



**NTNU – Trondheim**  
Norwegian University of  
Science and Technology

# MagnetGym

Resistance altering Gym Equipment with  
Biofeedback

**Even Aavestrud**

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Supervisor: Martin Steinert, IPM

Norwegian University of Science and Technology  
Department of Engineering Design and Materials



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***MagnetGym***

This master thesis is going to discover the possibilities and applications areas for exercising equipment using electromagnetic force instead of physical weights.

This will be a technology push task, there are no immediate needs for such equipment, but it has the possibility to compete with traditional equipment.

The equipment is going to use electromagnetic force that will make it easier to control the training load, it will make it able to have programmable training routines, e.g. drop sets.

The prototype will be small scale and includes a microcontroller to experiment with different codes and setups. The final goal is to make a full scale prototype.

The MagnetGym has many interesting aspects that will be examined and will hopefully make it better than existing equipment:

- The MagnetGym will eliminate the problem with weights lying around.
- The MagnetGym can potentially be used in space, so a comparison to today's solution will be done.
- Many of today's training routines are based on a certain percentage of your maximum load on a certain amount of repetitions and/or a specific time used on eccentric and concentric movement. An electromagnetic force is easier to change and therefore make it possible to train in a more efficient and correct matter.
- It could open the possibilities of connecting exercise equipment to the human body, to e.g. control the electromagnetic force to a certain percentage of your maximum load from outputs from the muscles.

Three weeks after start of the thesis work, an A3 sheet illustrating the work is to be handed in. A template for this presentation is available on the IPM's web site under the menu "Masteroppgave" (<http://www.ntnu.no/ipm/masteroppgave>). This sheet should be updated one week before the Master's thesis is submitted.

Performing a risk assessment of the planned work is obligatory. Known main activities must be risk assessed before they start, and the form must be handed in within 3 weeks of receiving the problem text. The form must be signed by your supervisor. All projects are to be assessed, even theoretical and virtual. Risk assessment is a running activity, and must be carried out before starting any activity that might lead to injury to humans or damage to materials/equipment or the external environment. Copies of signed risk assessments should also be included as an appendix of the finished project report.

The thesis should include the signed problem text, and be written as a research report with summary both in English and Norwegian, conclusion, literature references, table of contents, etc. During preparation of the text, the candidate should make efforts to create a well arranged and well written report. To ease the evaluation of the thesis, it is important to cross-reference text, tables and figures. For evaluation of the work a thorough discussion of results is appreciated.

The thesis shall be submitted electronically via DAIM, NTNU's system for Digital Archiving and Submission of Master's thesis.

Torgeir Welo  
Head of Division



A handwritten signature in blue ink, appearing to be "SW", with a long horizontal line extending to the right.

Navn på faglærer  
Professor/Supervisor

## **Preface**

This Master thesis, titled *MagnetGym, resistance altering gym equipment with biofeedback*, was written as my final work in Mechanical Engineering at the Norwegian University of Science and Technology (NTNU) spring 2014. The thesis was chosen based on my interest for training and fitness, and product development.

There are several I would like to direct my utmost gratitude to. Special thanks go to my supervisor Professor Martin Steinert for support, Staff Engineer Halvard Støwer as my component supplier, and Tobias Linkjendal for the idea of using magnetism as workout resistance. I wish to thank the office, the great guys at PLM Lab, for a healthy and supporting study environment. I also wish to thank my family and girlfriend for all encouragement, patience and support.

## Sammendrag

Masteroppgaven var opprinnelig tiltenkt å være et forsøk på å designe et konkurransedyktig produkt til dagens treningsutstyr ved hjelp av magnetisk motstand. Siden motstanden vil bli kontrollert elektronisk ble muligheten til å gjøre MagnetGym en lukket krets med innspill fra musklene ytret. Avhandlingen ble da utvidet med motstandskontroll med biofeedback. Med biofeedback, fra EMG sensorer på muskelen, var hypotesen at en nøyaktig prosentandelen av muskelaktivering, og derfor andelen av kraft en person kan generere, kan måles. Dette vil føye MagnetGym inn dagens rekke av smarte produkter.

Avhandlingens fokus vil være på produktutvikling. MagnetGym ble delt inn i seksjoner og konsepter for hver seksjon ble bevist. MagnetGym ble delt inn i motstand, EMG og kontroll. Kontroll ble delt inn i tre underkategorier; motstandsregulator, motstandskontroll, og motstandsvalg. Gjennom arbeidsperioden oppstod det enkelte hindringer, med begrenset budsjett og kunnskap endte sluttproduktet opp med å bli ikke så i dybden som håpet.

Hver seksjon ble evaluert for å finne den beste løsningen som endte opp i testbare prototyper. Motstanden vil bli generert av solenoider, hvor kjernen blir flyttbar. Motstandsregulatoren vil bli PWM som kontrollerer mengden av strøm som går igjennom spolen. Motstandskontrollen, som vil kontrollere at motstanden er riktig, er en lastcelle mellom brukeren og motstanden. Motstandsvalget blir i denne avhandlingen gjort av en LCD-ad-on med knapper som er designet for mikrokontrolleren, Arduino. Arduino vil koble MagnetGym sammen og gjør den til en lukket krets. MagnetGym vil bli koblet til kroppen via EMG, også en ad-on for Arduino.

Prototypetestene gikk fint, men den endelige prototypen ville ikke fungere. På grunn av de økonomiske og kunnskapsrelaterte hindringene ble en optimal prototype med riktige komponenter og spoler ikke oppnådd. MagnetGym ble en middelmådig idé som trolig ikke vil være konkurransedyktig med tradisjonelle og allerede eksisterende treningsutstyr på det stadiet oppgaven kom til. Men EMG-idéen kan være fremtiden for trening. Tester og teori viser at tolkningen av resultatene vil være en vanskelig oppgave å hankses med, men med videre forsøk kan det fortsatt være håp.

## **Abstract**

The Master thesis was originally intended to be an attempt to make a direct competitive product to today's workout equipment using magnetic resistance. Since the resistance will be controlled digitally, the option of making MagnetGym a closed circuit with inputs from the muscles was uttered. The thesis was then extended with biofeedback resistance control. With biofeedback, from EMG sensors, the hypothesis was that the exact percentage of muscle activation, and therefore the percentage of force a person can generate, can be measured. This indulging the MagnetGym into today's ranks of smart products.

The thesis' focus will be on product development, dividing MagnetGym into sections and give proof of concept to each section. MagnetGym was divided into resistance, EMG and controls. Controls was divided into three subcategories; resistance regulator, resistance control, and resistance selection. Throughout the work period restrictions occurred, with limited budget and knowledge the end product ended up being not as in depth as hoped.

Each section was evaluated to find the best solution, to solve the problems that ended in prototypes that were tested. The resistance will be generated by solenoids where the core will be moved. The resistance regulator will be done by PWM to control the amount of power traveling through the coil. The resistance control, which supervises that the resistance is correct, is a load cell between the user and the resistance. Resistance selection was in this thesis done by a LCD ad-on with buttons for the microcontroller Arduino, which will connect the MagnetGym together making it a closed circuit. The MagnetGym was connected to the body with EMG, also an ad-on for Arduino.

The proof of concept went fine, however the final prototype would not work. Because of the budget and knowledge restrictions an optimal prototype with correct components and coils was not accomplished. The prototype was made with alternative components that would give proof of concept, no more. The MagnetGym is a mediocre idea that probably will not be competitive with traditional and already existing gym equipment according to this thesis. The coil will generate a lot of heat, which means cooling is needed. This will make the gym equipment more high maintenance than necessary resulting in a less cost efficient gym equipment. However the EMG idea can be the future of training, the tests and theory shows that the interpretation will be a difficult task to overcome, but with further experiments there is hope.



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# 1 Preface

This master thesis is based on the idea of making gym equipment more high tech and using measured outputs from your muscles to make working out more effective and improve the results. The traditional weight stack equipment in a gym have no way to alter the weight once they are picked up. Many workout routines are based on percentage of your one rep maximum or number of repetition. To take outputs from the muscles could improve the workout. Instead of doing 10 repetition sets where the weights are to light in the beginning and do sets with weights on percentage you calculated from doing repetitions one day, maybe a bad day, the outputs from the muscles could control the force to be exact. E.g. the muscles will work at 90% every repetition throughout the movement, independent of the state of the day.

Whether or not a workout routine like this would be better is unknown before testing. The master thesis is aiming for a functional prototype with controllable force during sets. There already exists equipment where this is doable but there is no one or few that are directly controlled by outputs from the muscles.

The EMG ideas are based on a hunch that exact percentage load given by feedback from the muscles is more effective than estimated percentage, and the fact that EMG and muscle strength is comparable. Biomechanics show that muscles are more effective at certain positions (Knudson, 2003). To regulate the load to be the same percentage through the whole movement based on outputs from the muscles could make training more effective, in comparison to traditional weights where the limit is the position where the muscle is weakest.

This thesis will describe and evaluate MagnetGym as three main functions; the resistance, resistance controls and EMG. The goal is to give proof of concept to each function, and hopefully put them together to a functional prototype.

## 2 Resistance

This chapter will be about the resistance part of the MagnetGym. This is the main function of the MagnetGym, as in any other training equipment. Prototypes and research will show if magnetic resistance will be useful and competitive with already developed equipment that are capable of changing the force during movement.

Will magnet force be a competitive resistance solution?

### 2.1 Introduction to magnetism

This chapter offers a quick introduction to equations regarding this master thesis that hopefully can be used to predict some results. Electromagnetism and magnetism is quite complex and this just scratching the surface.

The first discovering of the relationships between magnetism to moving charges was discovered in 1820 by the Danish scientist Han Christian Oersted (Riper, 2011)

Oersteds law States:

“The magnetic field lines encircle the current-carrying wire

The magnetic field lines lie in a plane perpendicular to the wire

If the direction of the current is reversed, the direction of the magnetic field reverses.

The strength of the field is directly proportional to the magnitude of the current.

The strength of the field at any point is inversely proportional to the distance of the point from the wire.”

From this one can conclude with that the current is crucial in the magnetic field.

#### 2.1.1 Magnetic field

Calculating a magnetic field can be very complex and hard to do, but with some assumptions and accepting that the result is not 100% correct, a good estimation can be done. For instance is a short and fat solenoid is more complicated to calculate than a long and thin one (Young, Freedman & Ford, 2007, s 975). The electromagnetic field and magnetic field are controlled by a couple of formulas, and most of them are integrals and summations and not straight forward equations. There are different laws describing different aspects of what happens with electrons in a wire and a thorough explanation of magnetism are a thesis by itself.

The magnetic field is given by Biot-Savart law:

$$d\vec{B} = \frac{\mu_0}{4\pi} \frac{I d\vec{l} \times \hat{r}}{r^2}$$

Equation 1

Biot-Savarts law explains the magnetic field in a straight current carrying conductor

After some manipulations the magnetic field in a coil can be simplified to

$$B = \mu_0 \frac{N}{L} I$$

Equation 2

Equation 2 (Young, Freedman & Ford, 2007) calculate the geometric center of the magnetic field, given the length of the coil is significant larger than the radius, and the symmetric properties.

The transition between the magnetic field in an air core coil to the magnetic field in a coil with a core is

$$\mu_r \vec{B}_{coil}(r, z)$$

Equation 3

Equation 3 (Hawley, 2011b) shows the importance of the core material, the higher permeability the higher force.  $\mu_r$  is the symbol for relative permeability and is materials ability to be magnetized by a magnetic field.

A magnetic field will however rapidly decrease in strength with  $1/r^3$  when the length from the center increases. The magnetic field at a given point from the center is calculated by (Young, Freedman & Ford, 2007).

$$B_x = \frac{\mu_0 N I a^2}{2(x^2 + a^2)^{3/2}}$$

Equation 4

*a = radius of the coil*

*x = distance from the center*

*I = current*

*N = number of circular loops*

*$\mu_0$  = permability of air*

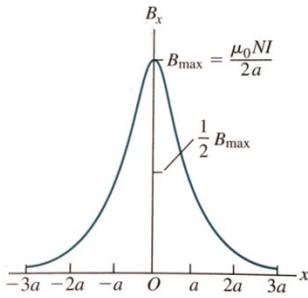


Figure 1: Graph of the magnetic field in distance  $x$ ,  $x$  as a function of radius,  $a$  (Young, Freedman & Ford, 2007)

With that kind of rapid decrease the effective area of the magnetic field become one of the biggest problems to overcome.

### 2.1.2 Solenoid coil - mechanical force

The magnetic field of a solenoid can be calculated as mechanical force, which is easier to understand since the average person has more knowledge about mechanical force, Kg, than Tesla, the magnetic force.

$$F = \frac{(NI)^2 \mu_0 A}{2g^2}$$

Equation 5

$$\mu_0 = 4\pi * 10^{-7}$$

$F$  = force in Newtons

$N$  = number of turns

$I$  = current in Amps

$A$  = area in length units squared

$g$  = gap between the geometric center of the solenoid and a piece of metal

To calculate the force of a solenoid with a metallic core, multiply the equation with the permeability of the material,  $\mu_r$ . This equation cannot be used when the distance goes to zero, since the force will then go to infinity

### 2.1.3 Solenoid coil - moving core

To calculate the force afflicted onto a moving core, the force afflicted on thin disks has to be calculated with Lorentz law and Biot Savart Law. The following equations are a number of equations from a paper that describes the procedure to calculate the force from a solenoid to a metallic core. These formulas are better explained in *The force on a cylindrical steel slug inside a finite solenoid* (Hawley, 2011b) and *The magnetic Field In and Around a Finite Cylindrical air-core Solenoid* (Hawley, 2011a). The papers also includes codes to calculate the magnetic fields and force on a slug in Visual Basic Express (Hawley, 2011b). The

paper also takes in consideration the saturation, where the core slug is saturated and is unable of producing higher magnetic field. The equations are not explained properly but are shown merely to give an image of the complexity of calculating magnetic fields.

$$\vec{F}_{disk} = \iiint_{VolumeOfDisk} \vec{f} dx dy dz$$

Equation 6

$$\vec{f}(r, z) = \frac{\mu_r^2}{\mu_0} \left( B_r \frac{\partial B_r}{\partial r} + B_r \frac{\partial B_z}{\partial z} + B_z \frac{\partial B_r}{\partial z} \right) \hat{r} + \frac{\mu_r^2}{\mu_0} \left( B_z \frac{\partial B_z}{\partial z} + B_r \frac{\partial B_z}{\partial r} + B_z \frac{\partial B_r}{\partial r} \right) \hat{z}$$

Equation 7

$$B_r = \frac{\mu_0 I}{4\pi} \sum_{m=1}^{m=N_{layers}} \sum_{n=1}^{n=N_{turns}} \sum_{\theta=0}^{\theta=2\pi} \frac{r_{Mth layer} (z - z_{Nth turn}) \Delta \theta \cos \theta}{\left[ r^2 + (z - z_{Nth turn})^2 + r_{Mth layer}^2 - 2rr_{Mth layer} \cos \theta \right]^{3/2}}$$

Equation 8

$$B_z = \frac{\mu_0 I}{4\pi} \sum_{m=1}^{m=N_{layers}} \sum_{n=1}^{n=N_{turns}} \sum_{\theta=0}^{\theta=2\pi} \frac{r_{Mth layer} (r \cos \theta - r_{Mth layer}) \Delta \theta}{\left[ r^2 + (z - z_{Nth turn})^2 + r_{Mth layer}^2 - 2rr_{Mth layer} \cos \theta \right]^{3/2}}$$

Equation 9

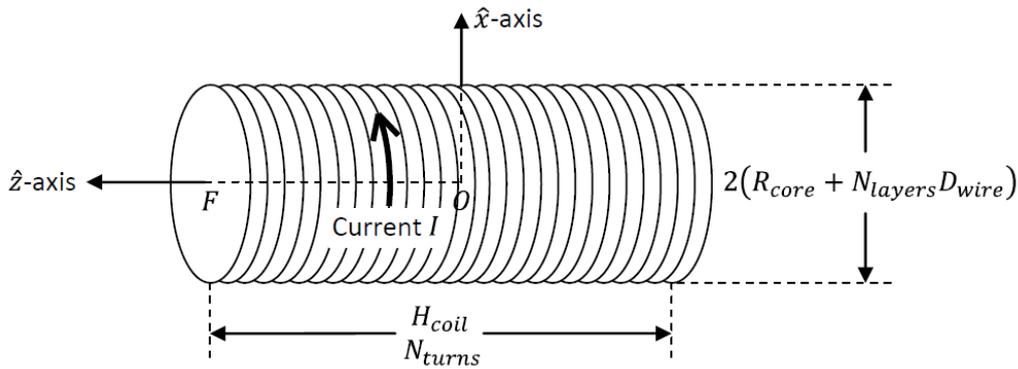
There is no third component because a solenoid is radially symmetric. These two equations can be used to calculate the magnetic field intensity in an air cored coil at a given point from r and z.

The equations above will eventually end up as

$$F_{Slug} = x \frac{2\pi\mu_r^2}{\mu_0} \left( \frac{\mu_0 I}{4\pi} \right)^2$$

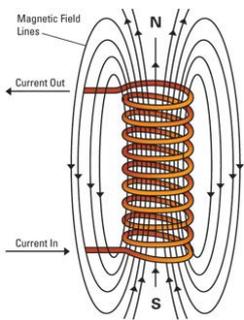
Equation 10

Where  $x$  is calculated from the equations above, this is done by the codes from *The force on a cylindrical steel slug inside a finite solenoid* (Hawley, 2011)



**Figure 2: Sketch of a coil (Hawley, 2011)**

$N_{layers}$  are number of layers with wire and  $N_{turns}$  are number of turns on the length of the coil



**Figure 3: Illustration of the magnetic field lines in a coil**

### 2.1.4 EMF

When dealing with coils and magnetic field there is a need to control the electromotive force, EMF. EMF is created by electromagnetic induction from altering magnetic field or the  $qE$  term from Lorentz force equation, electric force. EMF is also described by Faradays law.

Lenz's law: "the direction of any magnetic induction effect is such as to oppose the cause of the effect" (Young, Freedman & Ford, 2007, s.1004). This means that when the current in a coil is turned off the resisting magnetic field will create a current that will go back into the circuit, and can harm the components. Therefor there is need of a back EMF diode to eliminate this. Lenz law also explains the eddy currents, which are induced currents that circulate throughout the volume of the material, and will try to oppose the creation of the current by creating a force to stop the movement

Lorentz force law

$$F = q(E + v \times B)$$

Equation 11

### 2.1.5 Permanent magnet

Permanent magnets have a constant magnetic field created by aligned electrons inside the material. The magnetic field on the axis of a dipole magnet is given by (Vernier, 2014)

$$B = \frac{\mu_0 2\mu}{4\pi d^3}$$

Equation 12

Where  $d$  is distance from center of the dipole in meters,  $\mu$  is the magnetic moment measured.

The mechanical force of permanent magnets can also be calculated and there are numbers of great websites to calculate the force. Magcraft has a calculator with residual flux density inputs (Magcraft, 2014), K&J Magnetics has an even greater calculator though limited to magnet grades (K&J Magnetics, 2014), which also includes force between two magnets that increases the force and thereby the length.

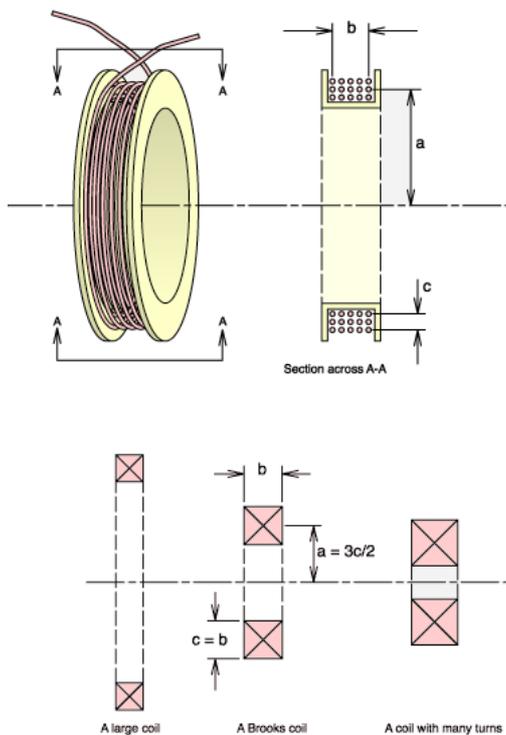
## 2.2 Resistance prototype - solenoid coil

The MagnetGym is going to use magnetic force to create resistance. As explained in the intro the intention for MagnetGym is going to be to create a closed circuit with feedback from the human body, if the intension was not to use magnetic force as resistance there are other solutions to create controllable force, two existing examples are mentioned in chapter 6.1.

The magnetic force opens up for a lot of different solutions, since the magnetic force can be created and directed in different ways and controlled in different ways. The magnetic force can be divided into two groups; electromagnetic and permanent magnetic. These can be combined to increase force and distance.

The main problem with magnetic fields is the effective range that decreases with  $1/r^3$  (Equation 4), where  $r$  is distance to the affected object. This distance is from where the magnetic field is concentrated like on the surface on the core of an electromagnet or the surface of a permanent magnet. To cope with the distance issue the force will be created with an air core solenoid where the core will be dragged out of the solenoid. This will increase the length because some of the core will always be in contact with the strongest field inside the coil.

An air core solenoid is an insulated copper wire wound around a non-metallic bobbin. The force of the solenoid is depending on wire thickness, length and thickness. According to Brooks the optimum coil has equal windings axial and radial, which means that the windings make a square cross section. The center of the windings has a radius of  $a = \frac{3}{2}c$ , where  $c$  is the thickness of the windings.  $b$  is the width of the windings and are equal to  $c$  (Grover, 2004)



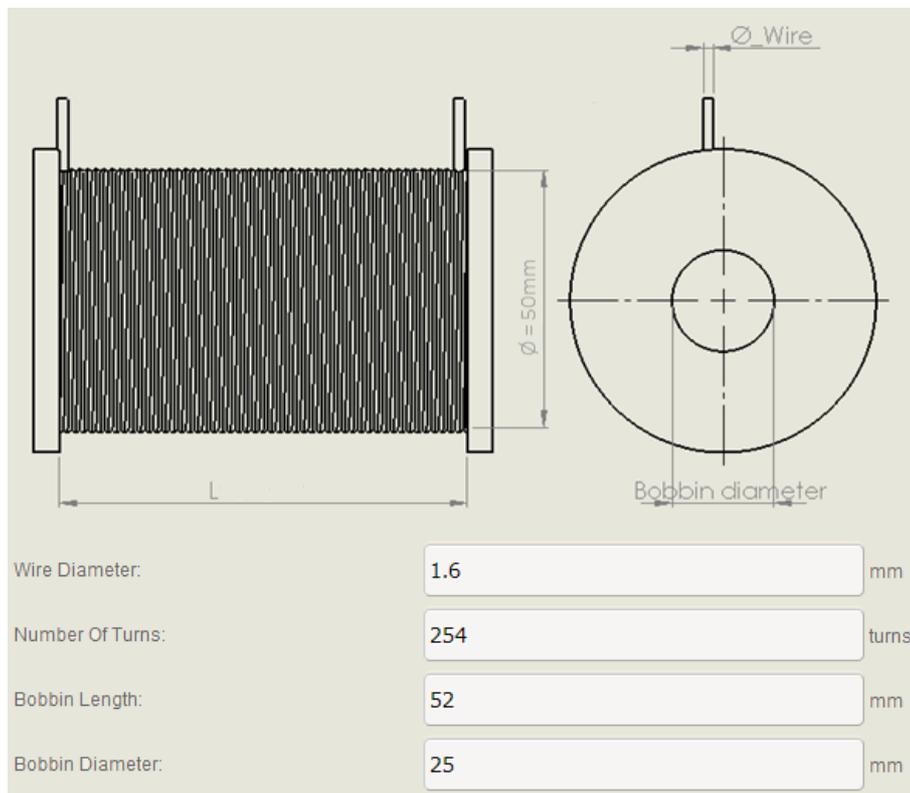
**Figure 4: Brooks coil (Clarke, 2010)**

A Brooks coil will probably not be suited for this purpose as the coil will become extremely thick as the length increases. This assumption is based on that the length of the solenoid will help increasing the effective length of the magnetic force afflicted on the core, thus increasing the length of effective

movement. The length of the core itself do not help increasing the movement length significant, the magnetic force are only effective when the end of the core are close to the end of the solenoid. However this is assumptions since the optimal coil setup has yet to be discovered.

When the solenoid is constructed with the optimal specifications, the only strength altering options are the current and core material. The material of the core has as influence on the force with its permeability, the higher permeability the bigger force. In addition permanent magnets can be added on the core in such way that it will repel when getting dragged against the solenoid. The problem with adding magnets is that the direction of the current on the coils and the position of the magnets have to monitored and controlled. If not, the magnets will start to repel the core with the drag direction and push itself out of the coil, ones pulled through the center of the solenoid.

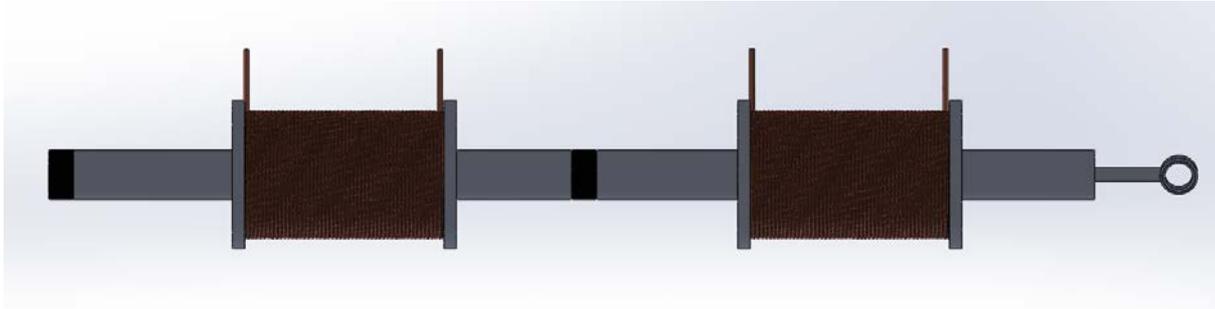
A proof of principal of the resistance was done with two equal solenoids, these where not perfect solenoids but gave a proof of principal.



**Figure 5: Coil specifications**

Normally a solenoid is made with a wire under 0.5mm in diameter, and around 1000 turns. Unfortunately smaller wire will create a lot more heat, since the resistance increases when the wire diameter decreases (Frenzel, 1996), which is not wanted in gym equipment that is going to be used all day. There are measures that can be done to cool down coils, e.g. oil bath. Such measures probably have to be done either way to be on the safe side. As an example the coil used in this thesis has a resistance of 0,4Ω, with a current of 10A this will result in a power of 40W, from the equation  $P=I^2 \cdot R$ . When the coil was tested with 10A over time

it was heated up to 141,2°C within 20min (see appendix D), and will probably continue to rise as the resistance changes with the temperature (Waygood, 2012). Another problem with the heating is if the coil get to hot the insulation on the wire could melt and the coil will short cut.



**Figure 6: 3D drawing of test setup**

The solenoids were force tested, the setup is illustrated in the pictured above. The core is divided into two to make it possible to add magnets in between as illustrated in figure 6 as black sections. The tests were done by dragging the core with a digital fish weight to measure the force. The test was done horizontally so some friction would interact. The magnets used when testing with magnets was weak ferrite magnets that did not make a remarkable contribution to the force. The rest of the tests were therefore performed without magnets to avoid the problem with the core getting pushed out. The core used was steel which has low permeability which is not ideal, more ideal would be to use soft iron that has a higher permeability.

**Table 1: Force test of two coils**

Current [A]		Force [Kg]
Coil 1	Coil 2	
5,059	10,15	1,7
0	10,15	1,3
5,054	5	0,72
5,059	2,5	0,4
2,503	5,02	0,6

The most sensational discovery was that the position of the strongest coil had an impact on the total force. When the weakest coil was in front the force decreased drastically, this still remains a mystery at the end of the thesis. See appendix B for the whole test.

The magnetic field generated in the coil was calculated to 0,0614Tesla (Equation 2), the force was also calculated with the equations from Hawley's paper. However the answers seemed wrong, and from physical tests and theory, a physical approach and experience are better to find the optimal coil.

## **2.3 Other ideas**

This is a quick insight on other ideas that are brainstormed around during this thesis. In addition to the coil idea other ideas has been developed, thought about and partial tested.

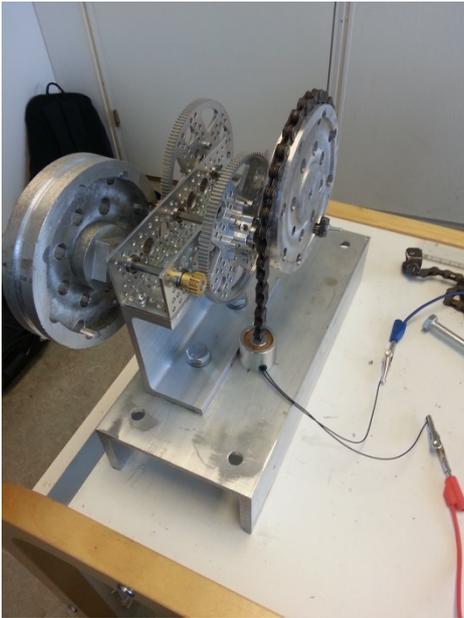
### **2.3.1 Electromagnet with gearbox**

The very first idea was to use an electromagnet, this idea become the first prototype and was a 24V DC magnet controlled with a controllable power supply. The relation of the narrow force field of magnetism was soon discovered. To cope with the narrow force field a gearbox was designed. The gearbox had to gear down the movement since normal exercises have at least 30cm travel distance, which is far outside the magnetic field of an electromagnet. Even greater distance is needed if the goal is to implement it in deadlifts, squats or snatches.

The electromagnet was a Kuhnke HT-D30-F (see appendix J) that is rated to 200N, taken the  $1/r^3$  is representative the force will decrease rapidly.

The issue when using a gearbox to gear down the movement is that the force will have the same ratio as the distance, therefore this idea reviled itself as unsuitable. An example is when doing biceps curl the average vertical distance traveled is 300mm. With a gear ratio of 1:60 the traveled distance from the magnet will be 5mm, given the magnet has full force at this distance the result is that an 1800Kg magnet is needed just to do curls with 30Kg. In real life the force at that distance is probably down to above one third of the magnets force i.e. a 5400+Kg magnet is needed to do 30Kg curls.

The distance can be increased by using a magnet as the object the electromagnet is attracting as the magnetic field will increase. This idea discarded because of the force issue. There exist strong electromagnets that can be used against each other, Magnetech Corporation for example delivers 1700lbs. magnets with size of Ø6"x3" (Magnetech Corporation, 2014). Because of the cost and that the gearbox has to go through extreme reinforcement the idea was discarded in this thesis.



