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Motor test plant

Department Mechatronics

Bachelor assignment for achievement of the Bachelor degree

Bachelor of Science in Engineering

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Presented to

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Abstract

The Bachelor thesis on a Motor test plant, is focused on a test stand for small DC-motors which is shown in Figure 1. The main task of the test plant is to measure the torque-velocity – curve of the test motor. The test motors will be used in a prosthetic ankle robot called SPARKy. The principle goal of the test stand is measure torque using a simple balance scale. The test motor and the load, another DC-Motor, are connected via a coupler and both of them are held to a mechanism that is free to rotate. The torque of the test motor is transferred via the coupler to the load. This torque will cause the test stand to rotate, but it is held by a beam. The load torque will flex the beam and this effect will cause strain in the beam. This strain is proportional to the torque and can be measured via strain gages. To measure the torque-velocity curve it is necessary to measure the curve at multiple points. The first point is to measure the starting torque of the test motor and multiple points will be measured at different speed values. To do these measurements it is required to develop two control loops, one position controller and one speed controller. The load is controlled via a microcontroller which is programmed with MATLAB Simulink, and Real Time Workshop.

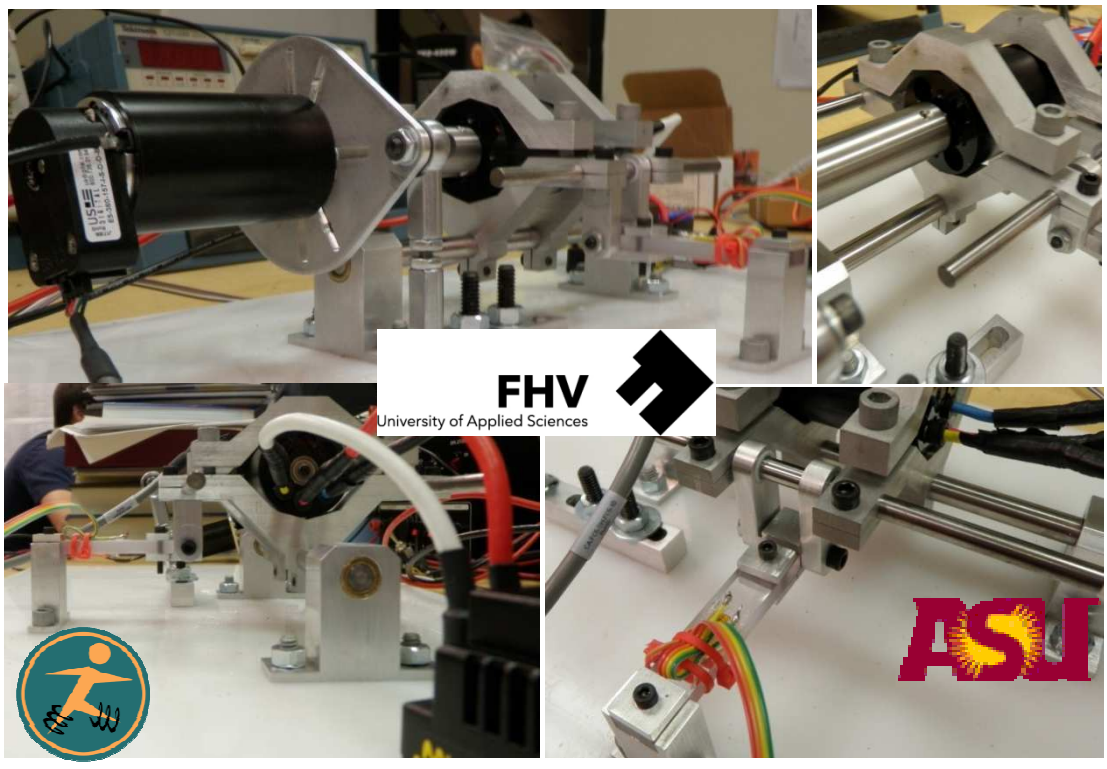

Figure 1: Motor test plant

Preface

For the Bachelor degree, it is necessary to complete an internship at a company or a laboratory before graduation. As part of the bachelor requirements, a technical document must be written. I, Lukas Fink, chose to work at the Human Machine Integration Laboratory. The Laboratory is part of the Arizona State University in Tempe and it is supervised by Dr. Thomas G. Sugar. The laboratory's primary project focuses on a foot prosthesis called Sparky, a powered robotic ankle.

I want to thank my internship supervisor Dr. Thomas G. Sugar. for the invitation to his Laboratory, for his mentoring and for the awesome time in the USA. I would also like to thank my academic supervisor, Prof.(FH) Dipl.-Ing. Horatiu O. Pilsan for helping me with my Bachelor thesis. Thank's to Sabine Stickel the Student Exchange Coordinator for the great help with the scholarship, and a thanks to the Marshallplan Jubiläumsstiftung for sponsoring me, without that I would not be able to have this great lifelong experience. And of course a big thank you to my buddies in the Laboratory, Alexander Böhler, Thierry Flaven, Mathew Holgate and Jeffery Ward. Last but not least I want to say thank you to the Head of Degree Program Dipl.-Ing. Dr. Johannes Steinschaden and all Faculties because they had always an open ear for any problems during my studies.

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List of abbreviations

SPARKy	Spring Ankle with Regenerative Kinetics
RC-Signal	Remote Control Signal

1. Introduction

The Introduction starts with the description of the main project of the Human Machine Integration Laboratory, the prosthetic ankle called SPARKy (Spring Ankle with Regenerative Kinetics). The next point of the introduction is the description of the Bachelor assignment. The Bachelor thesis is about a motor test plant; this test stand is required for the development of motors for SPARKy.

1.1. Sparky

1.1.1. What is Sparky

SPARKy, see Figure 2, is a powered prosthetic ankle for below the knee amputees or transtibial amputees. It is designed to harvest energy during the stance phase and use the energy to help propel a person forward. Springs are used to harvest and release energy because they are efficient, lightweight, and can release the energy in a powerful burst.

Figure 2: SPARKy
Source: http://springactive.com/index.htm

As the leg rolls over the ankle, the helical springs are stretched. As the springs are stretched, a small motor pulls on the springs as well adding additional energy to the springs. During “push–off”, the energy in the springs is released quickly in a powerful burst to propel the user forward.

1.1.2. Technical details / Functionality

SPARKy is able to allow below the knee amputees to walk over ground, walk up and down slopes, and ascend and descend stairs. It currently uses a Maxon RE40 motor with a roller screw transmission. It allows a person to walk from 0 to 1.8 m/s.

1.1.3. What makes the Sparky prosthesis unique

SPARKy is unique because it stores and releases energy in the springs. The motor is not the primary actuator. The springs are the primary actuation unit. The springs are properly tuned so that they store and release energy properly. If the springs are too soft, the user would fall over and the motor would pull on the spring uselessly. If the springs are too stiff, then the motor must supply the needed 250 Watts at push off. If the spring is properly tuned, the motor supplies the needed 20J of net power to the user and its peak power is only 80 Watts. The spring will supply the powerful burst of 250 Watts at push off.

1.1.4. Level of development

The SPARKy project has been developed over the last two years. Three subjects have worn the device with great success. Development efforts now include the design and use of better motors and transmissions.

1.2. Description of the Bachelor assignment

The task of the Bachelor assignment is to design a test-plant for testing the motors and the controllers which are going to be used for the Sparky prosthesis. The primary task of the test-plant is to measure the torque – velocity – curve of different types of DC motors. This curve and the stipulated characteristics of the motor, shown in Table 1 are crucial to finding the ideal motor for Sparky. After the motor is fixed, the proper mechanical design for Sparky can be optimized for this motor. The main parts which would have to be redesigned are the rate of the springs the length of the lever arm and the pitch of the roller screw; all of these parts are shown in the Figure 3.

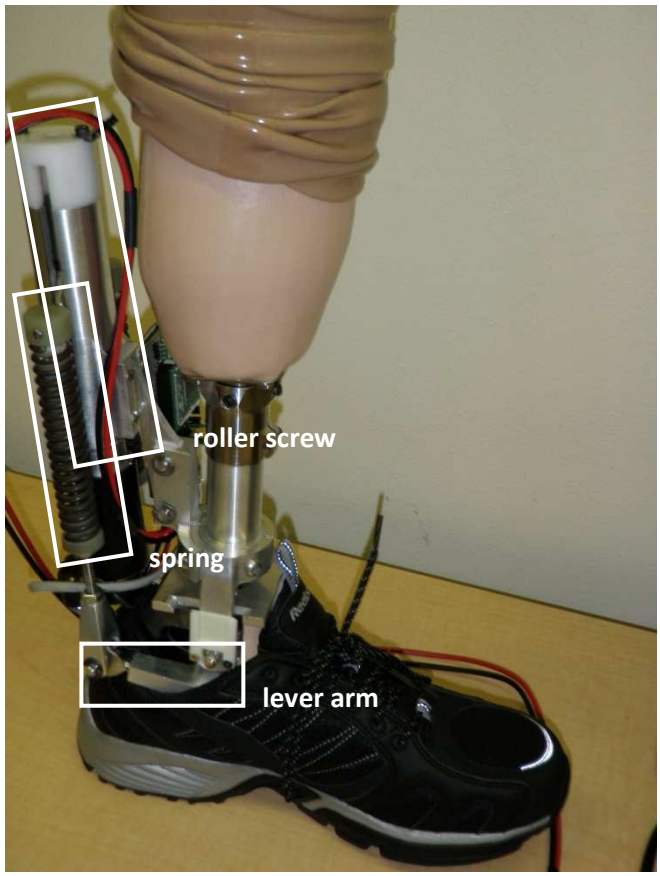

Figure 3: Sparky prosthesis

Table 1: stipulated characteristics of the Sparky motor

Characteristics for the motor	
type	**description**
size	as small as possible
torque	has to be high as possible
speed	dependent on the torque
durability	high
complexity to control	low

The secondary task for the test plant is to test and develop a controller which will be specially designed for the new motor. With the new motor and a powerful controller, a torque – velocity – curve will be measured. This curve is going to be used as a reference for the new controller.
The third task for the test-plant is to develop a tiny velocity – position sensor.

1.2.1. Challenges

The challenge for the test-plant is to measure the mechanical and the electrical characteristics of a test motor. The electrical attributes include the operating voltage and the motor current, but the focus of the test-plant is on the mechanical properties, torque and the rotational velocity. For measuring the test motor, it has to be connected via a coupler with a variable load. The brake-torque of the load depends on the rotational velocity and the temperature so it is not possible to calculate exactly the torque. To measure the torque accurately, it is necessary to measure it with an external sensor. Also, the rotational speed should be measured with an external sensor. The measured data must be sent to a PC for analysis. Lastly, the variable load will be controlled by a PC Program.

1.2.2. Boundary conditions

The following boundary conditions were set.

a. Test motors

The motors which will be tested are a Brush DC motor and a Brushless DC motor, for more information see Table 2. The characteristics of both motors determine the design of the test-plant. Figure 4 shows a torque – velocity curve with the maximum values of both motors. The test plant should be able to measure this kind of torque – velocity curve. The interface between the motor test stand and the test motors are the motor shafts.

Table 2: Test motors

Type	Brand	Name	Number	Voltage	Nominal speed	Power	Nominal torque
Brush DC Motor	Maxon	RE 40	148867	24V	6930 rpm	150 Watt	0,170 Nm
Brushless DC Motor	Maxon	EC-powermax 30	305013	24V	16 200 rpm	200 Watt	0,114 Nm

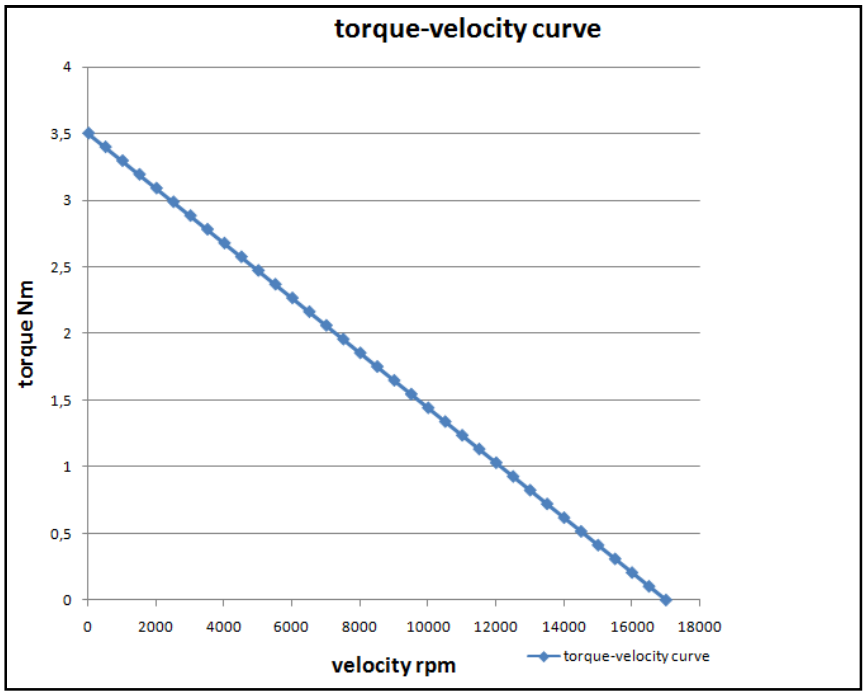

Figure 4: characteristic test motor

b. Load

The brake-torque of the load should be variable in the range of torques for the given motors, see Figure 4. Furthermore, the load should be able to be driven with a maximum rotational speed of 17000 rpm. The load should be able to resist larger powers than the test motors.

c. Coupler

For the coupler between the load and the test motor, it is important that it is very concentric. Another task for the coupler is that it should be able to connect very quickly and simply to the different motor shafts of the different test motors. The other side of the coupler will connect with the shaft of the load. It is also necessary that the shaft of the test motor be aligned to the shaft of the load. If the coupler is not aligned and cannot be adjusted to eliminate any differences, then it is important that these aligning errors be eliminated in another way.

d. Controller for the test motor

The controller of the test motor is given, and it is not a topic of this assignment.

e. Controller for the load

The load should be steered with a 16-Bit Digital Signal Controller type “DSPIC33FJ256MC710”. The programming of the chip should be done using the Program Matlab/Simulink Version R2007b and the Kerhuel blockset. In Matlab, the controller is designed using a graphical set of blocks, and the code is auto-generated using the Real Time Workshop toolbox.

f. Torque measurement

For measuring the torque, the common rotation axis of the test motor and load have to be on a swiveling holder, like a balance. The motion of the swiveling holder is resisted by a beam. The torque will bend the beam and the beam deflection will be measured in the stressed beam. The strain of the beam is a function of the torque of the load, and strain gauge sensors will be used to measure the strain.

g. Rotational speed measurement

The rotational speed will be measured by the encoders which are on the test motors, and the data must be sent to the controller board.

h. Electrical measurements

Computer measurement of the electrical attributes are not part of this assignment. Measurements will be done by the user with an oscilloscope to obtain the operating voltage and with a current clamp to measure the motor current.

i. Analysis of the measured data

The mechanical data from the test stand has to be sent to a PC for analysis. The controlling and the analysis of the data will be performed by Matlab/Simulink Version R2007b. Matlab directly interfaces with the Host PC and the controller board. The data is transferred to the Host PC using standard Matlab mat files. In this project, two controller boards were investigated; one is the ASU DSP33 Module and the other one is the Explorer 16 demo board from Microchip. The data from either board will be analyzed in Matlab.

j. General

The base plate of the test-plant should have enough space for additional test equipment. The base plate should also have a clamp to fix it on to different work benches. The power supply for the equipment of the test-plant is a standard 24V power supply unit from the Laboratory.

2. Motor test plant

The Motor test plant begins with the theoretical description of the principle of the test plant. After this, the technical specification of the Test plant will be described. The specifications are split into a mechanic section and an electronic section. The description of the mechanical parts with all the different selected components and the alternatives will be described, and after that the description of the electrical part will follow.

2.1. Description of the solution of the Test plant

The principle of the motor test plant is like a balance which is held by a beam. The load is fixed on a rotating bearing and is solidly connected via a coupler to the test motor. As soon as the test motor starts to turn, the torque from the test motor causes a moment in the shaft, coupler and the load. This torque transfered over a balance will cause a force on a beam and the strain in the beam will be measured. The strain in the beam is proportional to the torque and can be measured via a strain gage. The main task of the test plant is to get the exact torque-velocity curve of the test motor. To obtain the curve, it is necessary to measure the starting torque and the torque at different velocities. The starting torque is measured by holding the shaft of the load at the zero position respectively controlling the shaft at this position. The test motor will start to drive with full speed in one direction until the strain measured in the beam shows a constant value in a tolerance range. The torque needs to be constant. To measure the torque at different speeds, the test motor will be driven with the maximum speed without a load. After the motor reaches a maximum speeds, the load motor starts to drive in the other direction, to control the speed down to the desired speed value. As soon as the speed is constant in a tolerance range the torque in the beam can be measured. The interface between the test plant and a user should by a PC. Figure 5 shows the schematic of the test plant.

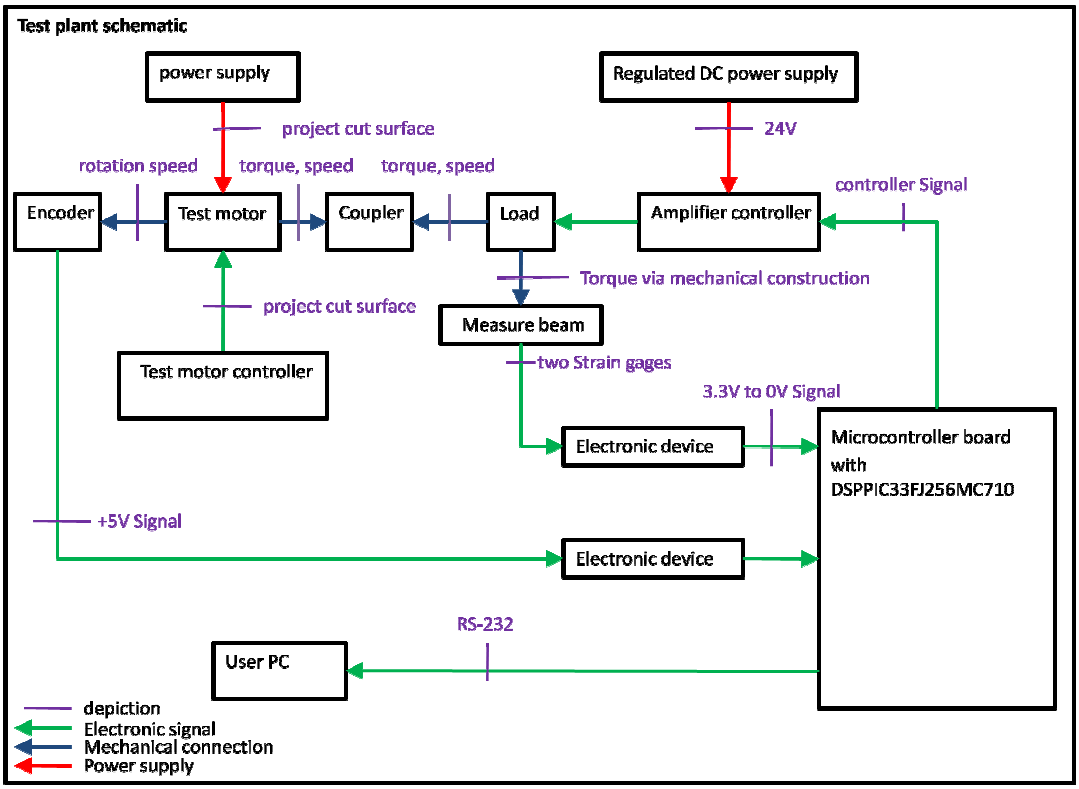

Figure 5: test plant schematic

2.2. Technical specification of the Test plant

The project is split of into two parts. One part is the mechanical part the other one is the electronic section. The main task for the mechanical section is to find an ideal base design for the test plant. The design included the holding system for the load with the balance mechanism and an ideal force transfer from the mechanism to the beam. Also, it is necessary to design a beam arrangement for the strain measurement. Moreover, a load for the test plant has to be found, and a coupler to connect the shaft of the test motor with the load must be created.

The electronic part has the task to measure the strain gages and the rotational speed. Also, the preparation of the measured signals and the analysis of the signal must be designed. Furthermore, another part of the electronics is to design the control loops for the position control and the speed control of the motor. An interface between the user and the test plant should be created via a PC.

2.2.1. Mechanical Part

a. Motor test plant base construction

At first the base construction must be designed so that the load is held via a rotating mechansim so that the torque can be measured. It should be possible to test a lot of different test motors very quickly, without changing a lot of the parts of the stand. Another point which is necessary for the design, is that the weight of the load should not alter the strain measurement. This means that the weight of the load should be held by the bearings and not by the measurement beam. For the strain measurement of the beam, it is necessary that the beam will be only stressed by a horizontal force. Above all it should be possible to fix a spring-force –scale on the test stand to calibrate the strain gage.

b. Load

The load should be much more powerful than both of the Maxon motors. This means that the load should be able to produce a torque more than 3.5 Nm and drive faster than 16.000 rpm. The power of the load has to be three times higher than the power of the test motors, about 600 Watt.

c. Coupler

The coupler between the test motor and load should be able to be rotated at speeds higher than 16.000 rpm. Another task for the coupler is that the coupler should transfer the torque from the test motor to the load. The shaft of the test motor and the load should be very concentric to guarantee a good measurement. Both shafts should be aligned exactly; variations between the shafts should be eliminated. The load must be coupled with the Maxon Motor RE40, shaft diameter 6mm, and at another time with the Maxon Motor EC-powermax30, shaft diameter 5mm. The design of the coupler should allow motors to be connected very easily for testing, even with different shaft diameters.

2.2.2. Electrical Part

a. Controller board description

For the controller board there are two possibilities. A custom board, ASU DSP33 Module-board, see Figure 6 on the left side, and the Microchip Explorer 16 Development Board, see Figure 6 on the right side. Both boards use the 16 Bit Microcontroller DSPPIC33FJ256MC710. One of these two boards should be used for the controlling the load. The description of the Microchip Explorer 16 Development Board is in the attachment. For the custom board, there is no documentation available. Both boards are programmed with a MPLAB ICD2, an In-Circuit Debugger, and they have a RS232 interface to communicate with MATLAB: The controller board must have the necessary interfaces for communication with the load amplifier controller and the measuring devices.

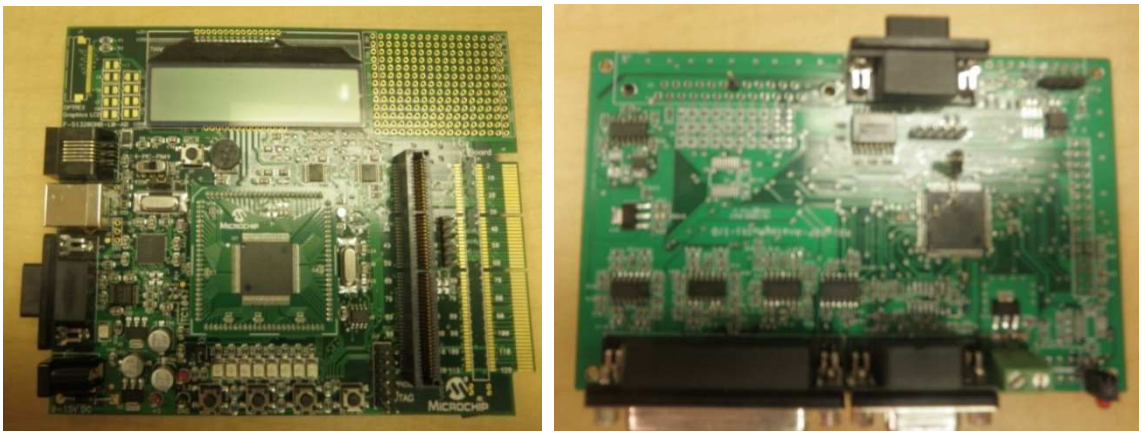

Figure 6: right Explorer Board / left ASU DSP33 Module-board

b. Torque measuring

The torque will be measured via strain gages which are placed on the beam. The Omega SG-3/350-LY11 strain gages and the Burr Brown INA125 instrumentation amplifier will be used. The goal is to develop an analog amplifier-circuit which is able to send the low voltage strain gage signal to the controller board.

c. Speed measuring

The speed is measured using the E5 Optical Kit Encoder. The laboratory uses this Encoder and the DSPIC33FJ256MC710 to measure joint angles. The communication between the encoder and the control board has been developed previously in the lab. The joint angle will be converted to a velocity in the Matlab Simulink code.

d. Load controller amplifier

For the motor amplifier, it is important that the power supply is not more than 24 volts. The motor amplifier will communicate with the Microchip board using either a PWM signal or a voltage signal generated by a D/A chip.

e. User interface

At first, it was necessary to build a very simple interface to measure the torque. A spring scale was used to measure the torque and a LED starts to blink when the time is correct to measure the torque signal. The second goal is to measure the torque with the strain gages and send the signal via a RS232 interface to a Matlab or Labview interface block.

2.3. Description of the Mechanical Part

2.3.1. Load

The load should be able to be driven in the whole range of the torque–velocity curve of the two Maxon motors, see Figure 4. Three different loads were investigated: a hysteresis brake, a magnetic particle brake and a brushless DC motor.

1. Hysteresis brake

A hysteresis brake consists of two basic parts, the pole structure and the rotor which interact magnetically to produce a braking force. The pole structure is the fixed member of a brake assembly; it has an inner and outer pole structure which are separated by an air gap. In the air gap there is the rotor which is coupled with the shaft. As current is supplied to the brake, a magnetic field proportional to the current is established within the air gap and the rotor becomes magnetized. The specific magnetic hysteresis of the rotor material causes a braking force on the rotor resisting movement creating braking torque between the rotor and the stator. The hysteresis brake produces torque using a magnetic field in the air gap without the use of magnetic particles or friction components. The advantage of this brake is that it is able to run at high rotational speeds. They also have a high torque and repeatable accuracy, and they are independent of temperature variations. The disadvantages are that the brake is expensive and complicated to control.

