig. 1). The force against the foot is a function of velocity, meaning the faster the gas is compressed, the greater the force will be. Gas spring shocks can be purchased commercially in various sizes with adjustable forces at a reasonable price. This flexibility would ensure a device that accurately fits the force requirements of this design. The gas spring shock would be connected to the boot with the use of a cable which would allow for more flexibility in the kicking motion without the use of a bar and ball joints. A major disadvantage of this design is that the device would spring back to its initial position when the force of the kick is finished. This forced return of the device would likely lead to the active return of the kicking leg to the rest position which would go against one of the major requirements of the project.

One-way Clutch

The second and third designs both utilize a one-way clutch, which is a device that freely turns in one direction, while rotation is restricted in the other direction. In the context of this design, the one way clutch would lock when the subject's foot is kicking

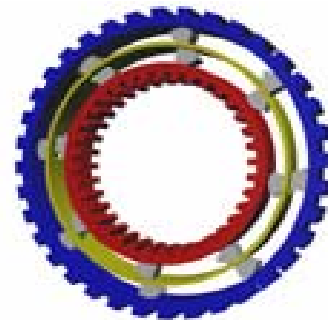


Fig. 2 Sprag clutch

forward and rotates freely when the foot is returning to the resting position. A one way clutch provides this uni-directional rotation in several different ways. Fig. 2 illustrates a sprag clutch which is one type of one-way clutch. The sprag clutch employs two rings with several sprags placed between. The sprags are placed at a slight angle from the normal to the rings. When the clutch is turned in one direction, in this case clockwise, the sprags are forced towards their slant and the rotating ring is free to turn. When the clutch is turned in the other direction, the sprags are forced towards the normal and become wedged between the two rings, preventing

the mechanism from turning. Another type of one-way clutch is shown in Fig. 3. This mechanism involves the use of four ball bearings which are placed between the hub and ring as shown. When the hub rotates clockwise, the ball bearings are forced into the corner where there is enough space for them to freely pass by the ring. When the hub is

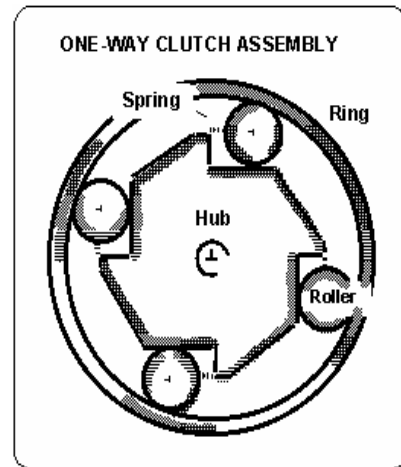


Fig. 3 One-way Clutch

rotated counter-clockwise, the ball bearings become wedged between the surfaces of the hub and ring which prevents the device from rotating. The use of a one-way clutch in the following two designs allows for simple, free return of the kicking leg at a reasonable cost.

One-way Clutch w/ Drum Brake

This design makes use of the one-way clutch described above and a drum brake as the resistive force. A

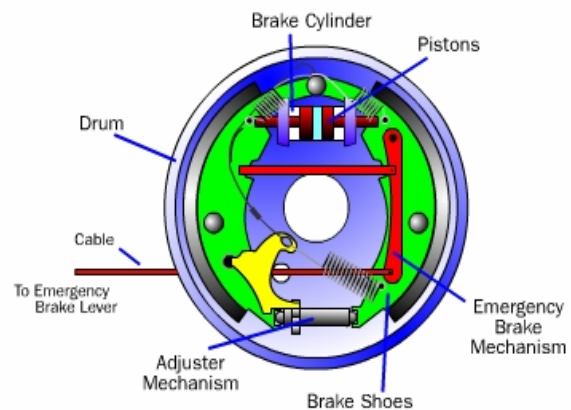


Fig. 4 Drum brake

drum brake is the type of brake that is found on the rear wheels of cars. This design would provide a constant force with no relationship to the velocity. The drum brake would provide a resistive force due to friction. The friction would come from two “shoes” pushing against the side of a drum as shown in Fig. 4. The resistive force could be changed by altering the normal force of the shoes to the drum. Some disadvantages of this design are that the properties of the brake pads could change with heat, which would also change the force of resistance. Also, the brake pads would need to be replaced as they wore down.