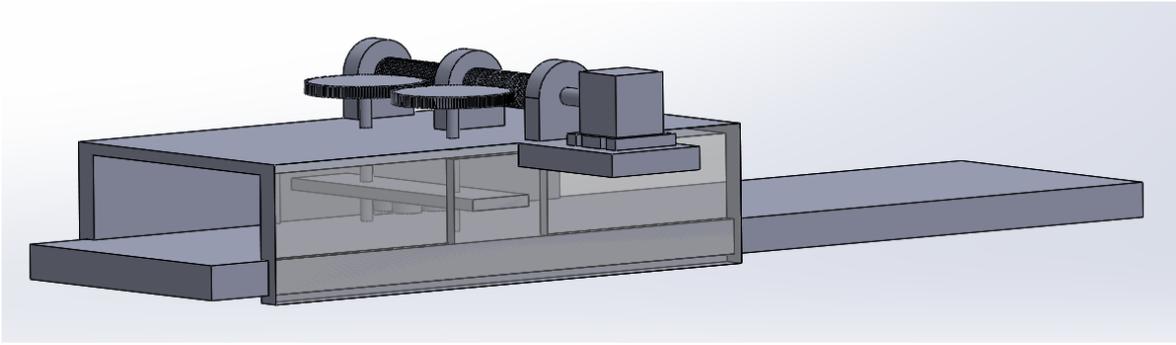
**Figure 7: The gearbox with a ratio of 1:64, parts from sparkfun.com**

In addition to the force problem, the gearbox will also be affected by the moment of inertia, this prototype was almost an eternity machine because of the inertia.

### **2.3.2 Eddy current**

Eddy current is one of few ways to avoid coils when using magnetic fields to generate resistance. Eddy current is induced electric current by a moving magnetic field, the electric currents create its own magnetic field that creates a force that opposes the creation of the induced current (Young, Freedman & Ford, 2007). The drag force the eddy current creates are given by the air gap between the magnet and the copper/aluminum plate, the thickness of the plate, the speed of the magnet and of course the strength of the magnet. Since the speed is a factor this equipment are not suited for slow repetitions, as there will be no force generated. The eddy current will never make a pulling force just a retarding force, this make it suitable for non-traditional equipment where the resistance is always retarding the movement. This makes it possible to do push and pull exercises at the same time, like simulating sawing motion. Simple gym equipment where you always have restraining force working against the movement could be designed. This could be handy e.g. for tennis players, where a backhand and normal strike could be exercised in the same movement. By adding sideways force with magnets stabilization muscles could be exercised at the same time, e.g. to exercise Gluteus Medius while doing squats, which is an important muscles for the knee stabilization (Sanchis-Alfonso, 2011)

The parameter to control during the movement is the distance, to do this a step motor idea was designed. The reason why the distance is crucial is as simple as the magnetic field from magnets is getting weaker at distances.



**Figure 8: Principal model of eddy current, the plate slides in two grooves**

The eddy current was quickly tested with a digital fish weight. Nine 34Kg magnets (see appendix G) were dragged across an aluminum plate to see the maximum force. The distance was altered by adding Plexiglas plates between the magnets and the aluminum plate. The test was not promoting the idea. Nine 34Kg magnets did generate just 0,78Kg retarding force with a distance on 0.



**Figure 9: Test setup on aluminum**

The test was also done on a steel plate, this showed that the force was almost linear with number of magnets. This also showed the rapidly decreasing force from 14,38Kg on 2mm to 4,58Kg on 4mm with 9 magnets (see appendix C). The main force is probably friction against the Plexiglas generated by the magnetic force pulling the magnets straight down to the table. This idea was also discarded since the main goal was to build a more or less normal equipment with force in both concentric and eccentric phase.

## 3 Controls

When the resistance was sorted out it had to be controlled on some sort of way, also here there are plenty of options to choose by. The task is to find the best option to each function. The controls were divided into three subcategories; resistance control, weight selection and resistance regulator. Arduino, an open sourced microcontroller, was chosen to bind the controller equipment together.

### 3.1 Introduction - Arduino

The Arduino is a limited open source microcontroller and there are lots of mistakes to do when coding to make the Arduino even slower. Some of the functions are blocking functions, this means that the Arduino will stop at this functions until its verified that it is performed. To implement such functions in the code will slow the code down.

### 3.2 Resistance regulator

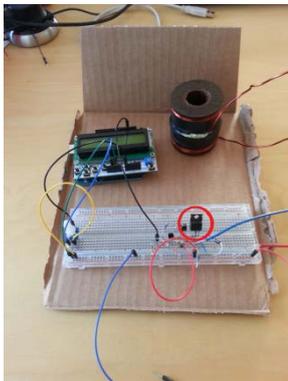
The first thing that needed be sorted out after the resistance was decided, is how to the regulate it. When working with electromagnetic fields the main force giving factor is the current. As mentioned there are other factors but no one that is suitable to regulate during movement. Since MagnetGym is going to be a closed circuit a digital regulation are preferred. The resistance will then be controlled by the amount of current. The problem with Arduino is that it is too weak to power a coil or the tested electromagnet, the 24V DC electromagnet. The Arduino has an output on 40mA (Arduino, 2014). That means that the Arduino has to control an external power source connected to the electromagnet. A coil is also capable for destroying the Arduino board without proper safety diodes, so called back EMF led. These diodes prevent any current going back to the Arduino or other parts of the circuit when the coil is “pushing” voltage back into the circuit when it is switched on and off (Trevenor, 2012).

To control the external power source there are different alternatives, the two most suitable alternatives is motorized rheostat and Pulse Width Modulation (PWM). A motorized rheostat is basically a potentiometer that are controlled by a motor, this requires a motor controlled by the Arduino, for instance a step motor that are discussed later on (chapter 3.2.1). Pulse Width Modulation is a way to control the power to electrical devices. The power is controlled by turning it on and off. If the power is turn on and off the same amount of time the result will be 50% of the max power (Holmes and Lipo, 2003). The advantage of PWM is that is has a less power loss than a motorized rheostat, which will lose lot of power to heat. The Arduino has a built-in PWM system that has 255 stages. That means that a Arduino system can change the resistance with 0,4% of maximum load. That is acceptable for at least the small scale prototype.

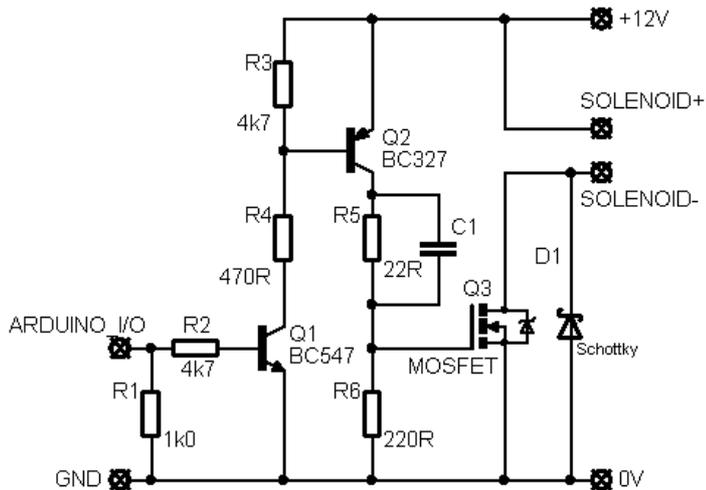
The writing of the PWM code is quite simple and only need one syntax. All that is needed to use PWM is to call `analogWrite(pin, value)`, `pin` is the pin that will be written to. On Arduino UNO there are 6 pins that supports PWM, these are marked with `~`. `Value` is a value between 0 and 255 where 255 are fully on.

The PWM system was tested with `Value` controlled by a potentiometer, the code is an example code from Arduino's homepage (see appendix code). The potentiometer is connected to analog in that reads 0-5V in 1024 stages. Since the value that controls the PWM needs to be between 0 and 255, the analog in value have to be divided on four. As mentioned the Arduino cannot directly power the coil so the PWM will be used to switch on and off a transistor to limit the current through the coil. The first trial where performed with an MOS IRF520, that are rated to handle 10A at 25°C (appendix I). The first tests went fine when controlling a power supply, with a max output on 3A, onto the 24V DC electromagnet. This MOS however cannot be "fully on" with just the Arduino as switch, since it is voltage controlled. Therefore a complementary Darlington pair was included to switch it fully on. A complementary Darlington pair is just smaller transistors that switches on and off a bigger transistor, here the MOS.

However the MOS is not suited for the coil tested, that need at least 10A, as the second test showed. By running 10A through the MOS without proper heat sink it gets heated above 25°C fast. At 100°C the MOS IRF520 is rated to 7A, this is called de rating, and causes it to eventually burn up.

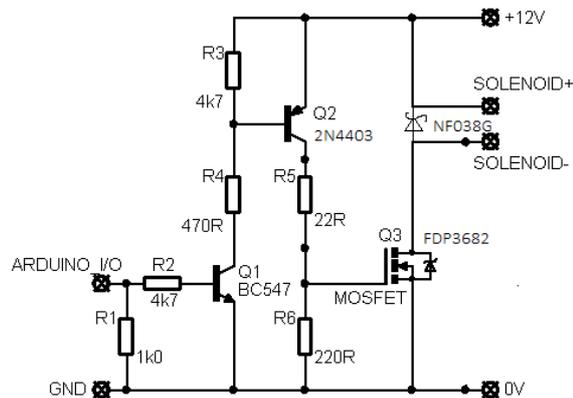
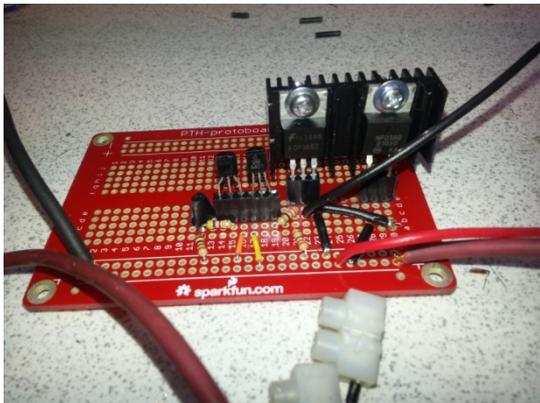


**Figure 10: The coil controlled by PWM with the MOS520 as transistor, red circle.**



**Figure 11: Schematics of the complementary Darlington pair (Soeren, 2011)**

The schematics was changed a bit to include a flywheel diode cross the solenoid, instead of the schottky from the solenoid to ground. This resulted in this set up

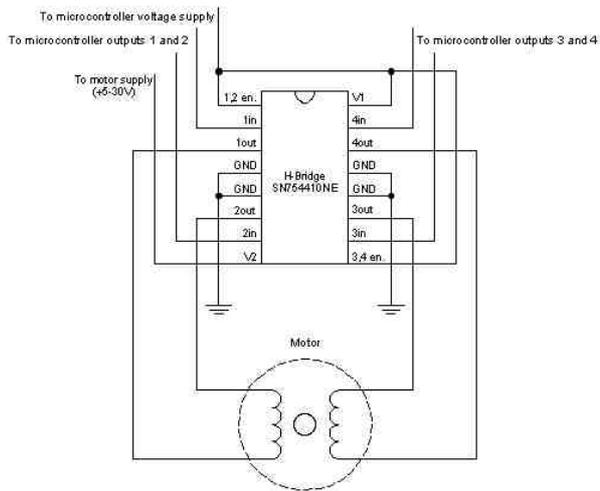


**Figure 12: Final setup of the transistor switch for the PWM.**

This is using a FDP3682 transistor which is rated to 30A (Sparkfun, 2014). For some reason this switch did not work. Probably the voltage is too low so the transistor will not turn on.

### 3.2.1 Step motor

As mentioned there is a possibility of using a step motor to control a motorized rheostat, but this was not preferred because of power loss as heat. The step motor was however tested since it could be used for the eddy current idea where the distance needs to be controlled (see chapter 2.3.2). Stepper motors are common accessory for the Arduino community however it occurred problems for this specific application. The stepper motor was connected as normal to the Arduino via an H-bridge motor driver.



**Figure 13: Stepmotor circuit, retrieved from Arduino homepage**

The Arduino uses the *stepper.h* library, this makes it possible to use *stepper.step("number of steps")* to control the motor. Or use *stepper.step(STEPS)* that make the motor turning forward, use *-STEPS* to make it turn backwards. This syntax was implanted into the complete code that was supposed to be used to test a MagnetGym prototype. The code (see appendix K) did work, however the step motor had quite a delay before it responded. The code had to think for 0,6 seconds extra whenever the motor had to be stopped or reversed when the load cell did not match the selected weight. This is too long of a delay, especially when one repetition takes in average 1-2 seconds. The problem was discovered by putting in *time ms* and *serial.println(time ms)*, the Arduino is then able to log the time used at certain steps. 0,6 seconds is a lot of time especial in explosive training. This means that the load will be wrong most of the time if the pulling speed is wrong. At least when using eddy current, where the speed is an important factor and it would be inappropriate to have to focus on having the same speed throughout repetitions. However there was established a proof of concept, all that is needed is a faster and better written code. Preferable a designated system designed for this use.

### 3.3 Resistance control

Since the force of an electric field depends on lots of factors it is not necessary as simple as turn on a calculated current to get the wanted resistance. All the ideas discussed have some floating factors that will change the force during exercise. The main factor for magnetic force is distance and the eddy current has speed in addition. To control and keep the resistance constant some sort of sensor is needed. The resistance control will supervise that the resistance matches the selected resistance. Magnetic fields strength is highly connected to the distance. Therefore distance sensors can be used to calculate the force, but as mentioned in chapter 2.1, the calculations of the magnetic field it is not always as straight forward as it seems. Given this and the fact that to use a solution like this the starting force also has to be calculated, making the resulting

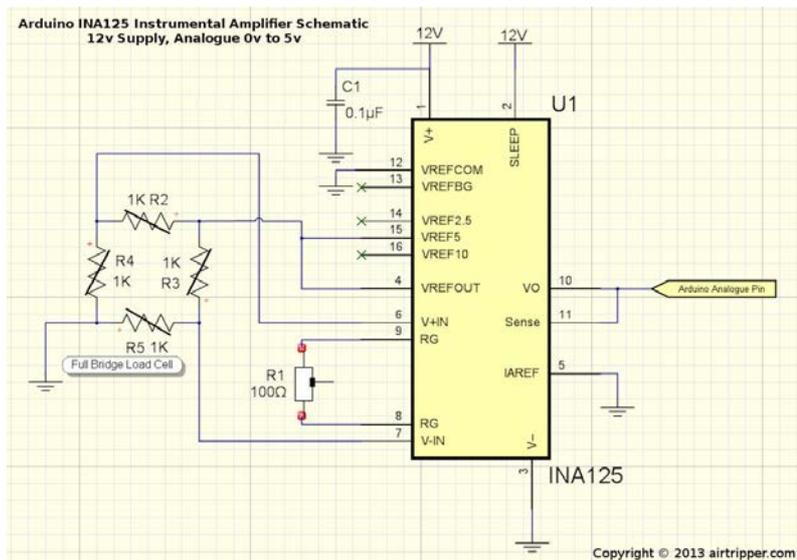
force outcome to be wrong. The resistance control could also be controlled by potentiometer. The pulling line then need to be directly connected to a potentiometer to control the force. Since the electromagnetic field is not linear the potentiometer have to be design after an equation to get an estimation of how the field will decrease or increase with the movement. This is not a preferred solution since both the starting force and the control of the force will be estimated from equations that can be wrong. This solution will neither work with an eddy current idea since the eddy current is sensitive to speed.

To keep the Arduino code as simple as possible and avoid to control the regulator from equations a direct sensor is preferred. To do this a load cell was chosen, this will eliminate any equations or assumption about magnetic fields. The load cell will be added on the pulling rope and will read the load directly and control the force regulator without any other equations than the calibration of the load cell itself.

A load cell is build out of strain gauges, which are basically a wire that changes resistance when it is stretched or compressed (Hannah, Reed, 1992). The strain gauges are often connected in a Wheatstone bridge, that can be either a quarter bridge, half bridge or a full bridge (Hoffman, 2008). The strain gauges are glued to a piece of metal and will sense the strain in the metal and change its resistance. The Wheatstone bridge has an excitation voltage applied to two corners, when force is applied the difference between the two other corners are measured in millivolts. When using a load cell with Arduino the output has to be amplified so the Arduino can read it. The load cell will be connected to an amplifier then to *Analog in* on the Arduino. The *Analog In* reads as mentioned 0-5V input signal in 1023 steps. Given a linear load cell the Arduino can read differences on ca 0,1% of the maximum load the load cell can handle.

The first idea was to use actual load cells and amplify the signal to read it with Arduino. This is the intention on a proper prototype, the problem was to find suitable load cells that will work on small scale prototype with a budget. Therefor the prototype became a simplified load cell to give a proof of concept.

A load cell will read the weight during the training and can match the value to the wanted weight. From this Arduino can increase or decrease the strength through the resistance regulator. The critical is to find a load cell that will work on a full scale prototype. A full scale prototype of the load cell should range from 0 - 300kg with hopefully 0,1Kg steps. This is hard to do with Arduino since the *AnalogIN* reads from 0 – 1023, if the range will be to 300Kg the load cell will have a precision of 0,29Kg. Fortunately there exist digital load cells that have better range, another thing to keep in mind is that a full scale equipment is probably not going to use Arduino and will therefore not have this problem



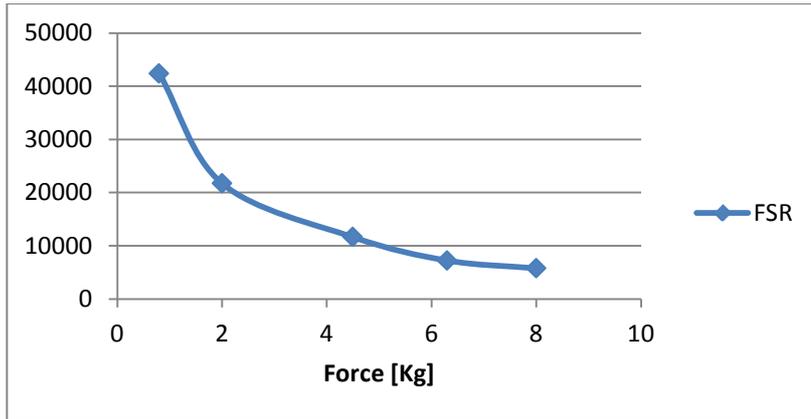
**Figure 14: INA125 circuit with a load cell (Airtripper, 2014)**

This setup, with the INA125 amplifier, is a common setup to use load cells with Arduino. The intention was to use this with a proper load cell, unfortunately the load cells that was available was either too big, not proper or malfunction. The big one, a HBM U2B (HBM Norge AS, 2014) worked but it was heavy and too rough. After several tries with load cells without any luck of getting a good range, the choice fell on a Force Sensitive Resistor (FSR). FSR is a force sensitive resistor, these will decrease their resistance when applied force. They are sensitive but not very accurate. A simple load cell with a FSR was designed. A FSR will be like a potentiometer and does not require amplification. This was a great way to get a quick prototype up and running. A quick prototype was design to have a relative accurate load cell. For a prototype there was no serious need for a super accurate load cell, to get a proof principal was after all the priority. To get a load cell that would have 1kg steps would work just fine. The prototype was made by a 0,5inch force sensitive resistor and a homemade pressure device to apply the pulling force as pressure on the force sensitive resistor (see appendix H). This was a great way to get a quick prototype up and running. This solution was used later in a MagnetGym prototype to show the critical functions.



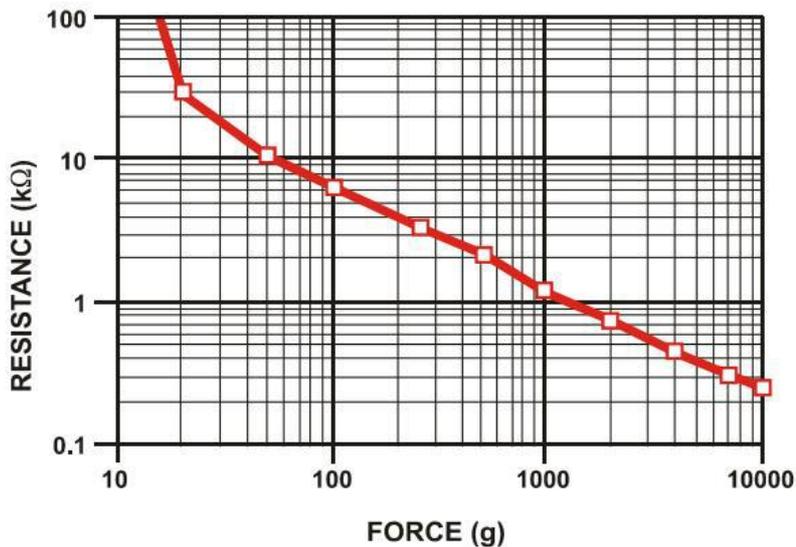
**Figure 15: Homemade load cell, exploded view to the right (see appendix H)**

**Table 2: Testing of the load cell E**



The FSR patch was not as linear as expected, but worked fine to test out the code

**Table 3: Graph from the FSR tutorial (Sparkfun, 2014b)**



The difference between the graphs is because of the homemade load cell. The load cell are not transferring the pull force properly onto the FSR patch

### 3.4 Weight selection

The crucial function of any work out equipment is the selection of resistance. As rest of the functions on the MagnetGym the weight choosing also has alternatives.

To make it modern and compatible with the load cell alternative the weight choosing has to be digital. An LCD screen with buttons is a great option to make it simple, there are alternatives with touch screens, wireless and high tech solutions, but to make it rough and sustainable a simple LCD screen with buttons will do. This will then send signal back to the Arduino and thus have something to compare the load cell with.

In addition the weight could be increased or decreased from buttons on the equipment. E.g. a curl bar with buttons on the sides, to change the weight mid-movement. This makes it easy to do e.g. drop sets, where the load is to be decreased when you are out of reps on a given load.

To select weight the choice landed on a LCD breakout board designed for the Arduino which uses a library on the Arduino. The hard part was to get the wanted functions, but for the prototype a simple code was written to choose the wanted weight and start a separate loop when the wanted weight was chosen (see appendix K)

There were some bugs, the intention was to make a smaller loop when the weight was chosen but this seemed to not work that great, at least with the step motor. The button had to be held in and the code did not stay in the designated sub loop.



**Figure 16: The LCD breakout board**

### **3.5 Arduino Code**

To put the controls together a proper Arduino code was needed. There are different ways to make the different inputs work together. As mentioned some functions are blocking functions, this means that the Arduino will stop at these functions until it is verified that it is performed. The best is to avoid such functions. The EMG code was unfortunately never written into a MagnetGym code, before this proper filtering has to be developed. Probably will a separate code for the EMG be better, to interpret the EMG values separately sending an already interpreted number to the MagnetGym code.

A possible explanation why the step motor was slow was that it had two libraries running. The PWM code just had to run the LCD library, since PWM is a single syntax controlled by *AnalogIn* inputs from the load cell. One thing to keep in mind is that the LCD board uses a lot of pins, therefore check out which pins that are free to use.

The Arduino code has suffered from little knowledge about coding, and can be improved significantly.

## 4 Biofeedback - EMG

The third element in the MagnetGym is the EMG function that could have the potential of revolutionize the ways of training. As mentioned in the master thesis description the possibility of having feedback from the muscles was a prioritized question to answer. This application is independent to the magnet resistance and should work with any equipment with digital control of the resistance, like the equipment from Kaizer or InMotionIntelligence discussed later on (see chapter 6.1). In fact this can be used as personal equipment that are brought around the gym and just hook it up to the wanted equipment. For instance the Kaizer has two buttons to regulate the force during movement, which should be fairly easy to be controlled by an attachment. The EMG does not have to know what the resistance is, and will just regulate the force up or down after feedback from the muscles saying it is under or above the wanted percentage of muscle strength

### Hypothesis

The EMG will measure the muscle activity, thus the strength of a person, and give biofeedback to the Arduino. The EMG will help athletes work out at a percentage calculated from the muscles form of today, and improve the training outcome.

### 4.1 Introduction - EMG

EMG stands for Electromyography and is used to measure the electrical activity of the muscles. If the maximum EMG signal is measured the hypothesis is that it should be possible to use it to calculate the percentage of muscle activity. From that feedback regulate the force to be exactly the percentage of your strength that is required or wanted

The type of EMG that is most suitable to this application is electrodes that are attached to the skin, surface EMG. These are easy to connect and remove, but since the electrodes are attached to the skin, the muscle will move compared to the electrodes. The electrodes will therefore register different volume of muscle activators (De Luca, 1993)

The hypothesis is however a bit wrong, the relationship between muscle fatigue and the electrical activity in the muscles is not as straight forward as anticipated. When dealing with muscle fatigue the EMG will change, there are multiple reasons that the EMG changes when the muscles fatigues. One of them is the change in frequency (Kraemer, Fleck & Deschenes, 2011) caused by action potential conduction velocity along the sarcolemma slows down. However this might not necessarily be related to physiological muscle fatigue changes (Potes, 2008)

## 4.2 EMG Testing

To prove the concept of using EMG to control the resistance some testing had to be done.

The tests was done with an Arduino ad-on, the eHealth from cooking-hacks.com, that is a sensor platform designed to give quick proof of concepts for projects that needs various feedbacks from the human body (Cooking Hacks. 2014). The EMG was tested with biceps curl in cable machine with various workout routines;

Five repetition cheat sets (see appendix A1)

Ten sets with five repetitions at 25kg (see appendix A2)

10 repetitions at various weights at fast and slow speed (see appendix A3)

Drop set (see appendix A4)

Isometric hold at various weights (see appendix A5)

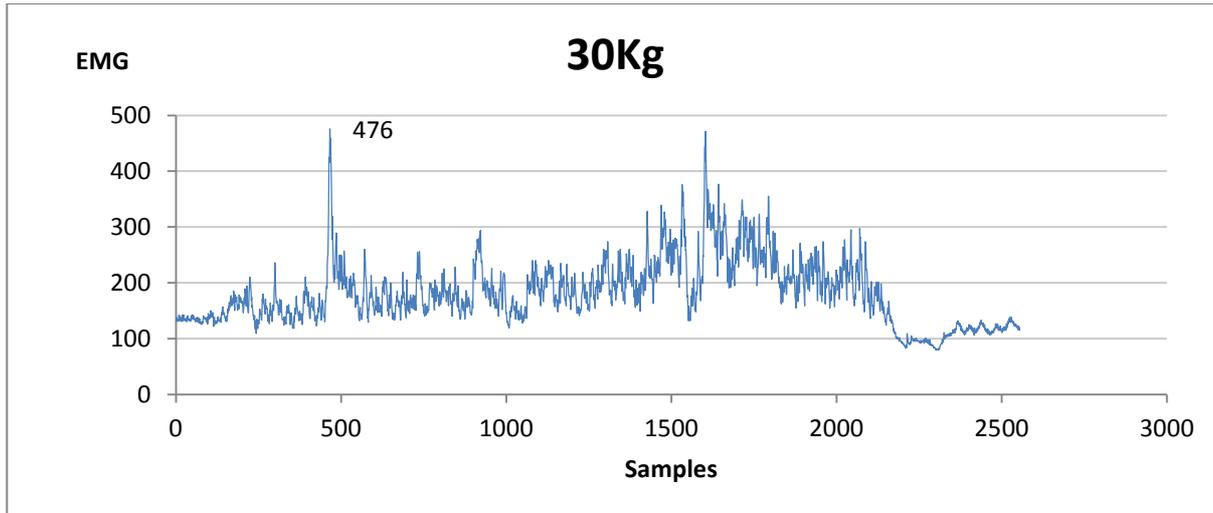
One repetitions at various weights (see appendix A6)

The tests were performed with two different codes, the first code (see appendix F) used was designed to be used with KST, a data process program to compute graphs with timestamps. The second one (see appendix F) was simple EMG reading. The first code was used in the first tests but was difficult to get the timestamp readings correct so the graphs were instead made from samples, thus the second code was preferred since there was a constant delay on 0,01 second between the samples making it easy to know the time. An EMG has three wires that are connected to the muscle, one to the middle of the muscle, one at the end, and one to a bone as ground. See appendix F for EMG setup of the eHealth. To capture the data and save it to text files RealTerm was used (Realtem, 2014).

The first test was single repetitions at various weights with the intention to get references (see appendix A1). These testes show a tendency of higher EMG values as the weight increases.

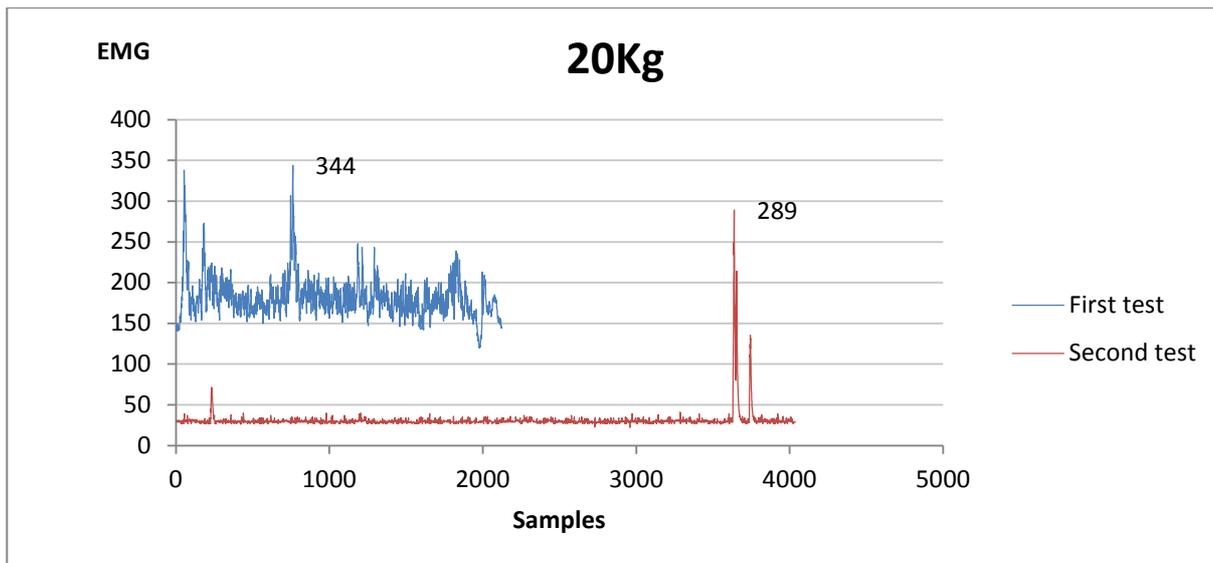
For the hypothesis to work the EMG value should also get higher when the same weight feels heavier as the muscle fatigues, to test this isometric hold to failure was performed. The isometric hold was performed with the underarm 90 degrees from the overarm. When holding 30kg the graph should get higher and higher towards failure.

**Table 4: Isometric hold, 30Kg to failure**



As table 4 shows, there are small tendencies that are supporting the assumption, however the EMG values dropped before actual failure. The graphs also show the importance of a good filtering program.

**Table 5: Isometric hold on two different patch attachments**



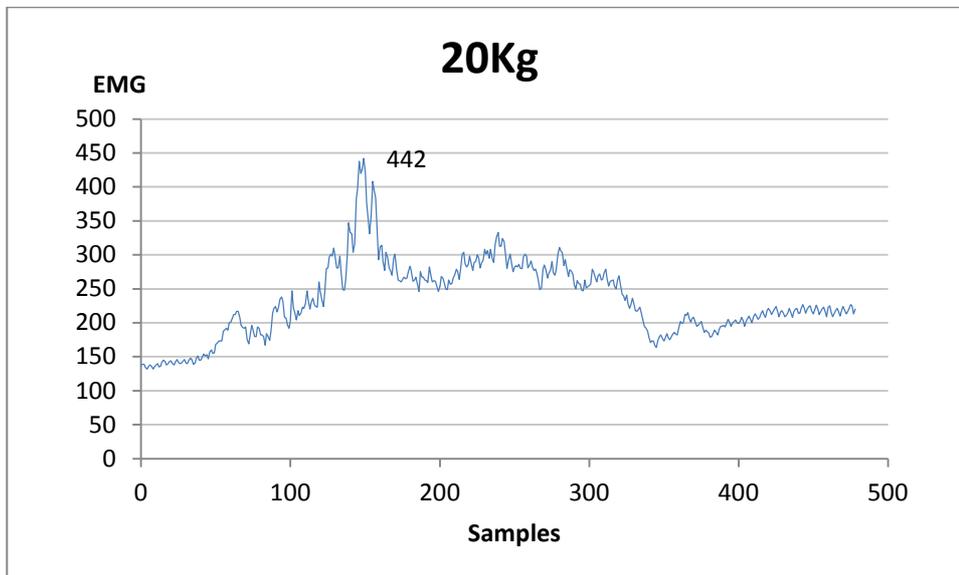
The tests were done over separate days, the thing to notice is the difference between *first test* and *second test* shown in table 5, these were done two separate days and have very different values. Presumably this is a result of different placement of the electrodes. This supports the assumption in De Luca's paper about volume (De Luca, 1993). By testing the highest EMG peak at every new attachment of electrodes, it should work fine. Whether this is a good assumption is questionable since there were some weird things that occurred the second time. Among others, the EMG value fell down to idle values while doing eccentric movement and isometric hold, as seen on *second test* in table 5.