2. Magnetic particle brake

The Magnetic particle brake works with tiny magnetic particles located in a cavity, and if there is no current, the particles are randomly dispersed. As a voltage and current is applied to a coil, the magnetic particles start to come together. If the voltage is increased, the coupling of the particles becomes stronger. The shaft of the brake must rotate through the coupling particles and will be braked. This kind of brake has a high torque range and they are very easy to control. The problem is that they are not able to rotate at high speeds which is necessary for the testing.

3. DC motor

The DC motor has to be controlled with two different controllers to be used as a load. To measure the starting torque the DC motor has to be controlled with a position controller. The position controller keeps the DC Load motor at a constant position so that the shaft does not move. The test motor will try to spin against the load and a starting torque can be measured at the beam.
The speed – torque curve will be measured at points where the motor will be spinning. For these points, the DC motor will be speed controlled. The test motor will spin at full speed and then the load motor will start to spin in the opposite direction and brake the speed of the test motor to the value which is going to be measured.
For high speeds, it is necessary to use a brushless DC motor. The controller for a brushless DC motor is more complicated than one for a brushed DC motor, but a brushed DC motor is not capable of spinning at high speeds.

Select Load

The decision to choose a type of brake was between the Hysteresis brake and the DC Brushless Motor, because the Magnetic particle brakes are not able to spin fast enough. The brushless DC motor was chosen for the test plant. One of the main reasons for this choice is that the laboratory wants to develop more experience with controlling brushless DC motors and testing different kinds of controllers. In future generations of Sparky, it is planned to use a brushless DC motor. Another reason is that the Hysteresis brake is expansive and the laboratory has no experience with controlling these brakes.

Brushless DC motor NeuMotor 1509 2.5

The load motor is a NeuMotor 1509 2.5. It is a brushless DC motor which is usually used for hobby airplanes. The advantage of this motor is that it is powerful and can spin fast. The continuous power rating is 750 watts and the maximum speed is 60000 rpm without a load. The disadvantage is that there is less documentation about this motor. Only limited characteristics are given, see Table 3. Another reason that this motor was chosen is that the laboratory wants to test this kind of motor to be used it for the bionic ankle.

Table 3: characteristic NeuMotor

Type	Brand	Name	Number	Voltage	Max. RPM	Power	Kv
Brushless DC Motor	NeuMotor	1509 2.5D/S	xxx	22V	60000 rpm	750 Watt	2700

2.3.2. Construction of the test plant

The construction consists of 22 parts, the description of the parts and all engineering drawing are in the Appendix A. The engineering drawings are drawn using the ANSI drawing norm. The construction is split into 3 main parts; one is the base part that includes the flexible clamping system which holds the load; the second is the coupler with the shaft adjustment, and third is the torque measuring device. Figure 7 shows the construction with the names of the main parts.

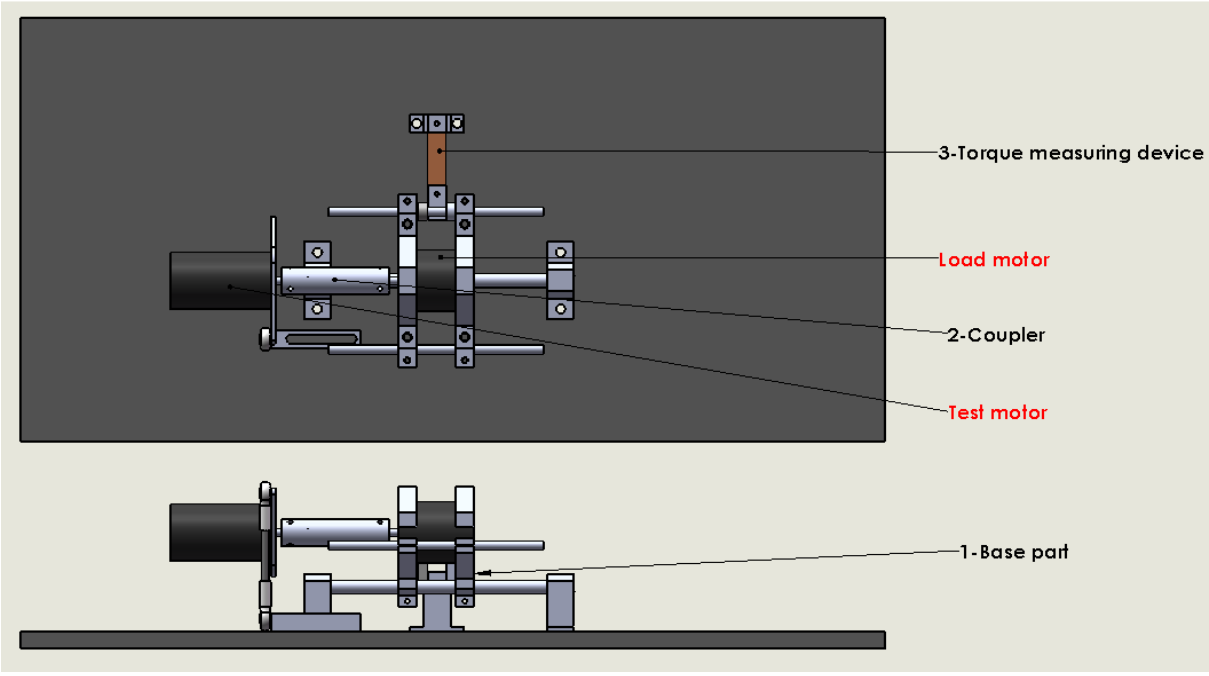

Figure 7: construction parts

Base part

The base part must resist the rotational bending of the load and must accommodate different sizes of load motors if it is necessary. The design allows different sizes of load motors as long they have a round case and they have a minimum diameter of 1.45 inches and a maximum diameter of 2.90 inches. To allow for a big tolerance range, the bracket must have two different chamfers, with two different angles. The maximum length of the load has to be smaller than 5 inches and must be bigger than 1.6 inches. The different lengths can be adjusted by opening the screws of the bracket. The load clamps are mounted on a shaft and the shaft is mounted on bearings which allows the system to rotate freely, see Figure 8. Because the system pivots freely, the torque of the load will be applied to the beam. The construction is designed so that the gravitational force of the load does not influence the measurement and is resisted by the bearing.

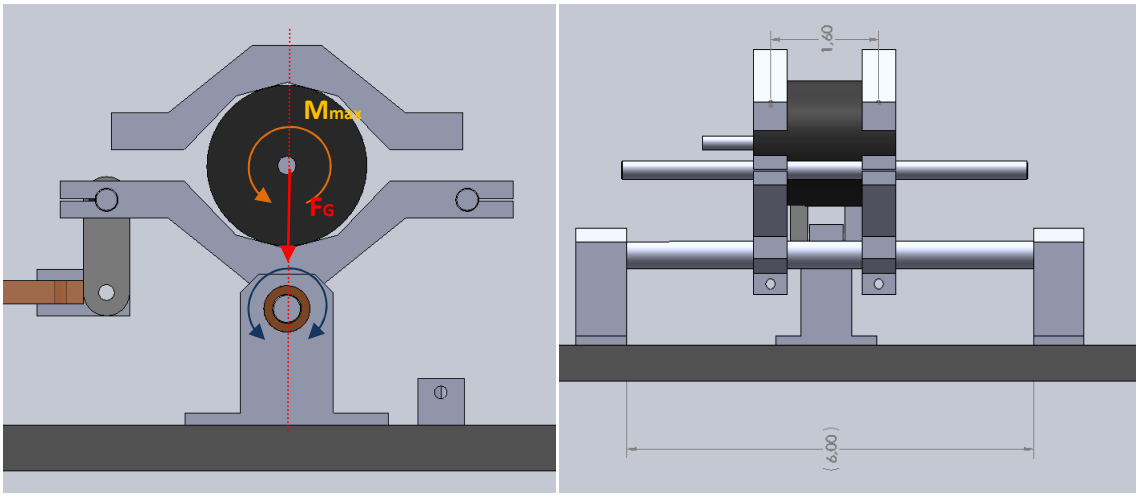

Figure 8: base part

Shaft adapter / Coupler

The major task of the coupler is to connect the shaft of the load with the shaft of the test motor. The coupler must connect the shafts in a very concentric manner because the motor can turn at high speeds. The coupler should also allow for small shaft misalignments. For the load measurement, it is also important that the coupler transfers the torque from the test motor to the beam. The coupler should also be easily removed if the test motor is changed.

The design focused on finding a good, rigid coupler, because these couplers are better for torque transfer and they do not influence the measurement. The disadvantage of these couplers are that they do not allow for shaft misalignments, but to fix this problem the test motor will be freely suspended on the shaft of the load, see Figure 9 left side.

There is only a small bracket which locks the test motor so that it does not spin. This small bracket mounts to the top and to the bottom with a high-strength ball joint rod end which keeps the test motor from spinning but allows small misalignments, see Figure 9 right picture.

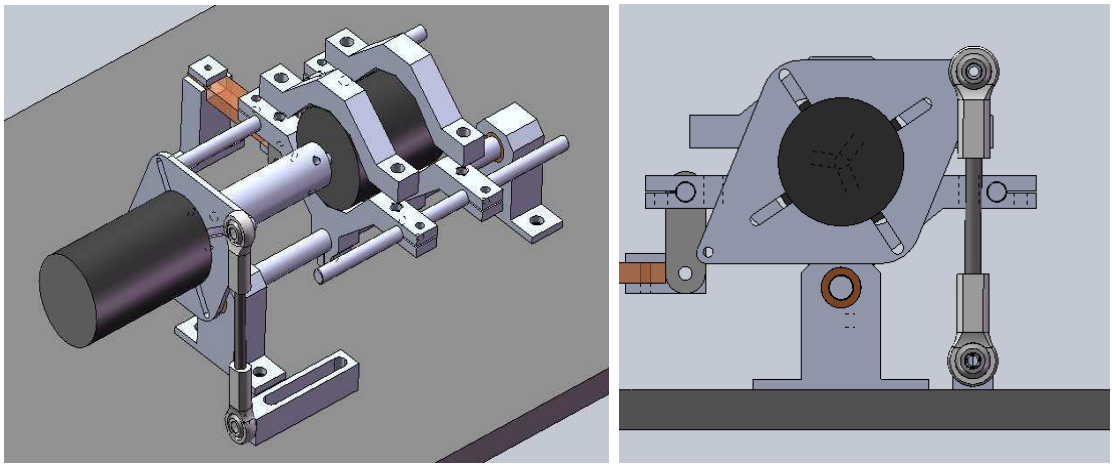

Figure 9: test motor suspended

There are three rigid couplings that were designed for this project. The first one is called a rigid coupling with a collet; the second one is also a rigid coupling with fittings and a set screw**,** and the third is a two half rigid coupling with screws.

1. Rigid coupling with collet

The big advantage of this coupling, see Figure 10 is that there is just one base part, and with the applicable collet different types of shafts can be connected. The maximum shaft diameter is about 10 mm. Another advantage of this coupler is that the shafts are connected in a very concentric manner.

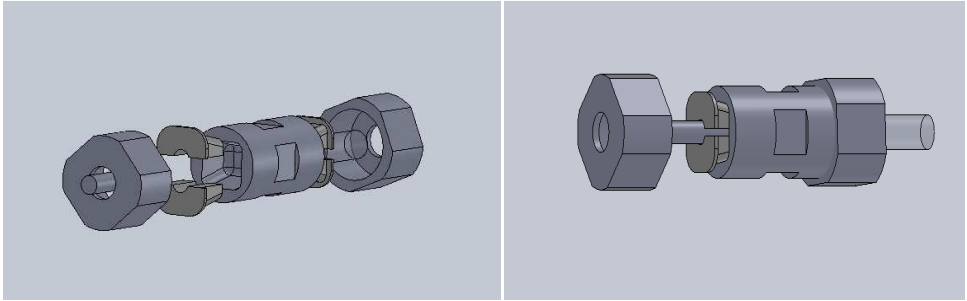

Figure 10: rigid coupling with collet

2. Rigid coupling with fittings and set screw

This coupling version, see Figure 11, is very cheap and fast to produce. Each hole has to fit with the respective shaft, so that the play is as small as possible. The set screws just fix the coupler with the motor shaft.

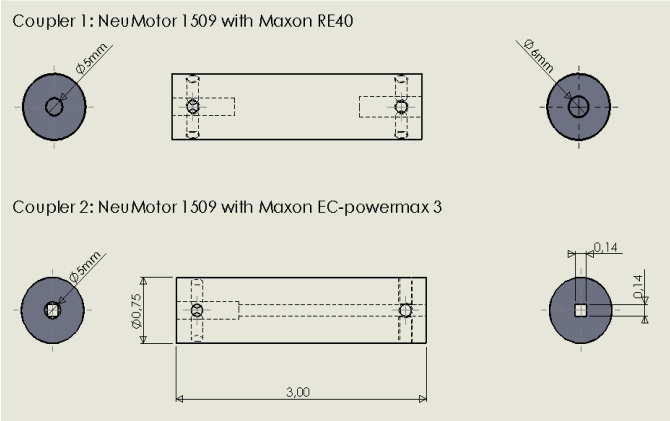

Figure 11: rigid coupler

3. Two half rigid coupling with screws

The two half rigid coupling, is also a very simple system to connect two shafts together. This coupling connects the shafts in a very concentric manner. The left side of Figure 12 shows the whole coupler, and the right side shows only one half of the coupler.

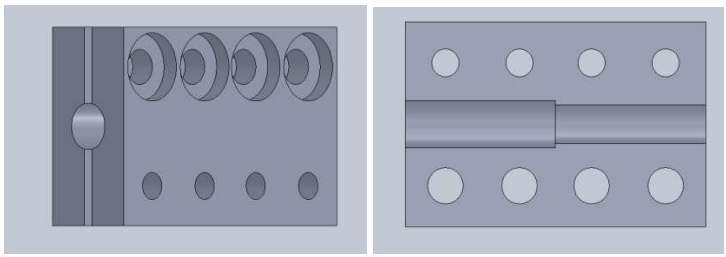

Figure 12:Two half rigid coupling

Select coupler

The decision to choose a coupler was made via a decision table, see Table 4. The result from the decision matrix was to build a simple rigid coupling with fittings and a set screw.

Table 4: decision table coupler

	valuation 0-5	fit coupling	two half coupler	collet coupling
torque transfer	**4**	**8**	**8**	**8**
concentric to clamp	**4**	**5**	**7**	**8**
high speed	**4**	**8**	**8**	**8**
price	**5**	**7**	**5**	**2**
change able	**2**	**5**	**5**	**8**
result		**126**	**124**	**119**

Torque measuring device

This device which is shown in Figure 13 is used to measure the load torque. The torque from the test motor is transferred by the coupler to the load and is resisted by the beam. The motor and the load are balanced on a swivel mechanism.

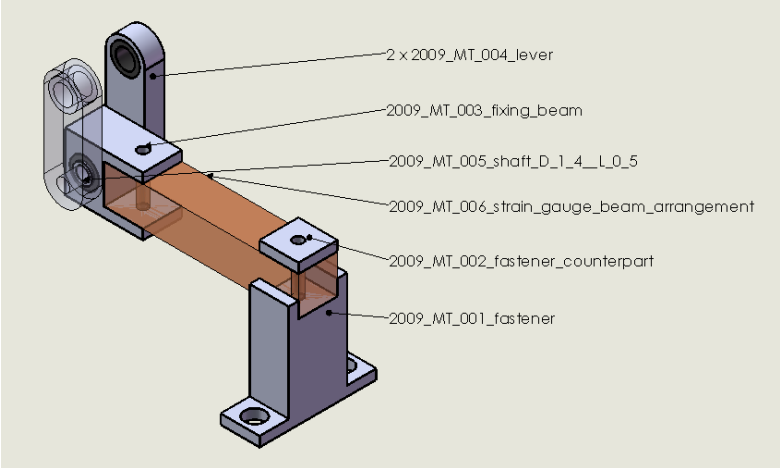

Figure 13: torque measuring device

To allow for easy calculations and consistent measurements, it would be good that the beam is only stressed by a vertical force. The moment which is on the top of the lever produces a vertical Y-Force and a horizontal X-Force see Figure 14. The bearings in the top of the lever resist the horizontal X-Force and the mechanism rotates. So that only the Y-Force of the moment stress the beam. The Y-Force produce a bending and a tensile stress in the beam because of the movement of the lever. As a result of the very small movement of the lever angle the tensile stress becomes negligible. The proof of this statement is in the Appendix B/Calculation/Tensile stress in the beam. The fastener counterpart on the other side of the beam is used to create a rigid restraint at the end of the beam.

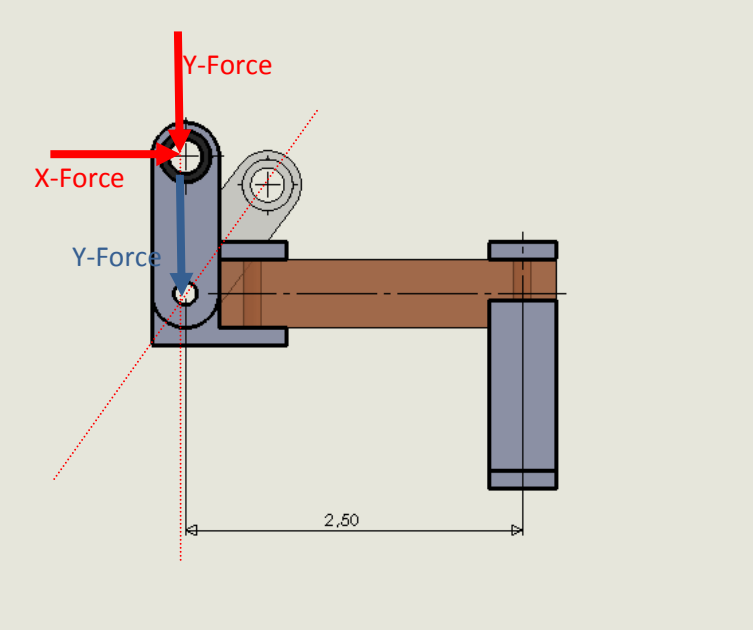

Figure 14: transmission of the force

The dimensioning of the beam was determined by analyzing the strain in the beam. The strain had to be large enough so that the strain gages could supply a large enough signal. The gages are used for the measurement of the strain, which is proportional to the torque. The maximum values of this calculation are the maximum torque , Mmax = 3.5 Nm, and the maximum strain in the strain gages; Omega SG-3/350 –LY11, can handle, $\varepsilon_{max} = 3\%$. To measure a low strain value, it is important to use a material which has a low elastic modulus. For the beam, polycarbonate was chosen which has a Young's moduluse of $E = 2.4 \cdot 10^{-3} \frac{N}{mm^2}$ but it also have a relative high stress value of about $\sigma_{allowed} = 63 \frac{N}{mm^2}$. The beam has dimensions 0.50" width, 0,25" high, and 2" long . For more details see the calculation "Dimension of the beam" in Appendix B/Calculation C. The calculations show that the geometry of the beam reaches the necessary target value of strain and will not brake when the maximum stress from the load is applied. The maximum strain by the maximum stress is about $\varepsilon = 0.0109 \approx 0.01 = 1\%$. The maximum stress by the maximum torque is about

$\sigma_{max} = 52.3 \frac{N}{mm^2} \leq \sigma_{allowed} = 63 \frac{N}{mm^2}$,so the beam will not brake.

2.4. Description of the Electrical Part

2.4.1. Control Load

A brushless DC Motor, the NeuMotor 1509 2.5, is used to create a load on the test plant. To control this motor via a microcontroller, a motor amplifier/controller is needed. For the test plant, a Mamba Monster motor amplifier is used, see Appendix D/Electronic plans. This controller was built for the hobby car market. The advantage of this motor amplifier/controller is that they are very powerful, see Table 5 which describes the characteristics of the controller. The controller can supply a large current, 120A, which is necessary to supply full power of the motor.

Table 5: characteristic amplifier controller

Type	Brand	Name	Current	Voltage
amplifier controller	Castle Creations	Mamba Monster ECS	120A	24V

The Mamba monster controller uses a Remote Control –Signal (RC-Signal) as an input. The RC-Signal is a simple pulse-width modulation which is used for hobby cars. The RC Signal is a simple rectangle impulse with a period of 20 ms. The length of the rectangle impulse can change in the range of 1 ms to 2ms. The neutral position is in the middle of the range, 1.5 ms. Figure 15 shows some standard signals.

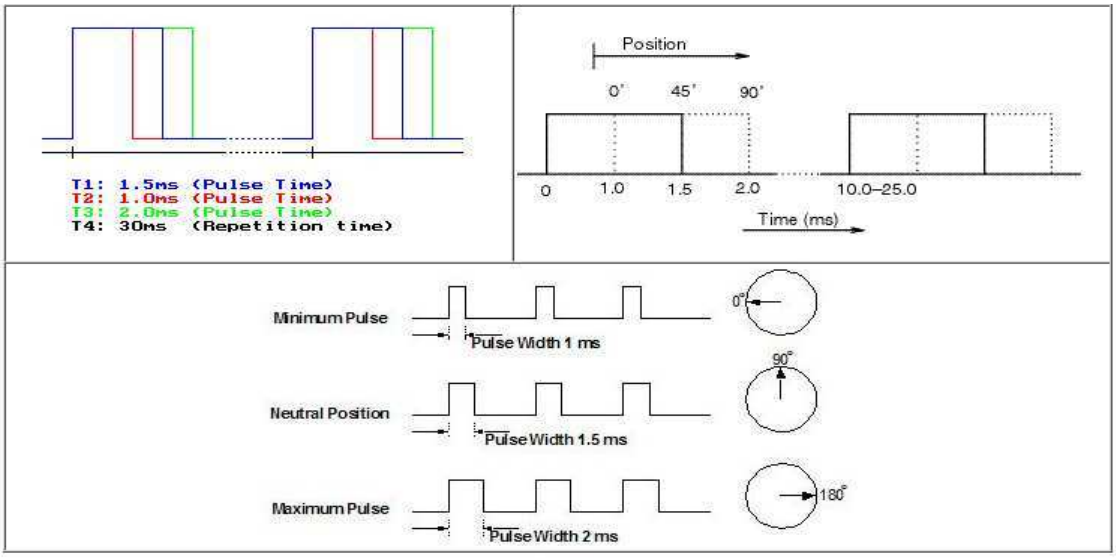

Figure 15: Control Signal 1

Source: http://www.superdroidrobots.com/product_info/RC.htm

The configuration of the Mamba Monster amplifier/controller can be changed. The configuration can change basic parameters and the Throttle Curve, see Figure 16. Detailed description of the configuration is given in their datasheet.

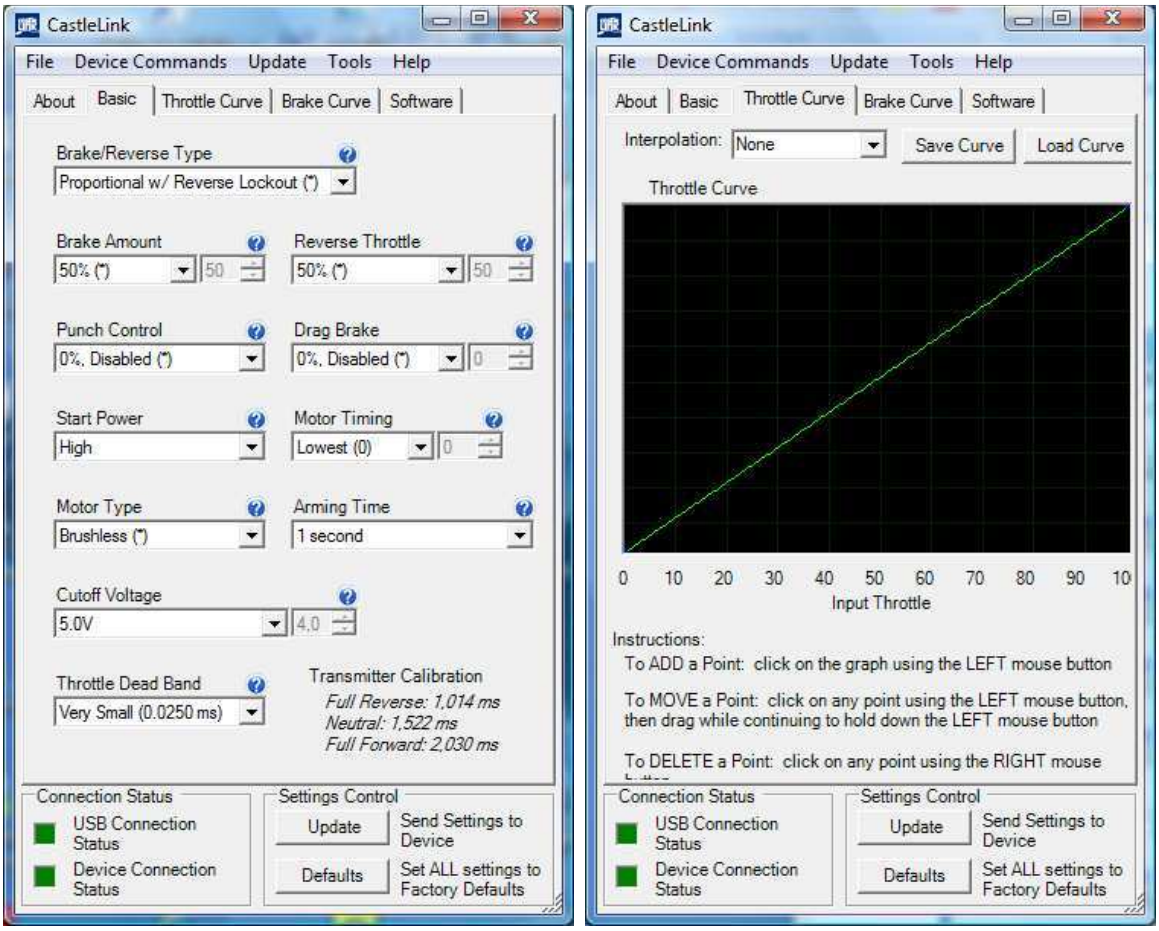

Figure 16: configuration Mamba Monster amplifier controller

2.4.2. Control element

For the control element there was two possibilities the ASU DSP33 Module-board and the Microchip Explorer 16 Development Board. Both of the boards use the DSPPIC33FJ256MC710. There are no important differences between the two boards only their peripherals. The choice to use the Explorer 16 board was determined because this board included better peripherals, buttons, an LCD-Display and a Card-Edge Connector to connect a prototype board for the electrical circuit. The DSPPIC33FJ256MC710 is programmed with Matlab Simulink. For this a special board, the Simulink Blockset for PIC/dsPIC Microcontrollers is going to be used, called the "Kerhuel blockset". This Blockset generated C-Code from the Simulink simulation and this code can be used for a special list of PIC / dsPIC microprocessors. Figure 17 shows the schematic of the programing process.