Proposed Design

The last design utilizes the one-way clutch as previously described along with a viscous friction device (Fig. 5). This device consists of two metal sheets with a liquid between them. The viscosity of the liquid would provide the resistance as the test subject kicked out, and then retract when the test subject brought their leg back. The researcher could change the work output of the test subject by altering the surface area between the surfaces.

There are several advantages to this design. Because the design is dependent on liquid, the work done by the test subject would not change as the temperature of the device changed. It would also be fairly easy to construct because the viscous friction device can be purchased

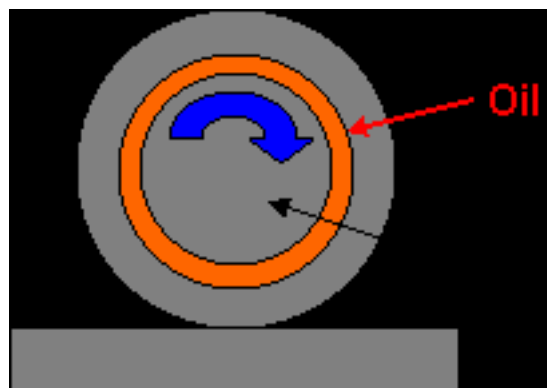


Fig. 5 Viscous Friction Device

separately and then attached to the one-way clutch.

There are also some disadvantages to this design. It may be more difficult to find and order the viscous friction device. Because this device would require the test subject's leg to be connected to a stiff bar, it would also provide less flexibility in the test subject's kicking motion.

A design matrix was utilized to aid in choosing one of the three alternative designs. In the design matrix (Appendix 2), the ability of the device to provide a passive kicking return and the overall reliability of the device were given the most weight. Some other considerations included the ease of construction, maintenance required, ease of use, ability to provide a consistent kicking force and flexible kicking motion, and the force adjustability. The gas spring shock design would be easy to construct and would provide a flexible kicking motion, but it would not provide a passive kicking return. Because this is one of the most important requirements of the design, the gas spring shock is not suited for this project. The one-way clutch with drum break scored higher than the gas spring shock, particularly on the ability to provide a passive kicking return, but it would not be overly reliable, and because this is also one of our largest client requirements, this design was not ideal. The last design, the one-way clutch with viscous friction device, scored very high on both overall reliability and the ability to provide a passive kicking return. Because it meets all of the client requirements, this design was chosen to propose to the client.

Future Work

This semester, the one-way clutch design with viscous friction device will continue to be finalized and developed. It will be constructed, tested, and modified. The tests will utilize human test subjects and will determine the safety and reliability of the project. This testing may result in some minor modifications. After these modifications are fixed, the design will be delivered to the client.

References

Maximal Perfusion of Skeletal Muscle in Man (Per Andersen and Bengt Saltin) 1984

Professor Frank Fronczak, Mechanical Engineering Dept., University of Wisconsin-Madison

ADCATS at Brigham Young University http://adcats.et.byu.edu/WWW/Publication/94-1/Paper1-12_6.html

Figure Sources:

Fig. 1 http://www.globalspec.com/FeaturedProducts/Detail/IndustrialGasSprings/Stainless_Steel_Gas_Springs_/34982/0?fromSpotlight=1

Fig. 2 <http://www.mie.utoronto.ca/staff/projects/cleghorn/Textbook/DataFiles/Appendix-B/Appendix-B.html>

Fig. 3 http://adcats.et.byu.edu/WWW/Publication/94-1/Paper1-12_6.html

Fig. 4 <http://www.howstuffworks.com/drum-brake.htm/printable>

Fig. 5 <http://galileo.phys.virginia.edu/classes/152.mf1i.spring02/Viscosity.htm>

Appendix 1: Project Design Specifications (PDS)

Project Design Specification—Leg Ergometer Amy Weaver, Cali Roen, Lacey Halfen, Hungjin Kim February 7, 2007

Function: The goal is to design a leg ergometer to be used by William Schrage in his lab. The test subject will use the ergometer to maintain a constant kicking motion while the femoral artery is imaged using an ultrasound. The information is used to determine blood flow to the leg during exercise.