Unfortunately there was not taken any pictures of the other attachment to compare, but this is the attachment from the first test day which was used on *first test* in table 5. The middle electrode is here placed high up on the arm, making the electrode to be on center of the biceps when fully flexed. If the electrode was attached more on the center of the upper arm when stretched out, the electrode will “fall off” the biceps when flexing.

Strength exerted in motion is of lower magnitude than static strength measured in positions located on the path (Kumar, 2004) from this the EMG values should be higher on isometric hold, this is not the case according to the tests.

**Table 6: One repetition with 20Kg**



Comparing table 6 with table 5 show higher values in motion which should not be the case according to Kumar. On the other hand this could be the result of fatigue as the test was done after some testing.

Another side note is that the machine probably is labeled wrong since I, the author, do not think I am capable of curl 40kg on one arm.

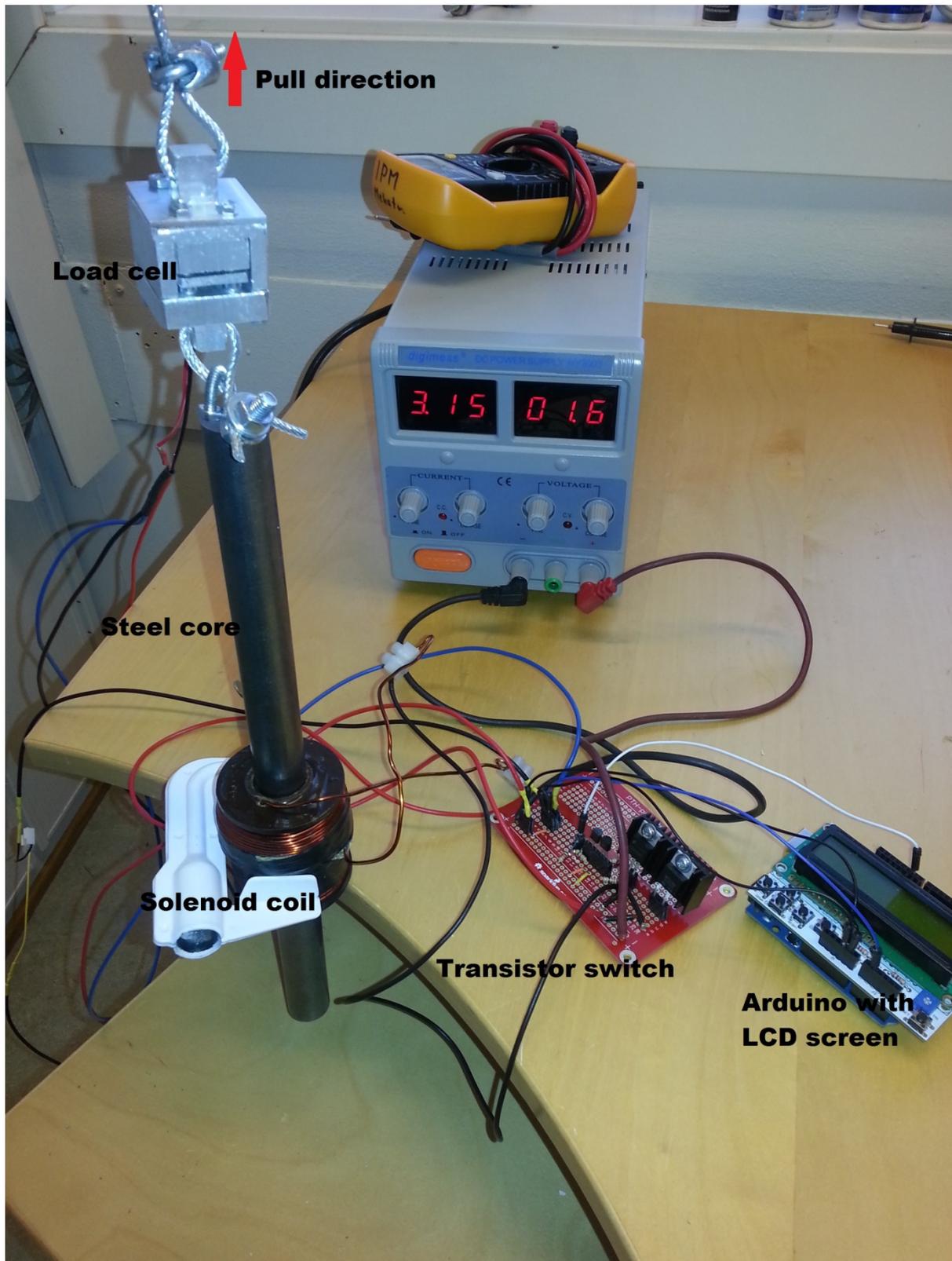
### 4.3 Thoughts

As the graphs illustrate a EMG setup will not be as straight forward as the author assumed, the EMG probably need an accurate data interpreting code to make the resistance more or less stable. The graphs show an unstable graph that will make a “nervous” resistance if used directly without filters. There are certain positions that are easier than other positions when lifting, to use an EMG to have the muscle work just as much the whole movement is an interesting possibility. But as mentioned the volume of muscle the electrodes senses changes.

To get a better overview of the EMG graphs, the graphs should be linked to the position of the arm, to get an accurate relationship between the position of the arm and the EMG output. This can be useful in developing the system. As the graphs illustrate the muscle activity goes up and down, probably in relation to the weight arm around the elbow.

The EMG idea can be too much for a normal gym, as people there often can be stressed and want to be done quickly, therefore connecting the body to the gym equipment to work out will not be a prioritized solution. Rehab training and athlete training will be more appropriate application areas where the attentions for details are higher. The EMG can also be used to prevent wrong training methods and activation of wrong muscles. E.g. supervise the shoulders so the muscles are not tensed when it should be relaxed.

## 5 Prototype



**Figure 17: Final setup of the prototype**

Unfortunately the final prototype did not work. The transistor switch did not work as wanted.

## 6 Competition and application area

To make equipment that can compete with ordinary gym equipment is difficult, today's equipment is effective and simple, and a normal gym user would probably want a simple version and not stress with hooking the body up to some equipment you are going to use for 10 to 15 minutes. However, as Henry Ford said "If I had asked people what they wanted, they would have said faster horses". MagnetGym itself as an option for physical weights are not required to use EMG, and would work exactly like normal equipment just more hightech. The EMG-version is probably not suited for a normal gym, if not the personal trainers want to use it to get to know the client. MagnetGym as an EMG based equipment should try to aim for rehab training and special environments, like space travels

### 6.1 Competition and application area

Maintaining body strength in space is a difficult task, and just short travels, 11 days, results in strength and volume loss up to 20% (Lyndon, 2014). Today's solutions are based on pneumatics to give linear resistance throughout the movement (NASA, 2014). In space there is a need to work out the whole body, much more critical than on earth, this means that there is a need to have the ability to do high weight, low rep workouts. To manage this, a gym equipment should be able to at least give 160Kg linear resistance to the user. Gym equipment made of magnets will have lots of magnetic force at 160Kg holding force. This could be dangerous if it starts to interfere with instruments. Instruments on space stations are very sensitive and even the slightest vibration could do damage (NASA, 2014). Since this is the case a huge coil could be too much. The mail sent to NASA was unanswered at the deadline for the thesis, so any possible magnet field restrictions is unknown

MagnetGym's other options could be rehab and research. These are fields that could make use of the resistance control that EMG would give. There are a lot of studies that uses EMG to see how muscles react to different kinds of exercises. In rehab correct training is important and to use the EMG to supervise the body and in worst case break off the workout if that is necessary would benefit the rehab.

In addition to traditional weight stack equipment MagnetGym also has competition that is capable to change the resistance mid-movement. Two outstanding equipment is Keiser (Keiser, 2014) and InMotionTechnology (InMotionIntelligence, 2014). While Keiser using pneumatic and focus on an alternative resistance generator to traditional equipment, are InMotionTechnology's using electro motors with more focus on recording the workout and testing the user. Keiser has developed their AIR-brand with pneumatic resistance which is easy to control and quick to change resistance. The main benefit is that the inertia is drastically reduced in comparison to weight stack machines (Keiser, 2014). InMotionIntelligence is a manufacturer of a work out machine based on electro motors, called TrainiTest. Today's equipment is

on the other hand not made for high weight training and the TrainiTest Syncro, that is two combined TrainiTest Pro, is capable of 110kg continuous load (InMotionIntelligence, 2014). Both these machines are capable of altering resistance in motion, this means that they could be used with EMG sensors. Which broadens the application area for the EMG idea, not restricting it to MagnetGym, therefore can be developed independent of MagnetGym

There also exists workout equipment using pure magnetism. These are restricted both in force and movement. One of them is O2 Magnetic dumbbell (Yoo, Kim and Lee, 2014), which are two electromagnetic bracelets put on each side of the elbow. This is a neat idea but restricted currently to the arms and a resistance of 24Kg

## **6.2 Workout routines**

The following suggestions are well known routines and/or the author's ideas on how to take advantage of resistance altering equipment with biofeedback. Whether or not EMG is necessary or more effective is unknown before any trials, especially the complex movement idea. Some are just curiosities to log your training. The fact is that EMG is widely used in muscle research, but there are some difficulties regarding the transition from the EMG fatigue to muscle fatigue (Potes, 2008). The combination of force altering equipment and EMG gives a lot of opportunities:

### **Percentage routine**

This routine will make you always work at the right percentage. The idea will be that before the workout routines you have to define your maximum pull or push when the EMG is on 100%. The program will then make it possible to choose a percentage and automatically drop the weight if it gets too heavy and the EMG goes above the preset value. This given the EMG idea is developed to functional state

### **Fixed Weight Routine**

Select a weight and do your workout, by connecting the EMG it will be possible to log the fatigue of the muscle through the repetitions and sets. This could be useful to track your physical state whether you want to see difference between working out day or night, log your state from stress full days to normal days, or see how your food intake acts on your stamina. Useful to find the optimal pre contest routine

### **Resistance both ways**

When making workout equipment out of magnetic force, the ability to change force direction is there. This means that the force could always work against the movement. E.g. when doing biceps curls instead of dragging the arms back down the force changes so you need to push it down. Thus combining biceps and triceps, and making an alternative super set. The downside is that you lose the negative phase, the

concentric phase, that many workout routines rely on. On the other create a new way to work out, you could simulate a sawing motion that have resistance both ways.

#### Predefined routines

There are lots of define routines out there, that says what you should do and how many reps and sets. With a home gym you can even make it monthly so it will log your whole workout and start the correct routine at the given day. E.g. RYP routine has a certain percentage gain per day so a possible MagnetGym Home Edition will keep track automatically.

The predefined routines would set the weight to the correct amount every time, or percentage. If you are working out with a percentage pyramid, the MagnetGym will set the weight to what you should manage, then correct the right amount from inputs from the EMG.

#### Rehab training

When rehabilitating from injuries it is more critical to train in a correct matter. Outputs from the muscles could help with this. Either by keep the force at the correct percentage so the patient do not overstrain the muscles, or by drop the weights if the patient start using muscles that should not be activated. Making them more aware when the wrong muscles are activated

#### Complex movements.

When training with complex movements like snatch or jerk, there will be certain positions that will be stronger than others. For example are majority of the people stronger in the legs than the shoulders. To make a study on whether an e.g. 90% load in all positions will be effective would be interesting. This can be accomplished by connecting the whole body to EMG. The challenge would be to determine which muscle group to control the electromagnet through the movement, and get the code to follow this.

#### More effective training

By using precise EMG to log the activation of the muscles a personal trainer, PT, can correct the way a customer train. A huge responsibility of a PT is to make sure the customer is training correct, but a PT often just has visual of the movement. To incorporate the EMG to see what muscles that are activated during certain exercises can help supervising. E.g. many people struggle with activation of the shoulders in unwanted scenarios. Adding EMG to warn them could prevent bad technique and injury.

## 7 Improvements

As mentioned knowledge and budget has been restriction for the build and there has been taken shortcuts to give proof of principal. The prototype can therefore benefit from several improvements. Combined there has been used much time to try to get insight to all new theory and several subjects at ones. The author should have relied more on interaction with experts on the respective fields.

### 7.1 Resistance

There were a lot of assumptions regarding the coil since the author has no real competence in this field. If the MagnetGym was to be improved there should be done better research on the optimal coil specifications. The coil used was of no means optimal. Test of the coil revealed however that the length of the core was irrelevant, so the final setup either have to be several coils or one long solenoid. In addition simulation can be performed to discover which specifications that is optimal, and simulate the interaction between several coils on the same core. The thumb rule to increase the magnetic field will be smaller wire and more turns. Furthermore could the test setup be made smoother to neglect the friction and get better readings when testing the force. Preferable a test setup where the force measurer are logging the force to interpret the numbers afterwards.

A Better insight to the cores influence on the force are also a consideration, is there any other factors than permeability that will influence the total force? Metglas is a foil material with permeability above 1 (Metglas, 2014), can the mixing of different materials affect the force?

### 7.2 Controls

To improve the MagnetGym a proper designed control system would be preferred. There are many ways to improve the load cell, the first thing would be to buy a load cell in the correct weight range preferable design for the intension so it could be integrated smoothly into the pulling rope. Second a designated analog-digital converter, e.g. a HX-100, to both have analog and digital output, and PUF-500-025-S\*C02 as the load cell both from Load Star Sensors (Load Star Sensors, 2014). The load cell mentioned here has a bit low accuracy on 0,25% on 500lb, that is 0,56Kg which is not optimal, but will work. Load Star Sensors has a wide range of load cells, and can also provide load cells for a smaller prototype.

To make the resistance regulator function properly, a transistor designed for Arduino should be used like RFP30N06LE (Sparkfun, 2014). Unfortunately the author was not aware of that kind of transistor early enough to order and test it. However if the MagnetGym was to be improved the Arduino should be replaced with a designated PWM system and control system.

### **7.3 EMG**

The EMG is an interesting idea, regardless the fact that EMG would probably fail, proper testing should be performed. With an expert on data interpretation making a proper filter code, there should be some hope of getting it to work.

There should also be done tests where two groups are compared. One which will train two months with a routine based on percentage from EMG, and the other group will train the same routine but with the percentage calculated from performance. This could reveal the advantages of EMG

As mentioned the EMG equipment is not restricted to the MagnetGym and should be usable with any force altering equipment like the TrainiTest form InMotionIntelligence or the Air-series from Kaiser.

## 8 Conclusion

The harsh reality is that MagnetGym probably is not a good solution with its heat generation, limited distance, and the need of high amperage that will make it unsuitable to use normal power sockets. This conclusion is on the other hand based on this thesis and limited knowledge, there may exist high performance solenoids that was overlooked that will improve the resistance, for an example will a solenoid with smaller wire manage with 10A. Given the same solenoid but with a wire half the size the number of turns will be 1015, giving four times stronger magnetic field at 10A. Since a magnetic field on 0.0614Tesla generates a retarding force on 1,7kg the final coil(s) probably have to, at least, be 6Tesla, given a linear relationship, which is not the case. Another problem is to prevent the core saturating before reaching the wanted resistance. The EMG however can be a break through, even though theory indicates an almost impossible task to get proper values that represent the muscle and muscle fatigue properly. The thesis has been a struggle and by bringing more experts onto the team would improve the thesis drastically, like have a multidisciplinary master team. Instead of searching around and try to learn everything, experts could have given proper answers within short time, and the focus could be on building, testing and improvements. All in all the MagnetGym is theoretically possible to build, the problem is heat, power use, and distance limits. In other words it overcomplicates simple exercises. The final prototype failed due to lack of theoretically insight and depth, however there has been give proof of concepts on every part of the gym, and therefore on can conclude with that the MagnetGym is a sleeping million dollar idea.

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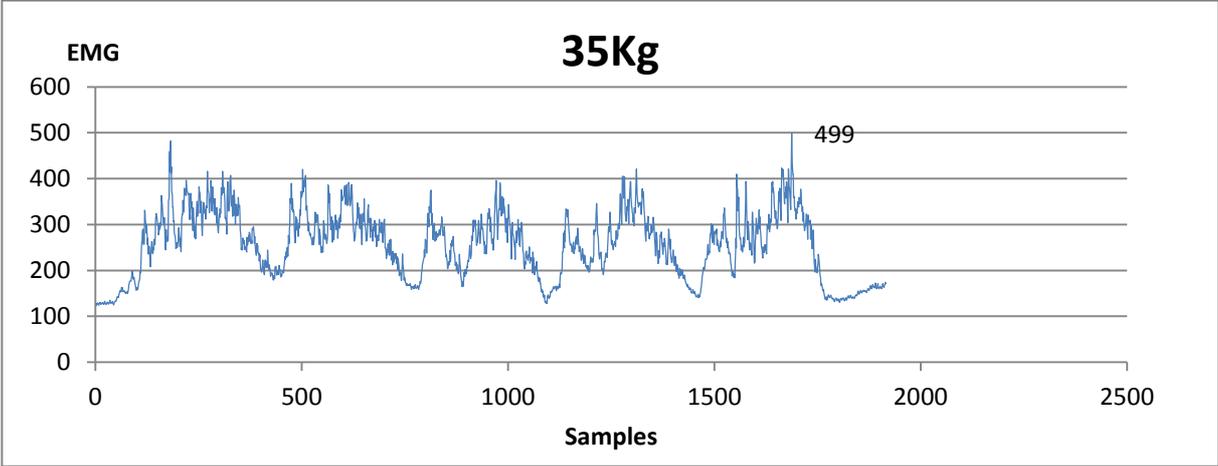
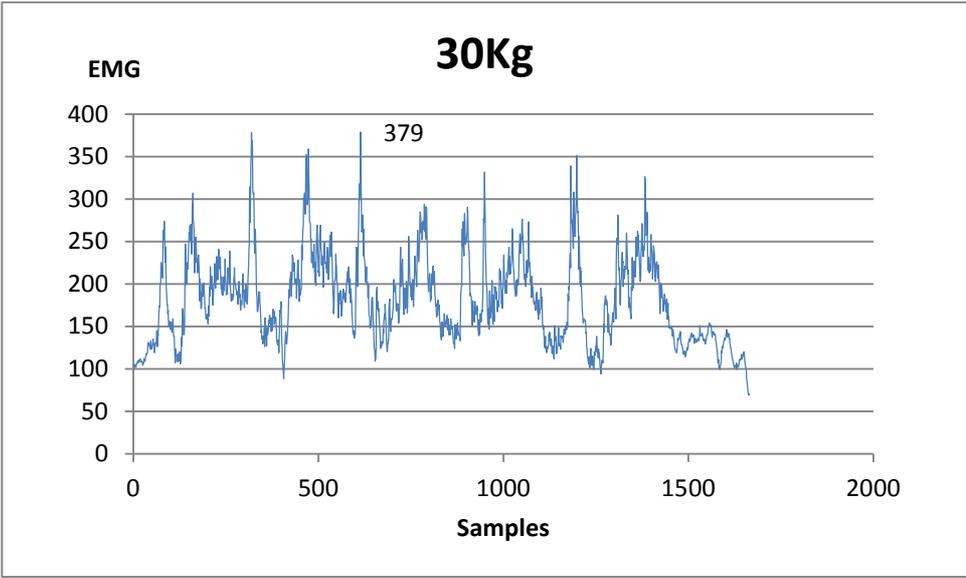
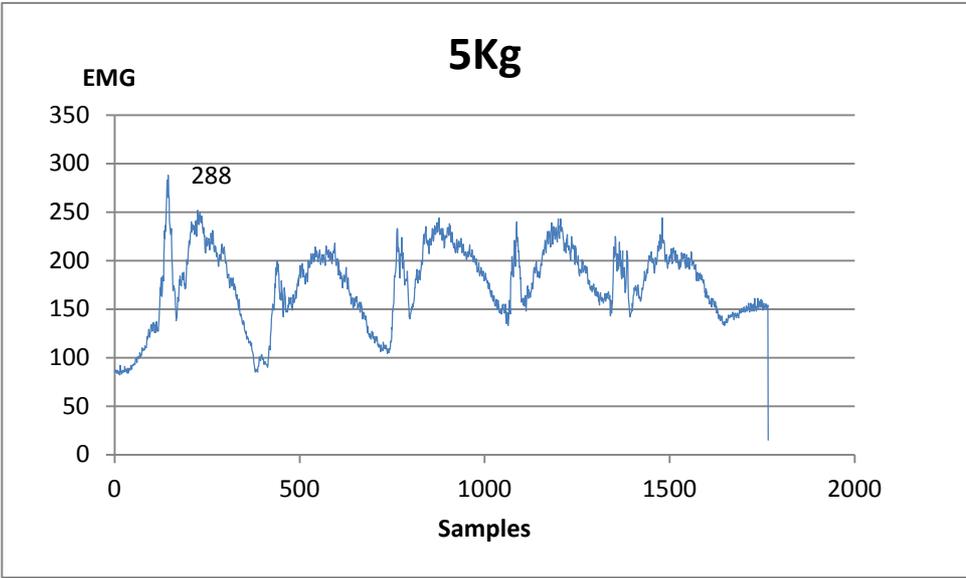
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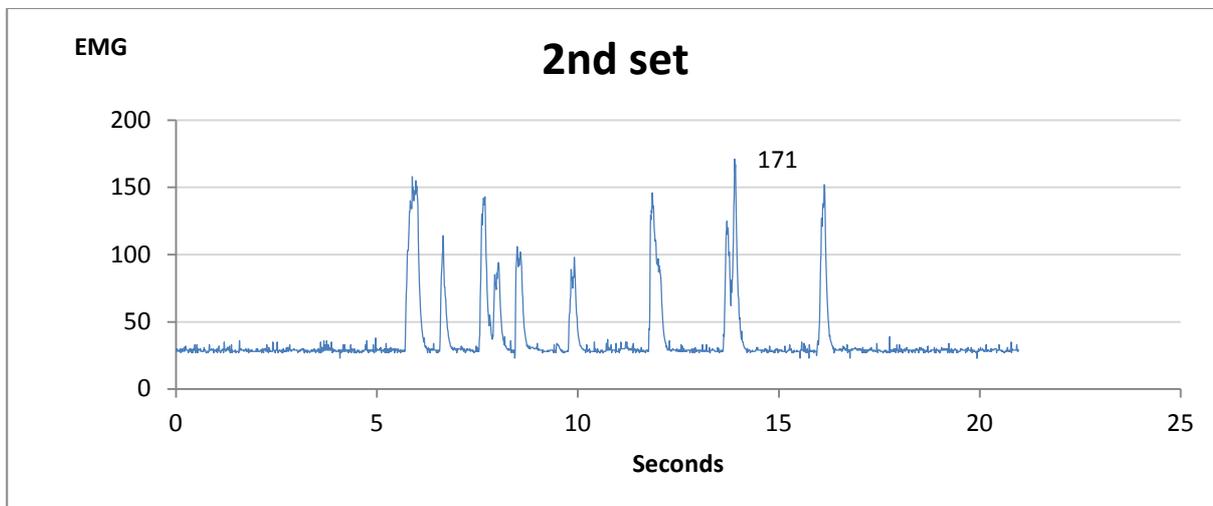
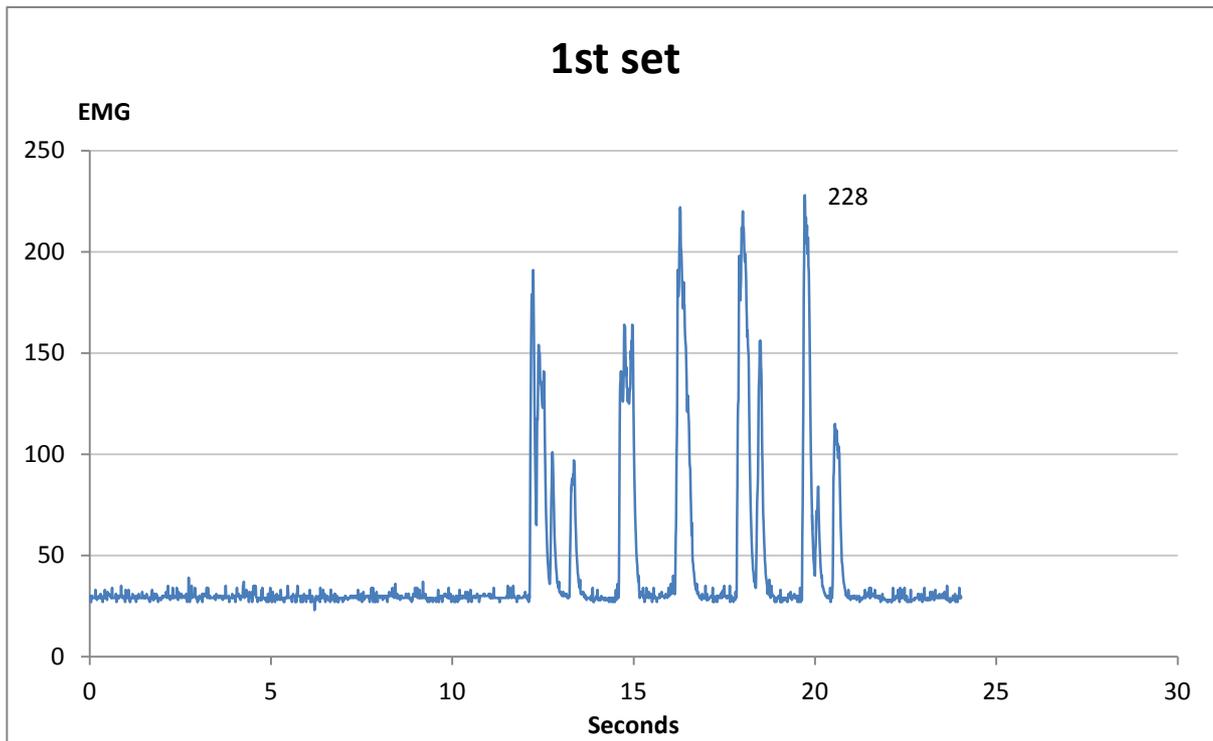
# Appendix A - EMG tests

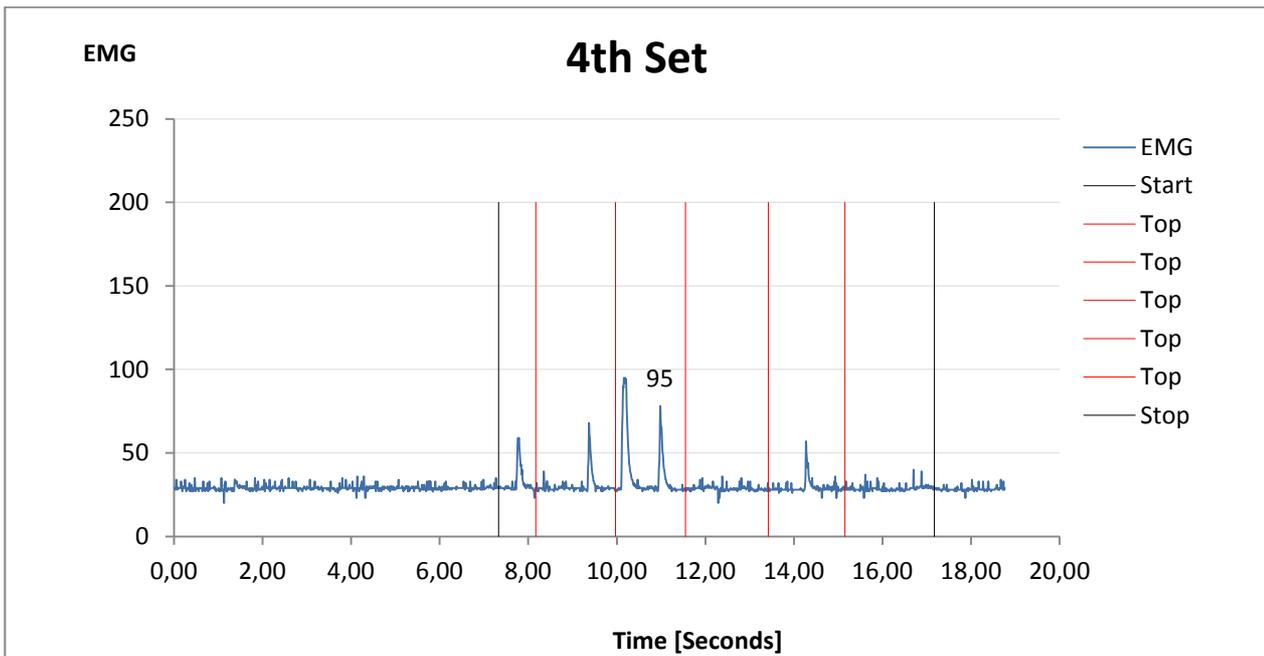
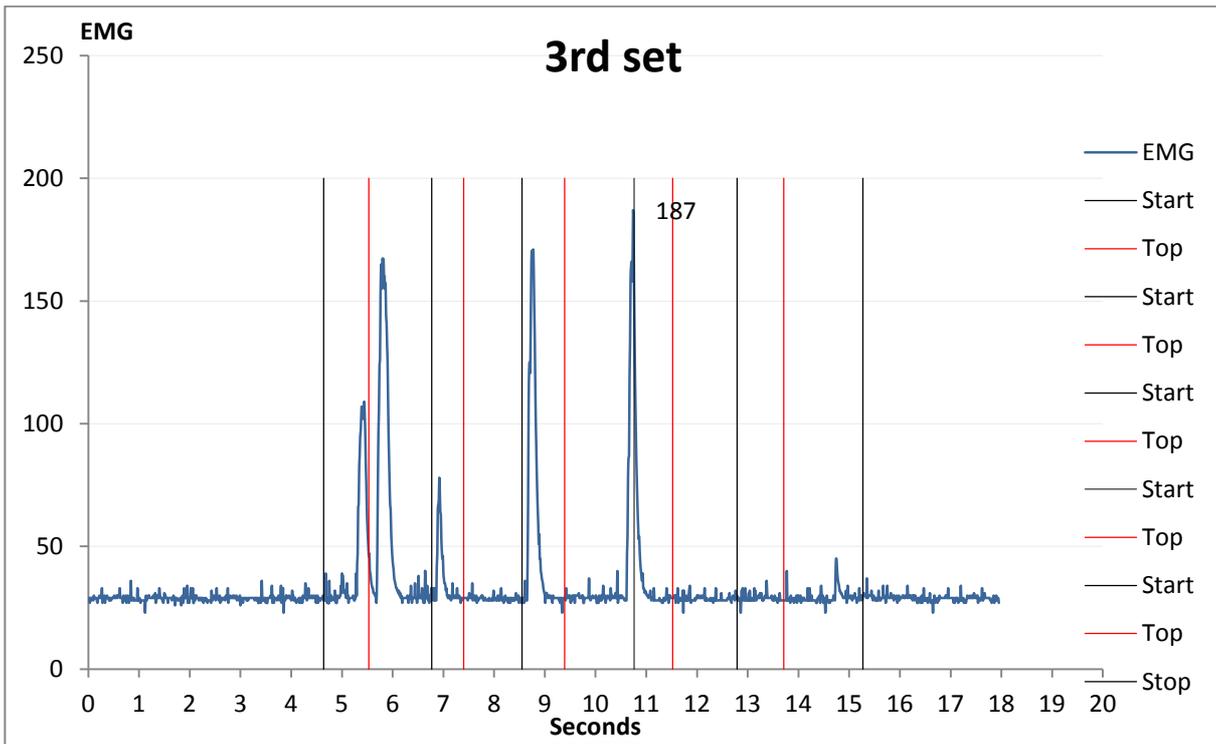
## Appendix A1: 5rep cheat sets