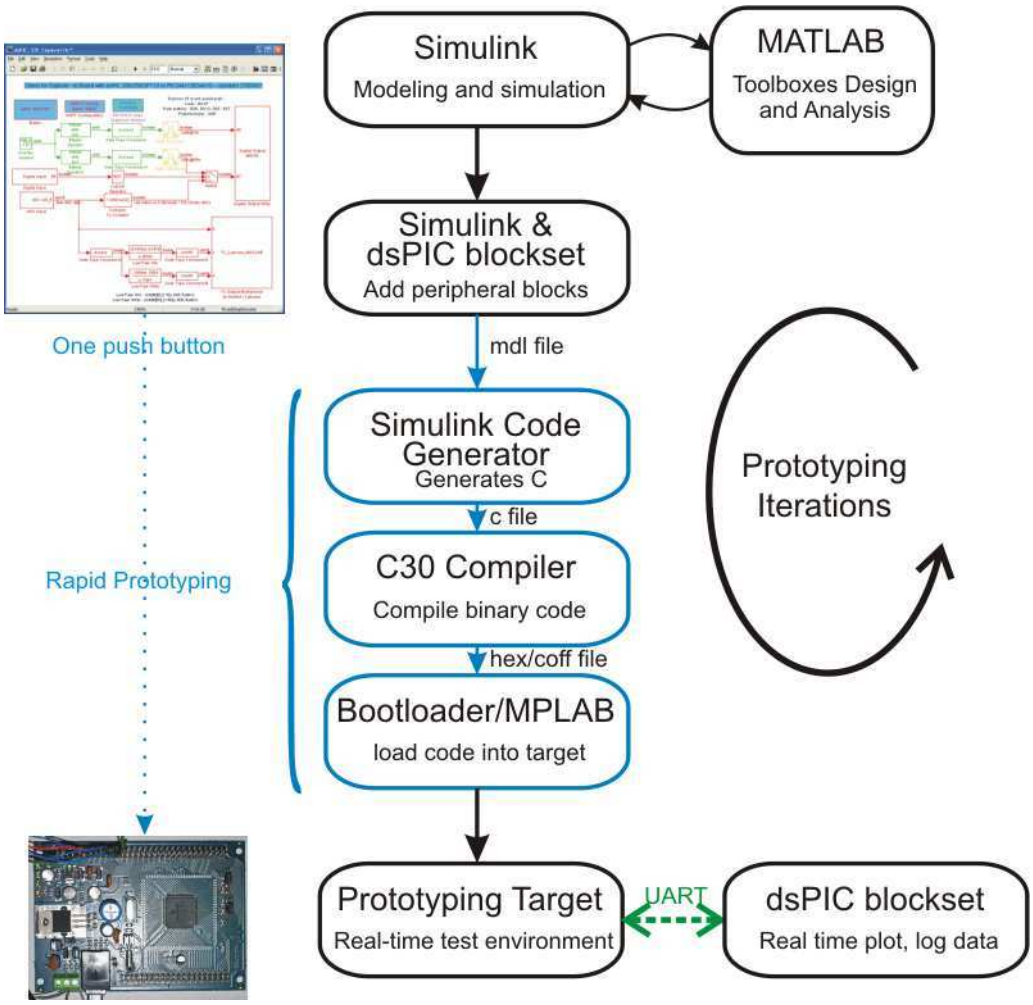

Figure 17: schematic of the programming process

Source: http://www.kerhuel.eu/wiki/Simulink_-_Embedded_Target_for_PIC

Embedded Target Block Set / Kerhuel blockset

By using this blockset, it is not necessary to study the DSPPIC33FJ256MC710 microchip because the blocks will generate automatically the code. It is important to know the settings when using the blocks. All of the special blocks are found in the library “Embedded Target for Microchip dsPIC”. For the test plant, the following blocks are used. All Simulink programs can be found in the appendix in conjunction with the motor test stand peripherals.

Using Blocks description:

Master: Define and conFigure dsPIC properties to create a compliant c code.

The master block is for the initialization of the microcontroller respectively the DSPPIC33FJ256MC710. The important settings in the block parameters of this block are the choice of the correct PIC and the setting of the Quartz or external clock frequency, see Figure 18.

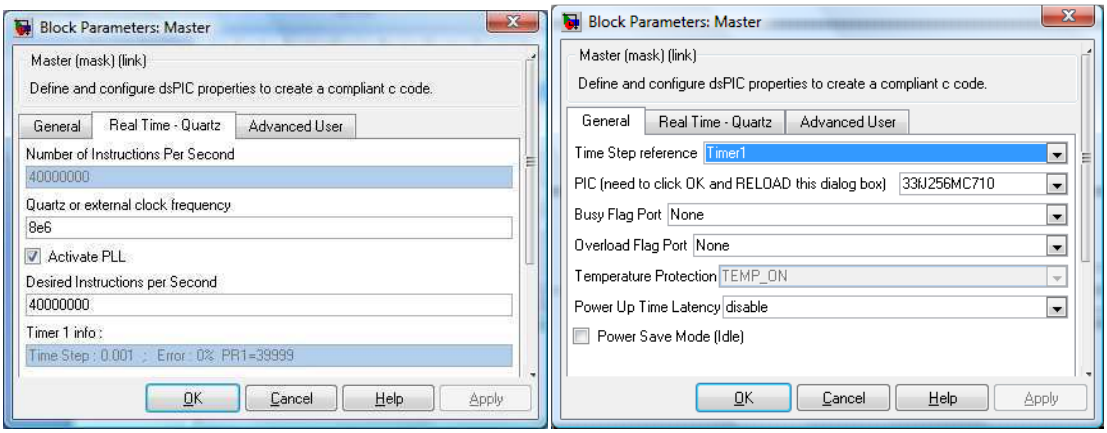

Figure 18: Block Parameters Master

Digital I/O:

The digital I/O blocks are going to be used to read and write the I/O ports on the dsPIC. The blocks are simple to set just choose the port and pin number and the Sample time, see Figure 19.

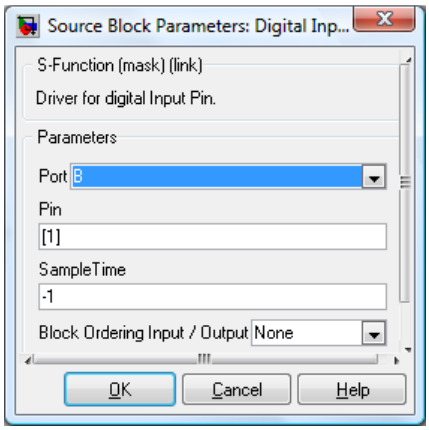

Figure 19: Digital I/O block

Output Compare: Pulse width modulation (PWM) signal generation

The output compare is going to be used to generate the Pulse-width modulation (PWM) impulse on the Output Compare peripheral. The Output Compare block needs two inputs to create the signal, one for the length of the period, the other one is for the length of the rectangle impulse. Figure 20 shows the Simulink simulation “RC_Signal_v1_2009”., This program produces a Remote Control – Signal (RC-Signal), with the output compare block. The RC-Signal is a special PWM signal, see Figure 15, which is used for the communication with the amplifier controller of the Load motor. The constant “OC6max” is the length of the period, the Sine wave create a sine between 1ms and 2ms which is the whole range of all possible values. Figure 21, the oscilloscope measurement of the output OC6/ R5, shows the PWM signal.

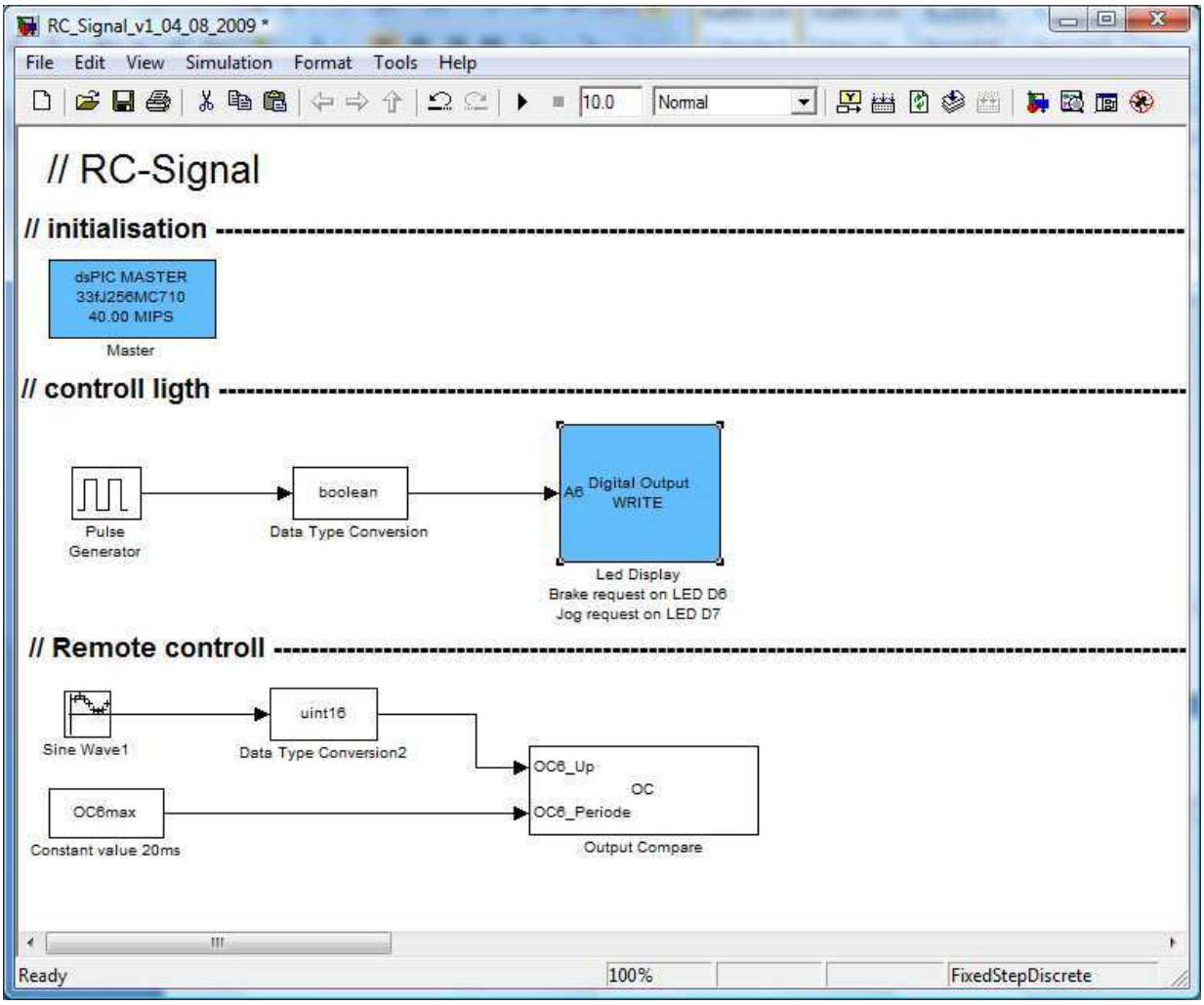

Figure 20: RC_Signal_v1_2009

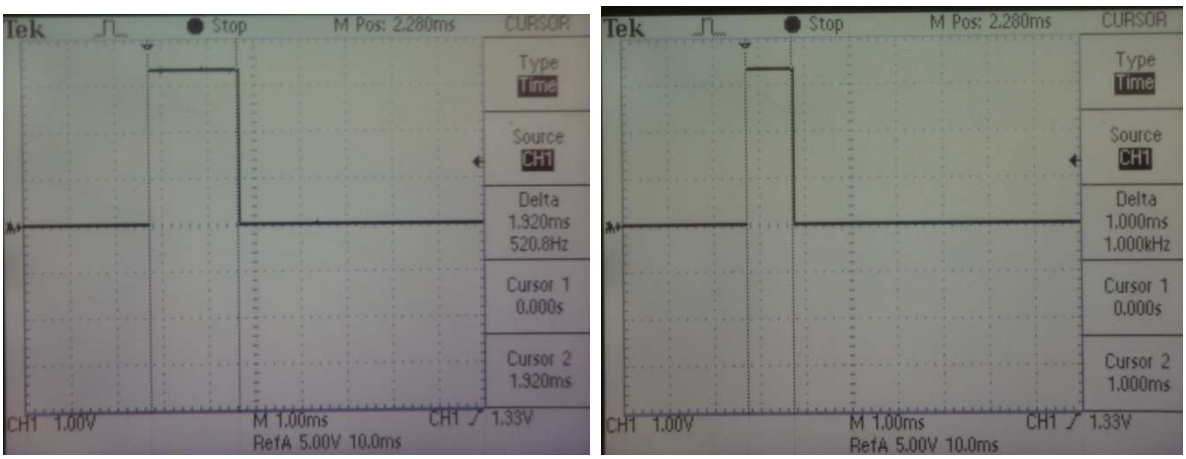

Figure 21: output signal OC6/RD5

The following Figure 22 shows the settings of the output compare block for the Simulink simulation "RC_Signal_v1_2009" and explains the important parameters. More detailed information can be found on the webpage: http://www.kerhuel.eu/wiki/Block/Output_Compare

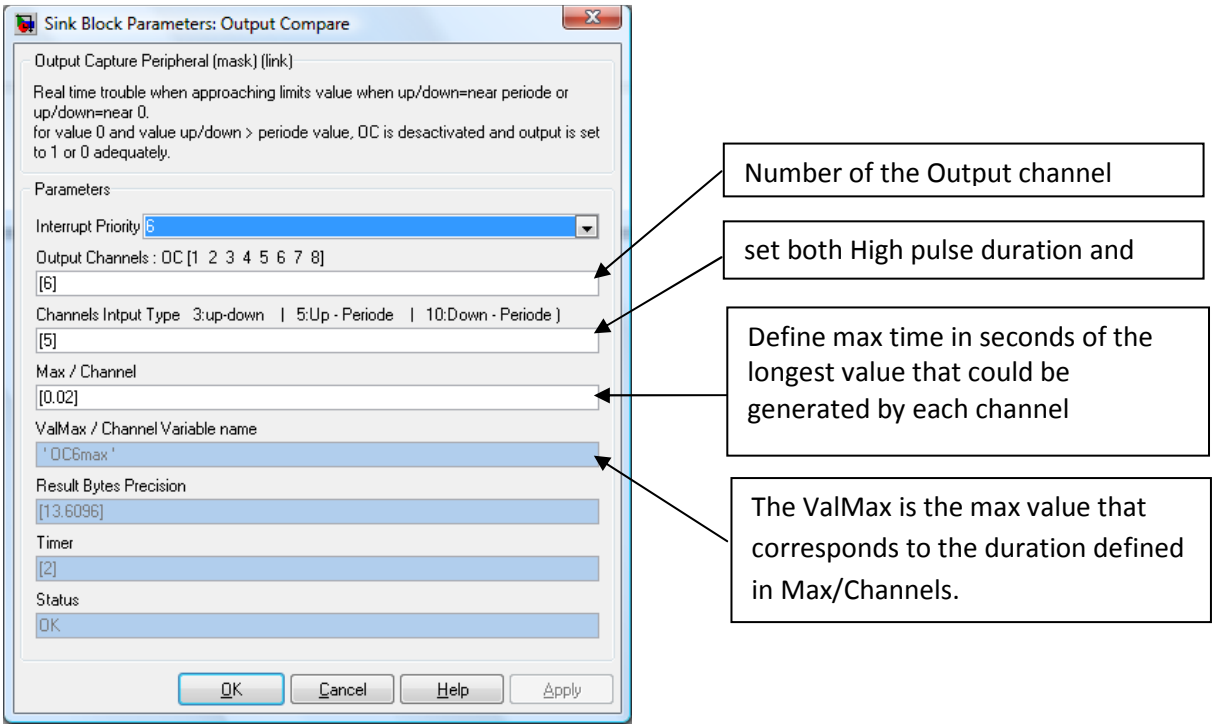

Figure 22: Block parameters: Output compare

ADC Input: Input driver for analog-to-digital converter (ADC)

The block ADC Input converts an analog signal from the PIC to a digital signal. The block allows the choice between a 12bit and a 10 bit converter as long as a PIC from the dsPIC 33f family can create the signal. The digital output signal is formated as the specified signed/unsigned and fractional/integer. The Simulink simulation "AD_converter_v1_2009", see Figure 23 uses the ADC Input to read in the Signal from the Torque measurement and convert it to a digital value.

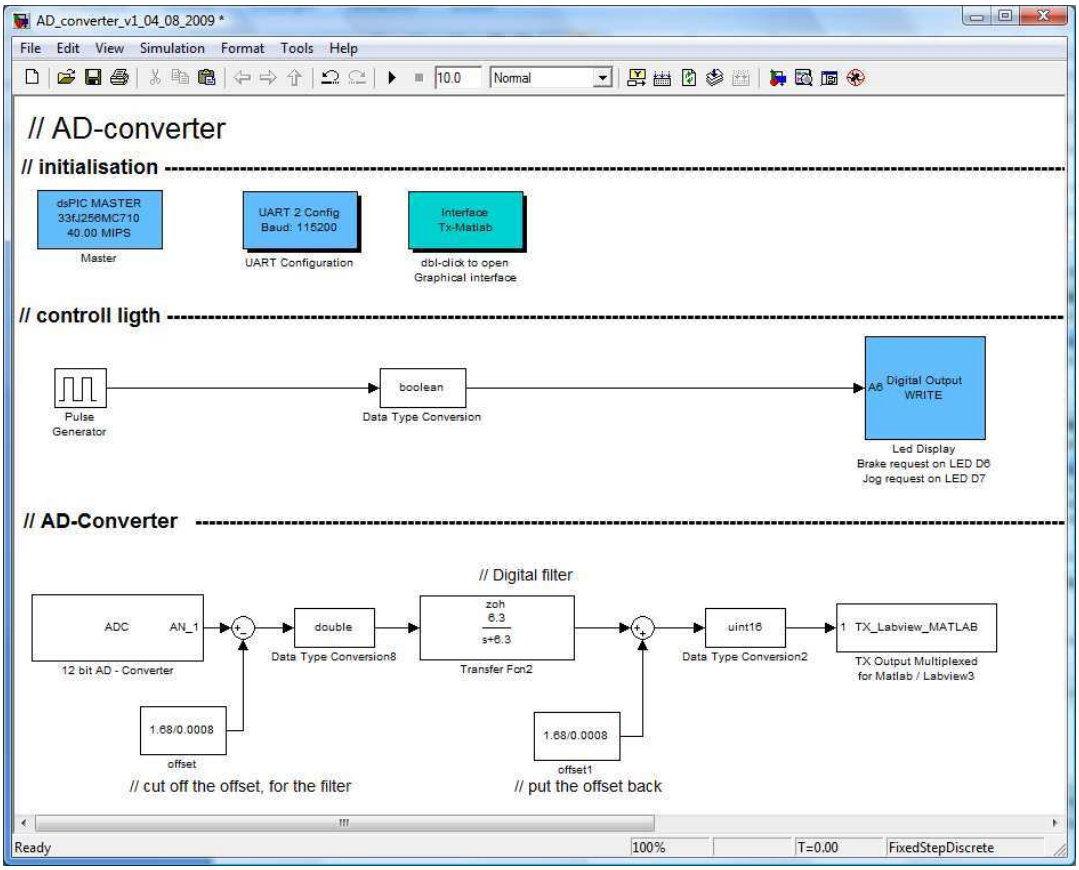

Figure 23: AD_converter_v1_2009

The following Figure 24 shows the settings of the ADC Input block for the Simulink simulation "RC_Signal_v1_2009" and explains the important parameters. More detailed information can be found on the webpage: http://www.kerhuel.eu/wiki/Block/Output_Compare

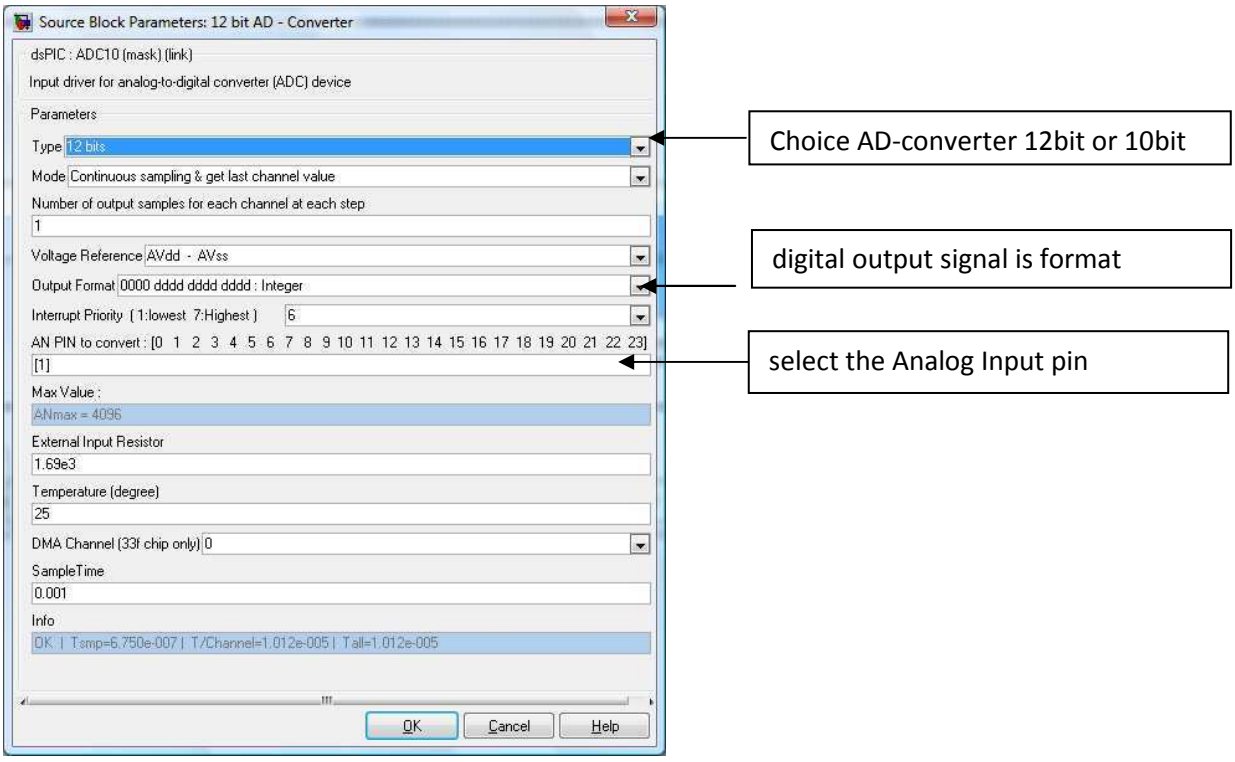

Figure 24: Block parameters: ADC Input

Interface Tx-MATLAB: User Interface to view variable evolution

The Interface allows one to watch different Input signals. To create an Interface with a dsPIC, it is necessary to put three blocks into the Simulink simulation. The first block is the “UART Configuration” block and is used to set the parameters in the UART. The block “Interface Tx-Matlab” is for setting the Serial COM, which is the connection to the dsPIC, to start the graphical interface, and to configure the plots. The third block, ”TX-Labview_MATLAB, is the Input block. It should be noted that the input signal for this block must be from the data type Integer.

The Simulink simulation “AD_converter_v1_2009”, see Figure 23 uses the Interface to watch the signal from the ADC-Converter. For a better result with the Interface Tx-Matlab block, it is necessary to filter the signal again. To filter the signal from the Torque measurement, the Offset in the signal must be deleted. Figure 25 shows the Interface graphic from the Interface Tx-MATLAP. The graph shows the Torque measurement of the Test plant. The X-Axis is the voltage in mV, and the Y-Axis is the measurement time. The signal shows different stresses in the beam.