Client Requirements:

- Must be sturdy, last at least 5 years
- Adjust for people heights 5'4" to 6'4"
- Maintain a constant wattage throughout testing
- Wattage (5-100 W) and kick rate (30-60 kicks per minute) output to a laptop through an A/D converter
- Flexible range of motion for kicking
- Leg must be able to fully extend when kicking (Range of 90 - 180°)
- Passive return to normal position of the leg after kicking
- Set up for right leg testing
- Minimal loose parts

Design Requirements:

1. Physical and Operational Characteristics

- Performance Requirements:* The ergometer should be able to be used at a rate of 30 to 60 kicks per minutes (kpm) and 5 to 100 W of constant power. The kicks per minute and power output should be measured and sent to a laptop through an A/D converter. The kicking leg should have a range of motion of 90 to 180°. The subject's chair should be able to adjust the angle from vertical.
- Safety:* The ergometer should be able to hold an average sized person without putting extreme stress on the components. Also, any elements under tension should be enclosed such that if they come loose, they do not cause harm to any persons near the device. The whole device should be as enclosed as possible so that nothing can get caught in the moving elements. There should be a sufficient amount of enclosed space left in front of the device to allow for full extension of the leg when kicking while ensuring that people in front of the device do not get kicked.
- Accuracy and Reliability:* The device must be able to be set to a single wattage and to run at that setting for at least 20 minutes without deviating. Any data collected from the machine should be consistently accurate.
- Life in Service:* Product should have a lifespan of at least five years.

- e. *Shelf Life*: Device should be stored at room temperature in a clean environment.
- f. *Operating Environment*: The ergometer needs to be durable enough to withstand the test subjects' weight. It also needs to withstand numerous tests with variable force levels and minor transportation.
- g. *Ergonomics*: The device must accommodate test subjects from 5'4" to 6'4" with variable weights. The subject should also sit 3' above the ground at an adjustable angle from vertical. The kicking portion of the ergometer needs a little left-right flexibility to accommodate different test subjects. Overall, the device should be comfortable for the test subjects as well as the researchers to use.
- h. *Size*: The ergometer needs to be approximately 5' long by 3' wide by 3-4' tall. It should be easily portable (with wheels).
- i. *Weight*: The product should contain a comfortable chair for the patient. Also a part which measures the force from the patient is needed. In order to include those parts, the product will be at least few hundred pounds. The ergometer will be placed in a room in a research facility; it is not necessary to move this machine often.
- j. *Materials*: If a belt is included in the design, materials other than nylon should be used, since the heat changes the length of the belt. Also, we need to use durable materials and a comfortable seat for the patient.
- k. *Aesthetics, Appearance, and Finish*: The previous design was somewhat crude looking. The new design should be streamlined and compact, with as few extra parts as possible.

2. Production Characteristics

- a. *Quantity*: The client only requires one unit at this time, although there is the possibility of additional units used in the future.
- b. *Target Production Cost*: The budget for this project is \$2,000.

3. Miscellaneous

- a. *Standards and Specifications*: Local and national safety standards must be met.
- b. *Customer*: Could have a platform for person holding the ultrasound to rest their arm so that it stays steady. Also the ergometer may be adaptable for use with the left leg in addition to the right leg.
- c. *Patient-related concerns*: The ergometer should provide relative comfort to the user while maintaining stabilization of the thigh while kicking.
- d. *Competition*: Ergometers are available in many different styles including ellipticals and stationary bicycles. There are examples of ergometers similar to this proposed design in use in several research facilities. One example of this type of ergometer was used in a research study published in the following article: P. Andersen and B. Saltin, Maximal perfusion of skeletal muscle in man. J Physiol..

Appendix 2: Design Matrix

	Weight	Gas Spring Shock	One Way Clutch w/ viscous friction	One Way Clutch w/ Drum Brake
Overall Reliability	20	0.75	0.9	0.65
Ease to Construct Maintenance Required	5	1	0.8	0.8
Ease of Use	15	0.8	0.8	0.6
Consistent Force	10	0.7	0.7	0.6
Flexible Kicking Motion	15	0.6	0.8	0.6
Passive Kicking Return	10	1	0.8	0.8
Force Adjustability	20	0.25	1	1
	5	1	1	0.7
Total (Out of 100)		68	86	72.5