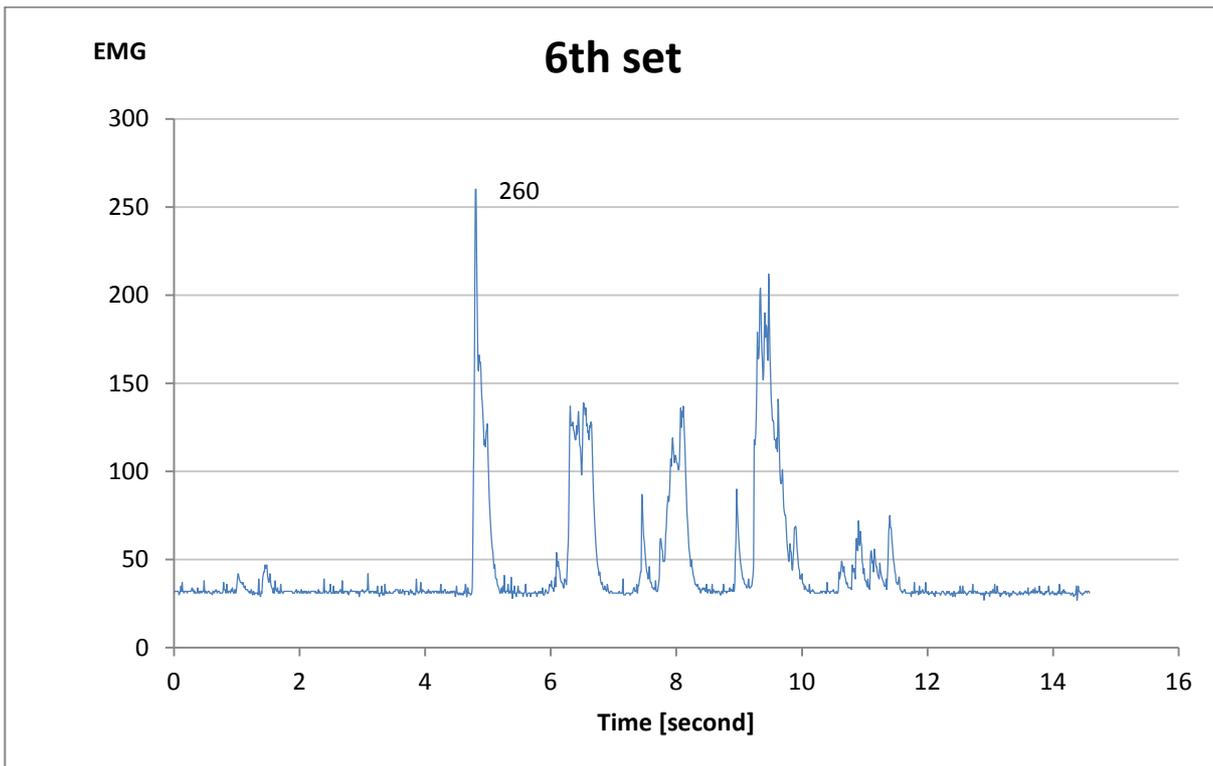
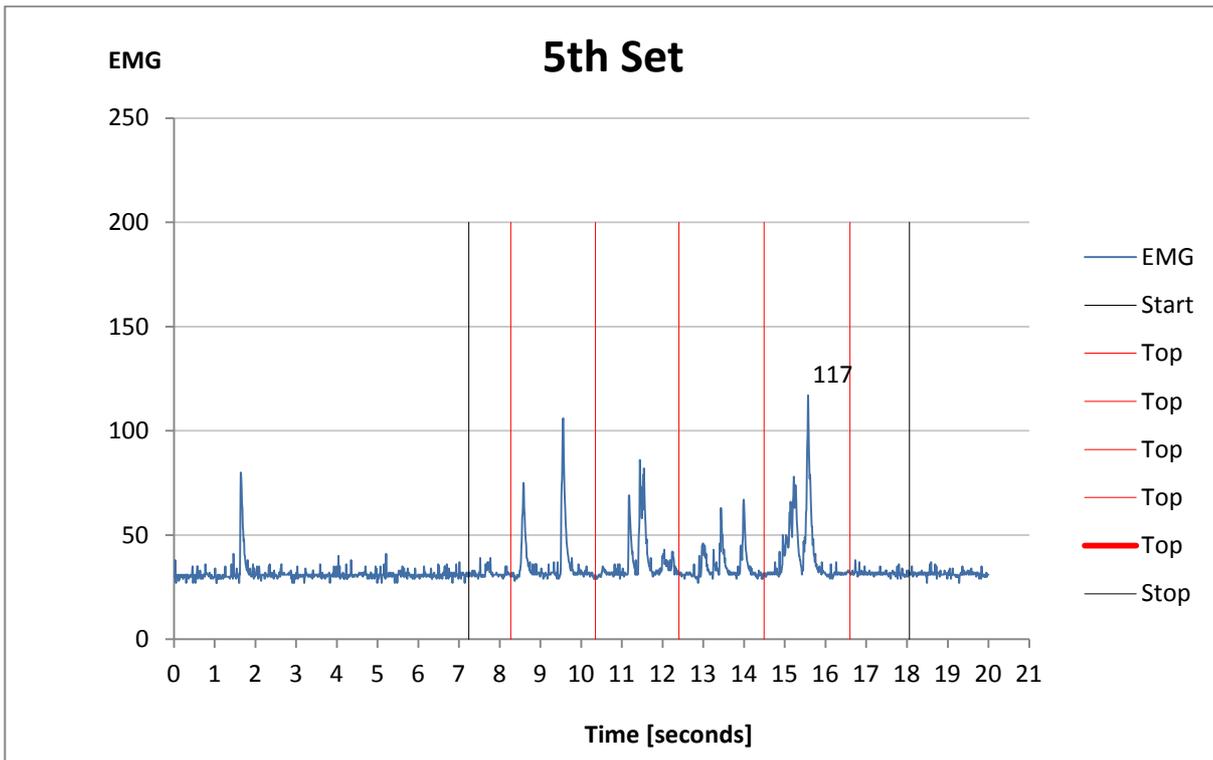


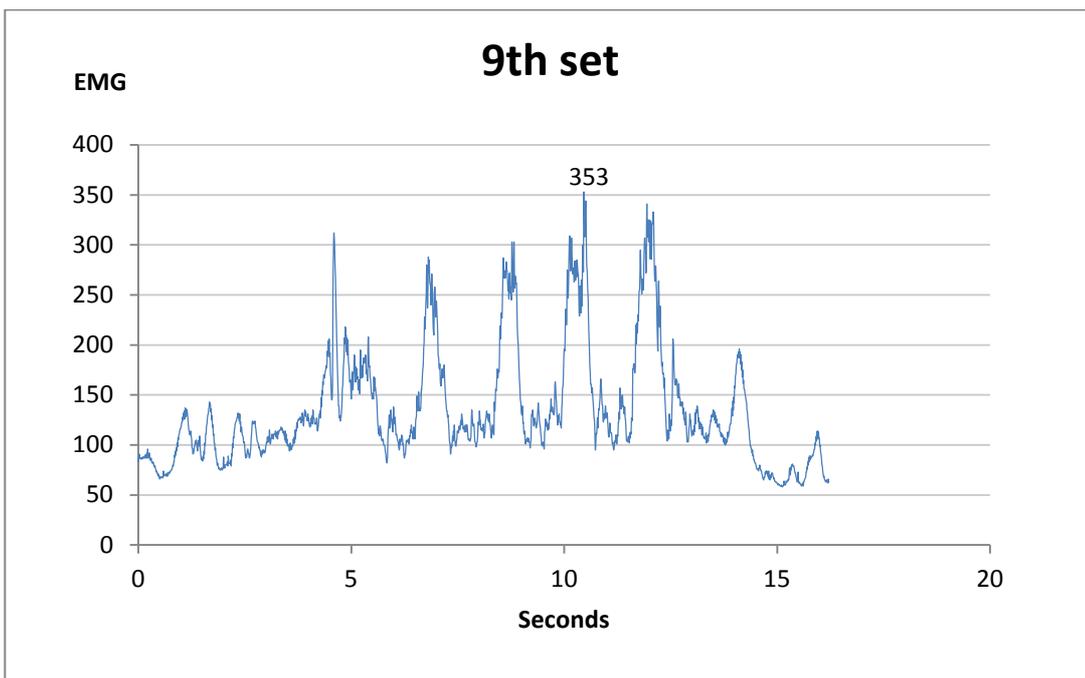
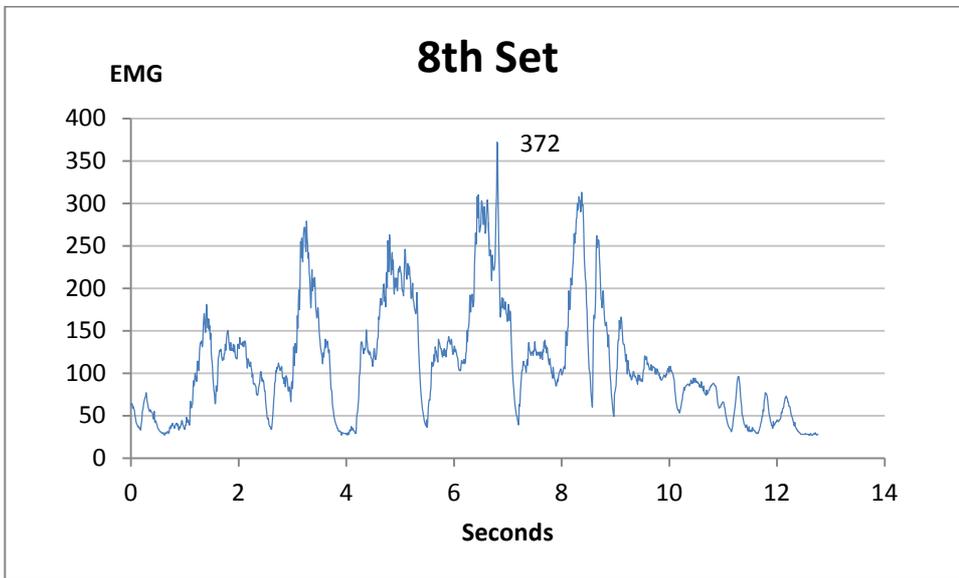
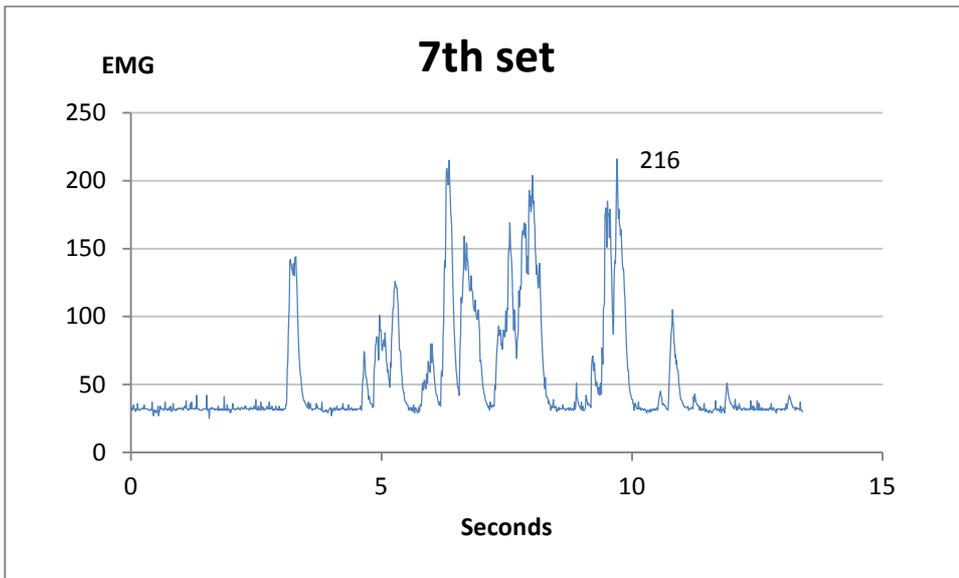
## Appendix A2: 25Kg 10 sets with 5 repetitions

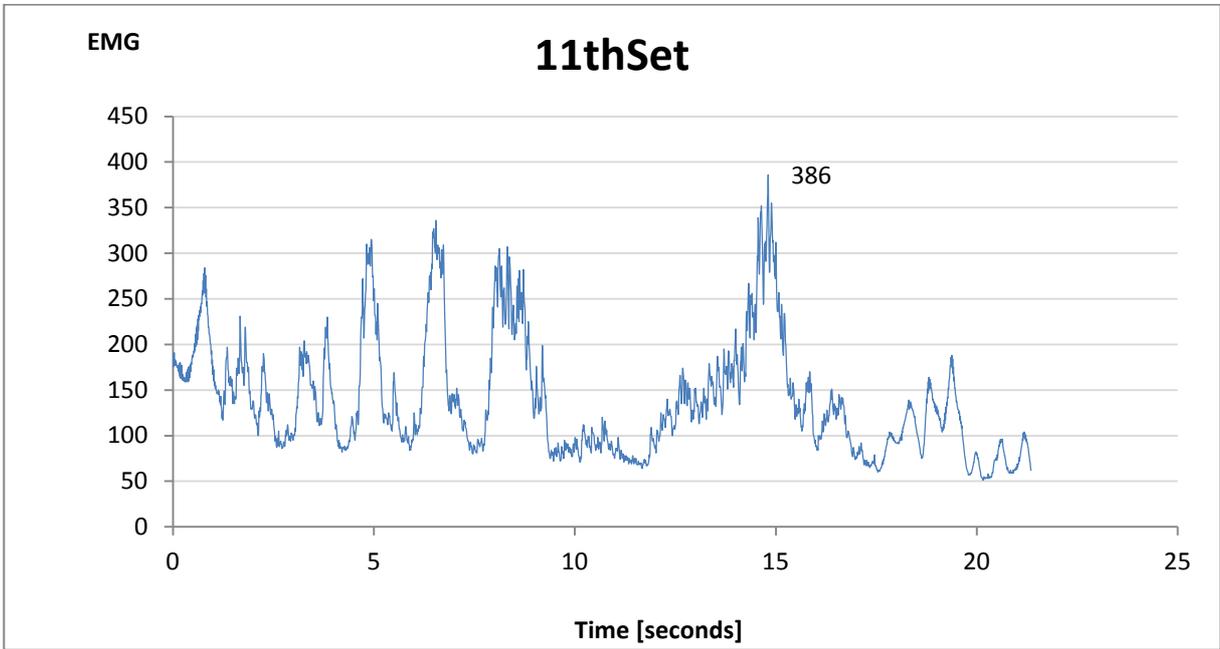
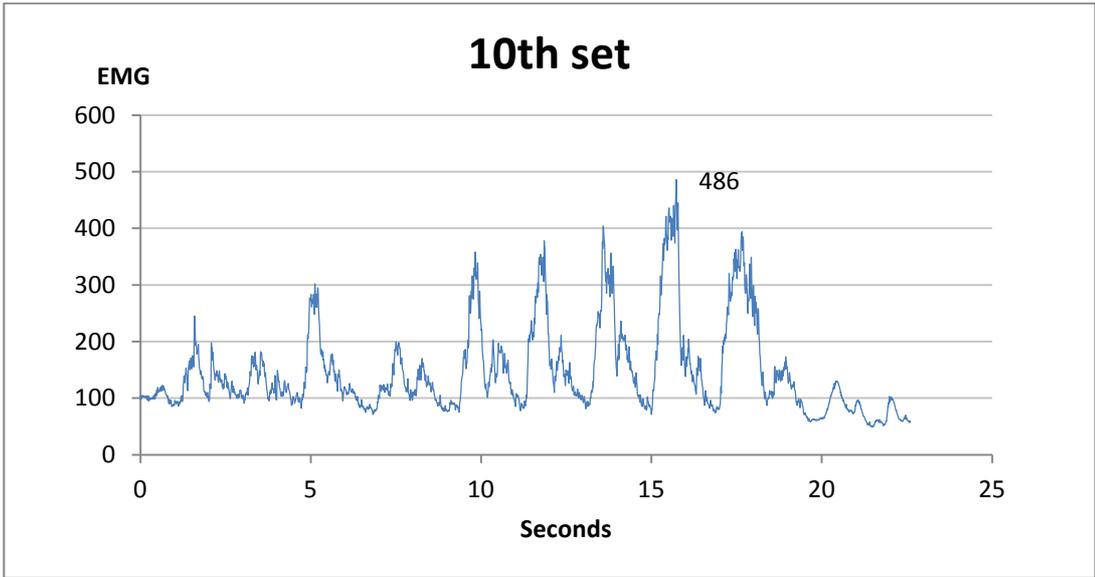
Used the second code during this test



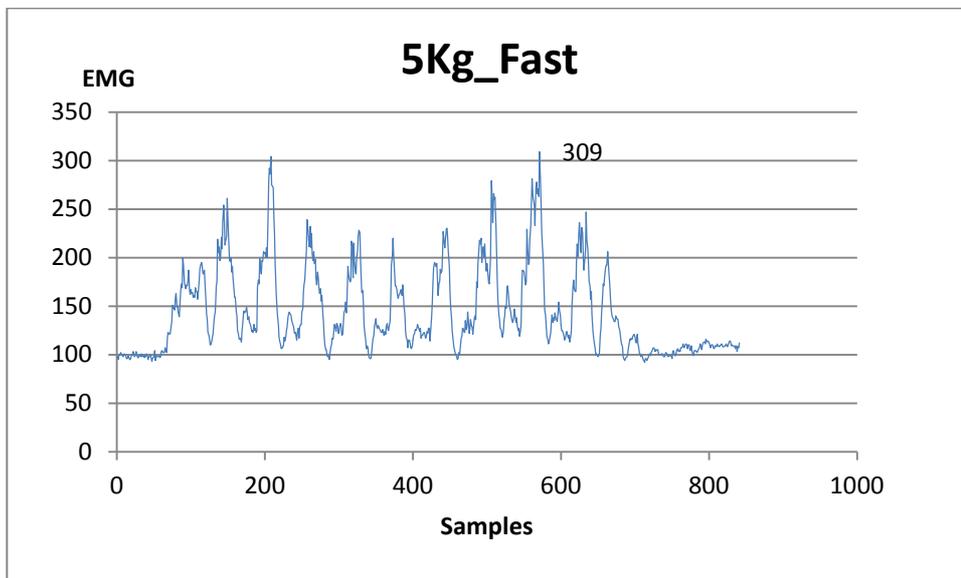
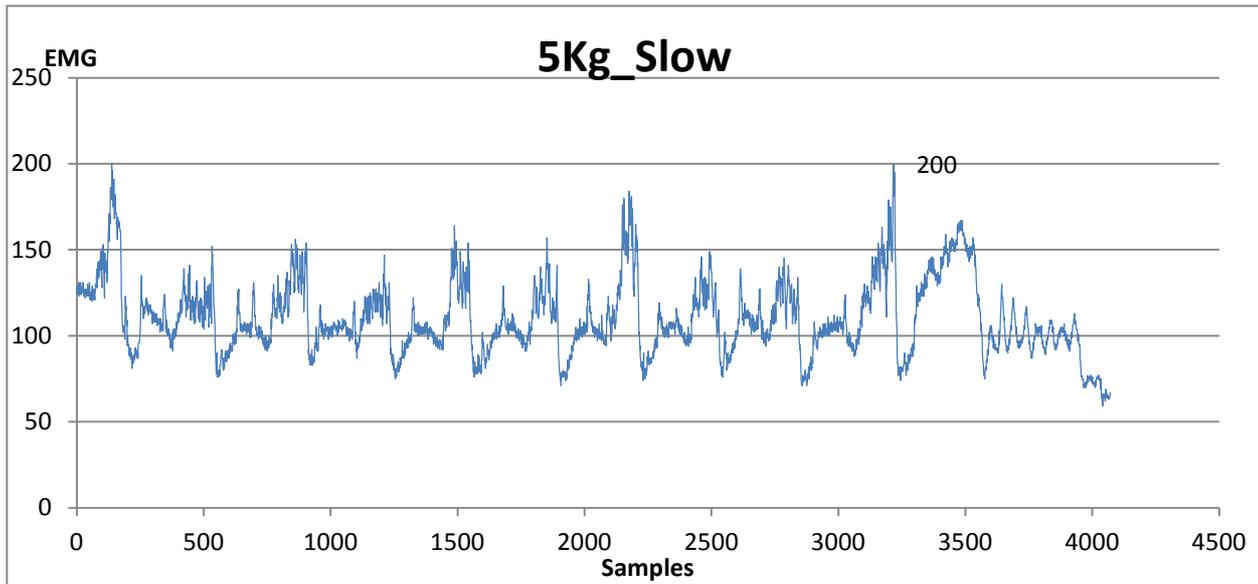


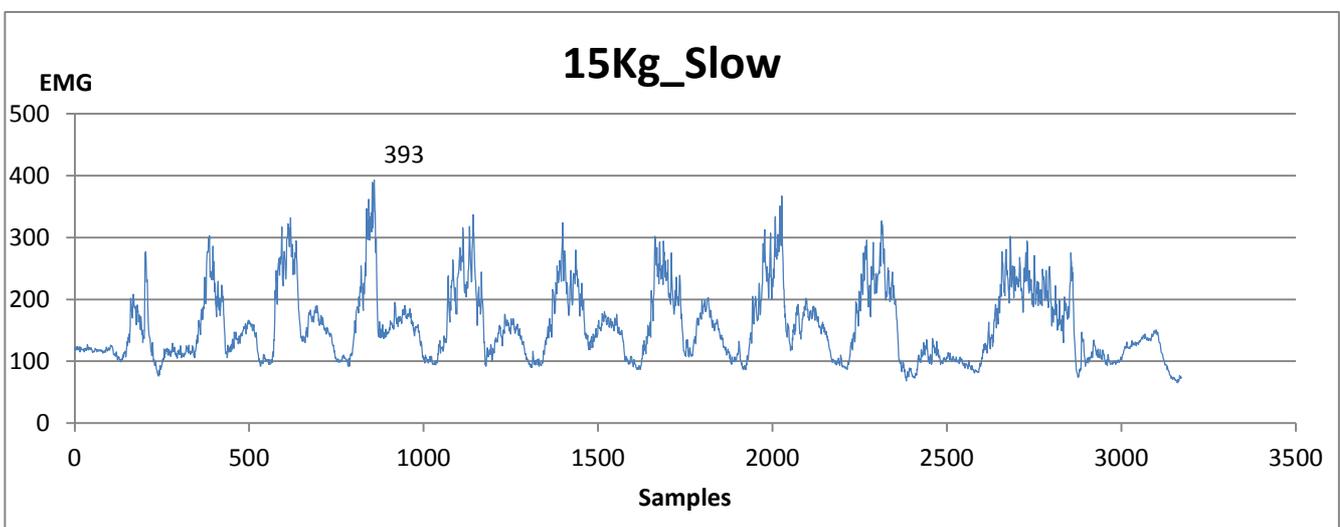
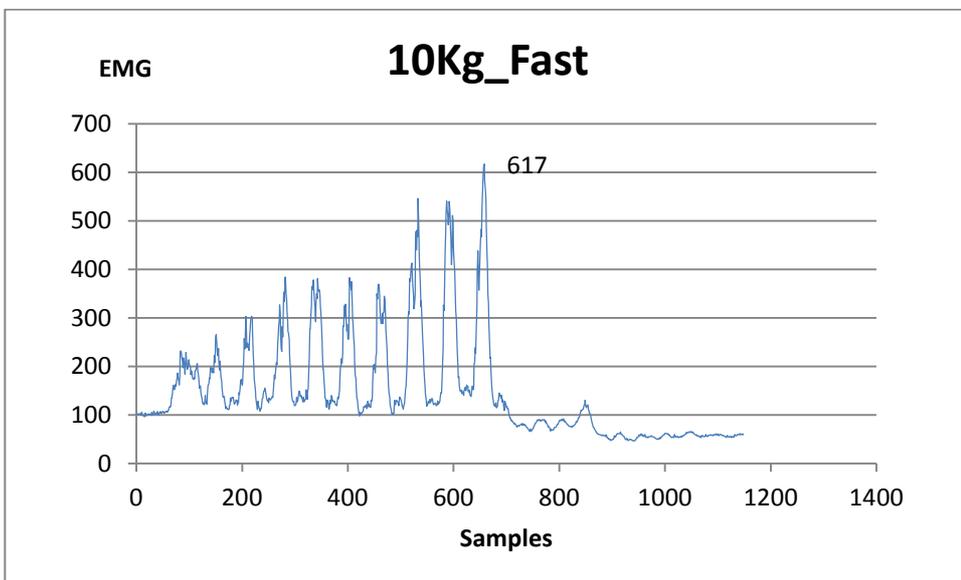
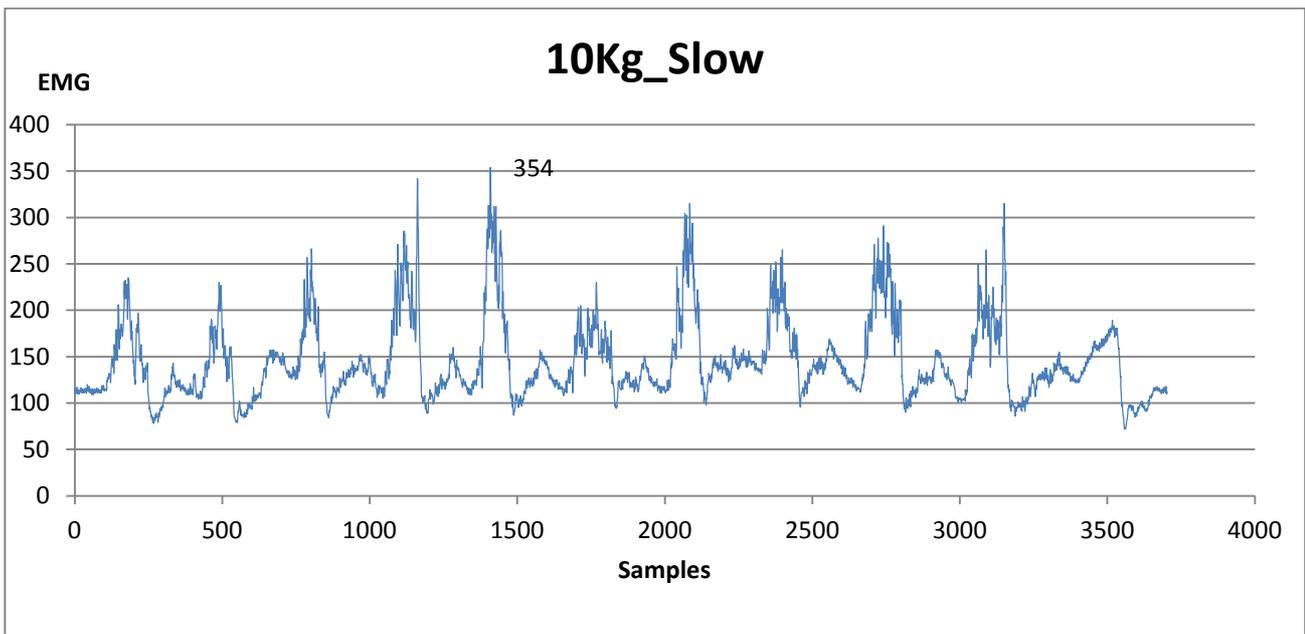


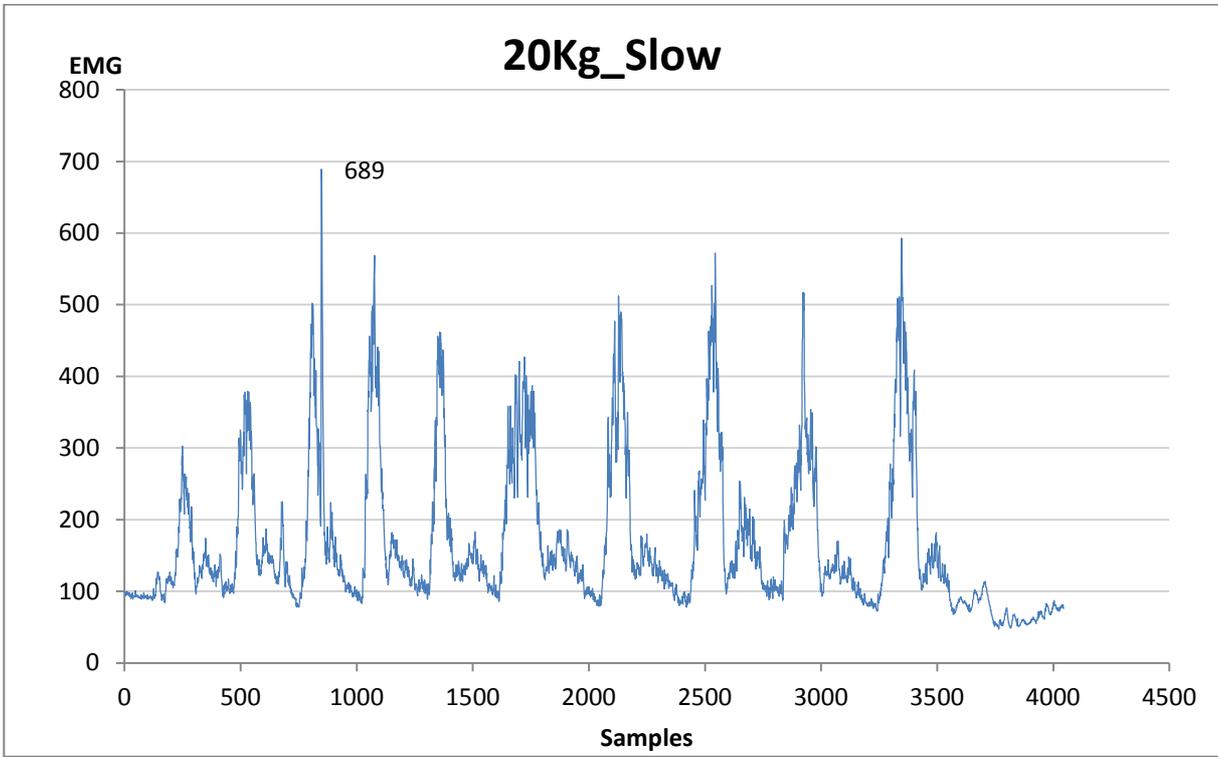
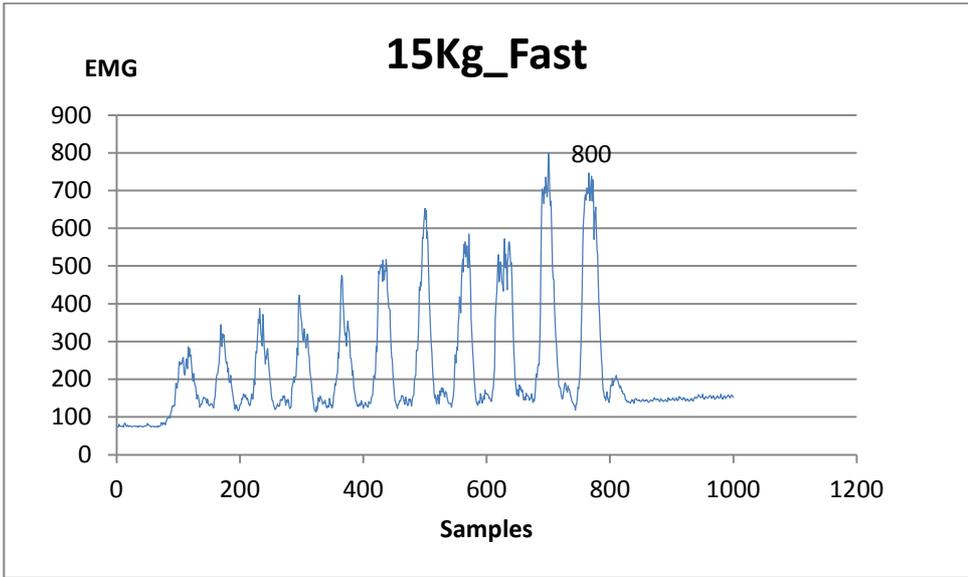