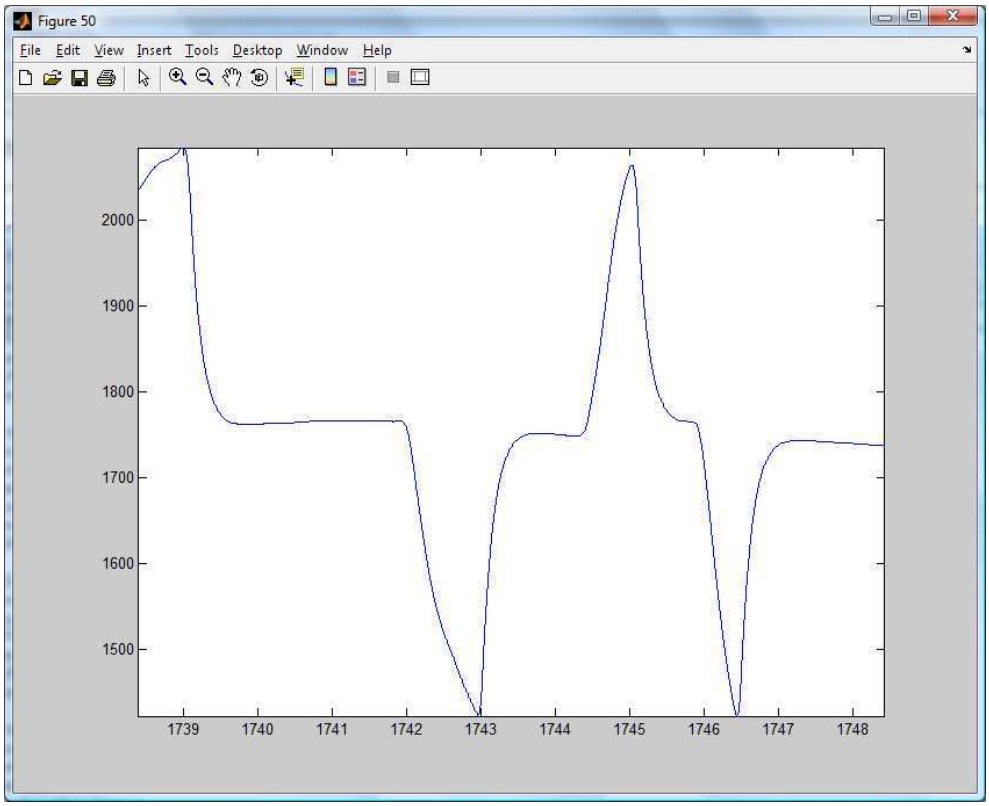

Figure 25: Interface graphic

I²C Master: Input driver for I2C Peripheral

The I²C Master block, is used to communicate with other chips or boards. In the block parameter, there is the possibility to change some bus settings. The communication with other bus devices works via the sequence setting in the block parameter. The sequence is a text consisting of letters and numbers which have to be between two single quotes, for example 'S A024 W056 W000 W001 P'.

Description of the I²C sequence

Example: 'S A024 W056 W000 W001 P'

First/last letter: Generating different condition on the bus

S	start condition
Sr	restart condition
P	stop condition

Second letter: Setting the address of this bus devices

A	address as a block input
Axxx	address, the address is a xxx decimal value

Third to before last letter: Write or read values to the bus devices

R	read
Rnack	Read without ack
W	write block input
Wxxx	write constant value, xxx decimal value

For the Test plant the I²C is going to be used to communicate with a DA-converter, type AD5627R. The simulink simulation “DA_converter_v1_2009”, see Figure 27 shows a code example of the communication between the microchip DSPPIC33FJ256MC710 and the DA-converter AD5627R.

The task of the program is to convert a digital sine wave to an analog signal. Figure 26 shows the result of the program. An oscilloscope measures the 12bit AD5627R DA-converter. To allow communication, both I²C output pins, RG2/SCL1 and RG3/SDA1,of the DSPPIC33FJ256MC710 are connected with a pull up resistor. The first step in the program is to set the reset Input to high. The reset input of the DA-converter is connected to the dsPIC pin RG13. After this, it is necessary to set the Internal Reference setup of the DA-converter chip AD5627R. To control the chip, an I²C Master block is used with the following I²C sequence 'S A024 W056 W000 W001 P'. The first 8 bits , A024, corresponds to the address; the next three 8 bit blocks set the set Internal Reference. The detailed description of this setup is in the AD5627R Datasheet page 26. If this is done, the DA-converter is ready to receive the digital data to convert it. The DA-converter is a 12 bit converter. One must send the 12 bit data via the I²C Master block the data in a set protocol. The function preparing the data splits the 12bit data in two 8bit chunks so that the I²C Master block can send the data to the 12bit converter. The function just bit shifts the input value and builds a MSB (Most Significant Bit) and a LSB. Before the I²C Master block can read in the data the data, it must be converted to an Unsigned 8bit Integer. The I²C Master block which writes the data to the DA-Converter must have this sequence 'S A024 W016 W W P'. The 8bit block after the address W016 sets the command: “Write to input register n, update all”. The next two 8bit blocks, W W , read the block input value. The last step is to setup the LDAC register, for this I²C Master block with the sequence 'S A024 W048 W000 W003P' is used. The description of this setup is on the AD5627R Datasheet page 24 and 25.

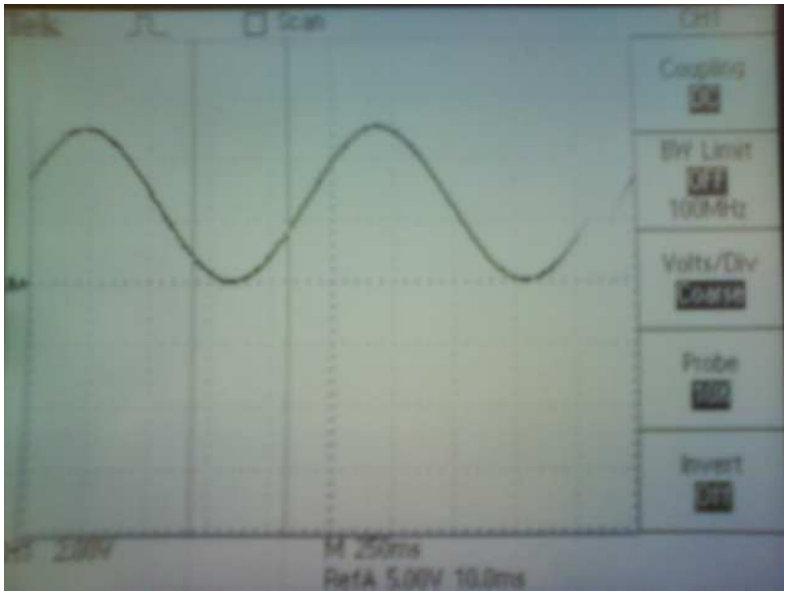

Figure 26: Analog output signal from the 12 bit DA-converter

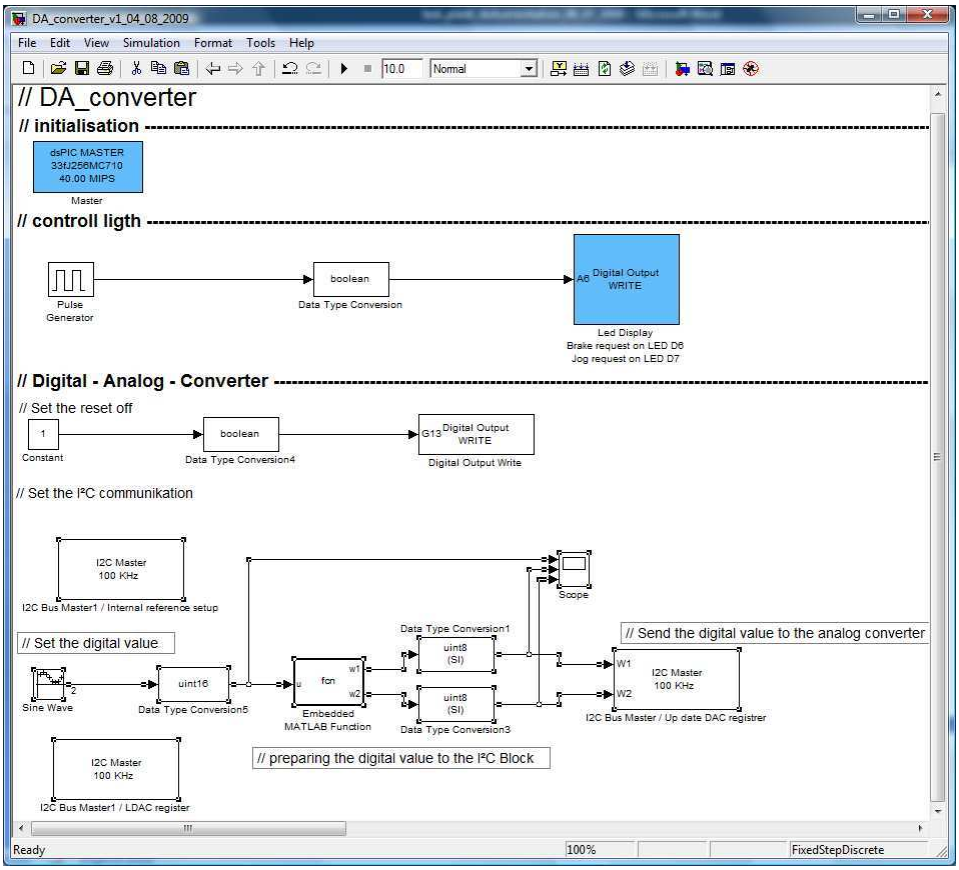

Figure 27: DA_converter_v1_2009

The following Figure 28 shows the settings of the I²C Master block for the Simulink simulation "RC_Signal_v1_2009" and explains the important parameters. More detailed information can be found on the webpage: http://www.kerhuel.eu/wiki/Block/Output_Compare

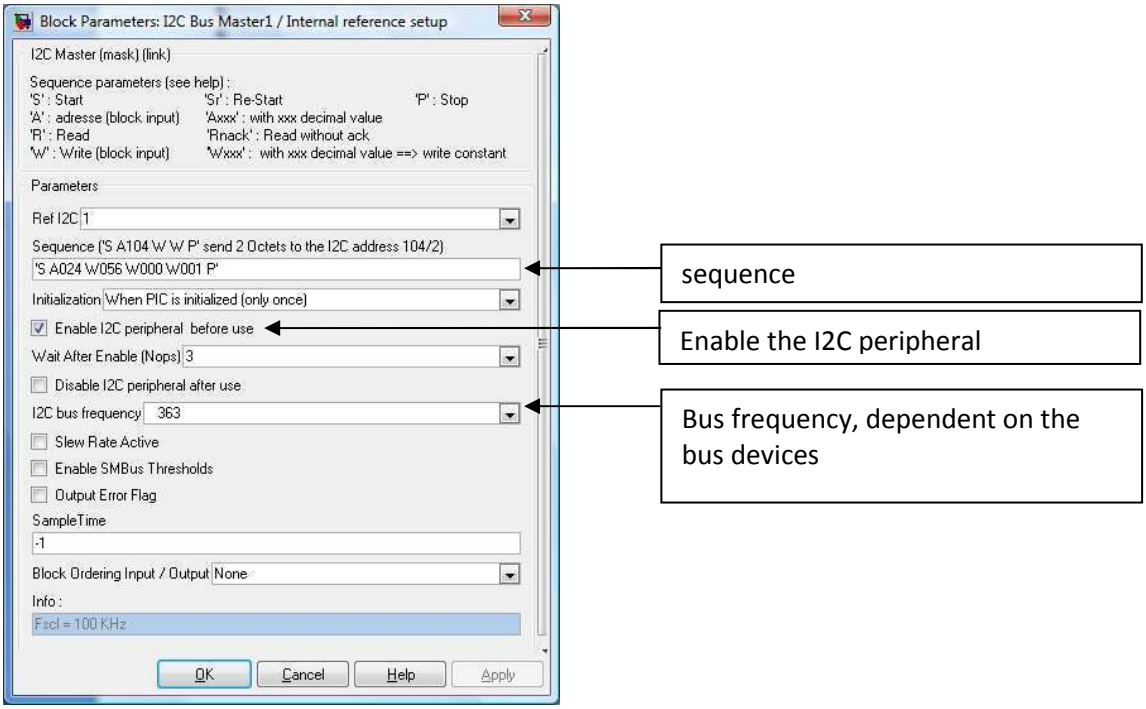

Figure 28: I2C Master block parameters

C-function call: Call custom write handed C function

This block is for calling a custom C-file block. The C-file is saved in the same directory as the .mdl file. It is also required to declare the C-file name in the Custom Code. This has to be done under Simulation->Configuration Parameters -> Custom Code -> C-filename.c, shown in Figure 30. For calling a function, the C-function call block parameters have to be set. Figure 29 shows an example of a block parameter setting. This block is going to be used for the C-function to measure the counts of the Quadrature Encoder. The return value of this block are the number of revolutions of the motor.

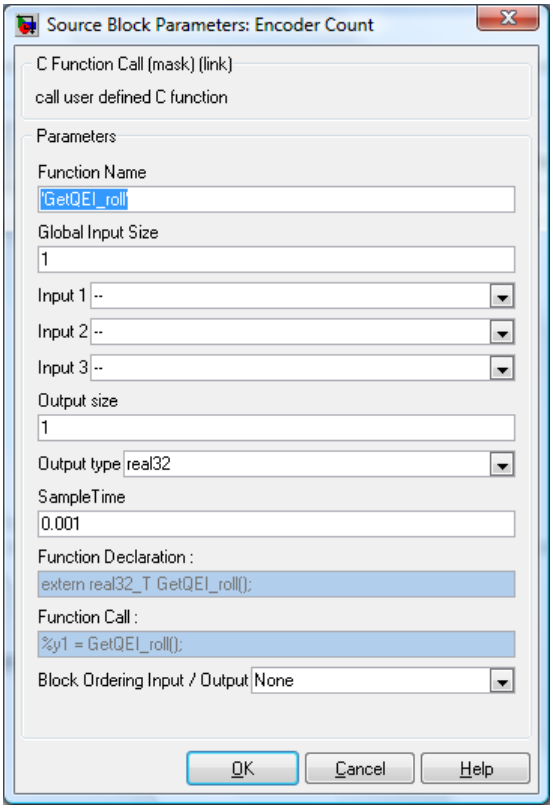

Figure 29: C-function call, block parameter

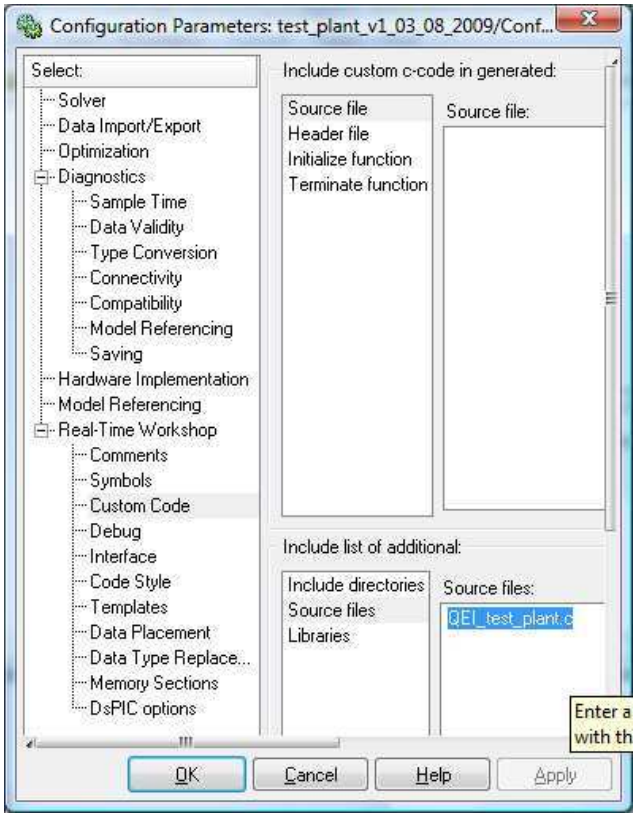

Figure 30: Source file

Motor Test plant program

The Simulink simulation “test_plant_v1_03_08_2009” see Figure 31, is for testing the control loops and for checking the whole system. The control light is for checking if the program is correctly downloaded or not. The main code is for selecting a control loop by pressing a button on the controller board. The Strain gage signal section shows the signal of the Torque measurement and includes a digital filter. The section Digital – Analog converter is made for the future to use another amplifier controller.

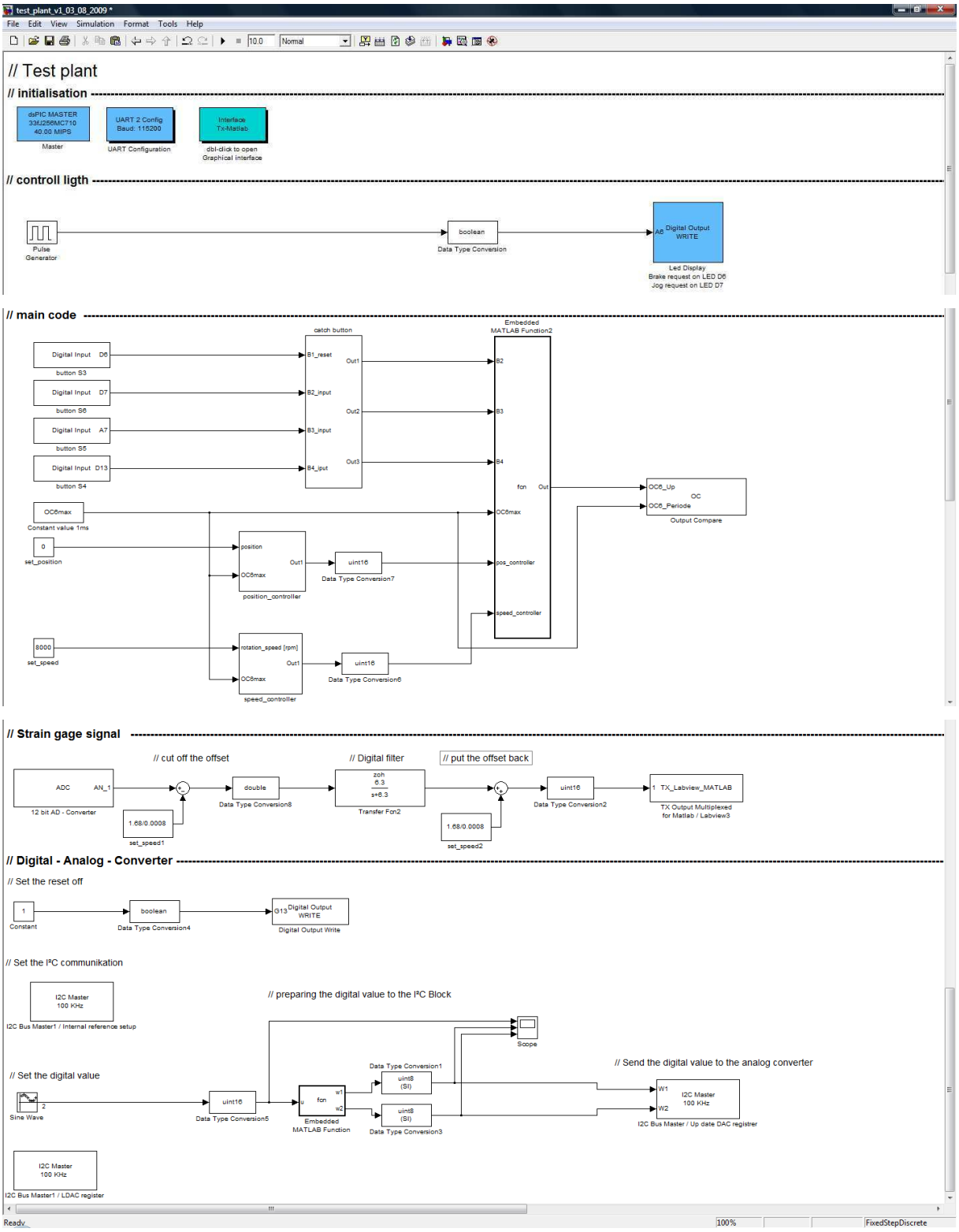

Figure 31: Motor Test plant

Controllers

For the Test plant there are two controllers which are going to used, a position controller and a speed controller. The position controller is going to be used to measure the starting torque of the test motor. The speed controller is for measuring the torque at different speeds along the torque-velocity curve. Figure 32 shows the control loops of both controllers. Both control loops never work at the sometime.

The position controller loop has to insure that the shaft of the load motor and therefore the shaft of the test motor stay at the zero position, but the test motor wants to turn with full speed so the load motor has to work against it. The speed controller loop has to control the speed during the at different velocity points. The measurement process allows the Test motor to drive with full speed and the load motor to drive in the other direction to bring the speed down to the desired speed.

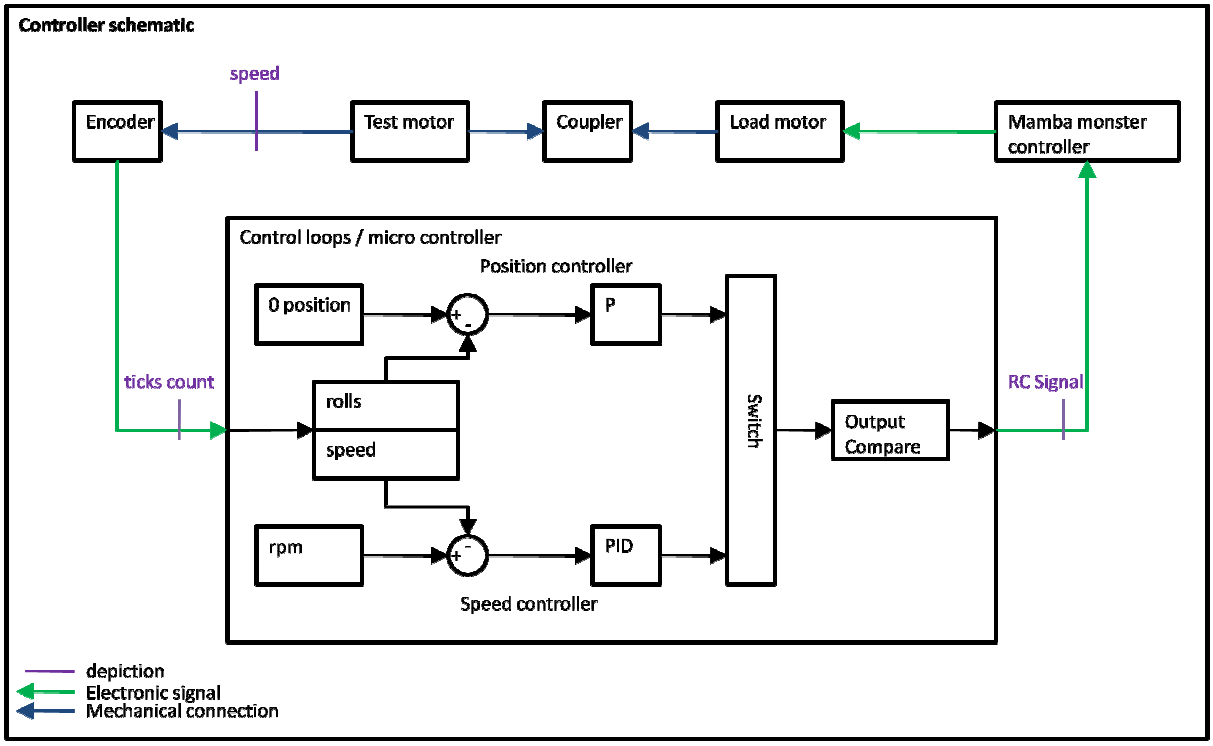

Figure 32: Control loops

Problem with both control loops:

After testing the control loops it was clear that the system can never work with this kind of motor controller. The problem with the control loops is that the amplifier controller “Mamba monster” is too slow for the load motor. This means that the load motor reacts all to time too sensitively to the control signal from the amplifier controller and the oscillations were too high.

The next problem with the Mamba monster controller is that there is a dead zone at the zero point. This dead zone denotes that the controller always stops the motor and waits before it drives the motor in the opposite direction. Because of these problems, it is necessary to change the amplifier controller.

By testing the control loop with, switching off of the amplifier controller, manually during the testing, and only checking the steering signal, it showed that the system can work.

2.4.3. Torque measurement

The torque is measured with a beam and two strain gages. The strain in the beam and respectively the change of the resistor value in the strain gage is coupled with a proportional factor to the torque $M = \Delta R \cdot k_{M-R}$. The proportional factor, k_{M-R}, for the test plant is $k_{M-R} \approx 0.373 \frac{Nm}{\Omega}$. The calculation of this value is in the Appendix B/Calculation. One strain gage is placed on the top of the beam and the other on the bottom, see Figure 33. With this design one strain gage will have a higher resistor value than normal and the other one will have a smaller one. The differential or difference between the two values will be higher and also the measurement is more accurate.

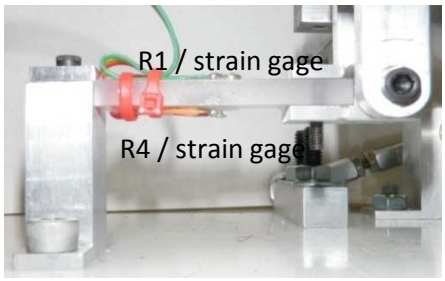

Figure 33: beam with strain gages

The strain gages are mounted in a measurement bridge and the differential voltage from the bridge is amplified using an instrumentation amplifier and the voltage is sent to the input of the dsPIC microcontroller. The signal is in the range of 0V to 3.3V. The microcontroller uses a 12 bit AD – converter resulting in a voltage resolution of 0,8mV which equates to a torque resolution of about 10 mNm. Figure 34 describes the block schematic of the torque measurement

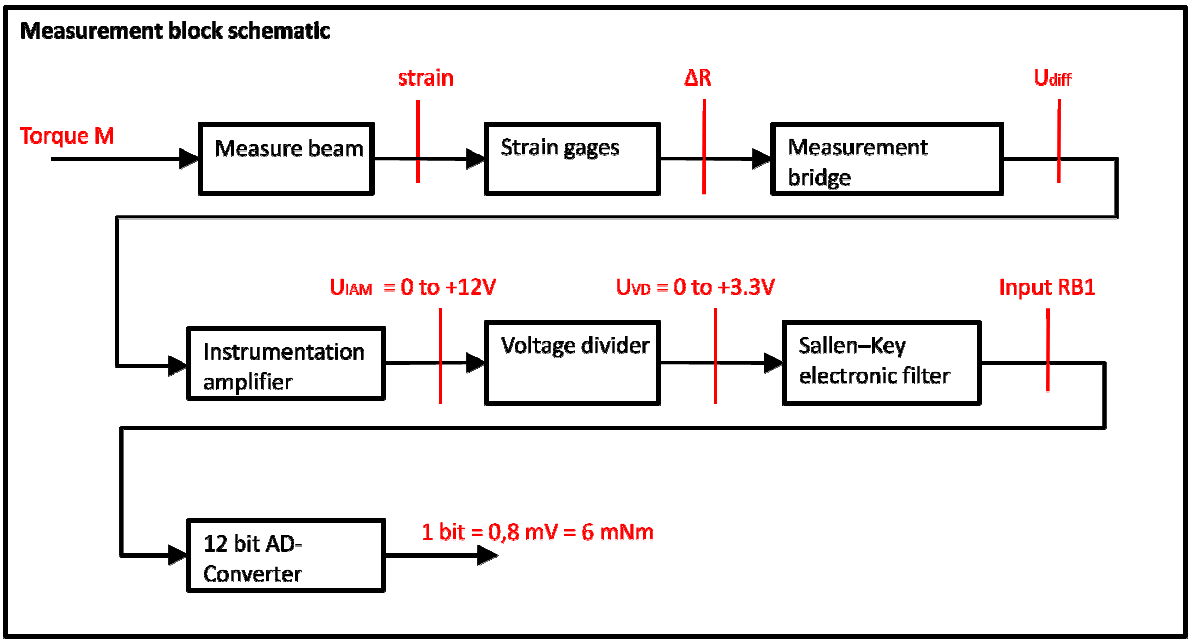

Figure 34: block schematic torque measurement

Measurement circuit:

The two strain gages for the measurement bridge are of type Omega SG-3/350-LY11. The measurement bridge is connected to an instrumentation amplifier, type INA 125. The instrumentation amplifier has a reference power supply to supply the bridge with 10V and max. 5mA. The measurement bridge consists of two strain gages with resistance of 350Ω and two additional resistors R=350Ω. The total resistance of the bridge is $R_{bridge} = 350\Omega$. In the bridge circuit diagram, both strain gages are placed on the upper side of the measurement bridge circuit, see Figure 35. With this placement of the gages, the temperate effect will be canceled. For the reference power supply, it is necessary that the current is less than 5mA, so two additional resistors are added which decrease the current to 4mA. The power supply of the instrumentation amplifier is +12V and -12V. Therefore, the output signal can have a maximum value of $\mp 12\mathrm{V}$. This output signal must be modified because the microcontroller can only read positive voltage values. It was necessary to split off the positive range of the output signal with a 6V psuedoground on the amplifier. The 6V psuedoground is supplied from a voltage divider which is powered by the 10V reference power supply of the INA 125 with 1mA. The gain of the instrumentation amplifier should be set so that the output signal of the amplifier is about +5V and -5V. The voltage input of the microcontroller must be less than 3.3V and the current should be less than 2mA. A second voltage divider is used to insure that the signal is lower than 3.3 V.

Dimensioning of the measurement circuit

The following layout, Figure 35, gives the schematic of the measurement circuit, the yellow marked components are calculated values. The calculation of the component values are described in the Appendix C/Calculation Measurement. The Appendix D/Electronic plans, include a picture of the Input-Output circuit board and the schematic plan of the board.

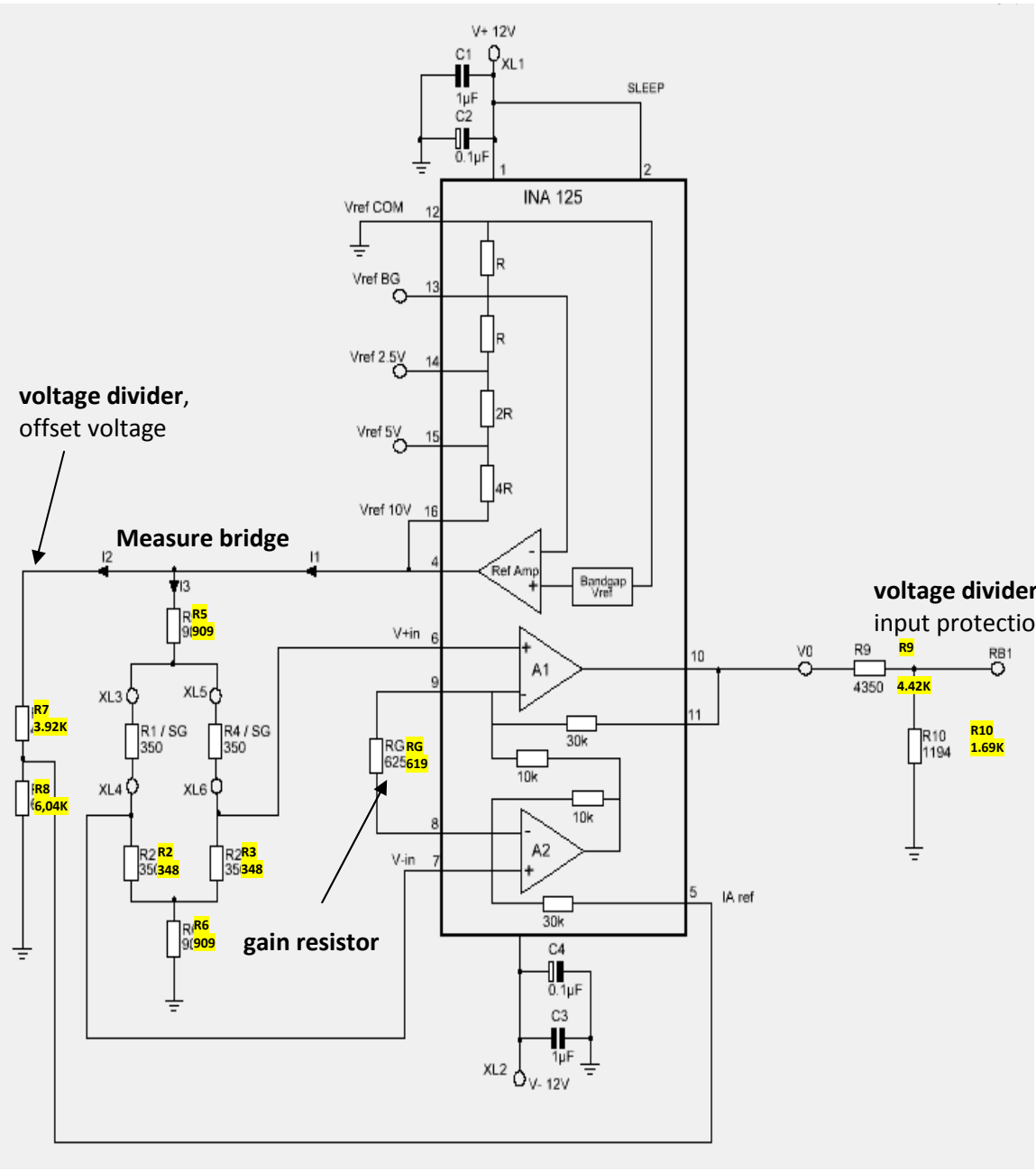

Figure 35: measurement circuit

2.4.4. Angular Velocity- Angular Position measurement

The rotational speed and the number of revolutions of the shaft are measured by an optical, incremental, quadrature encoder, type E5 from US Digital. The encoder has two channels, A and B, and an Index channel, but the Index channel is not used. The wheel of the encoder is spilt into 360 ticks. The encoder is powered by the explorer board. Channels A and B are connected via a 100Ω resistor to the inputs of the quadrature encoder interface, see Figure 36.

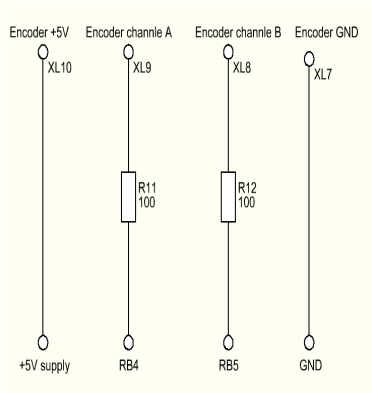

Figure 36: Encoder schematic

The quadrature encoder interface is a special function of the DSPIC33FJ256MC710b which allows an encoder to be connected very easily to the microchip. The interface has two different modes, the "16-BIT UP/DOWN POSITION COUNTER" and the ALTERNATE 16-BIT TIMER/COUNTER. For the position/revolution measurement and the velocity measurement the Position counter mode is used. The Position counter mode is split into sub modes. For this project the "Quadrature Encoder Interface enabled (x2 mode) with position counter reset by match (MAXxCNT)" is selected. This mode counts the rising edges of channels A and B, so the maximum counts per revolution is doubled, MAXCNT= 720 ticks. The actual count value is stored in the registry POSCNT. To read this register value, the maximum count per revolution MAXCNT, an interrupt start up, and the POSCNT are set. The interrupt function checks the direction of the wheel rotation and depending on the direction; the microchip will increase or decrease an external variable, called ct_turns. This variable is used for counting the number of revolutions. To read the position count in the Simulink code, a C-Function must be called. The following picture, Figure 37, shows the schematic.

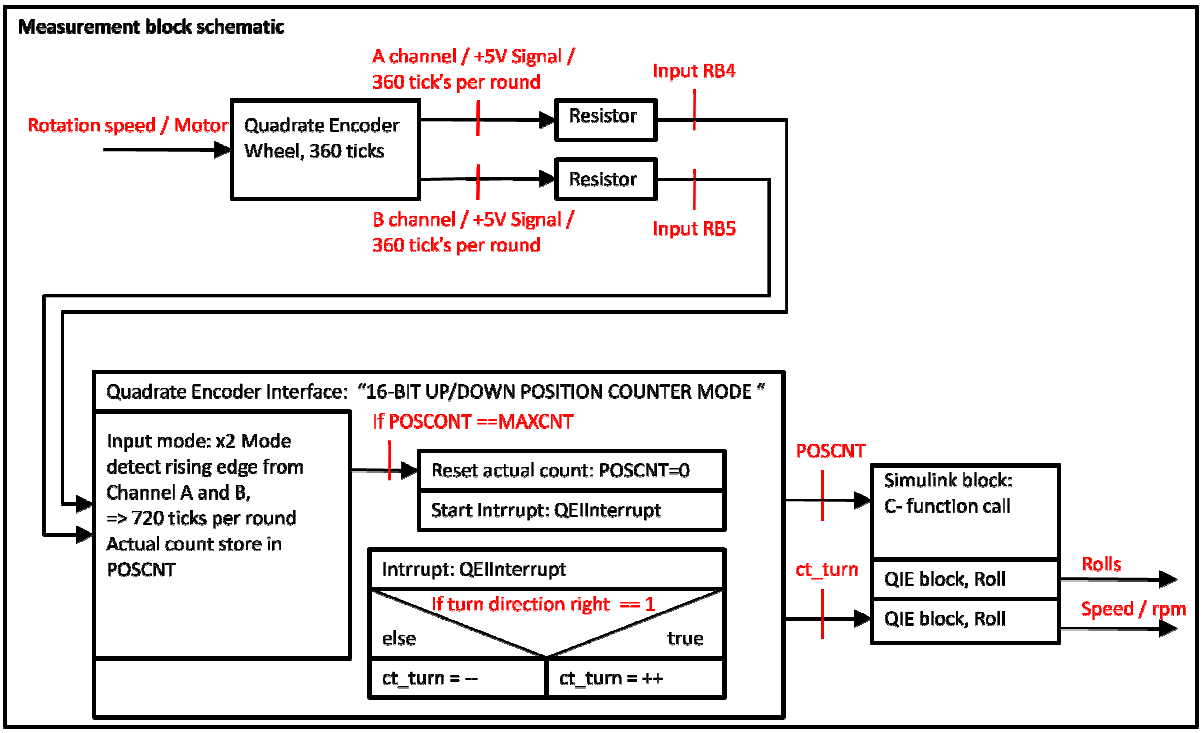

Figure 37: block schematic Encoder

Initialization of the position counter mode

The initialization of the "position counter mode" for the position/revolution measurement and the velocity measurement is very similar. The only difference is in the declaration of the "PROGRAMMABLE DIGITAL NOISE FILTERS" DFLTCON. The difference results in measuring higher speeds. It is important to make sure the signal has a large range. The initialization of both measurements is shown in the attached C-Function.

Position/revolution measurement:

To get the position count read into the Simulink code a block is called, Quadrature Incremental Encoder value ROLL, see Figure 38. The output of the block is the number of revolutions which the motor made from the starting position.

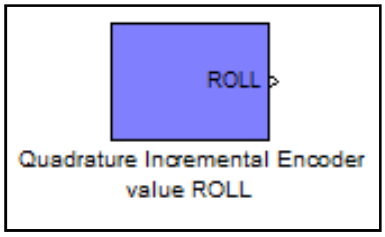

Figure 38: QIE block, Roll

The description underneath the block is show in Figure 39.

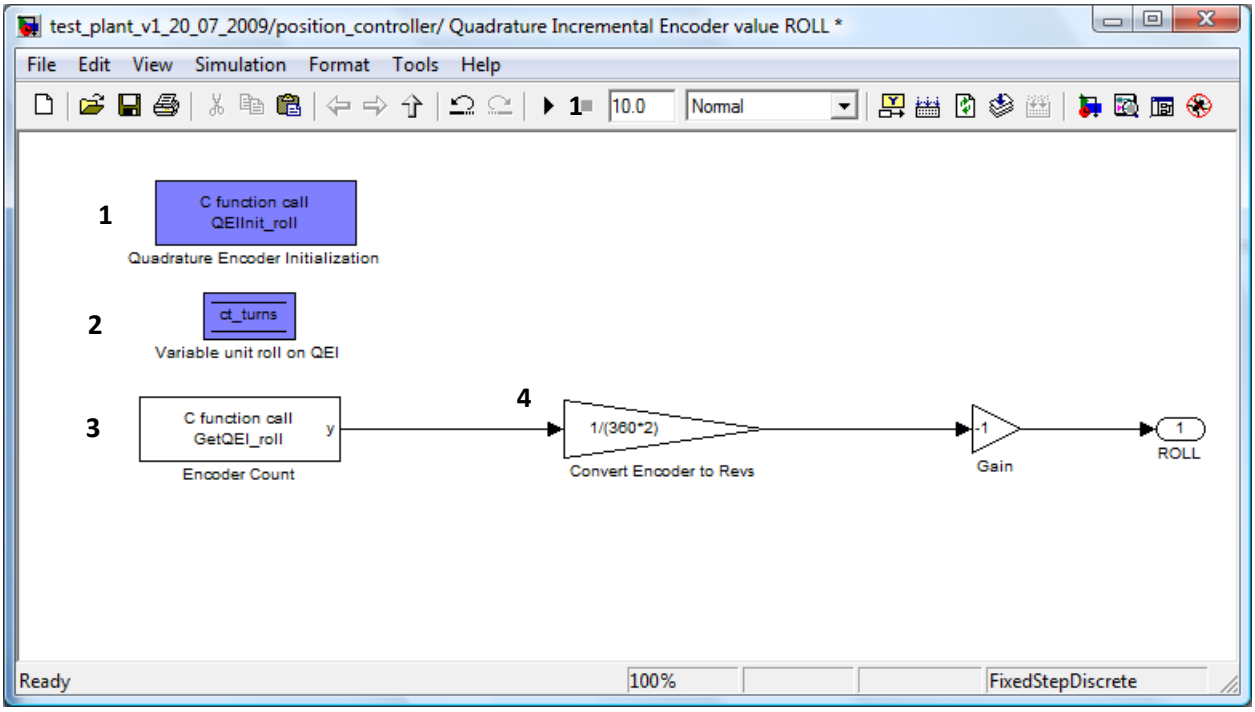

Figure 39: Inside Block QIE, Roll

Legend:

1….call the Initialization C-Code file for the position counter mode

2….declaration of counting the number of revoltions

3….call the C-function “GetQEI_roll” the return value is position count

4….calculate the number of revolutions from the position count

C-function “GetQEI_roll”:

This function is called every 0.001 sec. set by the sampling time. After the function is called, it returns the continuous position count. The value has to be calculated. It is the actual position count plus the maximum ticks MAXCNT multiplied by the revolutions of the shaft, ct_truns.

C-Code:

```
double GetQEI_roll()
    {
    extern volatile int ct_turns;                  // declaratat the external variable ct_truns
    return (double) ct_turns * MAXCNT + POSCNT;    //return value is the calculate the whole
                                                   position count
    //return (double) POSCNT;
    }
```

Velocity measurement:

The velocity measurement works similar to the position measurement. The difference is that this function measures the changing of the movement. The function will be called every 0.001 sec, the sample time. The result of this is the changing of the movement every 0.001sec. which represents the speed of the shaft. To get the value into the Simulink simulation, a special block has to be used. The name of the block is "Quadrature Incremental Encoder value SPEED", see Figure 40. The output of this block is the rotational speed in rpm.

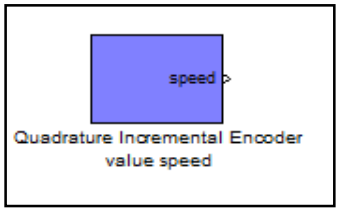

Figure 40: QIE block, speed

The description underneath the block is shown in Figure 41

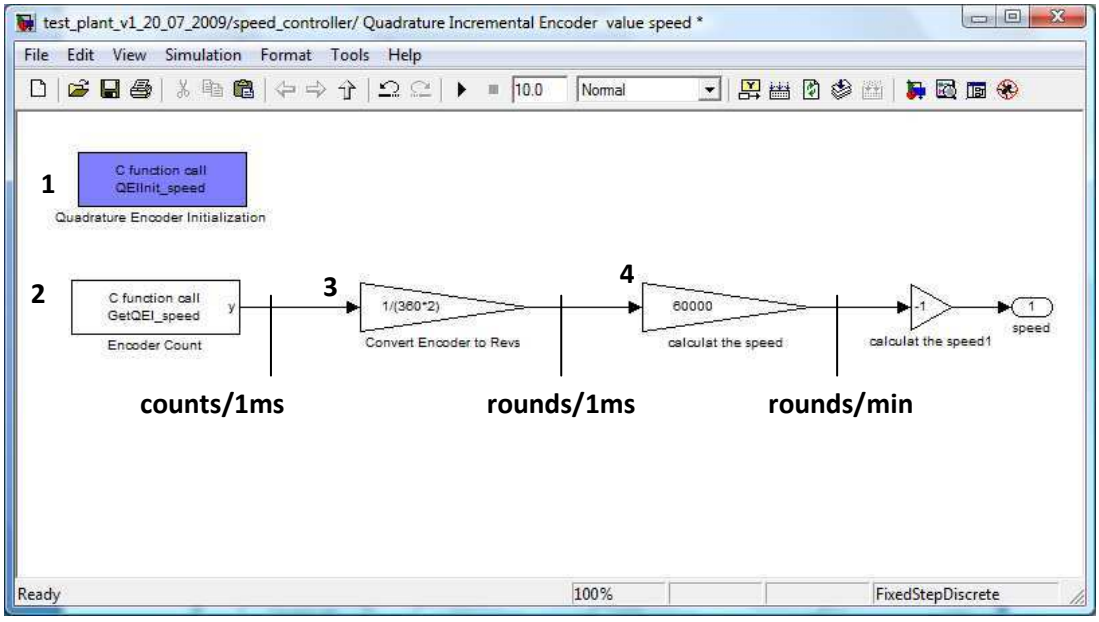

Figure 41: Inside Block QIE, Speed

Legend:

1…. call the Initialization C-Code file for the position counter mode

2…. call the C-function "GetQEI_speed", returns each 0.001sec., sample time the changing of the position count

3…. change the value from the change of the position count to the change in the number of revolutions

4…. Gain, calculate the rotational speed in rpm from the the roll value

C-function "GetQEI_speed":

The GetQEI_speed C-function is also called every 0.001 sec. The return value is the change of the position count. Every 0.001 sec (time), the function sends the change of position (change of counts), so that the value represents the speed of the shaft. When the function is called, the variable POSCNT and the variable ct_turns are used to calculate another variable, and then both variables are set to zero. This necessary to determine the change in the number of position counts.

C-Code:

```
double GetQEI_speed()
    {
    extern volatile int ct_turns;
    int count;
    int turn;
    count = POSCNT;
    POSCNT = 0;
    turn = ct_turns;
    ct_turns = 0;
    return (double)turn * MAXCNT + count;
    //return (double) POSCNT;
    }     // GetQEI_speed
```

3. Summary Motor test plant

The Bachelor thesis is on a Motor test plant for small DC-motors. The main task of the test stand is to measure the torque- velocity curve of DC-motors, to determine if different motors are able to be used for a powered prosthetic ankle. The principle of this Motor test plant is similar to a balance to measure the motor torque. The load is connected via a coupler to the test motor and both are held on a rotating table which is resisted by a beam. If the test motor produces a torque, this torque effect is measured as a strain in the beam. The strain in the beam is proportional to the torque and can be measured with strain gages.

The project is split into two parts, the mechanical part and an electronic part. The mechanical parts of the test stand consist of the Load motor, the Base, the swivel mechanism, the coupler, and the beam to measure torque. The electronic parts consist of the encoder speed measurement, the strain gages for the torque measurement, the microcontroller for controlling and analyzing the measured data, an Input/Output circuit board for electronic measurements, an amplifier for controlling the load, and the programming environment. Figure 42 shows the finished Motor test plant with all of the parts.

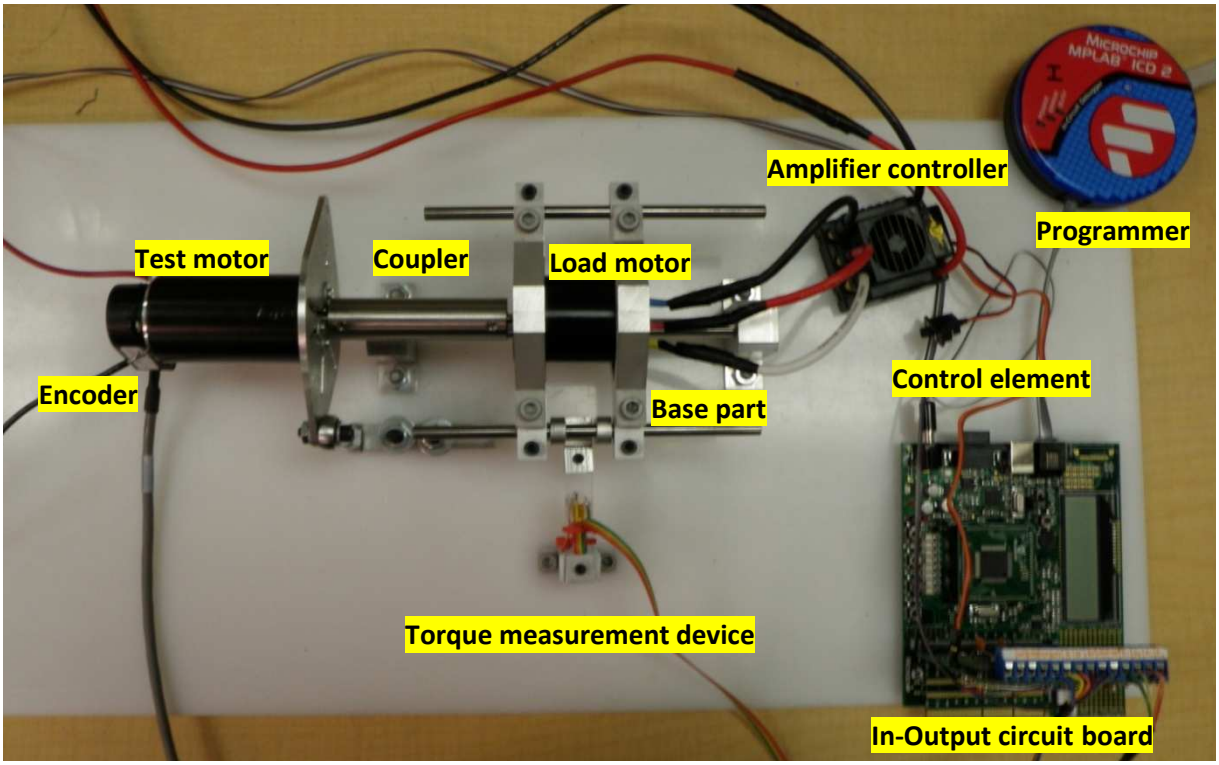

Figure 42: Motor test plant

The mechanical part of the Motor test plant operates very well. The load motor is able to move and to produce a strain in the beam. The behavior of the measurement beam is very satisfactory. The strain in the beam can be measured, and the beam moves back to the starting position after it is stressed. There is a small offset but it is negligible. One thing could be improved in the mechanical part is the bearing of the shaft which holds the load. It would be better to change the sleeve bearing to a ball bearing to reduce friction.

The results of the electronic part are not as successful as the mechanical section. The measurement of the torque and the speed works fine. To improve the measurement, the next step would be to put the measurement circuit closer to the microcontroller on one board. With this step the noise in the strain measurement signal would become much more less because the Sallen-Key-filter can be placed closer to the input of the microcontroller. The main problem with the electronic part is the amplifier/controller, Mamba Monster. The measurement of the torque- velocity –curve needs to use two control loops, a position controller and a speed controller. Both control loops do not work very well because the amplifier/controller of the load is too slow to control the reactive load motor. The next problem with this controller is that the controller stops the shaft for a millisecond before it starts turn in the other direction. The control loops are programmed with MATLAP Simulink. For that a special Embedded Target Block Set with a compiler is used. The compiler produces a C-Code file from the Simulink simulation, and stores this as a hex-file. A programmer downloads the code to the microcontroller hex-file.

The future step for the project is to change the amplifier/controller Mamba Monster to another controller. For that the In-Output circuit board is modified with a DA-converter so that the another controller with an analog input can be used. For the future it is also necessary to develop a better user interface which allows one to measure the data automatically. The goal should be to get the finished torque –velocity curve as a print-out. This can be realized with LabView.