## Appendix A3: 10reps done fast and slow

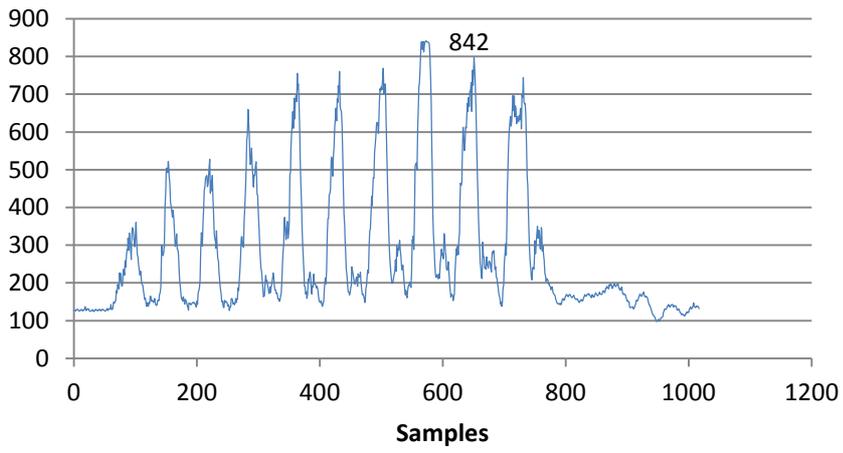




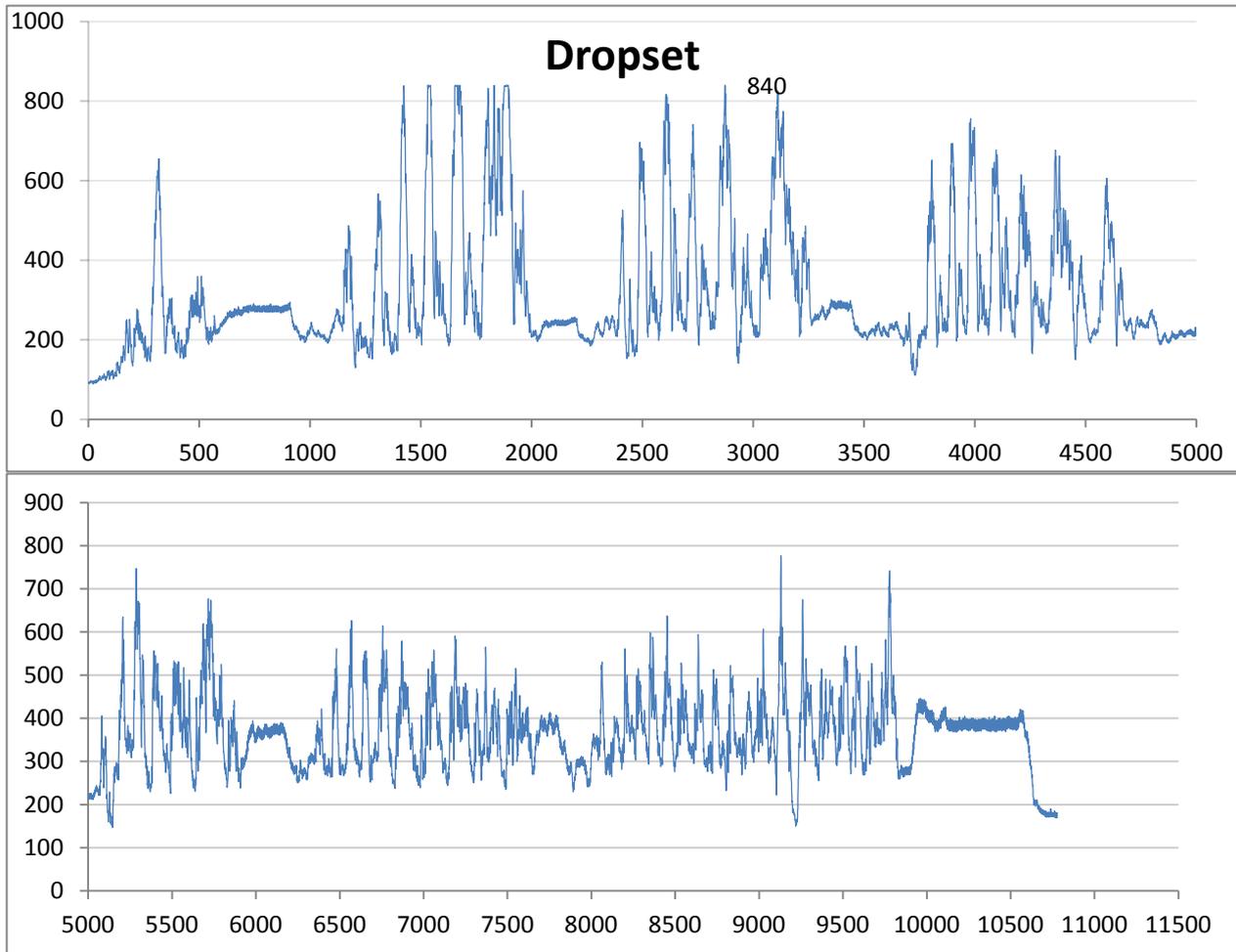


# 20Kg\_Fast

EMG



## Appendix A4: Dropset



The second graph is the rest of the first one

Dropset:

35Kg-2reps

30Kg-7reps

25Kg-6reps

20Kg-8reps

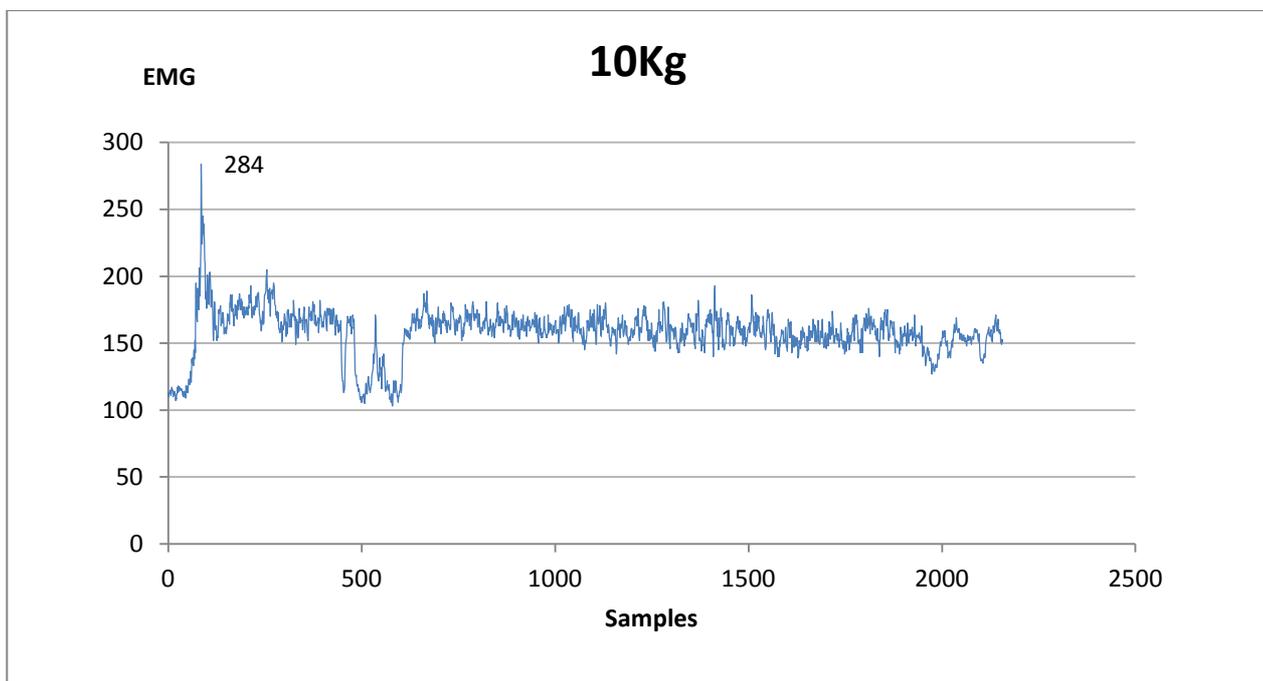
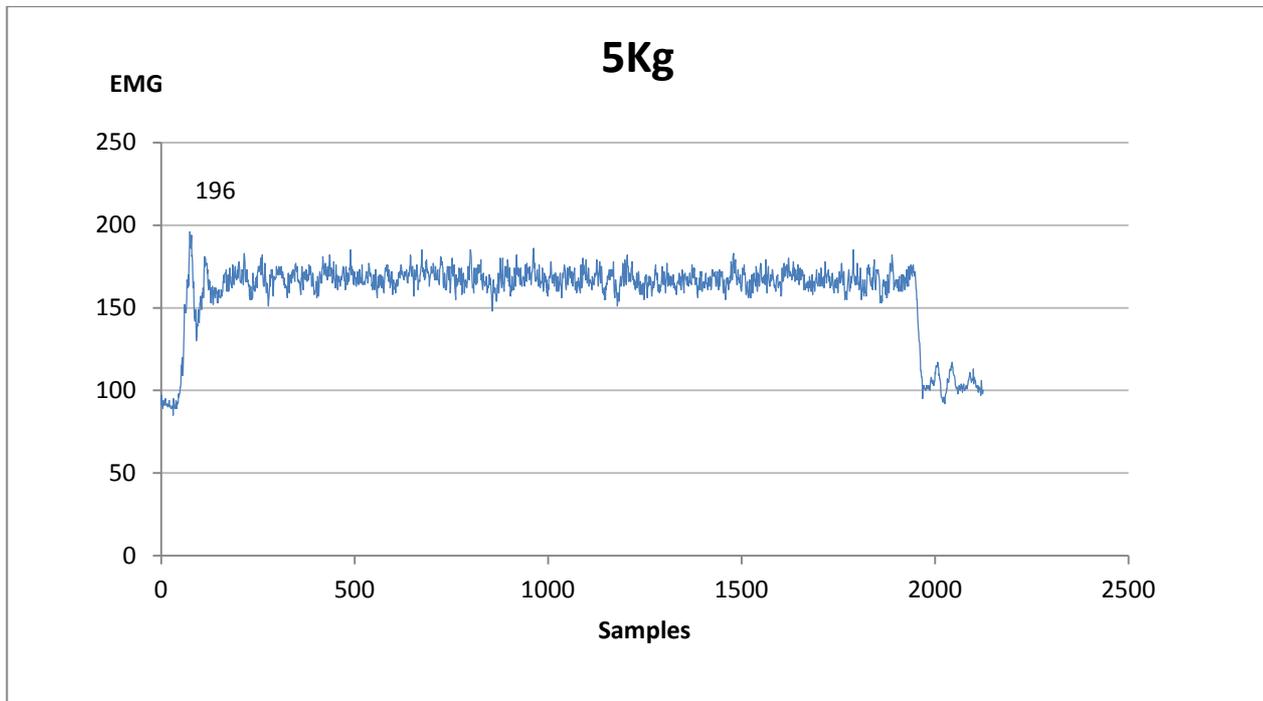
15Kg-8reps

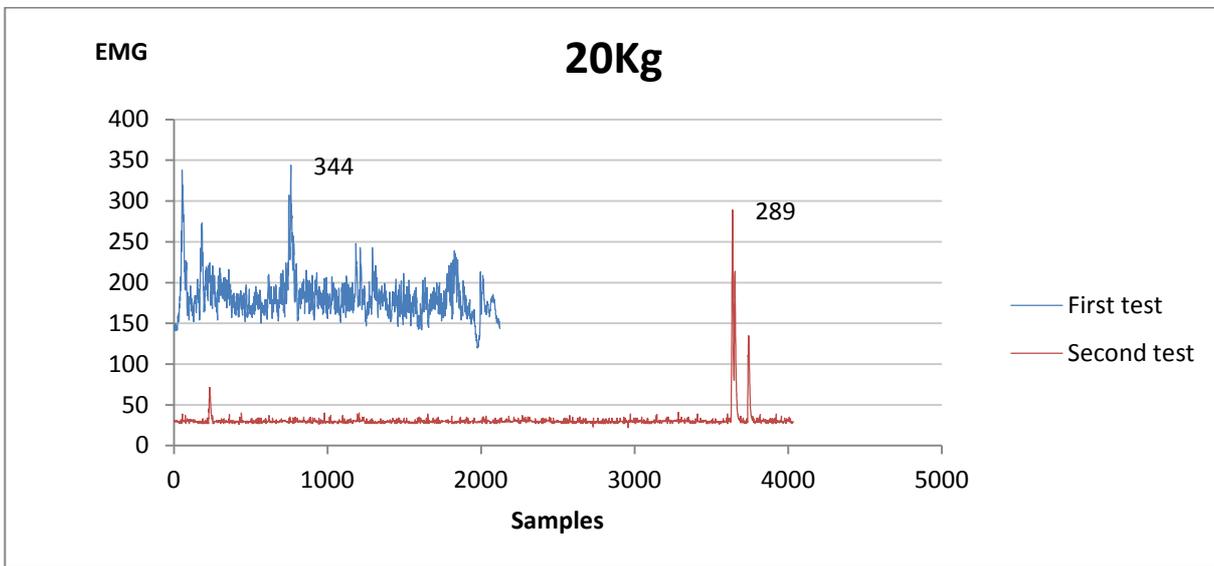
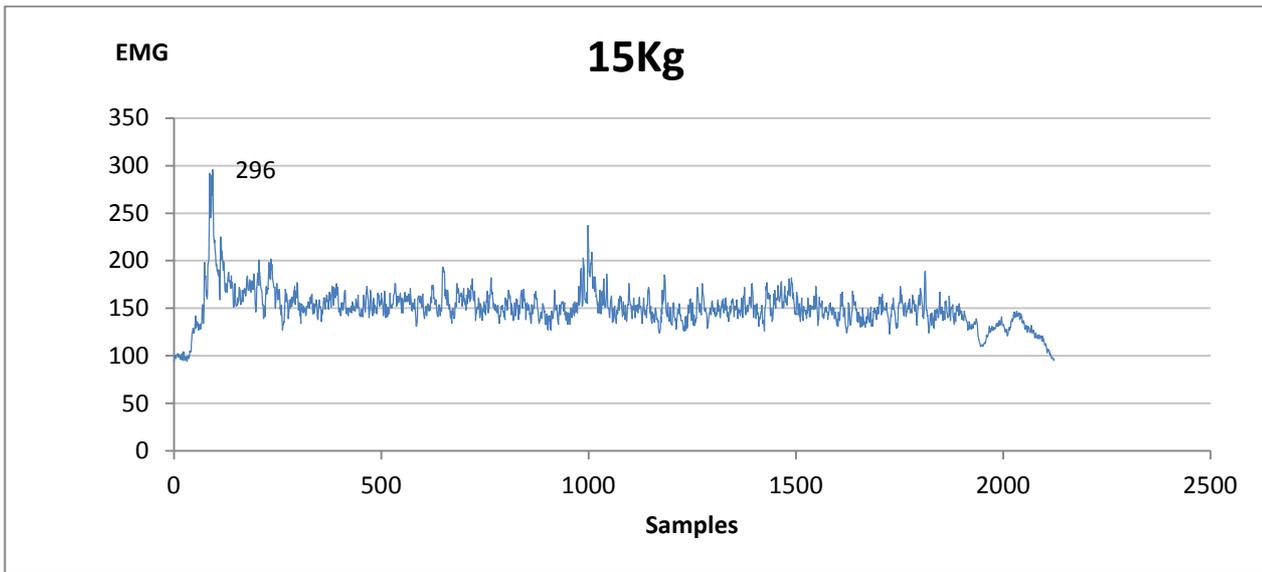
10Kg-10Reps

5Kg-20reps

## Appendix A5: Isometric hold

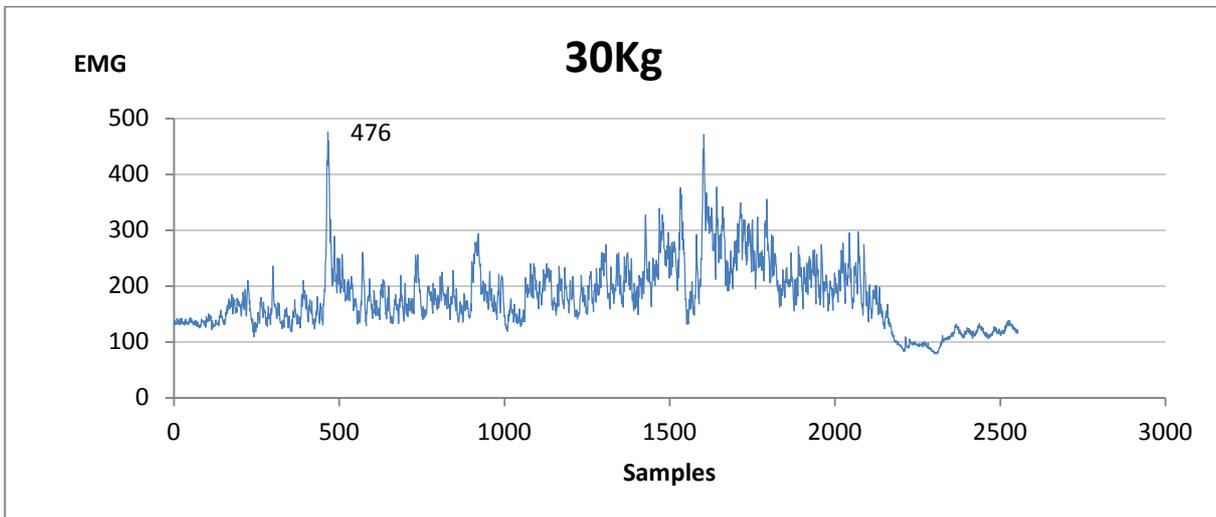
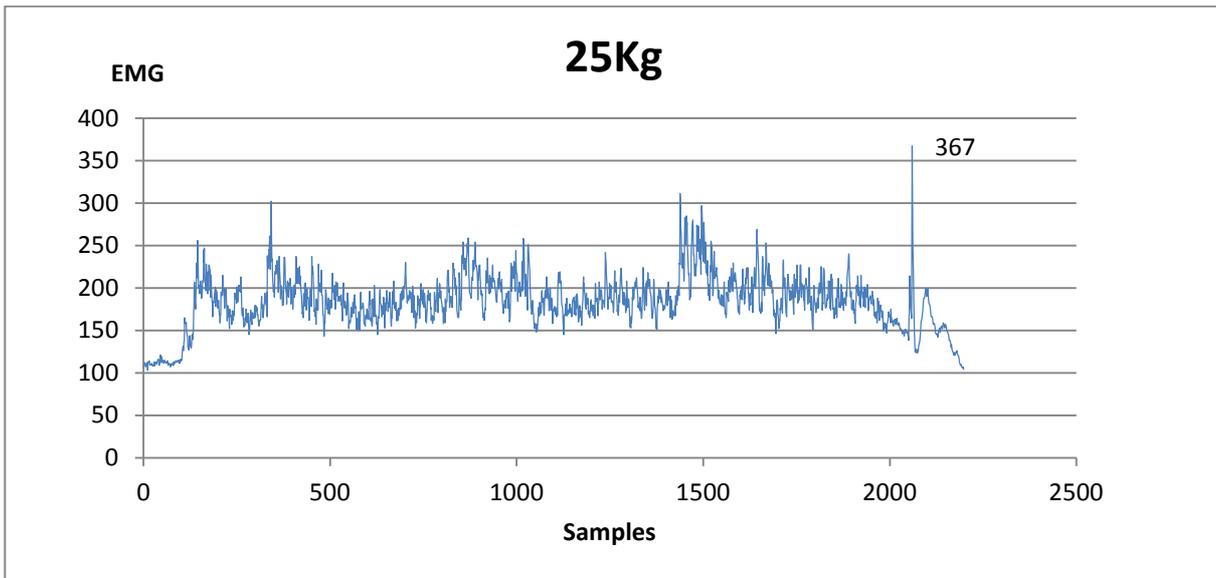
The following graphs are from 30seconds isometric hold with 6 different weights. Every test was started 1-2seconds after the logging started, that should be around 70-160 samples.





This test was done two different days, and with two different codes. The First test was done with the other isometric hold tests as the seventh test that day with little rest. The code has unknown samples per second, but inaccurate tests with a stopwatch indicate somewhere between 70-80 samples per second. The second test was done the next day after 11 sets and with a code with 100 samples per second. Fatigue-wise the tests were not that different so the gap between them is probably from different attachment of the electrodes.

Both tests was 30seconds.



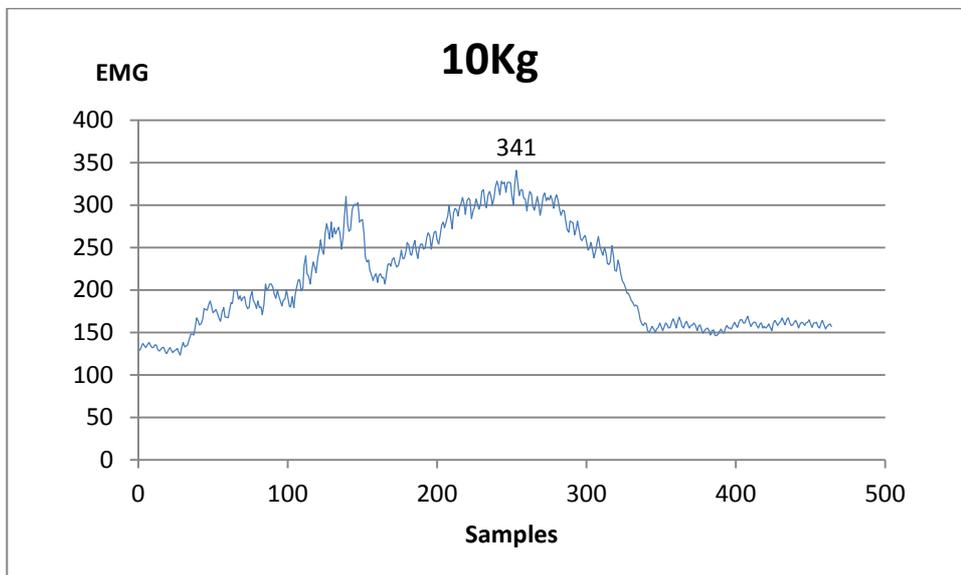
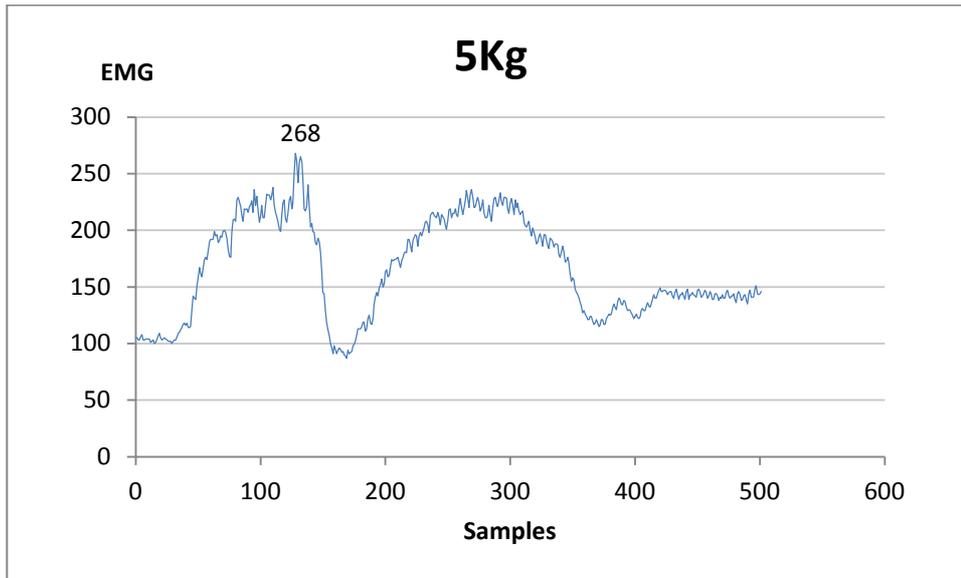
At 30Kg I failed at 28seconds.

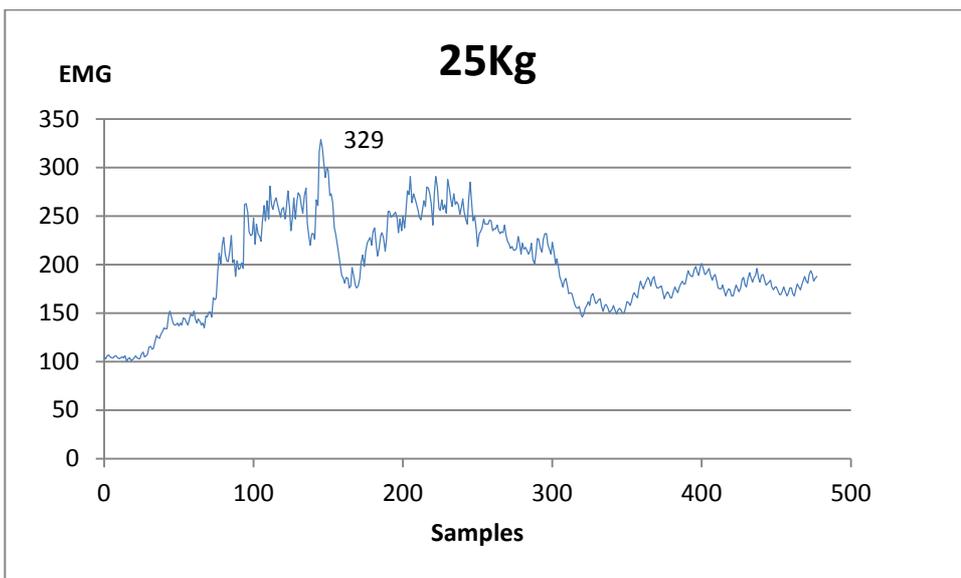
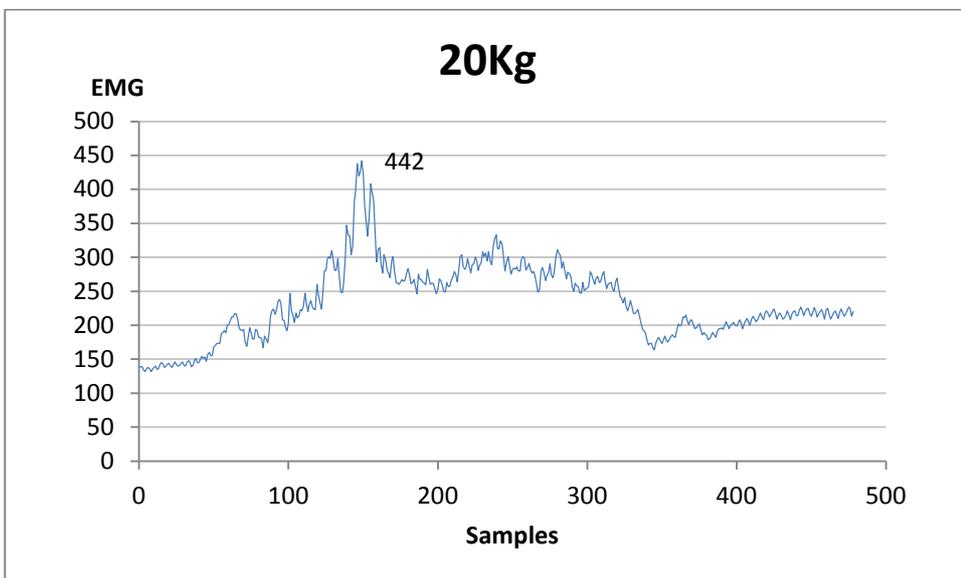
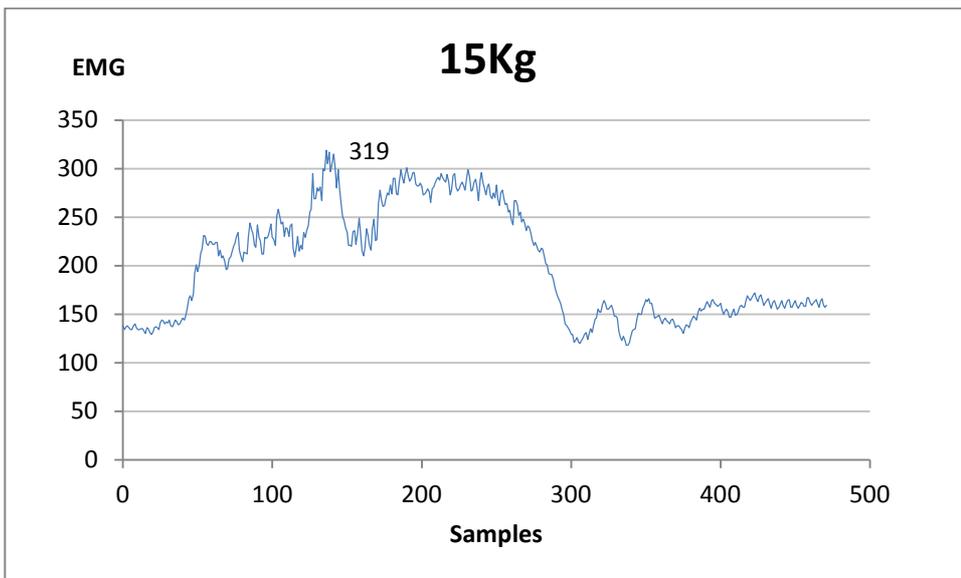
## Appendix A6: One rep tests

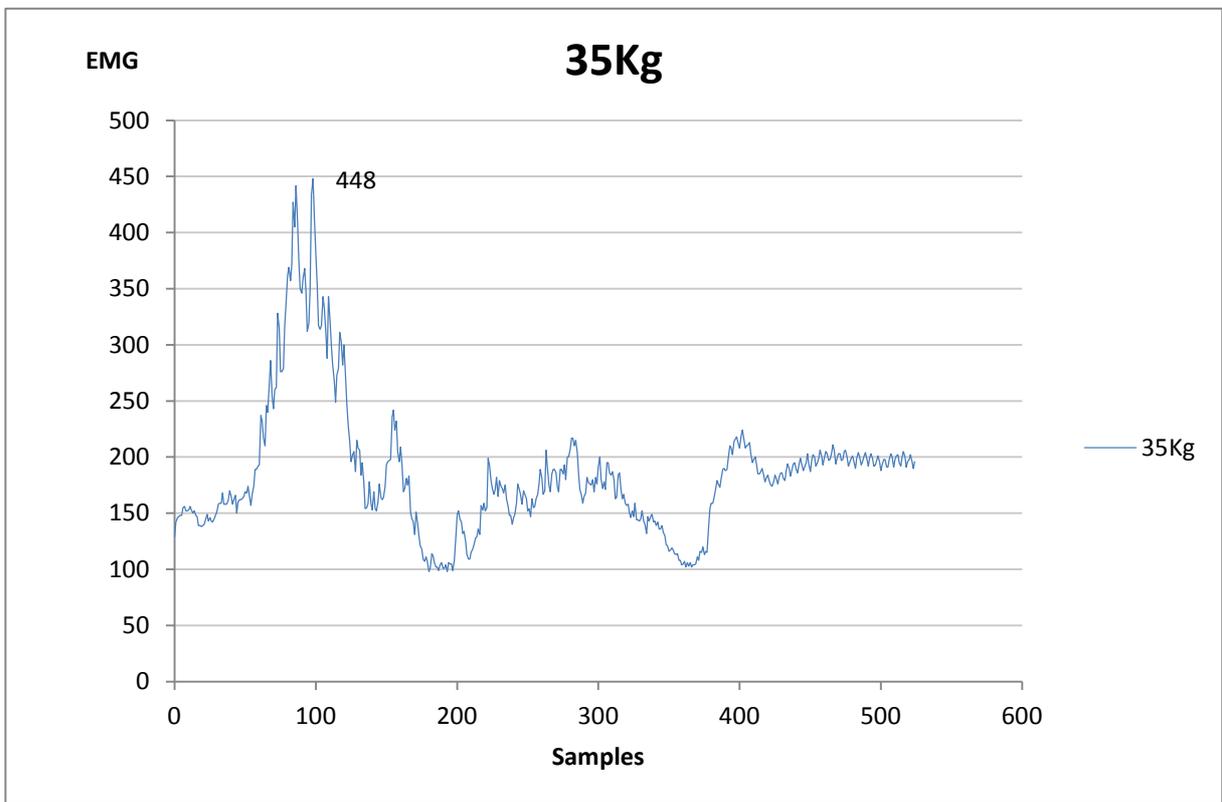
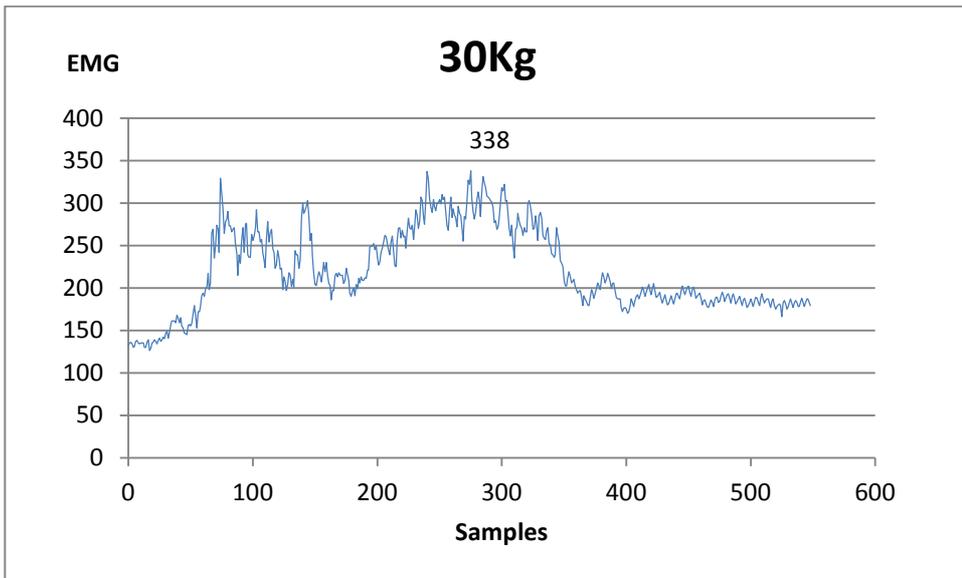
One rep test to see if it could be used as reference later.