4. Bibliography

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  (http://www.mobac.de, state 13.08.2009),
  Internet: http://www.mobac.de/deutsch/h_folder/strom-prinz.html

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  (http://www.superdroidrobots.com/, state 13.08.2009)
  Internet: http://www.superdroidrobots.com/product_info/RC.htm

5. Appendix

A Engineering drawings

- 2009_AS_001_cover_v1_asm
- 2009_CO_001_coupler_D5_D5_prt
- 2009_CO_002_coupler_D5_Q_prt
- 2009_MT_001_fastener_prt
- 2009_MT_002_fastener_counterpar
- 2009_MT_003_fixing_beam_prt
- 2009_MT_004_lever_prt
- 2009_MT_005_shaft_D_1_4__L_0_5_prt
- 2009_MT_006_strain_gauge_beam_arrangemen
- 2009_TM_004_Loadmotor_fastener
- 2009_TP_001_fastener_foot_prt
- 2009_TP_002_fixed_bracket_prt
- 2009_TP_003_flexible_bracket_prt
- 2009_TP_004_shaft_D_1_4__L_6_prt
- 2009_TP_005_shaft_D_3_8__L_7_5_prt
- 2009_TP_006_baseplate_v1_prt

B Calculations

- Tensile stress in the beam
- Dimension of the beam
- Proportional factor k_{M-R}
- Measurement circuit

C C-Code file

- QEI_test_plant.c

D Electronic plans

- In- Output circuit board
- Schematic plan In- Output circuit board
- Mamba Monster controller

E Datasheets

- Datasheet_DA_converter_AD5627RBRMZ
- Datasheet_Instrumentation_Amplifier_INA125P
- Datasheet_Operational Amplifiers_LM6134_AIM_NOPB
- Datasheet_Strain gage_SG_3_350_LY11
- Datasheet_Amplifier controller Mamba Monster Brushless Extreme ESC
- Datasheet_Explorer 16 Development Board
- Datasheet_Motor EC-powermax-30
- Datasheet_Motor_Maxon_RE-40
- Datasheet_Motor_NeuMotor_15XXTC Case
- Datasheet_Optical_Incremental_Encoder_HEDS_9100
- Datasheet_Rod_End_4483T212
- Datasheet_dsPIC33F_ Inter-Integrated Circuit
- Datasheet_dsPIC33F_Quadrature Encoder Interface
- Datasheet_DSPIC33FJ256MC710

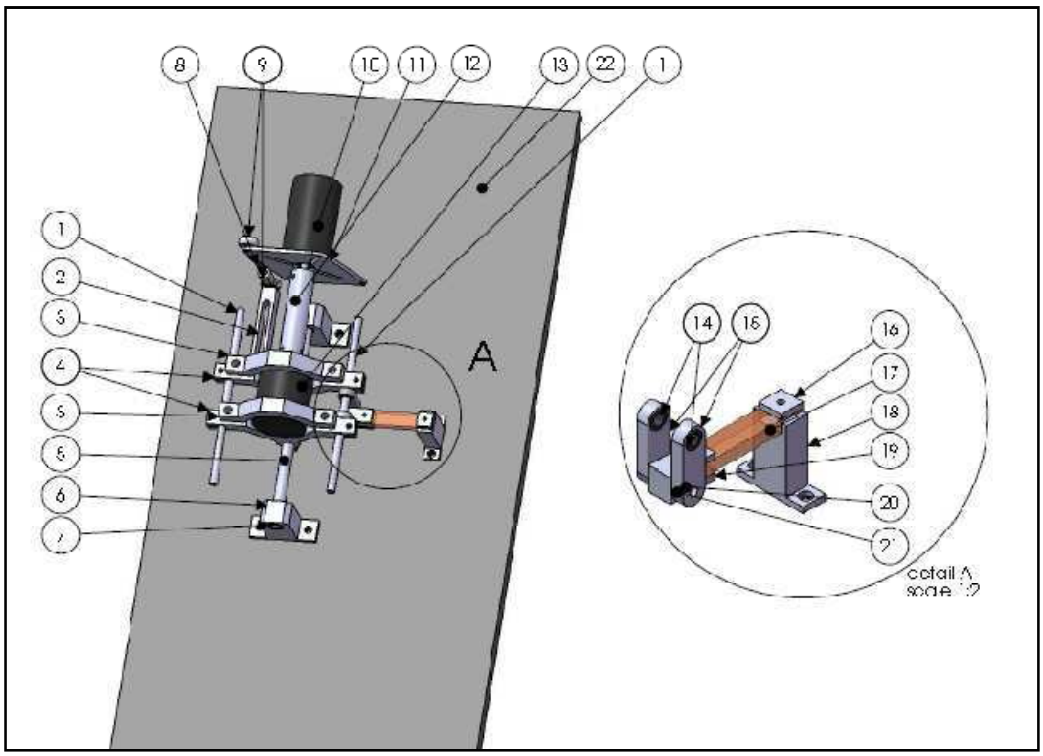
6. Affidavit

I hereby declare that this bachelor thesis has been written only by the undersigned and without any assistance from third parties. Furthermore, I confirm that no sources have been used in the preparation of this thesis other than those indicated in the thesis itself.
The thesis, in this form or in any another similar form, have not been provided yet to any other certifying authority and the thesis is also not published yet.

Dornbirn, the 26th of August 2009 _____

Lukas Fink

Engineering drawings



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3	2009_TP_003	flexible bracket	2
4	2009_TP_002	fixed bracket	2
5	2009_TP_005	shaft Ø 3/8 l 7.5"	1
6	2009_TP_001	fastener foot	2
7	SB1	sleeve bearing 5/16x1/2x3/4	2
8	2009_TM_005	thread rod #10-32 UNC	1
9	2009_TM_003	rod ends	2
10	RE40_24_150	Maxon RE40 24V 150W	1
11	2009_TM_001	test motor bracket	1
12	2009_CO_001	coupler Ø 5mm t/ Q 0.135	1
13	NM_1509/2.5D/S	NeuMotor 1509 2.5D S	1
14	SB2	sleeve bearing 1/4x3/8x1/4	2
15	2009_MT_004	lever	2
16	2009_MT_002	fastener counterpart	1
17	2009_MT_006	strain gauge beam arrangement	1
18	2009_MT_001	fastener	1
19	2009_MT_003	fixing beam	1
20	2009_MT_005	shaft Ø 1/4 l 0.5"	1
21	SB3	sleeve bearing 1/4x3/8x1/2	1
22	2009_TP_006	baseplate 1/2" x 12" x 24"	2

Engineering drawings		
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2009_CO_001	2009_CO_001_coupler_D5_D5_prt(.SLDDRW)	A4
2009_CO_002	2009_CO_002_coupler_D5_Q_prt(.SLDDRW)	A5
2009_MT_001	2009_MT_001_fastener_prt(.SLDDRW)	A6
2009_MT_002	2009_MT_002_fastener_counterpar(.SLDDRW)	A7
2009_MT_003	2009_MT_003_fixing_beam_prt(.SLDDRW)	A8
2009_MT_004	2009_MT_004_lever_prt(.SLDDRW)	A9
2009_MT_005	2009_MT_005_shaft_D_1_4__L_0_5_prt(.SLDDRW)	A10
2009_MT_006	2009_MT_006_strain_gauge_beam_arrangemen(.SLDDRW)	A11
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2009_TP_003	2009_TP_003_flexible_bracket_prt(.SLDDRW)	A15
2009_TP_004	2009_TP_004_shaft_D_1_4__L_6_prt(.SLDDRW)	A16
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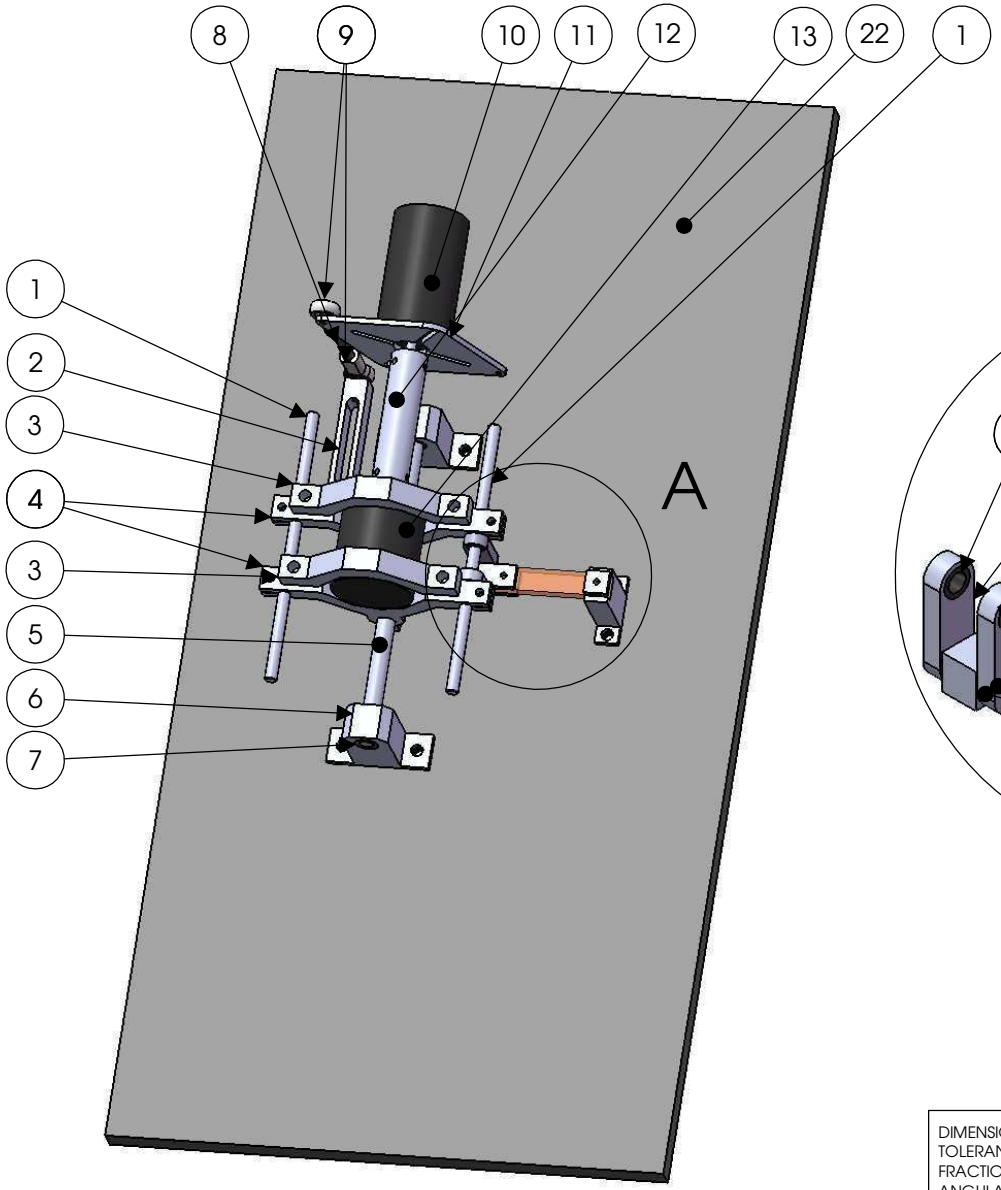

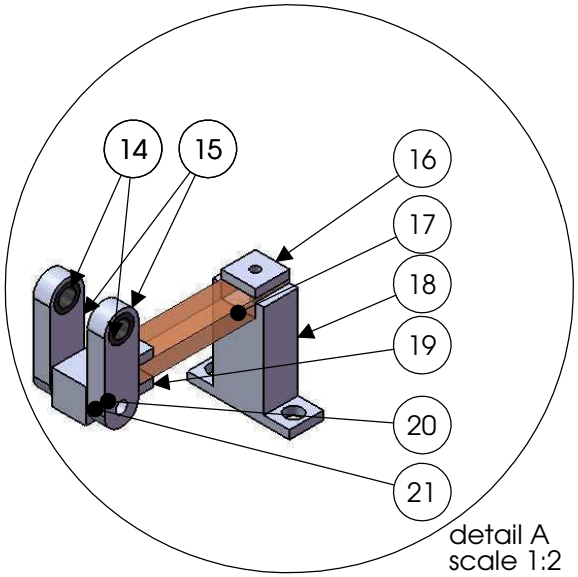

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DRAWN	Fink	05-09
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

Arizona State Univ

Projekt Test-plant

by Lukas Fink

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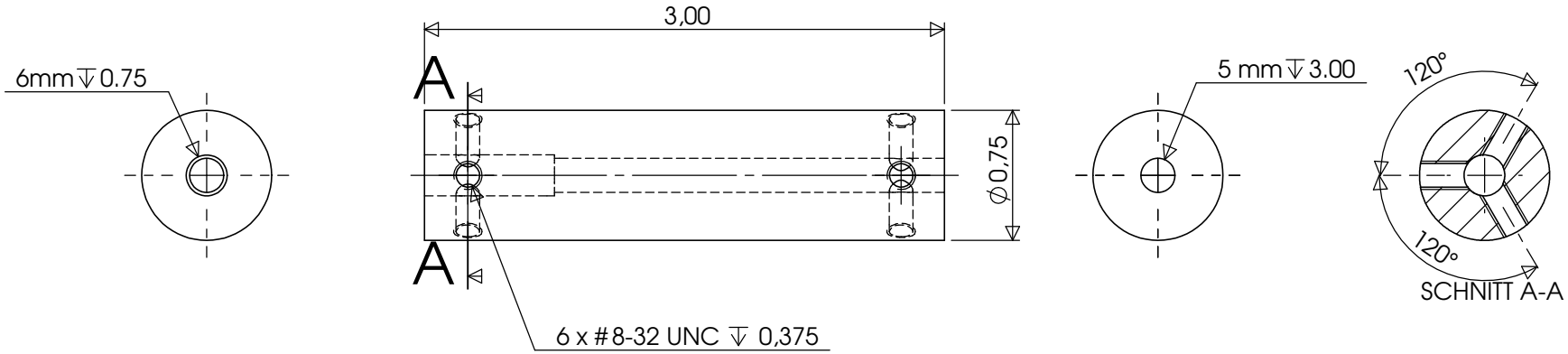

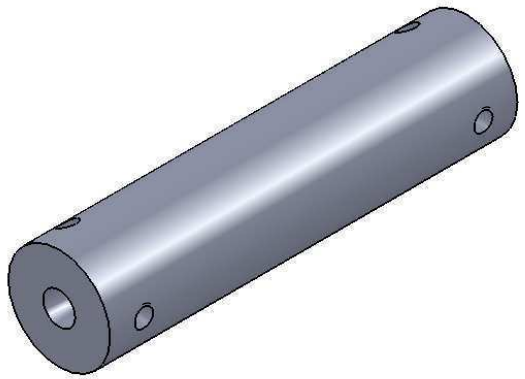

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Arizona State Univ

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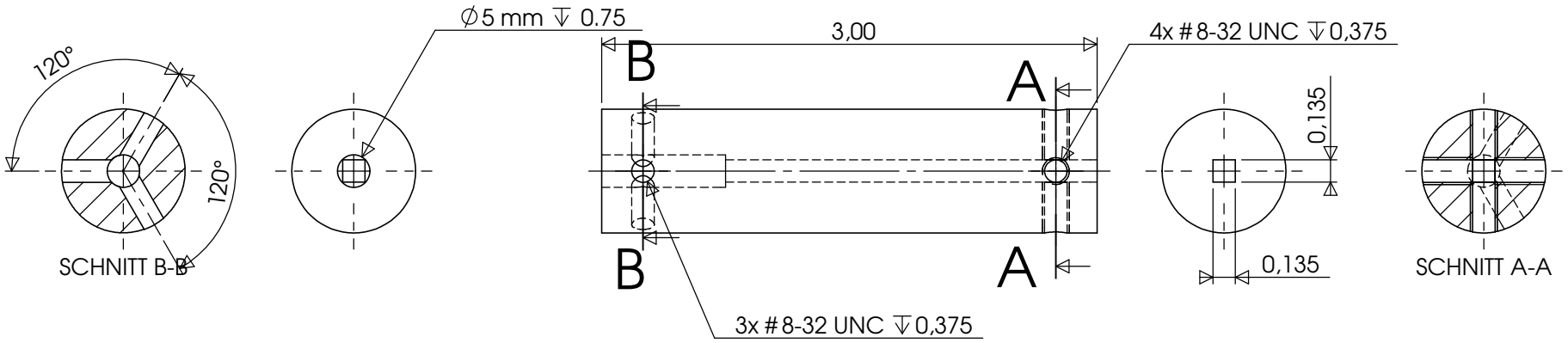

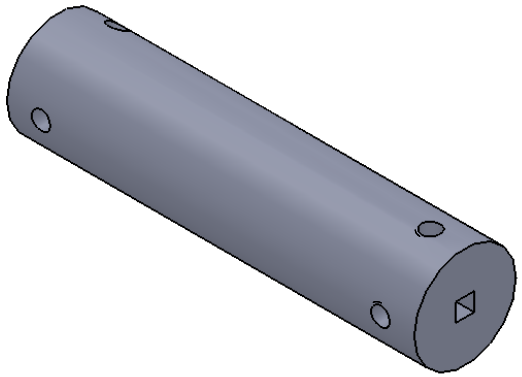

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Arizona State Univ

Coupler shaft D5 to Q

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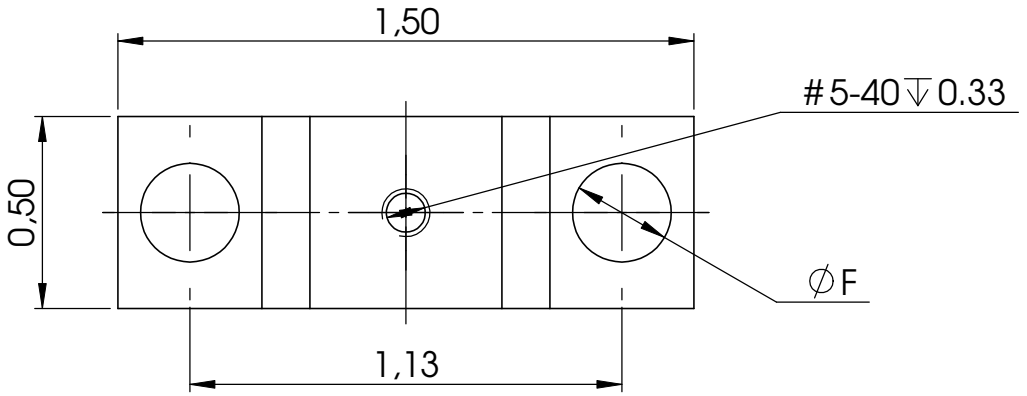

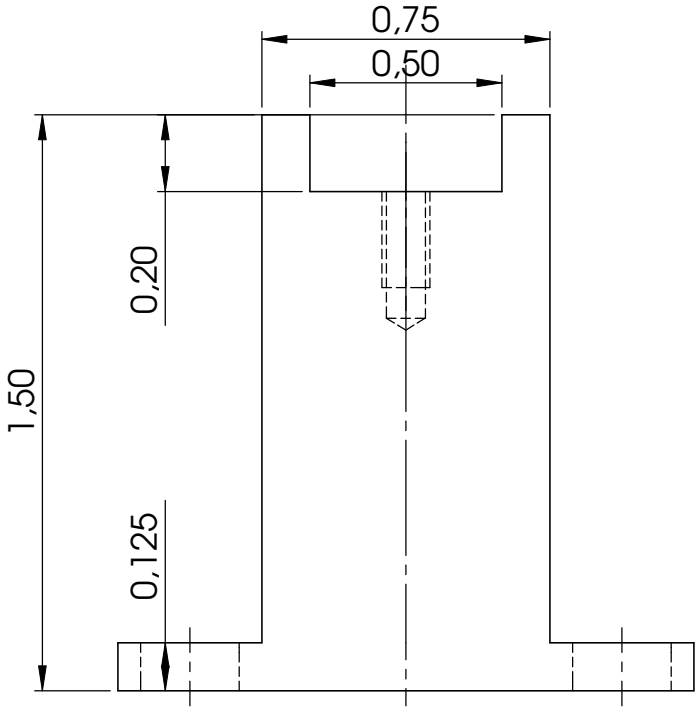

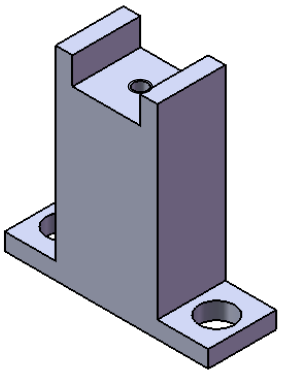

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measuring torque fastener

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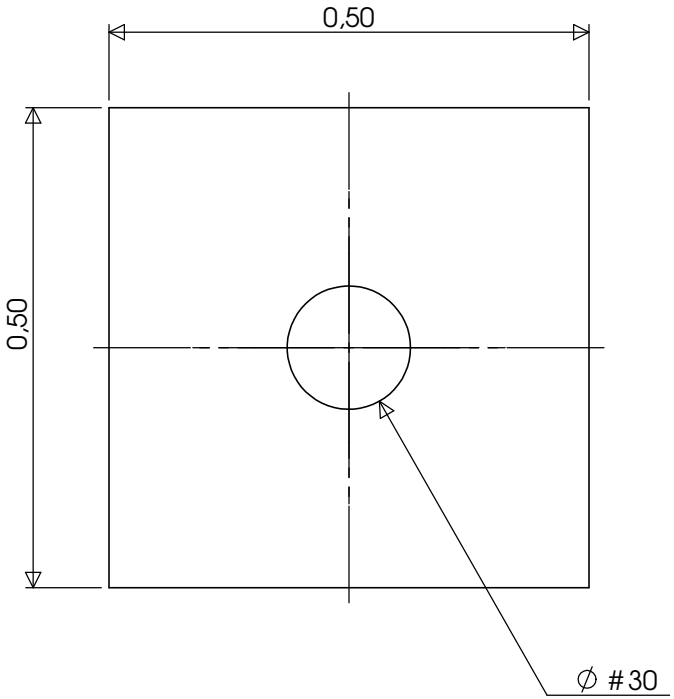

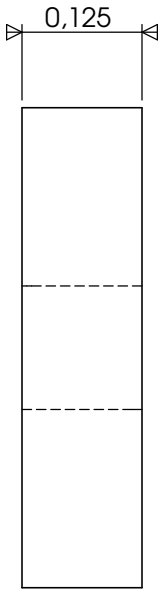

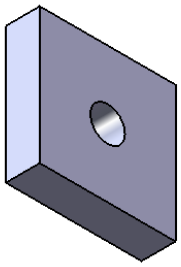

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		MATERIAL aluminum	Q.A.		
NEXT ASSY	USED ON	FINISH --	COMMENTS:		
APPLICATION		Scale 1:3			

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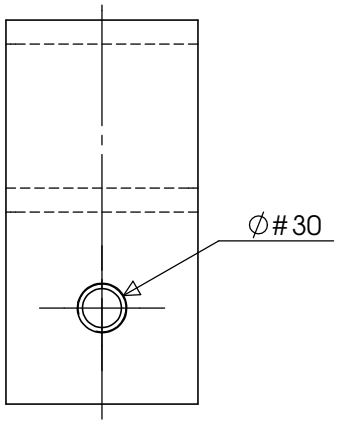
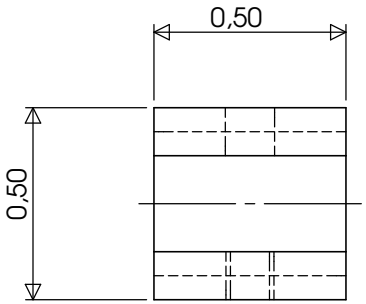
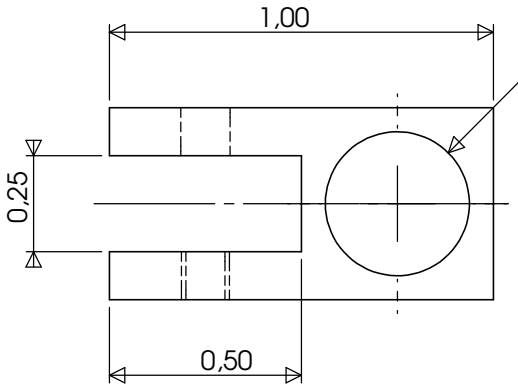
measuring torque fastener_counterpart

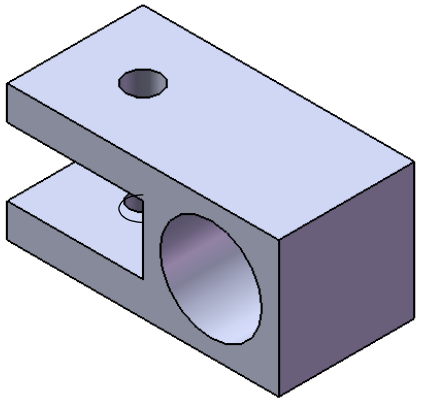
SIZE	DWG. NO.	REV.
A	2009_MT_002	0

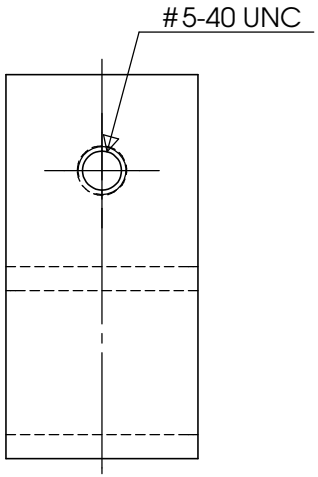
SCALE:5:1	WEIGHT:	page A7











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			MFG APPR.		
		MATERIAL aluminum	Q.A.		
NEXT ASSY	USED ON	FINISH --	COMMENTS:		
APPLICATION		Scale 1:3			

Arizona State Univ

measuring torque fixing_beam

SIZE	DWG. NO.	REV.
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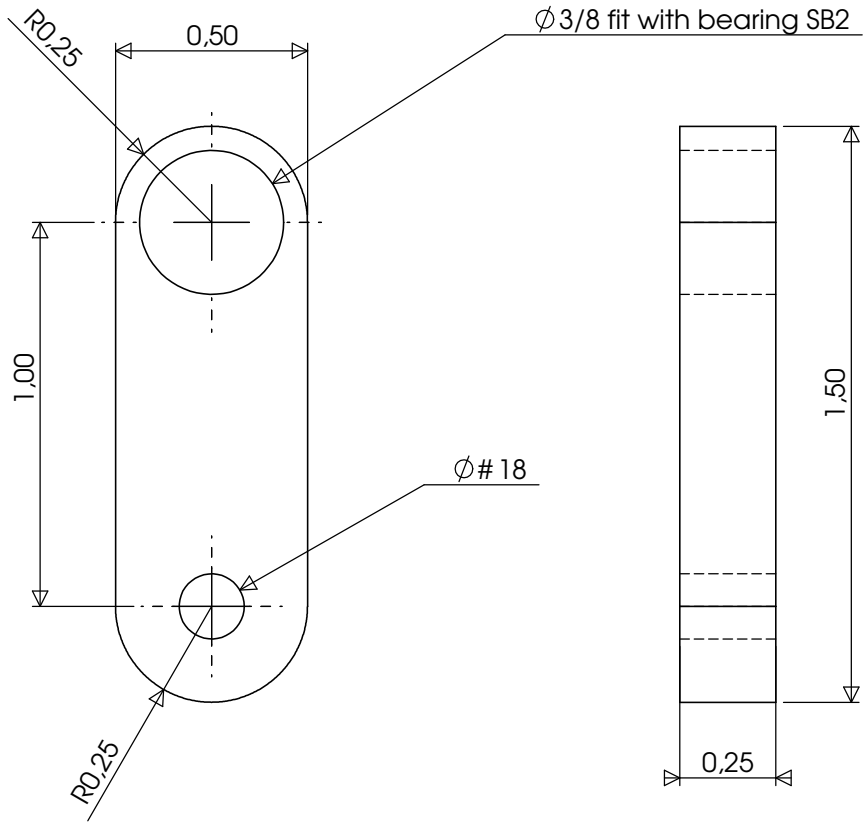
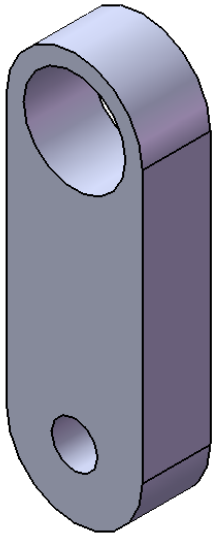
SCALE:2:1	WEIGHT:	page A8





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			MFG APPR.		
		MATERIAL aluminum	Q.A.		
NEXT ASSY	USED ON	FINISH --	COMMENTS: quantity 2		
APPLICATION		Scale 1:3			

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measuring torque lever

SIZE	DWG. NO.	REV.
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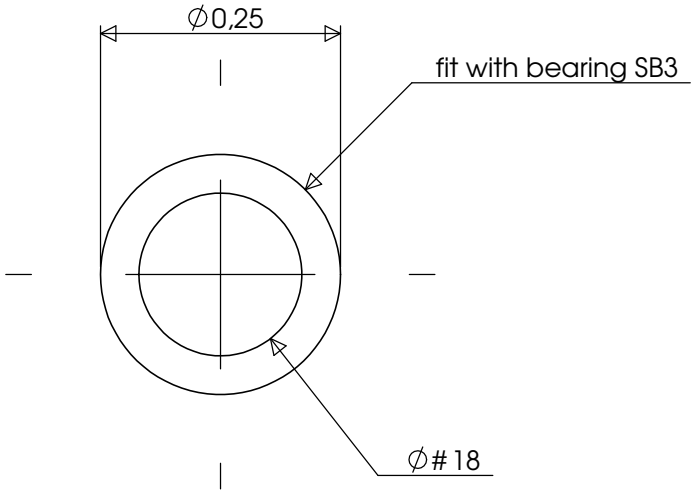
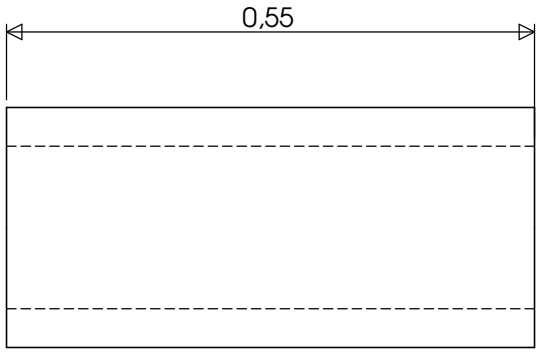
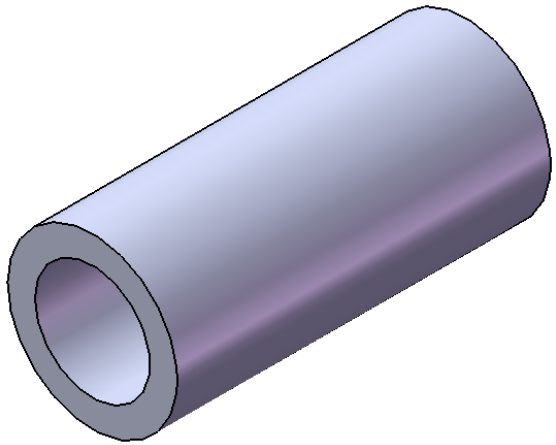
SCALE:2:1	WEIGHT:	page A9







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		MATERIAL standert steel	Q.A.		
			COMMENTS:		
NEXT ASSY	USED ON	FINISH --			
APPLICATION		Scale 1:3			

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measuring torque shaft D1/4 L0.5

SIZE	DWG. NO.	REV.
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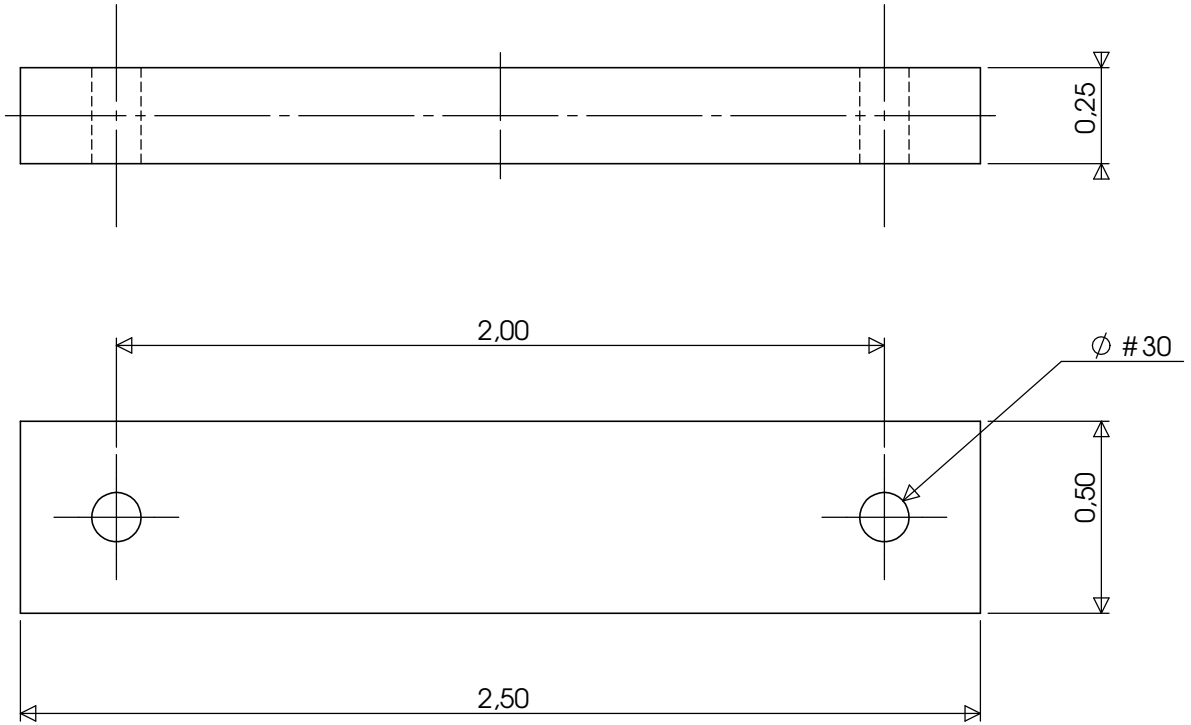
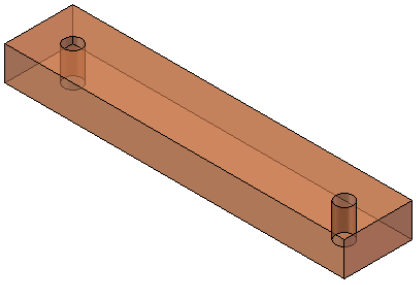
SCALE:5:1	WEIGHT:	page A10





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		MATERIAL polycarbonate	Q.A.		
			COMMENTS:		
NEXT ASSY	USED ON	FINISH --			
APPLICATION		Scale 1:3			

Arizona State Univ

measuring torque strain_gauge_ beam_arrangement

SIZE	DWG. NO.	REV.
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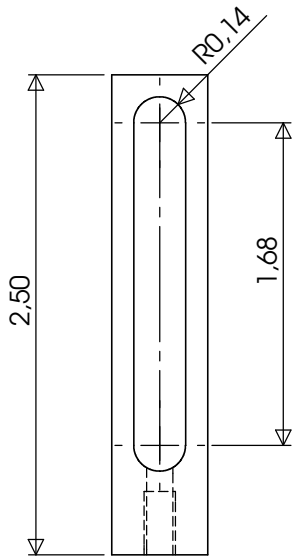
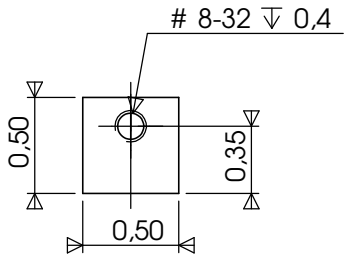
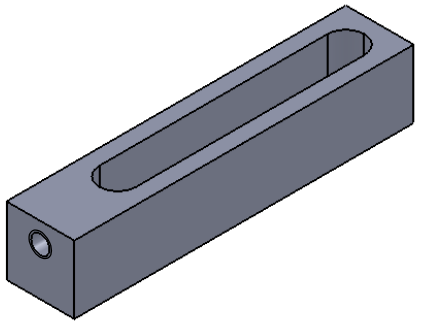
SCALE:2:1 | WEIGHT: | page A11







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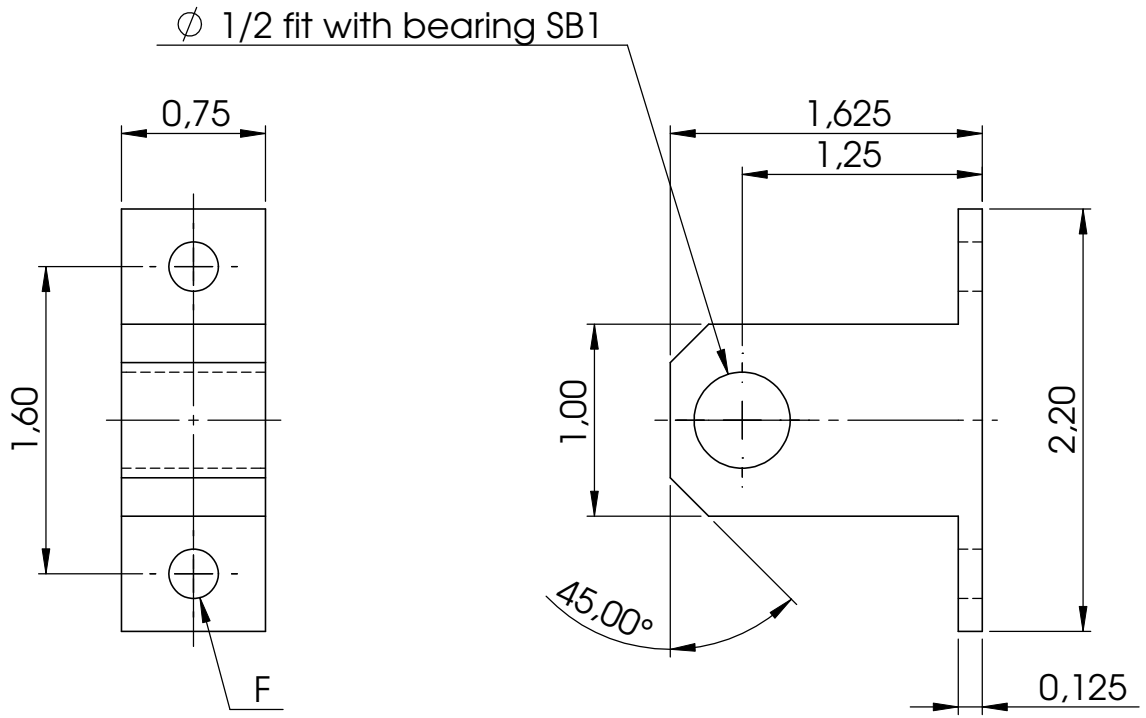
		MATERIAL aluminum	Q.A.		
NEXT ASSY	USED ON	FINISH --	COMMENTS:		
APPLICATION		Scale 1:3			

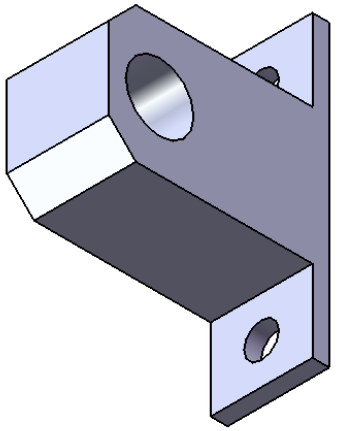
Arizona State Univ

Loadmotor fastener

SIZE	DWG. NO.	REV.
A	2009_TM_004	0

SCALE: 1:1	WEIGHT:	page A12





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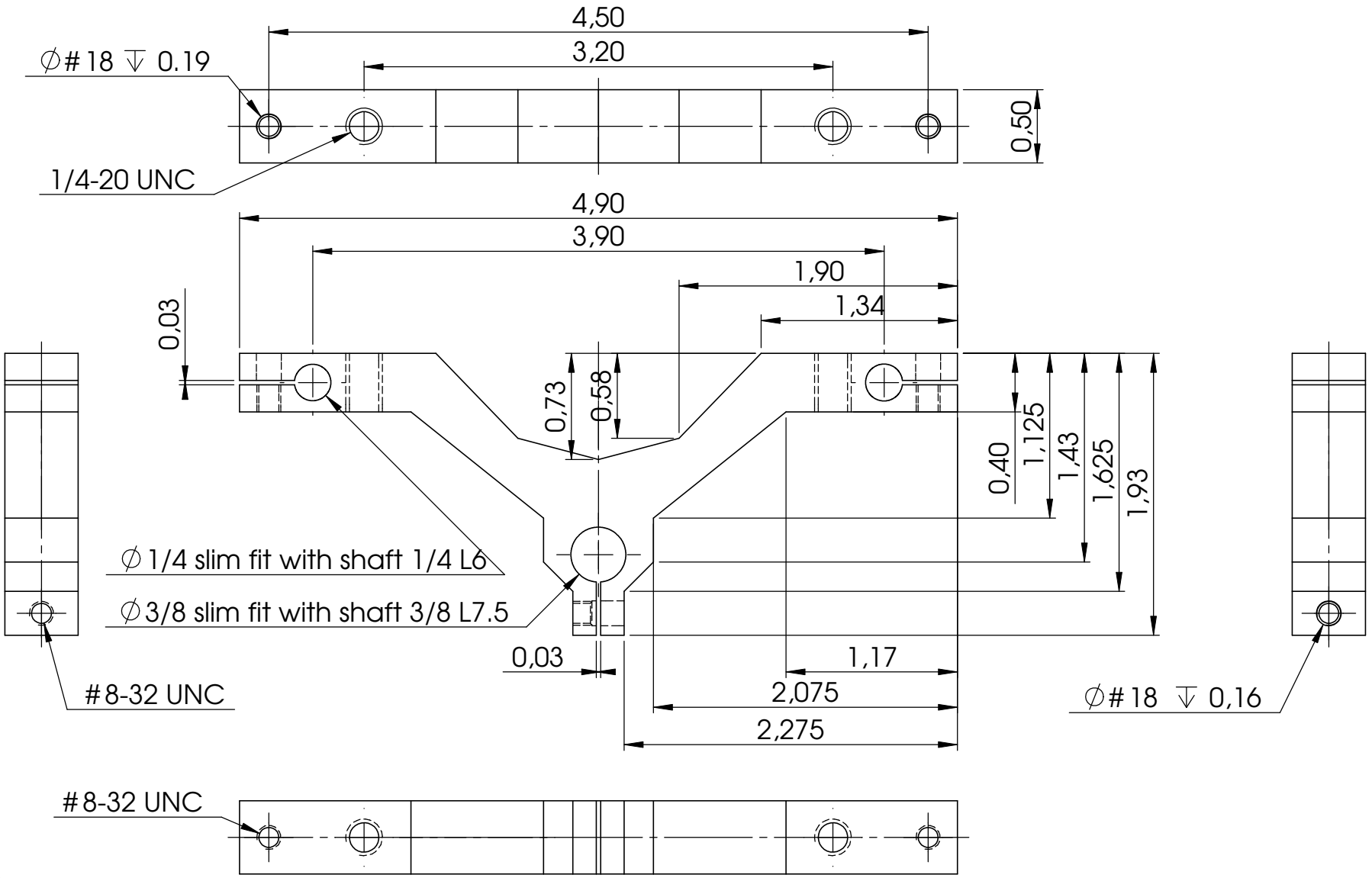
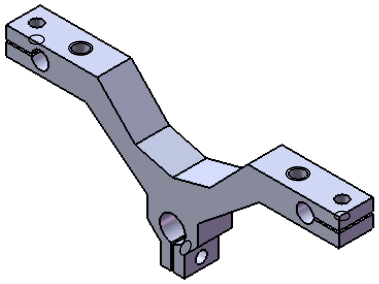
		MATERIAL aluminum	Q.A.		
NEXT ASSY	USED ON	FINISH --	COMMENTS: quantity 2		
APPLICATION		Scale 1:1			

Arizona State Univ

test_plant
fastener_foot

SIZE	DWG. NO.	REV.
A	2009_TP_001	0
SCALE: 1:1	WEIGHT:	page A13





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			MFG APPR.		
		MATERIAL aluminum	Q.A.		
NEXT ASSY	USED ON	FINISH --	COMMENTS: quantity 2		
APPLICATION		Scale 1:2			

Arizona State Univ

test_plant
fixed_bracket

SIZE	DWG. NO.	REV.
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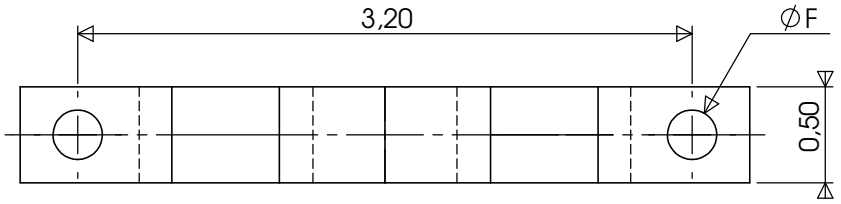
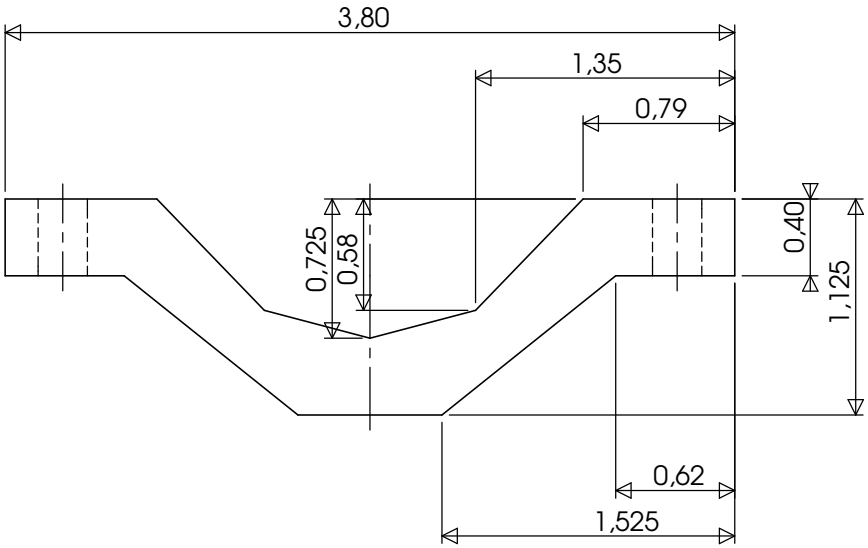
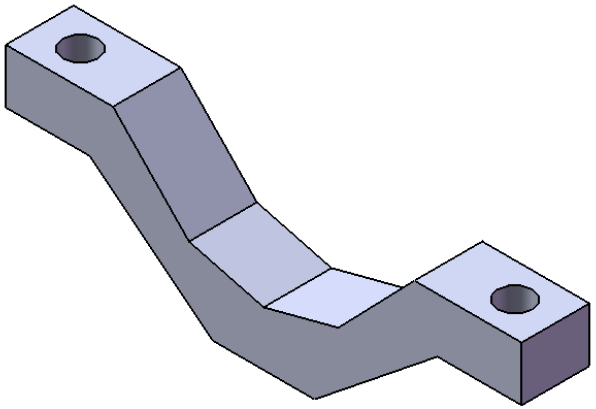
SCALE:1	WEIGHT:	page A14







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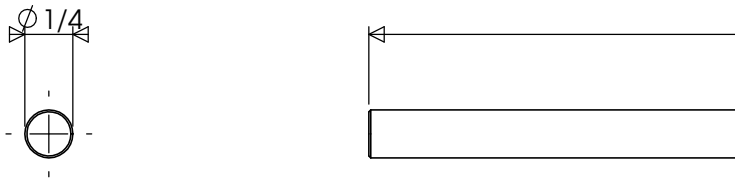
		MATERIAL aluminum	Q.A.		
NEXT ASSY	USED ON	FINISH --	COMMENTS: quantity 2		
APPLICATION		Scale 1:3			

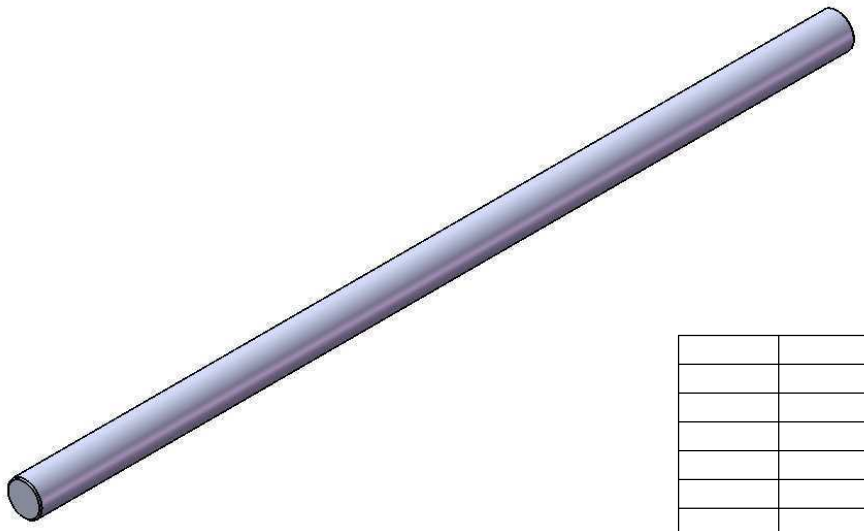
Arizona State Univ

test_plant
flexible_bracket

SIZE	DWG. NO.	REV.
A	2009_TP_003	0

SCALE: 1:1 | WEIGHT: | page A15





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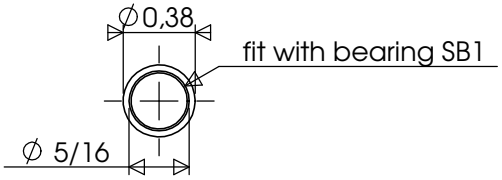
			Q.A.		
		MATERIAL standard steel	COMMENTS: quantity 2		
NEXT ASSY	USED ON	FINISH --			
APPLICATION		Scale 1:3			

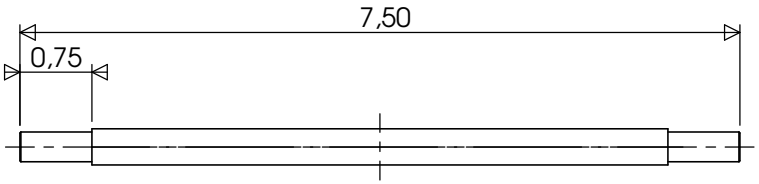
Arizona State Univ

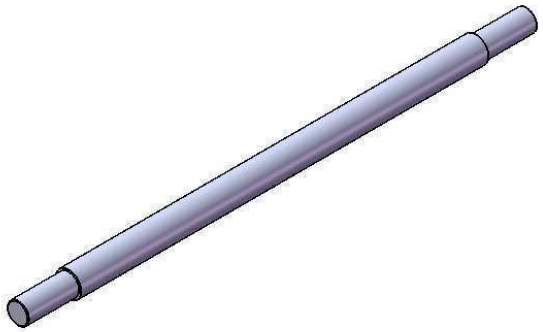
test_plant
shaft_D1/4_L_6

SIZE	DWG. NO.	REV.
A	2009_TP_004	0

SCALE: 1:2 | WEIGHT: | page A16







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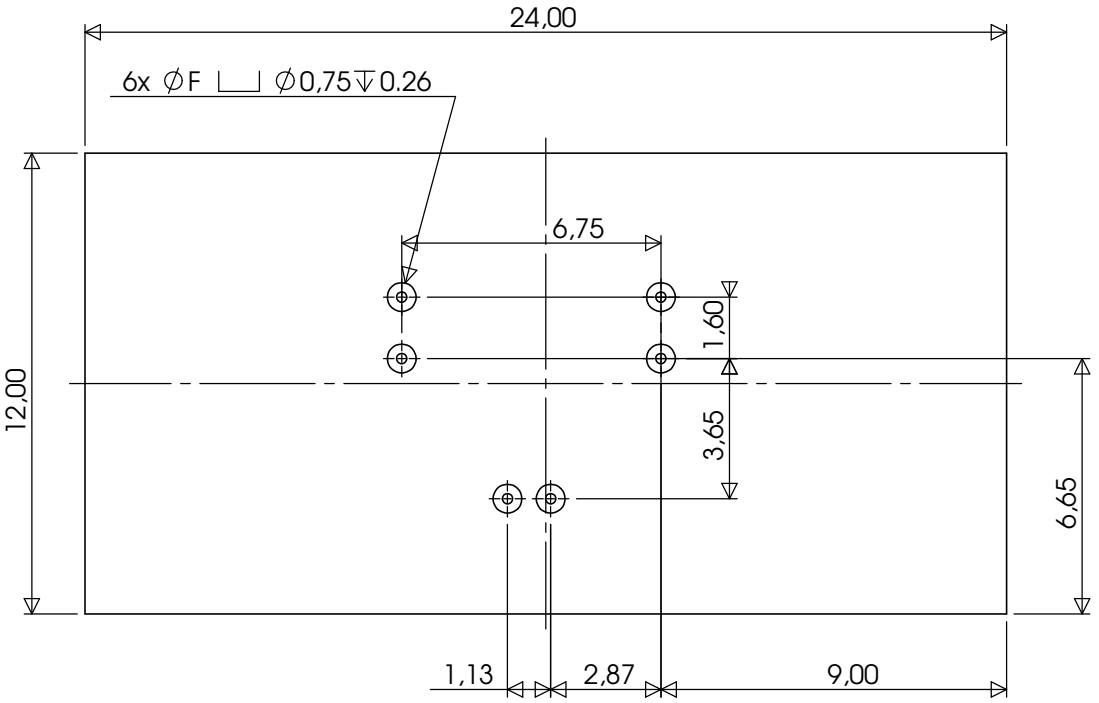
			MFG APPR.		
			Q.A.		
		MATERIAL standard steel	COMMENTS:		
NEXT ASSY	USED ON	FINISH --			
APPLICATION		Scale 1:3			

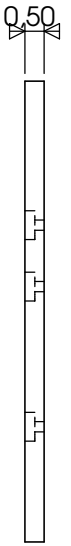
Arizona State Univ

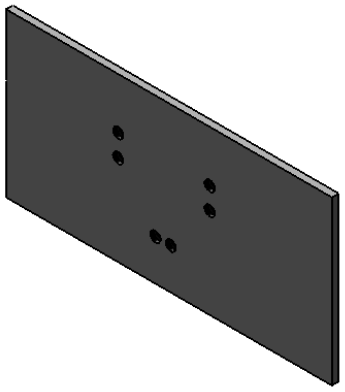
test_plant
shaft_D3/8_L_7.5

SIZE	DWG. NO.	REV.
A	2009_TP_005	0

SCALE: 1:2 | WEIGHT: | page A17







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			MFG APPR.		
		MATERIAL Polyethylene	Q.A.		
NEXT ASSY	USED ON	FINISH --	COMMENTS:		
APPLICATION		Scale 1:3			

Arizona State Univ

test_plant
baseplate

SIZE	DWG. NO.	REV.
A	2009_TP_006	0

SCALE: 1:10 | WEIGHT: | page A18

Tensile stress in the beam

The following calculation is the prove for the statement that the Fyx – Force which produce a additional tensile stress in the beam, is negligible. The Figure 43 show a simplified view of the force path. The black lines in the Figure 43 simulate the moved construction at the maximum torque. To draw the lines the maximum deflection without the influence of the Fyx force is use as a start value.