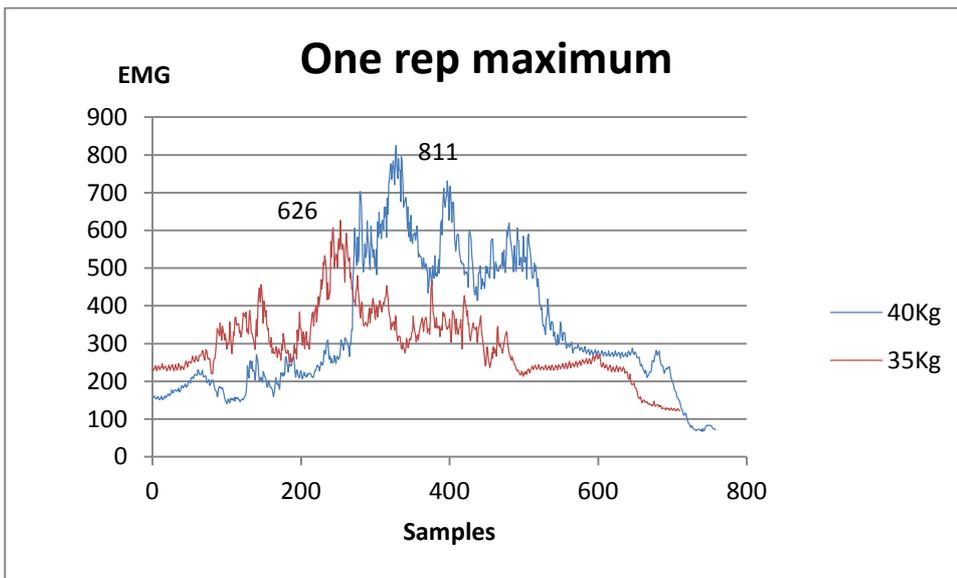
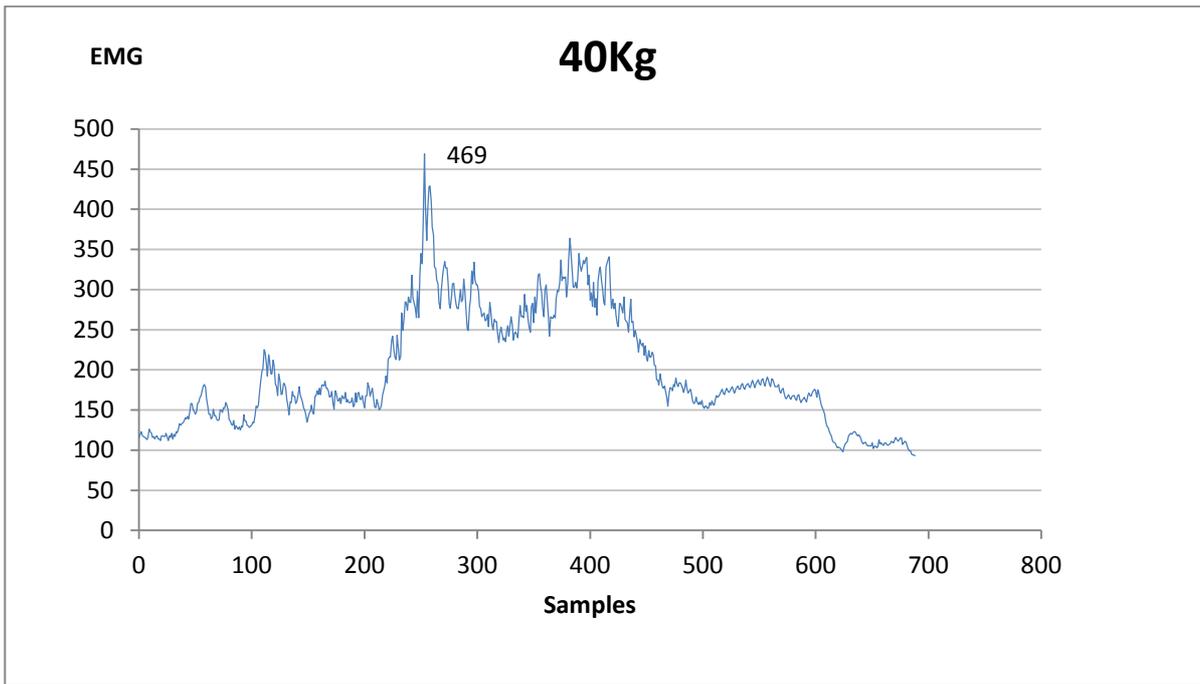
This was done as the first tests that day, so this is in rested stated, the tests where done without any other rest than setting up for the next test. It was done in upwards order starting a 5kg and ending at 40Kg as labeled on the machine.

Could be labeled wrong as I do not think I am able to do 40Kg one arm biceps curl.









These two last tests were done as the last that day. The 35Kg was the maximum rep right after the dropset test (see droptest test), therefore a fatigued case. The 40Kg test was the maximum rep after 2-3min break after the 35Kg max test.

## Appendix B - Coil test.

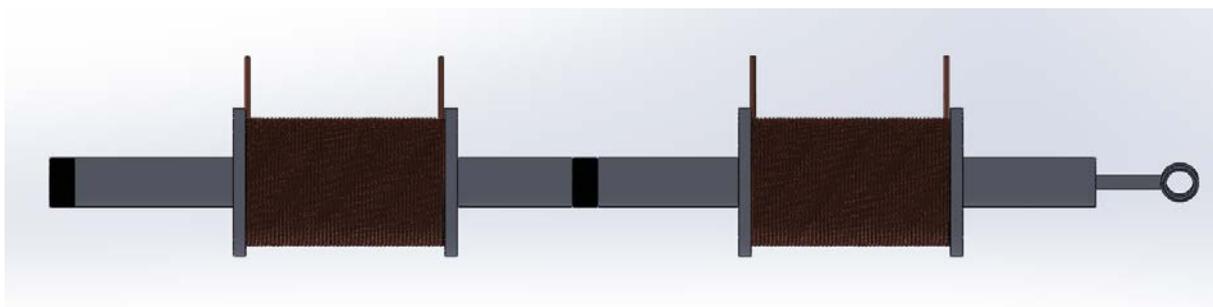
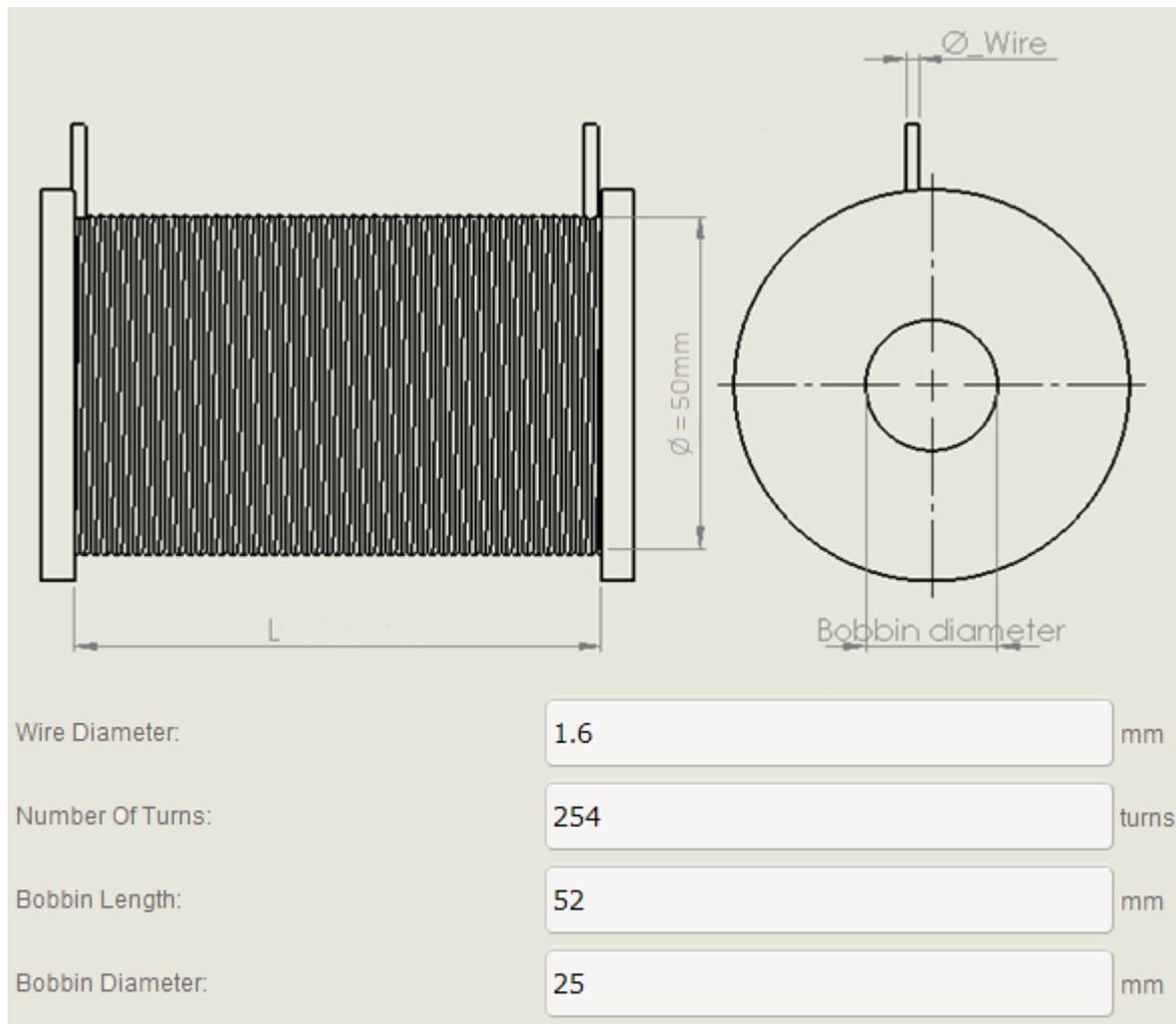
The coil idea was tested to give proof of principal. The rod was dragged through the coils with a digital weight to measure the force.

The coils were powered by two separate power supplies to control the current on each coil. The distance between the coils was constant.

The magnet has a north and a south pole as the coil has too. The magnet is therefore directed against the coil to get a repelling force to increase the total force. The downside with this is that when the magnets get through half of the coil the repelling force will change direction and push the rod out with drag direction.

Coil

specs:



First test where done with steel rod, with two magnets and power on just one coil, the one nearest the digital weight.

Current [A]	Max weight [Kg]
10,17	1,3
7	0,6
5,01	0,45
2,5	0,29

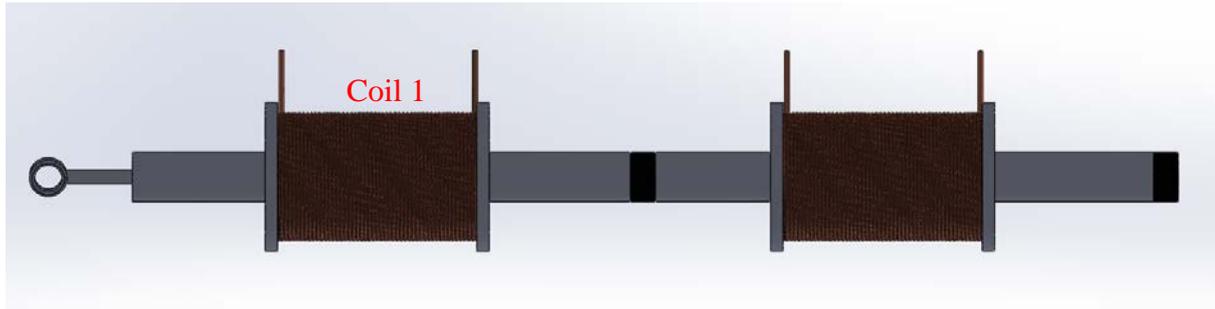
The second test was done with both coils, coil1 is the one nearest the weight

Current [A]		Force [Kg]
Coil 1	Coil 2	
10,17	5,058	1,3
7,01	5,058	0,83

The third test was without magnets

Current [A]		Force [Kg]
Coil 1	Coil 2	
10,16	5,059	1,3

The fourth test was reversed and without the magnets



This was done just to get the strongest power supply on the other end. Coil1 is still the one nearest the weight.

Current [A]		Force [Kg]
Coil 1	Coil 2	
5,059	10,15	1,7
0	10,15	1,3
5,054	5	0,72
5,059	2,5	0,4
2,503	5,02	0,6

Comparison of the tests show that for some reason having the weakest coil as coil 2 the force decreases.

Comparasment of test four and three revelse that it is better to have one coil alone rather than have a weaker coil as second, the force becomes the same. This could be a convincent since the reading of the digital weight was manually and there was some friction. But there is indications of having a weaker coil as second is a bad idea.

These tests was rough principal of proof so some friciton force occured but none than less there is a clear indication of the current influence as the theory said.

# Appendix C - Retarding force magnets and eddy current

Since the eddy current was one of the ideas a quick test was wanted. The test was performed with a digital fish weight dragging a plate with 9 34Kg magnets across an aluminum plate. The aluminum plate was 20mm thick. The test showed that the magnet needs to be very strong to be used this way. With 9 magnets on 34Kg each the test showed 0,78Kg when pulling quite fast cross the aluminum plate.

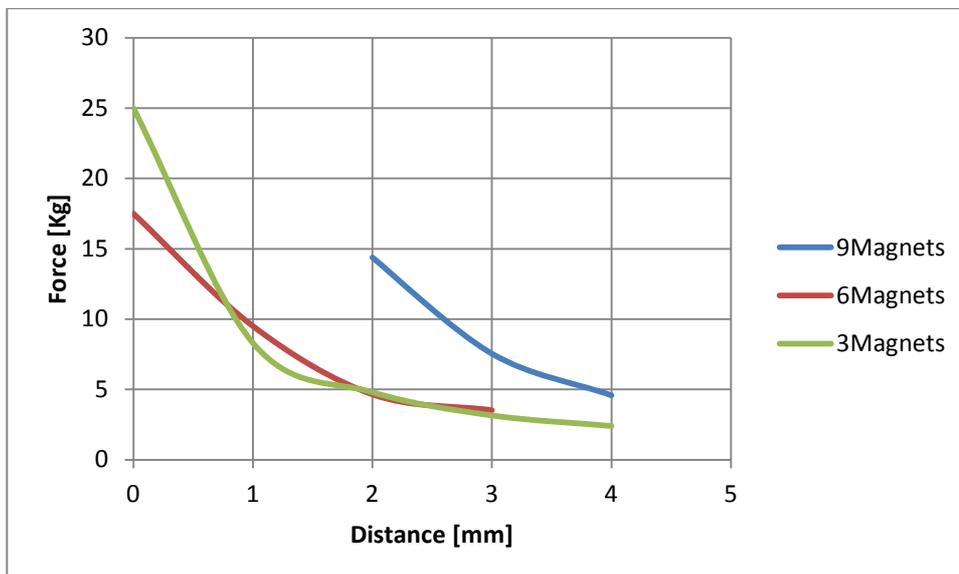


The same test was done on a welding table of steel to see what kind of force the magnets would generate against a steel plate. This is not eddy current working and the force will therefore not be affected by speed.

The distance was regulated by Plexiglas plates



Distance [mm]	9Magnets [KG]	6Magnets [KG]	3Magnets [KG]
0			25
1		17,5	8,3
2	14,38	9,5	4,8
3	7,54	4,65	3,15
4	4,58	3,52	2,4



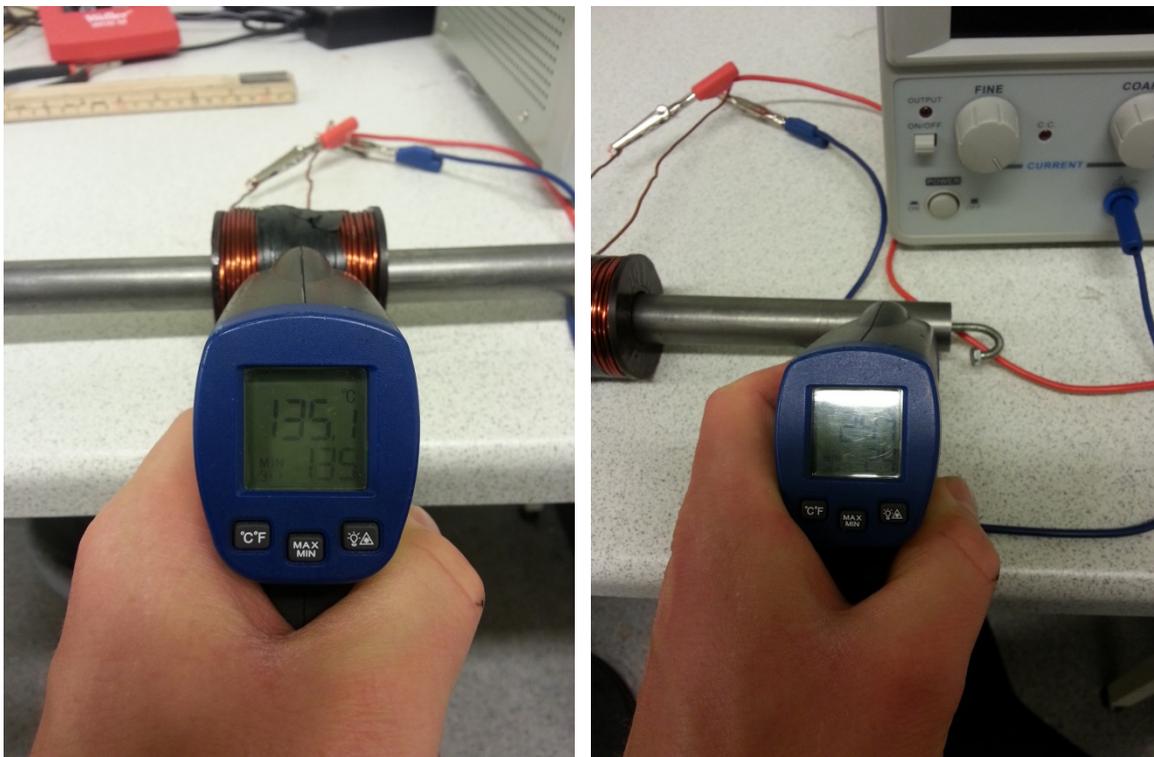
The ratio between pure magnetic force and friction due to pressure from the magnetic force is unknown. The numbers show a ratio between number of magnets, and at 2mm the force is almost linear. The ratio is not as consistent on the other distance but this could be because of different friction as the Plexiglas plates were of different quality.

## Appendix D - Heat generation

The heat generation by the wire could be a problem. To get a lead on how much this could interfere a quick test was done.

The coil was fed 10A for 20 minutes.

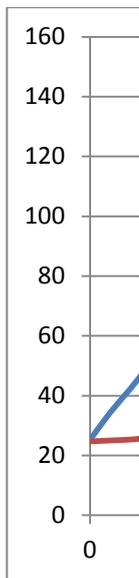
The temperature was measured on three places on the coil; left side, the middle and on the right side. The core was centered and was measured at the end which was 154mm from the center of the coil.



Left picture: the temperature after a short cool down after 20 minutes with 10A

Right picture: measure point on the rod,

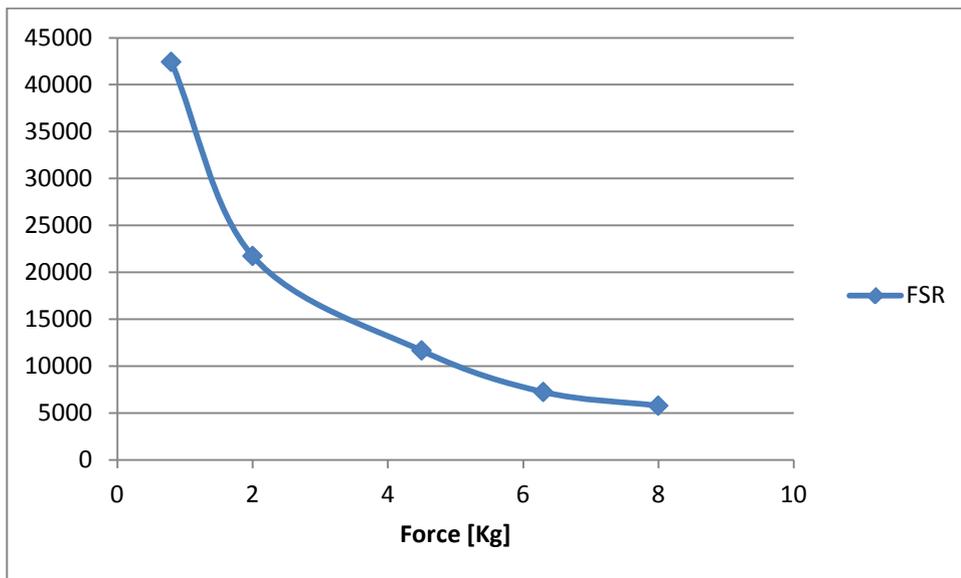
Tid [min]	Left side	Middle	right side	Average	End of rod
0	25,4	25,1	25,3	25	24,7
1	33,8	34	35	34	25
2	41	41,2	44	42	25,3
3	49	49	52,6	50	25,8
4	56	56	59,6	57	25,8
5	63	63,8	65,3	64	25,7
6	64,9	66	70,2	67	25,9
7	75	74,2	77,2	75	26,4
8	80,5	81,5	82,3	81	26,6
9	84	87,8	89,9	87	27
10	92	95	96	94	27,5
12,5	108	108,4	109,6	109	28,2
15	117,6	120,5	119,6	119	31,7
20	137,5	141,2	140,8	140	31,8



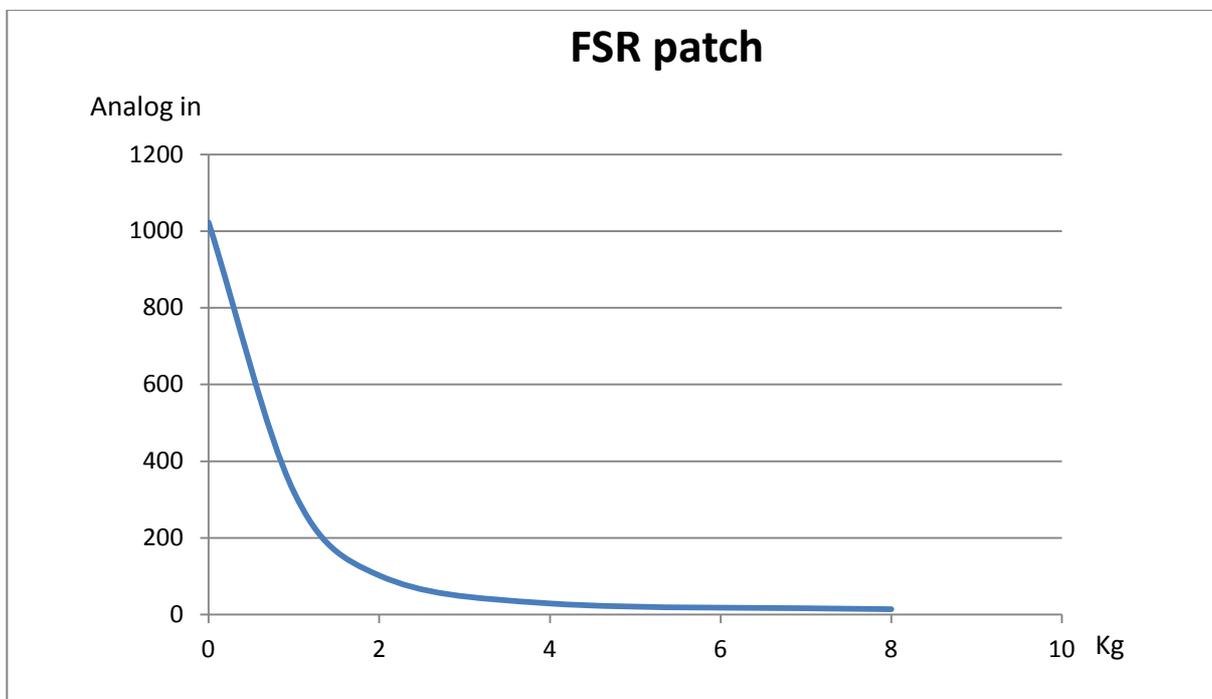
There was probably no point of measure three places on the coil, the temperature difference is most likely from the time it took to measure, which was 15-30 seconds

## Appendix E - FSR test

The test was done with a fish weight and a 8kg kettle bell. The homemade load cell was tied to the kettle bell in one end and lifted by the fish weight in the other hand. The force was compared to the given value on the Arduino.



FSR code



Test with analog in code

## Appendix F - Electromyogram (EMG) tutorial, Cookinghacks.com

### EMG sensor features

An [electromyogram \(EMG\)](#) measures the electrical activity of muscles at rest and during contraction.

Electromyography (EMG) is a technique for evaluating and recording the electrical activity produced by skeletal muscles. EMG is performed using an instrument called an electromyograph, to produce a record called an electromyogram. An electromyograph detects the electrical potential generated by muscle cells when these cells are electrically or neurologically activated. The signals can be analyzed to detect medical abnormalities, activation level, recruitment order or to analyze the biomechanics of human or animal movement.

EMG signals are used in many clinical and biomedical applications. EMG is used as a diagnostics tool for identifying neuromuscular diseases, assessing low-back pain, kinesiology, and disorders of motor control. EMG signals are also used as a control signal for prosthetic devices such as prosthetic hands, arms, and lower limbs.

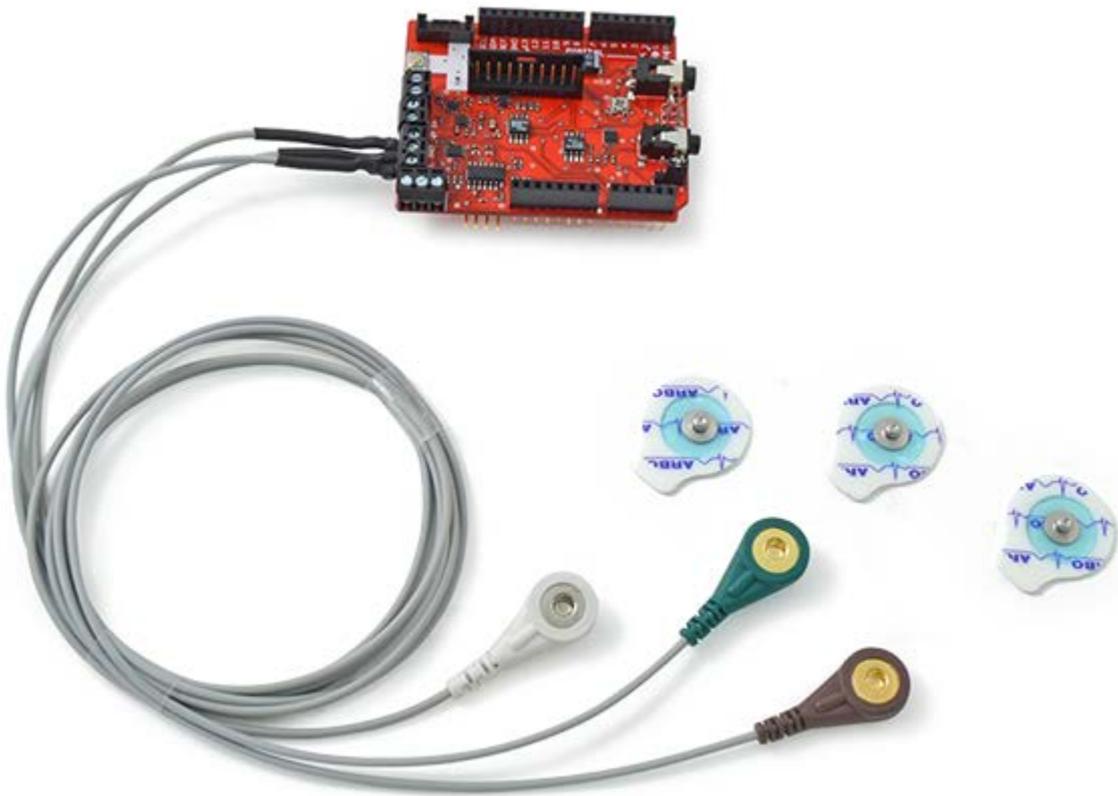
This sensor will measure the filtered and rectified electrical activity of a muscle, depending the amount of activity in the selected muscle.

### Features:

- Adjustable gain
- Small Form Factor
- Full integrated







Remove the protective plastic



This sensor use disposable pre-gelled electrodes.

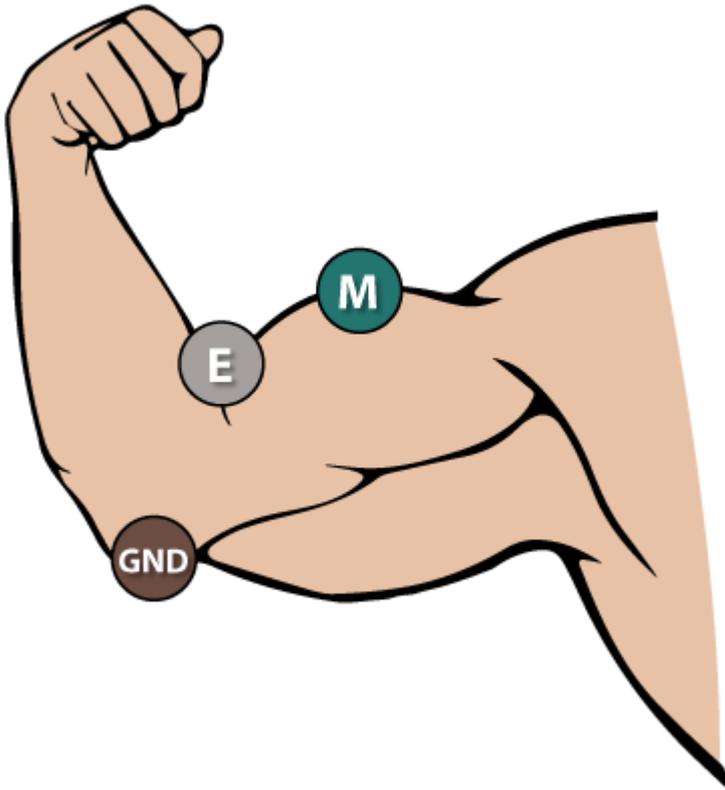
These high quality disposable electrodes are to be used to measure EEG, ECG and EMG. They are to be used once and are very handy because of integrated gel. They adhere very well to the skin and are clean to use.

The H124SG has a unique, patented pre-gelled adhesive side with non-irritating gel, especially developed to prevent allergic reactions. These foam electrode is latex free and therefore suitable for every skin type.

The snap-on connector can easily be pushed on or removed from the electrode lead.

Place the electrodes as shown below.





## Library functions

### Getting data

This EMG returns an analogic value in volts (read 0 – 1023 by the ADC) to represent the EMG wave form.

### Example:

```
{  
    float EMG = eHealth.getEMG();  
}
```

### Example

#### Arduino

Upload the next code for seeing data in the serial monitor:

#### [Hide Code](#)

```
/*  
 * eHealth sensor platform for Arduino and Raspberry from Cooking-hacks.  
 *  
 * Description: "The e-Health Sensor Shield allows Arduino and Raspberry Pi
```

\* users to perform biometric and medical applications by using 9 different  
\* sensors: Pulse and Oxygen in Blood Sensor (SPO2), Airflow Sensor (Breathing),  
\* Body Temperature, Electrocardiogram Sensor (ECG), Glucometer, Galvanic Skin  
\* Response Sensor (GSR - Sweating), Blood Pressure (Sphygmomanometer) and  
\* Patient Position (Accelerometer)."  
\*  
\* In this example we read the values in volts of EMG sensor and show  
\* these values in the serial monitor.  
\*  
\* Copyright (C) 2012 Libelium Comunicaciones Distribuidas S.L.  
\* <http://www.libelium.com>  
\*  
\* This program is free software: you can redistribute it and/or modify  
\* it under the terms of the GNU General Public License as published by  
\* the Free Software Foundation, either version 3 of the License, or  
\* (at your option) any later version.  
\*  
\* This program is distributed in the hope that it will be useful,  
\* but WITHOUT ANY WARRANTY; without even the implied warranty of  
\* MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE. See the  
\* GNU General Public License for more details.  
\*  
\* You should have received a copy of the GNU General Public License  
\* along with this program. If not, see <<http://www.gnu.org/licenses/>>.  
\*  
\* Version 2.0  
\* Author: Luis Martin & Ahmad Saad  
\*/

```
#include <eHealth.h>

// The setup routine runs once when you press reset:
void setup() {
  Serial.begin(115200);
}

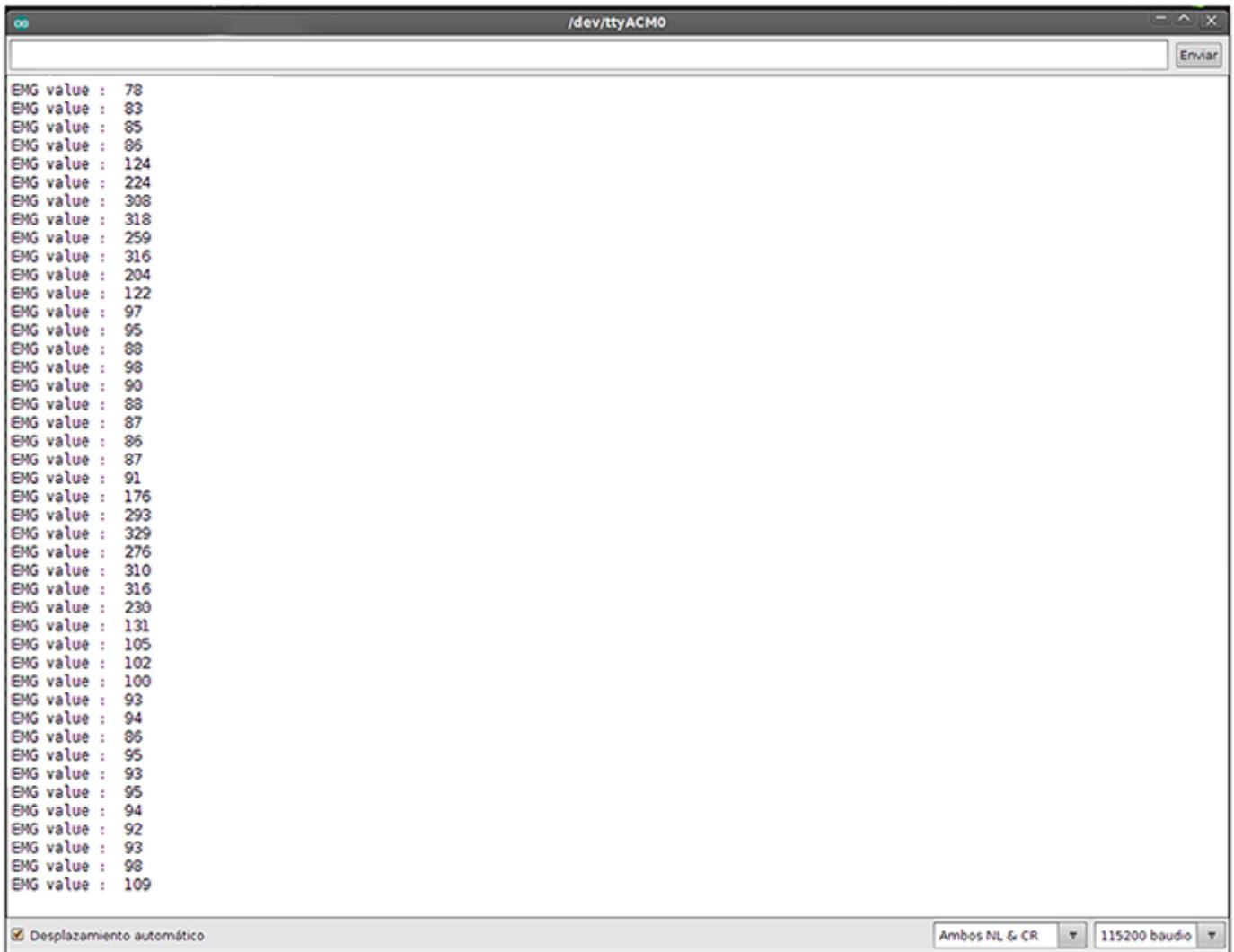
// The loop routine runs over and over again forever:
void loop() {

  int EMG = eHealth.getEMG();

  Serial.print("EMG value : ");
  Serial.print(EMG);
  Serial.println("");

  delay(100); // wait for a millisecond
}
```

Upload the code and watch the Serial monitor. Here is the USB output using the Arduino IDE serial port terminal:



The image shows a terminal window titled "/dev/ttyACM0" with a list of EMG values. The values are: 78, 83, 85, 86, 124, 224, 308, 318, 259, 316, 204, 122, 97, 95, 88, 98, 90, 88, 87, 86, 87, 91, 176, 293, 329, 276, 310, 316, 230, 131, 105, 102, 100, 93, 94, 86, 95, 93, 95, 94, 92, 93, 98, 109. The terminal also has a "Desplazamiento automático" checkbox checked and a baud rate of 115200.

```
EMG value : 78
EMG value : 83
EMG value : 85
EMG value : 86
EMG value : 124
EMG value : 224
EMG value : 308
EMG value : 318
EMG value : 259
EMG value : 316
EMG value : 204
EMG value : 122
EMG value : 97
EMG value : 95
EMG value : 88
EMG value : 98
EMG value : 90
EMG value : 88
EMG value : 87
EMG value : 86
EMG value : 87
EMG value : 91
EMG value : 176
EMG value : 293
EMG value : 329
EMG value : 276
EMG value : 310
EMG value : 316
EMG value : 230
EMG value : 131
EMG value : 105
EMG value : 102
EMG value : 100
EMG value : 93
EMG value : 94
EMG value : 86
EMG value : 95
EMG value : 93
EMG value : 95
EMG value : 94
EMG value : 92
EMG value : 93
EMG value : 98
EMG value : 109
```

## Raspberry Pi

### [Show Code](#)

/\*

\* eHealth sensor platform for Arduino and Raspberry from Cooking-hacks.

\*

\* Description: "The e-Health Sensor Shield allows Arduino and Raspberry Pi

\* users to perform biometric and medical applications by using 9 different

\* sensors: Pulse and Oxygen in Blood Sensor (SPO2), Airflow Sensor (Breathing),

\* Body Temperature, Electrocardiogram Sensor (ECG), Glucometer, Galvanic Skin

\* Response Sensor (GSR - Sweating), Blood Pressure (Sphygmomanometer) and

\* Patient Position (Accelerometer)."

\*

```
* In this example we read the values in volts of EMG sensor and show
* these values in the serial monitor.
*
* Copyright (C) 2012 Libelium Comunicaciones Distribuidas S.L.
* http://www.libelium.com
*
* This program is free software: you can redistribute it and/or modify
* it under the terms of the GNU General Public License as published by
* the Free Software Foundation, either version 3 of the License, or
* (at your option) any later version.
*
* This program is distributed in the hope that it will be useful,
* but WITHOUT ANY WARRANTY; without even the implied warranty of
* MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE. See the
* GNU General Public License for more details.
*
* You should have received a copy of the GNU General Public License
* along with this program. If not, see <http://www.gnu.org/licenses/>.
*
* Version 2.0
* Author: Luis Martin & Ahmad Saad & Anartz Nuin
*/
```

```
//Include eHealth library
```

```
#include "eHealth.h"
```

```
// The setup routine runs once when you press reset:
```

```
void setup() {
```

```
Serial.begin(115200);
}

// The loop routine runs over and over again forever:
void loop() {

  int EMG = eHealth.getEMG();

  printf("EMG value : ");
  printf("%d\n",EMG);

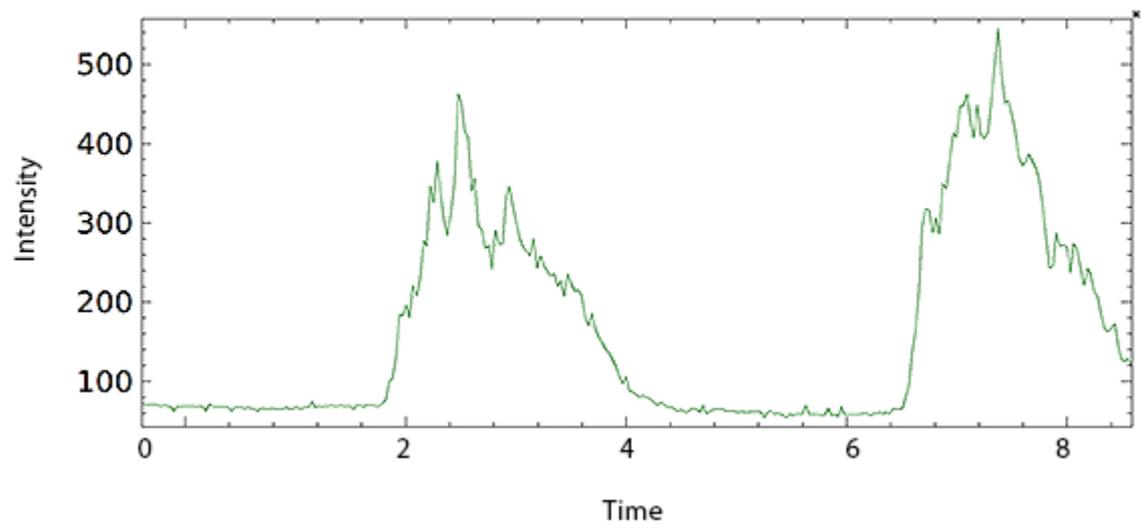
  delay(100); // wait for a millisecond
}

int main(){
  setup();
  while(1) loop();
  return 0;
}
```

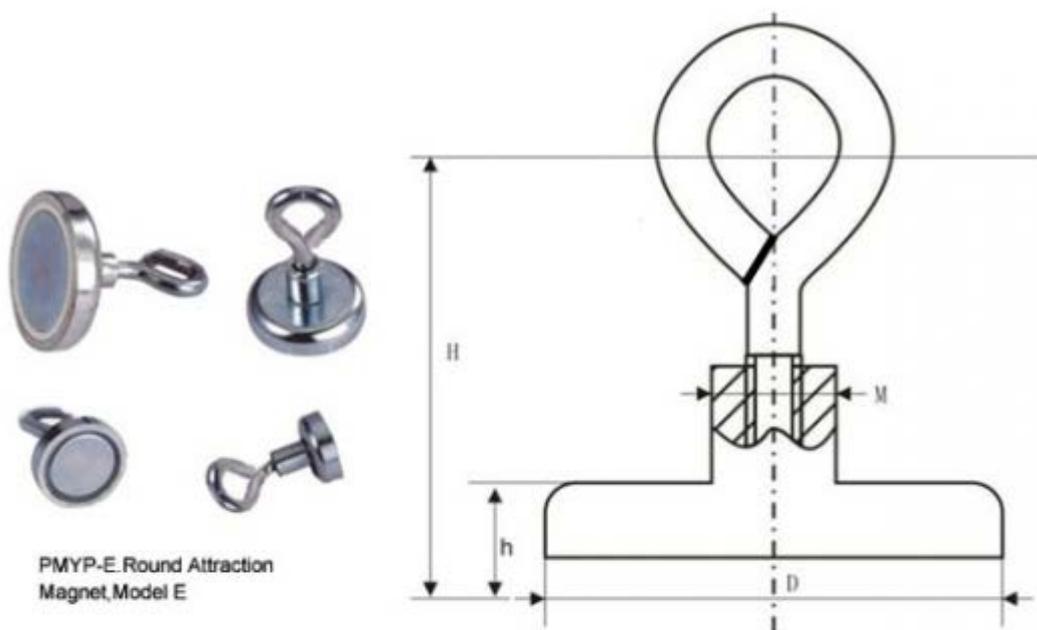
**KST**

KST program shows the EMG wave. [KST](#)

Muscle Test



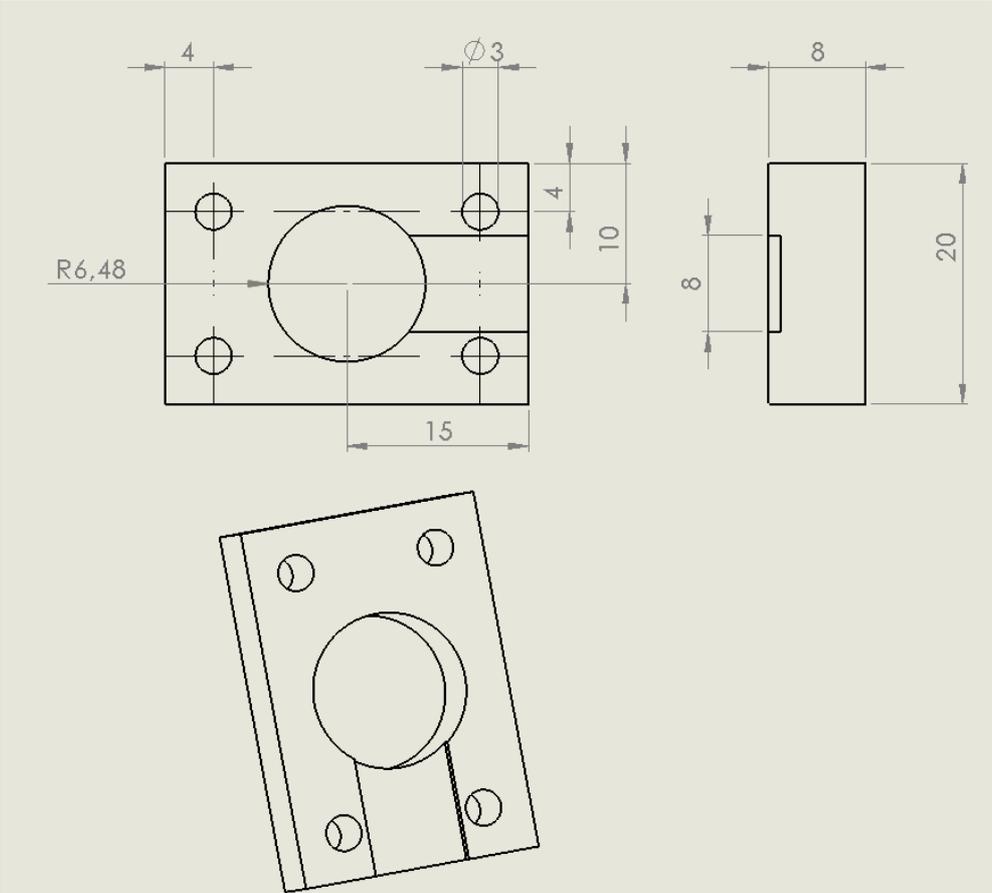
## Appendix G - Holding magnet



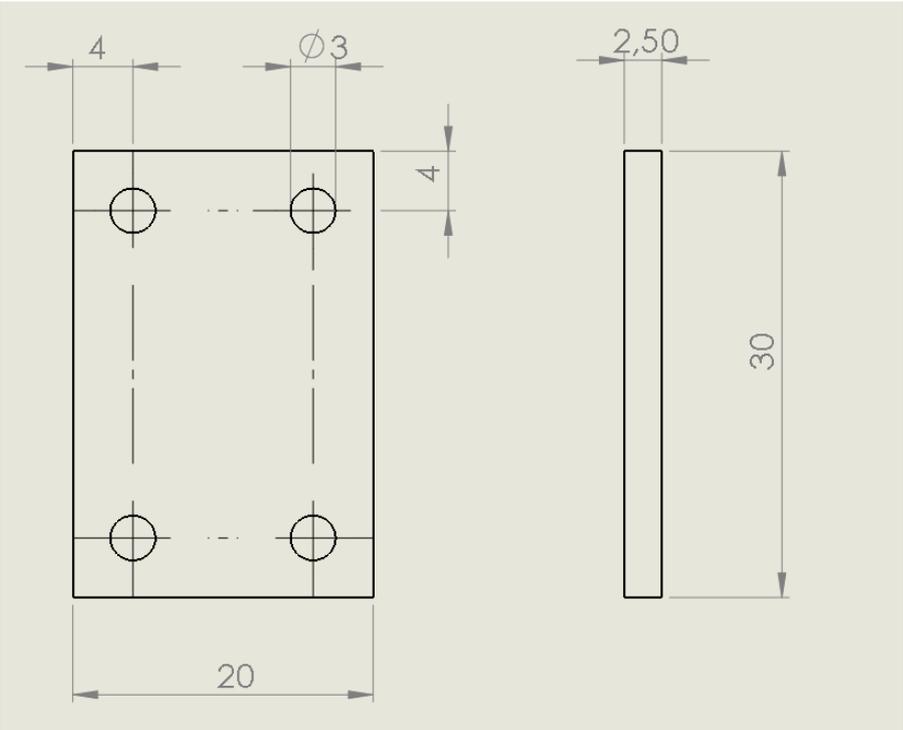
Modell	D	M	Haltekraft
F10	10 mm	3 mm	2.2 kg
F12	10 mm	3 mm	3.3 kg
F16	16 mm	4 mm	5.5 kg
F20	20 mm	4 mm	9 kg
F25	25 mm	5 mm	22 kg
F32	32 mm	6 mm	34 kg
F36	36 mm	8 mm	41 kg
F42	42 mm	8 mm	68 kg
F48	48 mm	8 mm	81 kg
F60	60 mm	10 mm	113 kg
F75	75 mm	10 mm	164 kg

# Appendix H - Load cell drawings

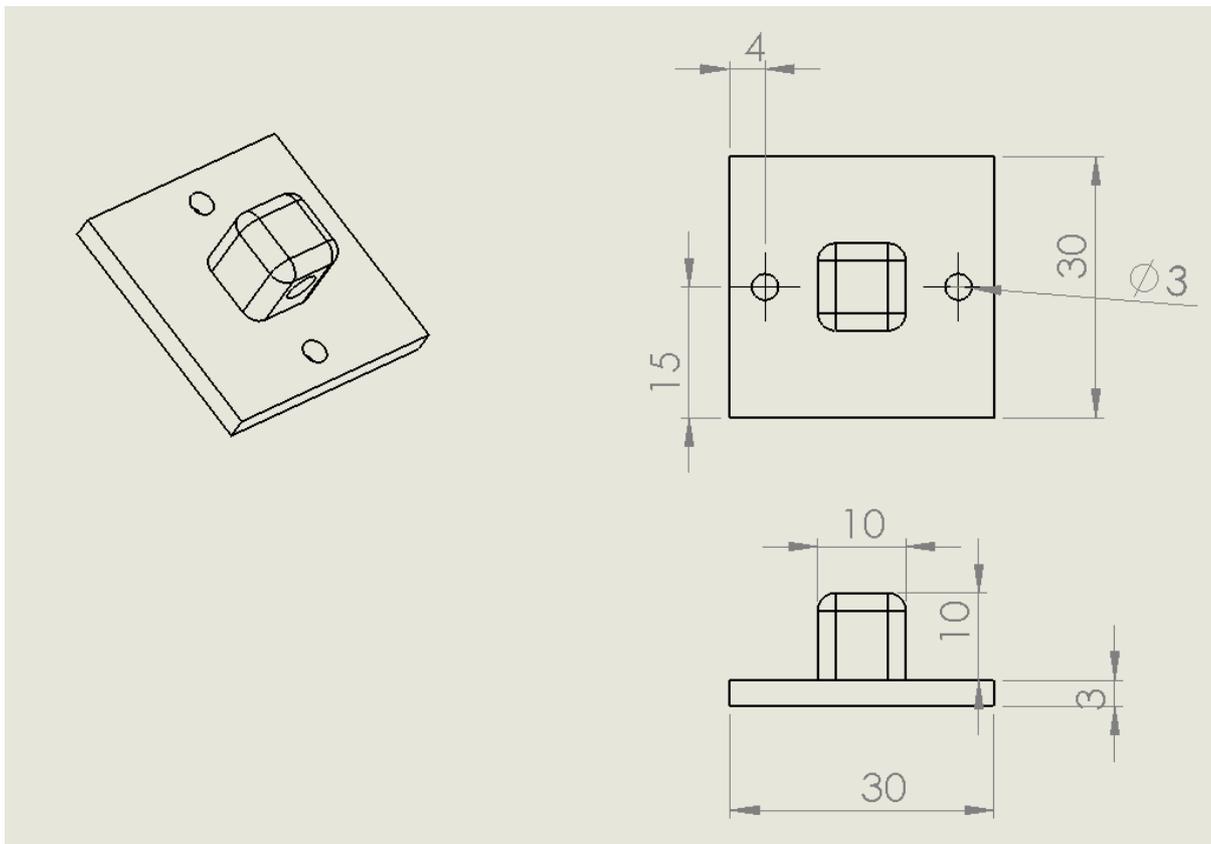
Sylinder



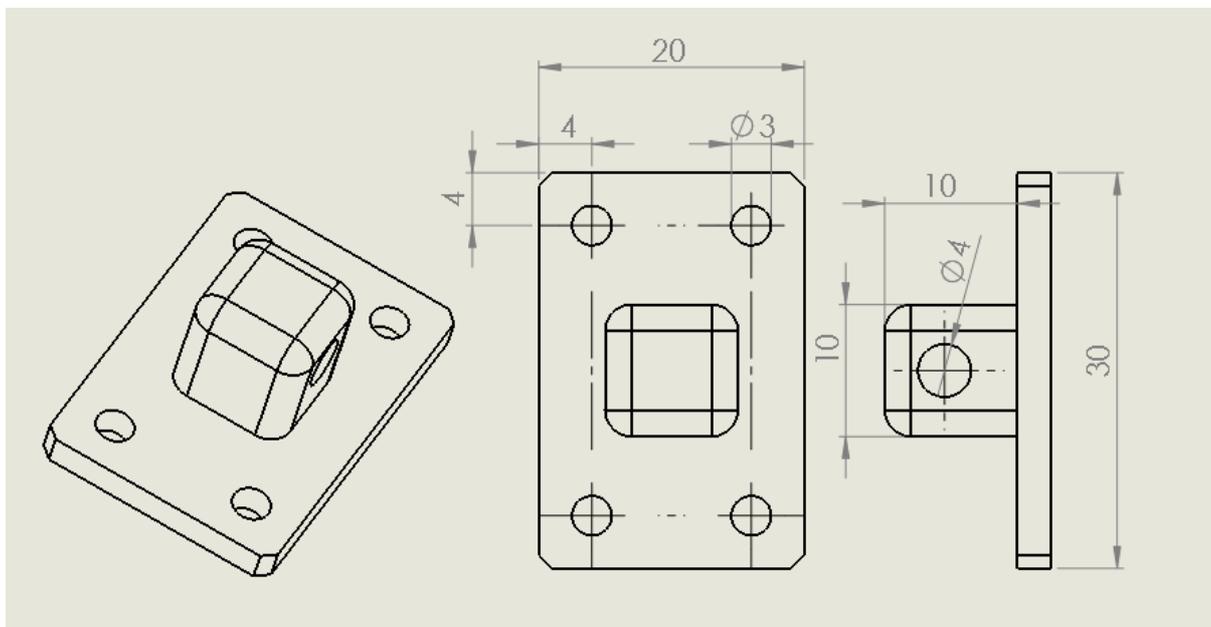
Plate



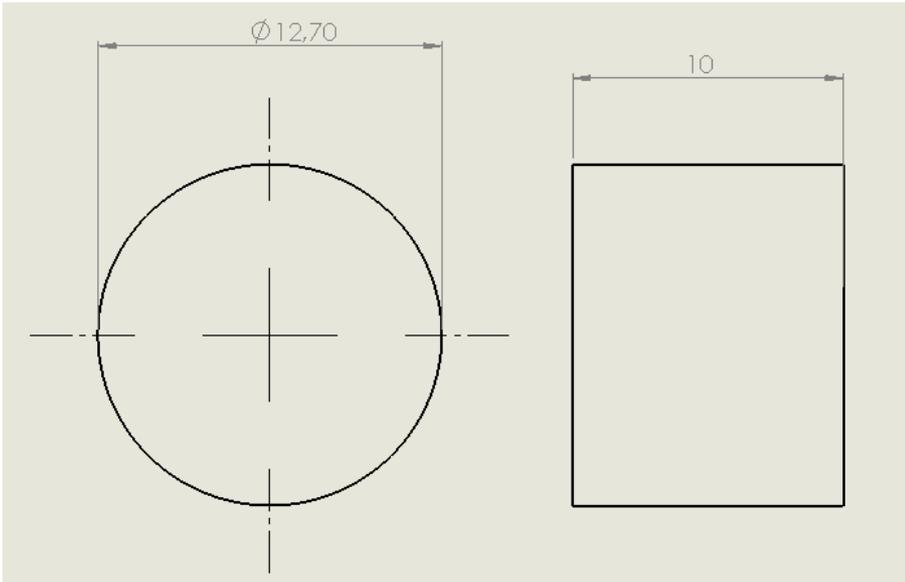
Top plate



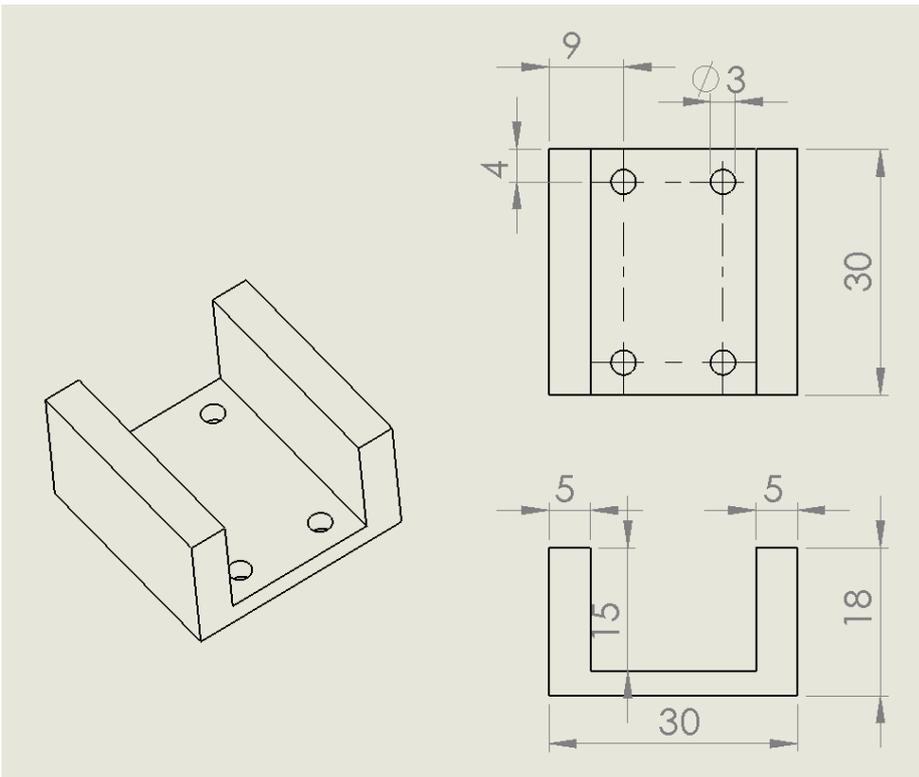
Bottom plate



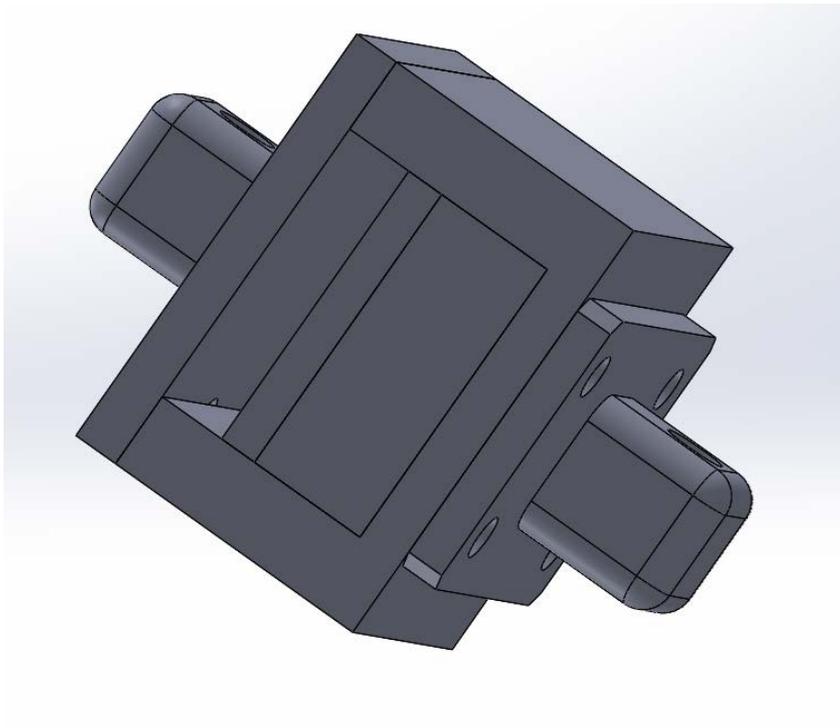
## Cylinder



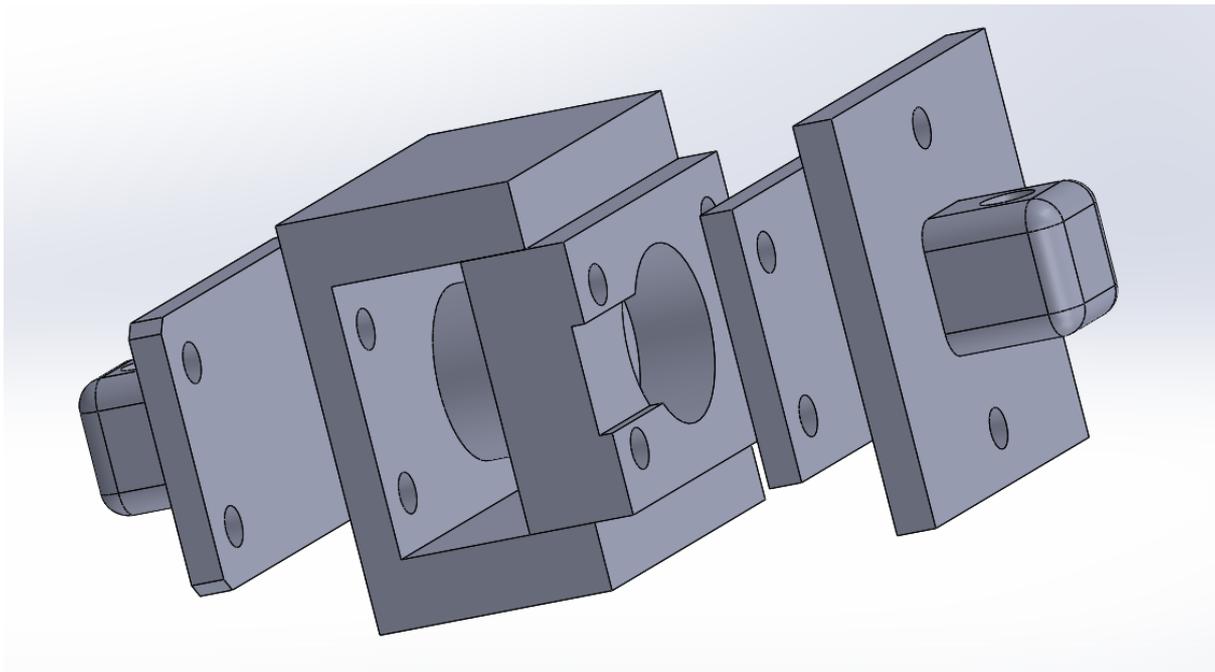
## End



## Assembly



Exploded view



# Appendix I - MOS IRF520



**IRF520**  
**IRF520FI**

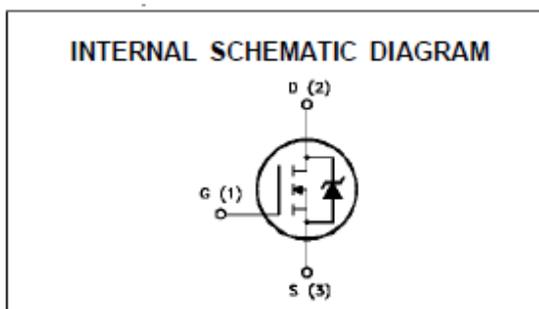
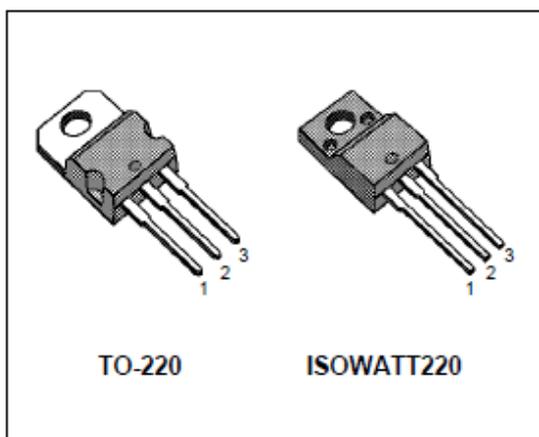
## N - CHANNEL ENHANCEMENT MODE POWER MOS TRANSISTORS

TYPE	V <sub>DSS</sub>	R <sub>DS(on)</sub>	I <sub>D</sub>
IRF520	100 V	< 0.27 Ω	10 A
IRF520FI	100 V	< 0.27 Ω	7 A

- TYPICAL R<sub>DS(on)</sub> = 0.23 Ω
- AVALANCHE RUGGED TECHNOLOGY
- 100% AVALANCHE TESTED
- REPETITIVE AVALANCHE DATA AT 100°C
- LOW GATE CHARGE
- HIGH CURRENT CAPABILITY
- 175°C OPERATING TEMPERATURE

### APPLICATIONS

- HIGH CURRENT, HIGH SPEED SWITCHING
- SOLENOID AND RELAY DRIVERS
- REGULATORS
- DC-DC & DC-AC CONVERTERS
- MOTOR CONTROL, AUDIO AMPLIFIERS
- AUTOMOTIVE ENVIRONMENT (INJECTION, ABS, AIR-BAG, LAMPDRIVERS, Etc.)



### ABSOLUTE MAXIMUM RATINGS

Symbol	Parameter	Value		Unit
		IRF520	IRF520FI	
V <sub>DS</sub>	Drain-source Voltage (V <sub>GS</sub> = 0)	100		V
V <sub>DGR</sub>	Drain- gate Voltage (R <sub>GS</sub> = 20 kΩ)	100		V
V <sub>GS</sub>	Gate-source Voltage	± 20		V
I <sub>D</sub>	Drain Current (cont.) at T <sub>c</sub> = 25 °C	10	7	A
I <sub>D</sub>	Drain Current (cont.) at T <sub>c</sub> = 100 °C	7	5	A
I <sub>DM</sub> (*)	Drain Current (pulsed)	40	40	A
P <sub>tot</sub>	Total Dissipation at T <sub>c</sub> = 25 °C	70	35	W
	Derating Factor	0.47	0.23	W/°C
V <sub>ISO</sub>	Insulation Withstand Voltage (DC)	—	2000	V
T <sub>stg</sub>	Storage Temperature	-65 to 175		°C
T <sub>J</sub>	Max. Operating Junction Temperature	175		°C

(\*) Pulse width limited by safe operating area

## IRF520/FI

### THERMAL DATA

		TO-220	ISOWATT220		
$R_{thj-case}$	Thermal Resistance Junction-case	Max	2.14	4.29	$^{\circ}C/W$
$R_{thj-amb}$	Thermal Resistance Junction-ambient	Max	62.5		$^{\circ}C/W$
$R_{thc-s}$	Thermal Resistance Case-sink	Typ	0.5		$^{\circ}C/W$
$T_l$	Maximum Lead Temperature For Soldering Purpose		300		$^{\circ}C$

### AVALANCHE CHARACTERISTICS

Symbol	Parameter	Max Value	Unit
$I_{AR}$	Avalanche Current, Repetitive or Not-Repetitive (pulse width limited by $T_j$ max, $\delta < 1\%$ )	10	A
$E_{AS}$	Single Pulse Avalanche Energy (starting $T_j = 25^{\circ}C$ , $I_D = I_{AR}$ , $V_{DD} = 25 V$ )	36	mJ
$E_{AR}$	Repetitive Avalanche Energy (pulse width limited by $T_j$ max, $\delta < 1\%$ )	9	mJ
$I_{AR}$	Avalanche Current, Repetitive or Not-Repetitive ( $T_c = 100^{\circ}C$ , pulse width limited by $T_j$ max, $\delta < 1\%$ )	7	A

### ELECTRICAL CHARACTERISTICS ( $T_{case} = 25^{\circ}C$ unless otherwise specified)

#### OFF

Symbol	Parameter	Test Conditions	Min.	Typ.	Max.	Unit
$V_{(BR)DSS}$	Drain-source Breakdown Voltage	$I_D = 250 \mu A$ $V_{GS} = 0$	100			V
$I_{DSS}$	Zero Gate Voltage Drain Current ( $V_{GS} = 0$ )	$V_{DS} = \text{Max Rating}$ $V_{DS} = \text{Max Rating} \times 0.8$ $T_c = 125^{\circ}C$			250 1000	$\mu A$ $\mu A$
$I_{GSS}$	Gate-body Leakage Current ( $V_{DS} = 0$ )	$V_{GS} = \pm 20 V$			$\pm 100$	nA

#### ON (\*)

Symbol	Parameter	Test Conditions	Min.	Typ.	Max.	Unit
$V_{GS(th)}$	Gate Threshold Voltage	$V_{DS} = V_{GS}$ $I_D = 250 \mu A$	2	2.9	4	V
$R_{DS(on)}$	Static Drain-source On Resistance	$V_{GS} = 10V$ $I_D = 5 A$		0.23	0.27	$\Omega$
$I_{D(on)}$	On State Drain Current	$V_{DS} > I_{D(on)} \times R_{DS(on)max}$ $V_{GS} = 10 V$	10			A

### DYNAMIC

Symbol	Parameter	Test Conditions	Min.	Typ.	Max.	Unit
$g_{fs} (*)$	Forward Transconductance	$V_{DS} > I_{D(on)} \times R_{DS(on)max}$ $I_D = 5 A$	2.7	4.5		S
$C_{iss}$	Input Capacitance	$V_{DS} = 25 V$ $f = 1 MHz$ $V_{GS} = 0$		330	450	pF
$C_{oss}$	Output Capacitance			90	120	pF
$C_{rss}$	Reverse Transfer Capacitance			25	40	pF

**ELECTRICAL CHARACTERISTICS (continued)**  
**SWITCHING RESISTIVE LOAD**

Symbol	Parameter	Test Conditions	Min.	Typ.	Max.	Unit
$t_{d(on)}$	Turn-on Time	$V_{DD} = 50\text{ V}$ $I_D = 5\text{ A}$ $R_{GS} = 4.7\ \Omega$ $V_{GS} = 10\text{ V}$ (see test circuit)		10	15	ns
$t_r$	Rise Time			50	75	ns
$t_{d(off)}$	Turn-off Delay Time			25	40	ns
$t_f$	Fall Time			20	30	ns
$Q_g$	Total Gate Charge	$I_D = 10\text{ A}$ $V_{GS} = 10\text{ V}$		15	25	nC
$Q_{gs}$	Gate-Source Charge	$V_{DD} = \text{Max Rating} \times 0.8$		7		nC
$Q_{gd}$	Gate-Drain Charge	(see test circuit)		4		nC

**SOURCE DRAIN DIODE**

Symbol	Parameter	Test Conditions	Min.	Typ.	Max.	Unit
$I_{SD}$	Source-drain Current				10	A
$I_{SDM}(\bullet)$	Source-drain Current (pulsed)				40	A
$V_{SD}(\ast)$	Forward On Voltage	$I_{SD} = 10\text{ A}$ $V_{GS} = 0$			1.6	V
$t_{rr}$	Reverse Recovery Time	$I_{SD} = 10\text{ A}$ $di/dt = 100\text{ A}/\mu\text{s}$ $V_{DD} = 20\text{ V}$ $T_J = 150^\circ\text{C}$		80		ns
$Q_{rr}$	Reverse Recovery Charge			0.22		$\mu\text{C}$

(\*) Pulsed: Pulse duration = 300  $\mu\text{s}$ , duty cycle 1.5 %

( $\bullet$ ) Pulse width limited by safe operating area

Rest of the sheet can be found online

# Appendix J - The Electromagnet

## 1. Begriffserklärung nach VDE 0580<sup>1)</sup>

### 1.1 Haftmagnete

**Einfachhaftmagnet** ist ein Magnet ohne Anker, dessen gewünschte Funktion erst wirksam wird, wenn gerätefremde, magnetisierbare Teile mit ihm zusammengebracht werden. Die Form der Teile ist im wesentlichen unabhängig vom Gerät.

Der Begriff Haftmagnet wird in der VDE 0580 nicht geführt, entspricht aber dem Begriff **Lasthebemagnet**.

tens 1/4 des Mittelpoldurchmessers bei runden Magneten bzw. 1/2 der Mittelpolbreite bei rechteckigen Magneten betragen. Die Stahlplatten müssen bei runden bzw. eckigen Lasthebemagneten mindestens die Haftfläche der Magnete überdecken.

Die **Haftkräfte** gelten bei aufliegender Stahlplatte, entgegen der VDE 0580 § 44 d, die einen Luftspalt in Abhängigkeit der Haftflächendurchmesser angeben.

### 9.1.1 Permanenthftmagnet

Im Vergleich zu einem Elektro-Haftmagneten, bei dem durch Bestromung einer Magnetspule eine Haftkraft erzeugt wird, ist der Haftmagnet mit Permanentmagnet in der Lage, eine Haftplatte in stromlosem Zustand zu halten.

Lediglich ein kurzer Stromimpuls reicht aus, um die Haftplatte mit Unterstützung einer externen Kraft abzuwerfen.

### 1.2 Lasthebemagnete

**Lasthebemagnet** ist ein Gerät zum Festhalten von Lasten mit ferromagnetischen Eigenschaften, z. B. für Transportzwecke.

### 1.3 Mechanische Begriffe

Als **Abreißkraft** bei Lasthebemagneten gilt die Kraft, die der Magnet auf einen Prüfkörper ausübt (VDE 0580 § 44 d).

Als **Tragkraft** gilt das Gewicht eines vom Magneten erfassten definierten Arbeitsgutes.

Die **Abreißkraft** wird gemessen als Kraft auf eine ebene Stahlplatte aus unlegiertem, kohlenstoffarmen Stahl, z. B. St. 34, St. 37, bei definiertem Luftspalt<sup>2)</sup>. Die Dicke der Stahlplatte muss mindes-

## 1. Definition according to VDE 0580<sup>1)</sup>

### 1.1 Holding solenoids

A **holding solenoid** is a solenoid without armature which, on energisation, will attract any magnetic material. The expression holding solenoid is not used in VDE 0580, however, it corresponds to the expression **latching solenoid**.

of the width of the central pole. As far as latching solenoids of circular and square design are concerned their steel plates must at least cover the latching surfaces.

We talk about **holding forces** when the steel plate rests on the pole, against VDE 0580 § 44 d where an air gap relates to the diameter on the latching surface.

### 9.1.2 Permanent holding solenoid

In contrast to a standard holding solenoid, which generates the holding-force in the energized state only, a permanent holding solenoid is capable to attract the holding-plate in a non-energized state. A short current pulse only reduces the holding force to near zero, so that an external force can release the holding-plate.

### 1.2 Latching solenoids

A **latching solenoid** is a device for the holding of loads with ferromagnetic characteristics, e. g. for transport purposes.

### 1.3 Mechanical data

The **break force** of a latching solenoid is the force that is exerted by the solenoid on a test device (VDE 0580 § 44 d).

The **holding force** is measured as the force exerted on a plane steel plate made of unalloyed steel that is low in carbon, e. g. steel 34, steel 37. The air gap must be defined<sup>2)</sup>. The thickness of the steel plate must at least amount to 1/4 of the diameter of the central pole or – regarding solenoids of square design – to 1/2

## 2. Montagehinweise

Für die Befestigung sind die aus den Zeichnungen ersichtlichen Gewindebohrungen vorgesehen. Die Schraubenlänge ist so zu wählen, dass die Spule nicht beschädigt wird.

- 1) Sinngemäß aus 0580/9.79 übernommen. Die Wiedergabe erfolgt mit freundlicher Genehmigung der VDE-Verlag-GmbH Berlin.
- 2) Abstand zwischen Polfläche und Oberfläche der Stahlplatte.

## 9.1.3 2. Mounting instructions

For fixing purposes the solenoids are provided with mounting holes as shown in the drawings. The length of the screws must be chosen so as not to damage the coil.

- 1) Based on 0580/9.79. The abstracts are reproduced with the approval of VDE-Verlag-GmbH, Berlin, Germany.
- 2) The air gap is the distance between the pole surface and the surface of the steel plate.



In zylindrischer Bauweise

In cylindrical design

Bestellformel	HT	D	25	- F -	24 V DC	100 % ED	Order specifications
Haftmagnet	HT						Holding solenoid
Bauart							Design type
Zylindrische Bauweise		D					Cylindrical design
Größe (20, 25, 30, 40, 50, 55, 70)			25				Size (20, 25, 30, 40, 50, 55, 70)
Anschlussart							Coil terminals
Litze (Standardlänge 20 cm)				F			Flying leads (20 cm standard length)
Nennspannung (Standardspannung) <sup>1)</sup>					24		Nominal voltage (standard voltage) <sup>1)</sup>
Zulässige relative Einschaltdauer bei Luftkühlung (LK)						100% ED	Perm. duty cycle under air cooled conditions (LK)

<sup>1)</sup> Andere Spannungen auf Anfrage

<sup>1)</sup> Other voltages can be supplied on request

Thermische

Klasse: B (T<sub>grenz</sub> = 130 °C)

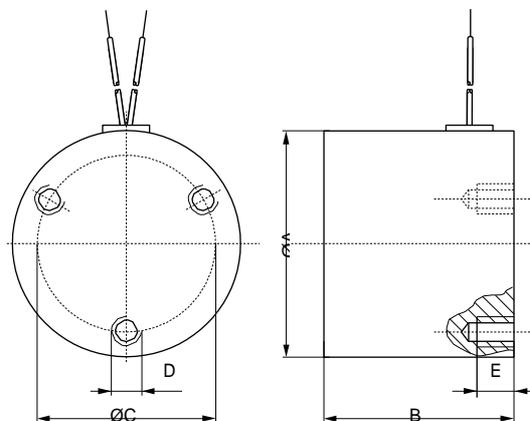
Prüfspannung: 800 V (eff)

Restmagnetismus ca. 15 % der Haftkraft.



Thermal stability: B (max. permissible temperature = 130 °C)  
 Test voltage: 800 V (eff)

Remanence approx. 15 % of holding force.



Typ Type	Ø A	B	C	D	E*	Mindestdicke der Gegenplatte/Min. thick- ness of counterplate	Gewicht Weight	Nennleistung Nominal rating	Haftkraft Holding force
	mm						g	W	N
HT-D20	20	15	z**	M3	3	2,0	25,0	2,5	40,0
HT-D25	25	20	16	M3	3	2,5	50,0	4,0	115,0
HT-D30	30	25	z**	M4	5	3,5	130,0	3,8	200,0
HT-D40	40	27	z**	M5	6	4,5	230,0	6,0	400,0
HT-D50	50	30	34	M4	5	5,0	350,0	11,0	750,0
HT-D55	55	37	34	M4	5	6,0	550,0	10,0	1.000,0
HT-D70	70	40	56	M4	8	7,0	800,0	19,0	1.400,0

## Appendix K - Step motor code

/\*

This example code is in the public domain.

-----

This program demonstrates button detection, LCD text/number printing, and LCD backlight control on the Freetronics LCD & Keypad Shield, connected to an Arduino board.

Pins used by LCD & Keypad Shield:

A0: Buttons, analog input from voltage ladder

D4: LCD bit 4

D5: LCD bit 5

D6: LCD bit 6

D7: LCD bit 7

D8: LCD RS

D9: LCD E

D10: LCD Backlight (high = on, also has pullup high so default is on)

ADC voltages for the 5 buttons on analog input pin A0:

RIGHT: 0.00V : 0 @ 8bit ; 0 @ 10 bit

UP: 0.71V : 36 @ 8bit ; 145 @ 10 bit

```

DOWN: 1.61V : 82 @ 8bit ; 329 @ 10 bit
LEFT: 2.47V : 126 @ 8bit ; 505 @ 10 bit
SELECT: 3.62V : 185 @ 8bit ; 741 @ 10 bit

*/

/*-----*/

Includes
-----*/

#include <LiquidCrystal.h> // include LCD library
#include <Stepper.h> // include stepper control

/*-----*/

Defines
-----*/

// Pins in use

#define BUTTON_ADC_PIN      A0 // A0 is the button ADC input
#define LCD_BACKLIGHT_PIN   10 // D10 controls LCD backlight

// ADC readings expected for the 5 buttons on the ADC input

#define RIGHT_10BIT_ADC     0 // right
#define UP_10BIT_ADC        145 // up
#define DOWN_10BIT_ADC     329 // down
#define LEFT_10BIT_ADC     505 // left
#define SELECT_10BIT_ADC   741 // right

#define BUTTONHYSTERESIS   10 // hysteresis for valid button sensing window

//return values for ReadButtons()

#define BUTTON_NONE        0 //
#define BUTTON_RIGHT       1 //
#define BUTTON_UP          2 //
#define BUTTON_DOWN       3 //

```

```

#define BUTTON_LEFT      4 //
#define BUTTON_SELECT    5 //

//some example macros with friendly labels for LCD backlight/pin control, tested and can be
swapped into the example code as you like

#define LCD_BACKLIGHT_OFF()  digitalWrite( LCD_BACKLIGHT_PIN, LOW )
#define LCD_BACKLIGHT_ON()   digitalWrite( LCD_BACKLIGHT_PIN, HIGH )
#define LCD_BACKLIGHT(state)  { if( state ){digitalWrite( LCD_BACKLIGHT_PIN,
HIGH );}else{digitalWrite( LCD_BACKLIGHT_PIN, LOW );} }

// change this to the number of steps on your motor

#define STEPS 100

/*-----
Variables
-----*/

byte buttonJustPressed = false;    //this will be true after a ReadButtons() call if triggered
byte buttonJustReleased = false;   //this will be true after a ReadButtons() call if triggered
byte buttonWas         = BUTTON_NONE; //used by ReadButtons() for detection of button
events

/*-----

Init the LCD library with the LCD pins to be used
-----*/

LiquidCrystal lcd( 8, 9, 4, 5, 6, 7 ); //Pins for the freetronics 16x2 LCD shield. LCD: ( RS, E,
LCD-D4, LCD-D5, LCD-D6, LCD-D7 )

// create an instance of the stepper class, specifying
// the number of steps of the motor and the pins it's
// attached to

Stepper stepper(STEPS, 10, 11, 12, 13);

```

```

float Counter = 0;
int LoadCellRead = A1;
int Load = 0;
int Weight = 0; //calculated weight
int previous = 0; // the previous reading from the analog input NOT NECASARY

/*-----*/
setup()
  Called by the Arduino framework once, before the main loop begins
-----*/

void setup()
{
  Serial.begin(9600);
  //button adc input
  pinMode( BUTTON_ADC_PIN, INPUT );    //ensure A0 is an input
  digitalWrite( BUTTON_ADC_PIN, LOW ); //ensure pullup is off on A0
  //lcd backlight control
  digitalWrite( LCD_BACKLIGHT_PIN, HIGH ); //backlight control pin D3 is high (on)
  pinMode( LCD_BACKLIGHT_PIN, OUTPUT ); //D3 is an output
  //set up the LCD number of columns and rows:
  lcd.begin( 16, 2 );
  //Print some initial text to the LCD.
  lcd.setCursor( 0, 0 ); //top left
  //      1234567890123456
  lcd.print( "Select Weight" );

```

```

//

lcd.setCursor( 0, 1 ); //bottom left

//      1234567890123456

lcd.print( "Btn:" );

// set the speed of the motor to 30 RPMs

stepper.setSpeed(50);

}

/*-----

loop()

Arduino main loop

-----*/

void loop()

{

    byte button;

    byte timestamp;

//get the latest button pressed, also the buttonJustPressed, buttonJustReleased flags

button = ReadButtons();

//blank the demo text line if a new button is pressed or released, ready for a new label to be
written

//read the loadcell

    Load = analogRead(LoadCellRead); //Load cell will give a number between 0-1023

    Serial.println(Load);

```

```

//_____Button_Select transfer the code into a running loop just to controll the
magnet_____

if(buttonJustPressed == true){
  if(button == BUTTON_SELECT) //problem!! have to hold it in.....
  {
    do {

      Load = analogRead(LoadCellRead); //Load cell will give a number between 0-1023
      Serial.println(Load);

      Weight = Counter * 100; //testnumber

      //Controll Magnet from loadcell and LCD input
      if(Load > Weight - 100){
        stepper.step(-STEPS); // decrease the magnet lenght, motor backwards
      }
      if(Load < Weight + 100){
        stepper.step(STEPS); // increase the magnet lenght, motor forward
      }
      else {
        stepper.step(0); //Keep the magnet strenght
      }
    }
    while(button != BUTTON_DOWN);
  }
}

```

//\_\_\_\_\_selection

of

Kg\_\_\_\_\_

```
if(buttonJustPressed == true){

    if(button == BUTTON_UP) {
        Counter++;
    }
    if(button == BUTTON_DOWN){
        if (Counter - 1 > 0.0) {
            Counter = Counter - 1;
        }
        else {
            Counter = Counter;
        }
    }
    if(button == BUTTON_RIGHT){
        Counter = Counter + 0.1;
    }
    if(button == BUTTON_LEFT){

        if (Counter - 0.1 > 0.0) {
            Counter = Counter - 0.1;
```

```

    }
    else {
        Counter = Counter;
    }
}
}

    lcd.setCursor( 4, 1);

    lcd.print(Counter);

    Serial.println(Counter);

```

```

// print the number of seconds since reset (two digits only)

timestamp = ( millis() / 1000 ) % 100 ); //"% 100" is the remainder of a divide-
by-100, which keeps the value as 0-99 even as the result goes over 100

    lcd.setCursor( 14, 1 );

    if( timestamp <= 9 )

        lcd.print( " " ); //quick trick to right-justify this 2 digit value when it's a single
digit

    lcd.print( timestamp, DEC );

/*

//debug/test display of the adc reading for the button input voltage pin.

    lcd.setCursor(12, 0);

    lcd.print( "   " ); //quick hack to blank over default left-justification from
lcd.print()

```

```

    lcd.setCursor(12, 0);    //note the value will be flickering/faint on the LCD

    lcd.print( analogRead( BUTTON_ADC_PIN ) );

    */

    //clear the buttonJustPressed or buttonJustReleased flags, they've already done
their job now.

    if( buttonJustPressed )

        buttonJustPressed = false;

    if( buttonJustReleased )

        buttonJustReleased = false;

}

/*-----*/

ReadButtons()

Detect the button pressed and return the value

Uses global values buttonWas, buttonJustPressed, buttonJustReleased.

-----*/

byte ReadButtons()

{

    unsigned int buttonVoltage;

    byte button = BUTTON_NONE; // return no button pressed if the below checks
don't write to btn

    //read the button ADC pin voltage

    buttonVoltage = analogRead( BUTTON_ADC_PIN );

    //sense if the voltage falls within valid voltage windows

    if( buttonVoltage < ( RIGHT_10BIT_ADC + BUTTONHYSTERESIS ) )

    {

        button = BUTTON_RIGHT;

    }

```

```

else if( buttonVoltage >= ( UP_10BIT_ADC - BUTTONHYSTERESIS )
        && buttonVoltage <= ( UP_10BIT_ADC + BUTTONHYSTERESIS ) )
{
    button = BUTTON_UP;
}
else if( buttonVoltage >= ( DOWN_10BIT_ADC - BUTTONHYSTERESIS )
        && buttonVoltage <= ( DOWN_10BIT_ADC + BUTTONHYSTERESIS )
)
{
    button = BUTTON_DOWN;
}
else if( buttonVoltage >= ( LEFT_10BIT_ADC - BUTTONHYSTERESIS )
        && buttonVoltage <= ( LEFT_10BIT_ADC + BUTTONHYSTERESIS ) )
{
    button = BUTTON_LEFT;
}
else if( buttonVoltage >= ( SELECT_10BIT_ADC - BUTTONHYSTERESIS )
        && buttonVoltage <= ( SELECT_10BIT_ADC + BUTTONHYSTERESIS
))
{
    button = BUTTON_SELECT;
}

//handle button flags for just pressed and just released events
if( ( buttonWas == BUTTON_NONE ) && ( button != BUTTON_NONE ) )
{
    //the button was just pressed, set buttonJustPressed, this can optionally be used
to trigger a once-off action for a button press event

```

```
        //it's the duty of the receiver to clear these flags if it wants to detect a new  
button change event
```

```
        buttonJustPressed = true;
```

```
        buttonJustReleased = false;
```

```
    }
```

```
    if( ( buttonWas != BUTTON_NONE ) && ( button == BUTTON_NONE ) )
```

```
    {
```

```
        buttonJustPressed = false;
```

```
        buttonJustReleased = true;
```

```
    }
```

```
        //save the latest button value, for change event detection next time round
```

```
        buttonWas = button;
```

```
    return( button );
```

```
    delay(1000);
```

```
}
```

## Appendix L - PWM Code.

Paste this in instead for the stepmotor

```
//_____Button_Select transfer the code into a running loop just to controll the magnet_____
```

```
if(buttonJustPressed == true){
```

```
if(button == BUTTON_SELECT) //problem!! have to hold it in.....
```

```
{
```

```
//read the loadcell
```

```
Load = analogRead(LoadCellRead); //Load cell will give a number between 0-1023
```

```
Serial.println(Load);
```

```
Weight = Counter * 10 * 10.23; //100g = 10,23 analog input. converts counter into number to conpear with load cell
```

```
//Controll Magnet from loadcell and LCD input
```

```
if(Weight > Load + 15){
```

```
MagnetControl = MagnetControl + 1; // increase the magnet strenght
```

```
}
```

```
if(Weight < Load - 15){
```

```
MagnetControl = MagnetControl - 1; //decrease the magnet strenght
```

```
}
```

```
if(Weight == Load){
```

```
MagnetControl = MagnetControl; //Keep the magnet strenght
```

```
}
```

```
//Magnet strenght adjustment
```

```
analogWrite(MagnetStrenght, MagnetControl);
```

}  
}