Given values:

$l = 1.96" \approx 49.8mm$	length from the rotation point to the bottom of the lever
$l_{beam} = 2.5" = 63.5mm$	maximum length of the whole beam
$\beta = 8.87°$	maximum angle of the lever by maximum torque
$M_{max} = 3.5Nm$	maximum Moment
$E = 2.4 \cdot 10^3 \frac{N}{mm^2}$	young's Modulus for polycarbonate
$w = 0{,}50" = 12.7\ mm$	width of the bream
$h = 0{,}25" = 6.35\ mm$	height of the beam
$e = 0{,}125" = 3.175\ mm$	maximum distance from the neutral axis
$[\mathrm{F}] = N$	force from the torque
$[F_Y] = N$	Y –component of the force F
$[\sigma_{max}] = \frac{N}{mm^2}$	maximum stress by maximum torque (Fy)
$[\sigma_{max_{Fyy}}] = \frac{N}{mm^2}$	maximum stress by maximum torque (Fyy)
$[\sigma_t] = \frac{N}{mm^2}$	stress on the strain gage position
$[f] = mm$	deflection of the beam

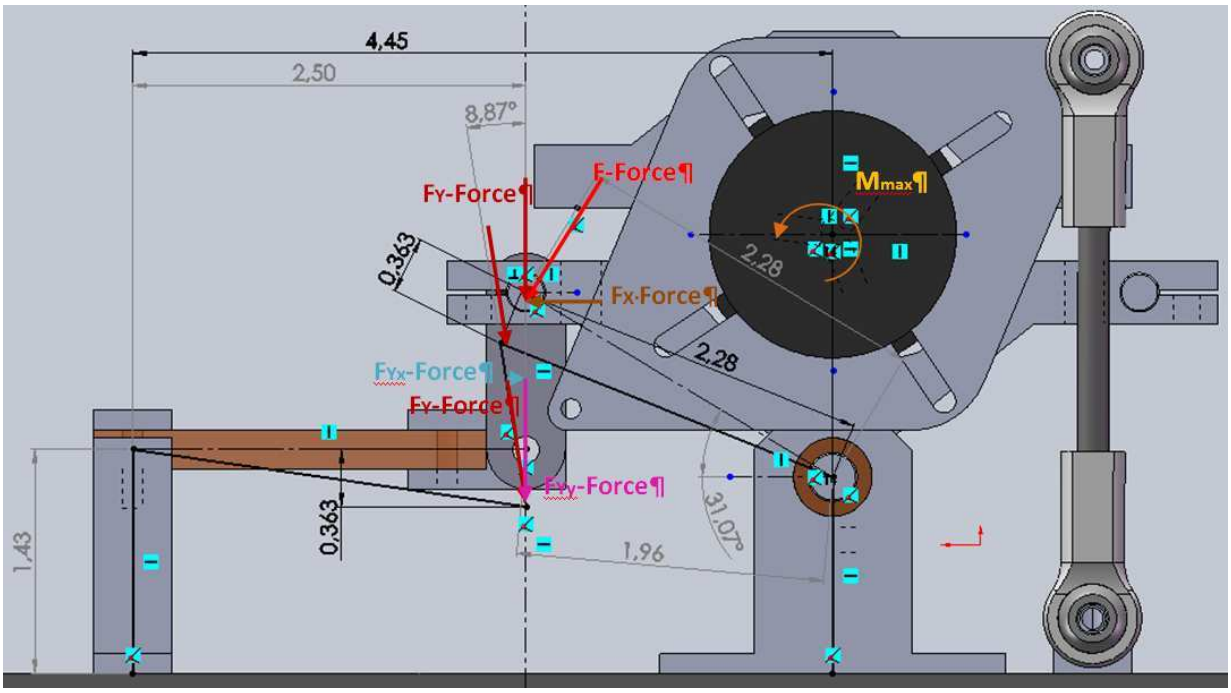


Figure 43: Sketch of the Force path to the beam

Calculation F.1: $\boldsymbol{F_Y}$

Calculate the maximum force which will stress the beam.

$$F_Y = \frac{M_{max}}{l} = \frac{3.5\ Nm}{49.784 \cdot 10^{-3} m}$$

$$\boldsymbol{F_Y \approx 70.3N}$$

Calculation F.2 maximum deflection without the influence of the Fyx force

$$f = -\frac{F_Y \cdot {l_{beam}}^3 \cdot}{3\ E\ I} = -\frac{Fy \cdot {l_{beam}}^3 \cdot 12 \cdot}{3 \cdot E \cdot w \cdot h^3} = -\frac{80.4N \cdot 63.5^3 mm^3 \cdot 12}{3 \cdot 2.4 \cdot 10^3 \frac{N}{mm^2} \cdot 12.7mm \cdot 6.35^3 mm^3}$$

$$\boldsymbol{f = -9.22mm = -0.363}"$$

Calculation F.3: $\boldsymbol{F_{Yx}}$ & $\boldsymbol{F_{Yy}}$ component of the force $\boldsymbol{F_Y}$

$$F_{Yx} = \sin(\beta) \cdot\ F_Y = \sin(8.87°) \cdot 70.3N$$

$$\boldsymbol{F_{YX} \approx 10.8N}$$

$$F_{Yy} = \cos(\beta) \cdot\ F_Y = \sin(8.87°) \cdot 70.3N$$

$$\boldsymbol{F_{Yy} \approx 69.46N}$$

Calculation F.4 comparison of the bend stress

Without the influence of the Fyx force:

$$\sigma_{max} = \frac{M_{Bmax} \cdot e}{I} = \frac{F_Y \cdot l_{beam} \cdot e \cdot 12}{w \cdot h^3}$$

$$\boldsymbol{\sigma_{max} \approx 52.3 \frac{N}{mm^2}}$$

With the influence of the Fyx force

$$\sigma_{max_{Fyy}} = \frac{F_{Yy} \cdot l_{beam} \cdot e \cdot 12}{w \cdot h^3}$$

$$\boldsymbol{\sigma_{max_{Fyx}} \approx 51.68 \frac{N}{mm^2}}$$

The difference of the stress in the beam is negligible small, $\Delta\sigma \approx 0.63 \frac{N}{mm^2}$ and therefore also the strain difference.

Tensile stress in the beam from the influence of the Fyx force.

$$\sigma_t = \frac{F_{Yy}}{w \cdot h} = \frac{13.7N}{12.7mm \cdot 6.35mm}$$

$$\boldsymbol{\sigma_t = 0.134 \frac{N}{mm^2}}$$

The result of the calculation show that the tensile stress which is going to be produced by the Fyx force is also negligible.

Dimension of the beam

The Test plant is designed in the English (Inch) system but the calculations are done in the metric system. The Figure 44 shows the geometry of the test plant with the values of the length.

Given values:

$l = 1.96" \approx 49.8mm$	length from the rotation point to the bottom of the lever
$l_{beam} = 2.5" = 63.5mm$	maximum length of the whole beam
$lb = 1.5" = 38.1mm$	length from the force point to the middle of the beam where the strain gages are mounted
$M_{max} = 3.5Nm$	maximum Moment
$E = 2.4 \cdot 10^3 \frac{N}{mm^2}$	young's Modulus for polycarbonate
$\sigma_{max} = 63 \frac{N}{mm^2}$	maximum stress which the polycarbonate can handle
$\varepsilon_{max} = 3\%$	maximum strain which the strain gages can handle
$F_Y = 70.3N$	Y –component of the force F, from Calculation F.1
$[\sigma_b] = \frac{N}{mm^2}$	stress on the strain gage position
$[I] = mm^4$	moment of inertia
$[h] = mm$	height of the beam
$[w] = mm$	width of the bream
$[e] = mm$	maximum distance from the neutral axis
$[f] = mm$	deflection of the beam

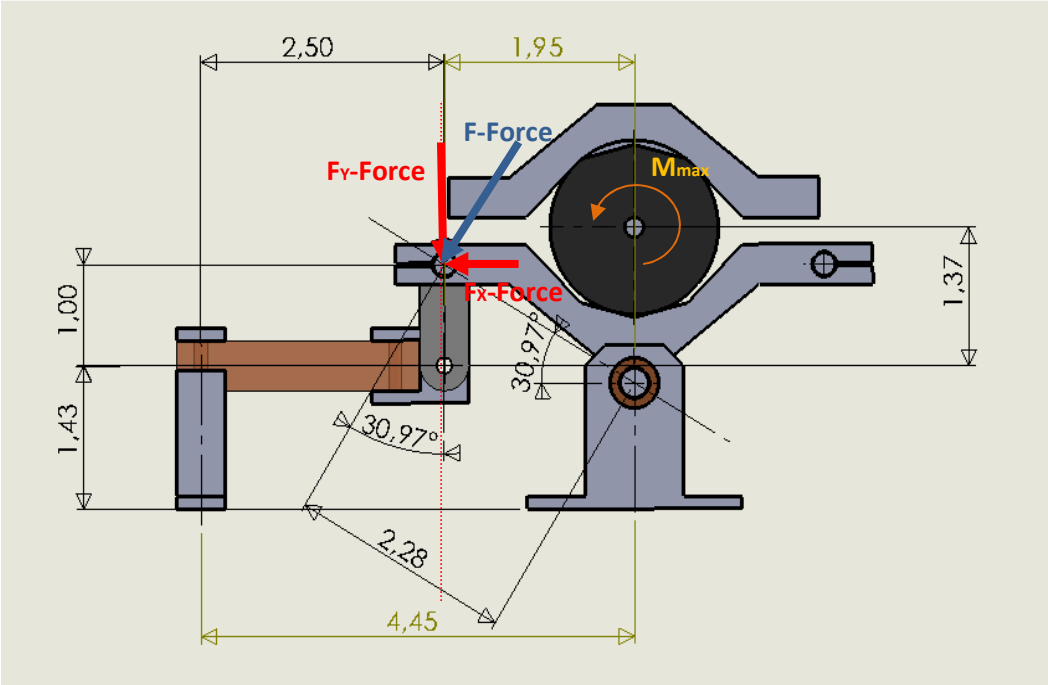


Figure 44: geometry of the construction

Calculation B.1: maximum strain

The maximum strain is calculated in the strain gages. The strain must be less then $\varepsilon_{max} = 3\%$ and more than $\varepsilon_{min} = 1\%$. If the strain is too much the strain gages will be damaged. If the strain is too low, the range of the measurement is too small and will not be reliable.

Given values:

$\sigma_b = \frac{F_Y \cdot lb \cdot e \cdot 12}{w \cdot h^3}$ from Calculation B.3

$E = 2.4 \cdot 10^3 \frac{N}{mm^2}$ Young's Modulus of Polycarbonate

$$\varepsilon = \frac{\sigma_b}{E} = \frac{F_Y \cdot lb \cdot e \cdot 6}{E \cdot w \cdot h^3} = \frac{70.3N \cdot 38.1\,mm \cdot 3.175mm \cdot 12}{2.4 \cdot 10^3 \frac{N}{mm^2} \cdot 12.7mm \cdot 6.35^3 mm^3}$$

$\varepsilon \approx 0.013$

$\boldsymbol{\varepsilon_{min} = 1\% \leq \varepsilon = 1.3\% < \varepsilon_{max} = 3\%}$

Calculation B.3 break strength

The maximum stress is calculated to determine if the beam will break

$$\sigma_{max} = \frac{M_{Bmax} \cdot e}{I} = \frac{F_Y \cdot l_{beam} \cdot e \cdot 12}{w \cdot h^3}$$

$$\boldsymbol{\sigma_{max} \approx 52.3 \frac{N}{mm^2}}$$

Safety factor **s=1.2**

$$\boldsymbol{\sigma_{safty} = \sigma_{allowed} \cdot s = 63 \frac{N}{mm^2} \cdot 1.2}$$

$$\boldsymbol{\sigma_{safty} = 52.5 \frac{N}{mm^2}}$$

$$\boldsymbol{\sigma_{max} = 52.3 \frac{N}{mm^2} \leq \sigma_{safty} = 52.5 \frac{N}{mm^2}}$$

The maximum stress is lower than the yield strength, so the beam will not break.

Calculation B.4 σ_b

$$\sigma_b = \frac{M_B \cdot e}{I}$$

$$\boldsymbol{\sigma_b = \frac{F_Y \cdot lb \cdot e \cdot 12}{w \cdot h^3}}$$

Geometry of the rectangular cross section of the beam:

The geometry of the rectangular cross section is shown in Figure 45. The section is checked using the stress and strain calculations.

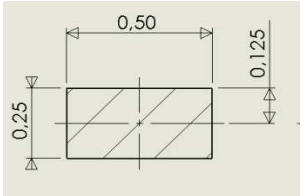


Figure 45: quadratic cut surface of the beam

$e = 0{,}125" = 3.175\ mm$

$w = 0{,}50" = 12.7\ mm$

$h = 0{,}25" = 6.35\ mm$

$$I = \frac{w \cdot h^3}{12}$$

Proportional factor k_{M-R}

The gain factor between the Torque and the resistance change in the strain gage is calculated.

Given values:

$E = 2.4 \cdot 10^3 \frac{N}{mm^2}$	young's Modulus for polycarbonate
$h = 6.35\ mm$	height of the beam
$w = 12.7\ mm$	width of the bream
$e = 3.175\ mm$	maximum distance from the neutral axis
$l \approx 49.8mm$	length from the rotation point to the bottom of the lever
$lb = 38.1mm$	length from the force point to the middle of the beam where the strain gages are going to be placed
$F_Y = 70.3N$	Y –component of the force F, from Calculation F.1
$[\mathrm{F}] = N$	force from the torque
$[\sigma_b] = \frac{N}{mm^2}$	stress on the strain gage position
$R\ = 350\ \Omega$	normal resistor value of the strain gage top side
$k_{constantan} = 2.05$	material factor of the strain gages
$[\Delta R]\ = \Omega$	variable resistor value of the strain gages

---

The resistance change in the strain gages depends on the material of the strain gage and the strain which is in the strain gage. The following formal, $\Delta\mathrm{R} = \mathrm{R} \cdot \mathrm{k} \cdot \varepsilon$ [1] is used to calculate the resistance change.

Variation of the resistor value created by the strain

$$\Delta \boldsymbol{R} = \boldsymbol{R} \cdot \boldsymbol{k} \cdot \boldsymbol{\varepsilon}$$

The relationship of the supplied torque to the strain is calculated. The strain in the beam is:

$$\varepsilon = \frac{\sigma}{E}$$

$$\Delta \boldsymbol{R} = \boldsymbol{R} \cdot \boldsymbol{k} \cdot \frac{\boldsymbol{\sigma_b}}{\boldsymbol{E}}$$

Set $\sigma_\mathrm{b} = \frac{\mathrm{F_Y \cdot lb \cdot e \cdot 12}}{\mathrm{w \cdot h^3}}$ from calculation B.4

$$\Delta R = R \cdot k \cdot \frac{F_Y \cdot lb \cdot e \cdot 12}{E \cdot w \cdot h^3}$$

1 Friedrichstabellenbuch, page 8-14 Dehnungsmessstreifen

The next step is to replace the F_Y with $F_Y = \frac{M}{l}$

$$\Delta R = R \cdot k \cdot \frac{M \cdot lb \cdot e \cdot 12}{l \cdot E \cdot w \cdot h^3}$$

$$\Delta R = M \cdot \left[k \cdot \frac{R}{l} \cdot \frac{lb \cdot e \cdot 12}{E \cdot w \cdot h^3}\right]$$

$$M = \Delta R \cdot \frac{1}{\left[k \cdot \frac{R}{l} \cdot \frac{lb \cdot e \cdot 12}{E \cdot w \cdot h^3}\right]}$$

$$\boldsymbol{M = \Delta R \cdot k_{M-R}}$$

Calculation of the value of the Proportional factor k_{M-R}

$$k_{M-R} = \frac{1}{\left[k \cdot \frac{R}{l} \cdot \frac{lb \cdot e \cdot 12}{E \cdot w \cdot h^3}\right]}$$

$$k_{M-R} = \frac{1}{\left[2.05 \cdot \frac{350\Omega}{49.8 \cdot 10^{-3} m} \cdot \frac{38.1mm \cdot 3.175\, mm \cdot 12}{2.4 \cdot 10^3 \frac{N}{mm^2} \cdot 12.7\, mm \cdot 6.35^3 mm^3}\right]}$$

$$\boldsymbol{k_{M-R} \approx 0.373 \frac{Nm}{\Omega}}$$

Measurement circuit

Calculation MC.1 : measurement bridge

The following calculation is used to determine the maximum voltage difference. Figure 46 shows the circuit of the measurement bridge.

Given values:

$R = 350\ \Omega$	normal resistor value of the strain gage top side
$[\Delta R] = \Omega$	variable resistor value of the strain gages
$[\Delta R_{max}] = \Omega$	maximum variable resistor value of the strain gages
$R_1 = R \mp \Delta R$	resistor value of the strain gage top side
$R_4 = R \mp \Delta R$	resistor value of the strain gage bottom side
$R_2 = R_3 = 350\ \Omega$	compare resistors
$\Delta R_{max} = 21.525\Omega$	value from Calculation MC.2
$\mathrm{U_{bridge}} = 1.63\mathrm{V}$	value from Calculation MC.3
$[U_{diff}] = V$	voltage difference in the bridge

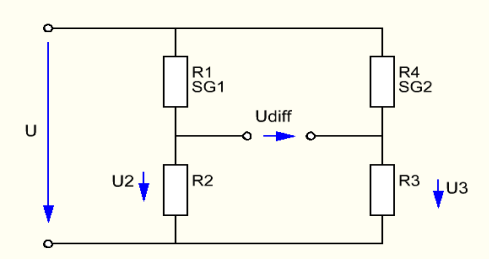


Figure 46: measurement bridge

$$U_{diff} = U_3 - U_2$$

$$U_{diff} = U_{bridge} * \left(\frac{R_3}{R_3 + R_4} \cdot \frac{R_2}{R_2 + R_1}\right)$$

$$U_{diff} = U_{bridge} * \left(\frac{R}{2R - \Delta R} - \frac{R}{2R + \Delta R}\right)$$

$$U_{diff} = U_{bridge} * \left(\frac{2R \cdot \Delta R}{4R^2 - \Delta R^2}\right)$$

$$U_{diff} = 1.63V * \left(\frac{2 \cdot 350\Omega \cdot 21.5\Omega}{4 \cdot 350^2 - 21.5^2}\right)$$

$$\boldsymbol{U_{diff} = 0.05V}$$

Calculation MC.2: $\Delta \boldsymbol{R_{max}}$

The calculation MC.2 determines the maximum resistor change of the strain gages.

Given values:

$R_{SG} = 350\Omega$	Resistor value of the strain gage
$\Delta \mathrm{R}_{\max}$	maximum resistor variation of the strain gage
$\frac{\Delta \mathrm{l}}{\mathrm{l}} = \varepsilon$	Strain
$[k_{constantan}] = 2.05$	material factor of the strain gages

$$\frac{\Delta R}{R} = k \cdot \frac{\Delta l}{l} = k \cdot \varepsilon$$

$$\Delta R_{max} = R \cdot k \cdot \varepsilon_{max} = 350\Omega \cdot 2.05 \cdot 0.03$$

$$\boldsymbol{\Delta R_{max} = 21.525\Omega}$$

Calculation MC.3 U_{bridge}

The bridge is supplied by the 10V reference voltage of the instrumentation amplifier. The maximum current of the reference supply has to be less than 5mA. The maximum resistor value of the bridge is only R_{bright}=350 Ω. To decrease the current it is necessary to add additional resistors to the bridge to get a bigger load, see circuit Figure 47.

Given values:

$R_5 = R_6 = 900\Omega$	additional resistor
$I_{max} \approx 5mA$	maximum current for the reference power supply
$U_{ref} = 10V$	voltage from the reference power supply
$R_{bridge} = 350\Omega$	resistor value of the whole bridge
$[I_3] = mA$	current for the measurement bridge

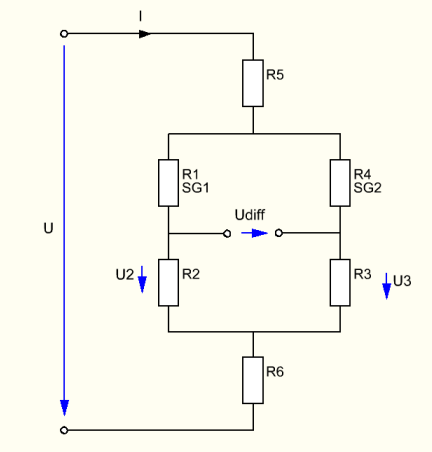


Figure 47: measurement bridge with additional resistor

$$I_3 = \frac{U}{R_{brigde}+R_5+R_6} = \frac{10V}{2150\Omega}$$

$$I_3 = \mathbf{4,65mA} \leq \boldsymbol{I_{max}} = \mathbf{5mA}$$

With the additional resistor the supply voltage for the measure bridge will be about:

$$U_{bridge} = I \cdot R_{brigde} = 4.65mA \cdot 350\ \Omega$$

$$\boldsymbol{U_{bridge}} = \mathbf{1.63V}$$

Calculation MC.4 Offset voltage:

The amplifier is supplied +12V and -12V. The maximum output signal of the amplifier can reach plus or minus 12V. The problem is that the microchip can only read positive values. It is necessary to split the positive range of the output signal and put a psuedoground to the amplifier. To get the 6V for the psuedoground a voltage divider circuit is used, see Figure 48. The voltage divider is supplied by the reference voltage of the instrumentation amplifier. It is important that the current is less than 1 mA.

Given values:

$I_2 = 1mA$	current for the voltage divider for the offset voltage
$U_{ref} = 10V$	voltage from the reference power supply
$[R_7] = \Omega$	resistor
$[R_8] = \Omega$	resistor
$[R_{7\&8}] = \Omega$	resistor value of the whole voltage divider

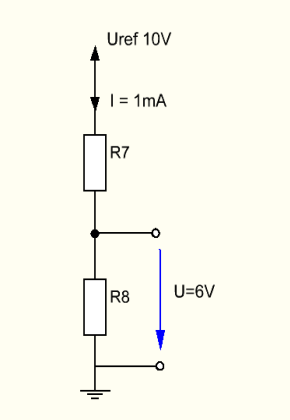


Figure 48: voltage divider, offset voltage

$$R_{7\&8} = \frac{U_{ref10V}}{I} = \frac{10V}{1mA} = \mathbf{10k\Omega}$$

$$R_8 = \frac{U_{6V}}{I} = \frac{6V}{1mA}$$

$\boldsymbol{R_8 = 6k\Omega}$ **select value** $\boldsymbol{R_8 = 6.04k\Omega}$

$$R_7 = R_{7\&8} - R_{7\&8}$$

$\boldsymbol{R_7 = 3.96k\Omega}$ **select value** $\boldsymbol{R_8 = 3.92k\Omega}$

Calculation MC.5 gain resistor RG

The maximum differential voltage of the measurement bridge is ± 0.05V. The maximum of the output voltage of the amplifier should be about ± 5V. The gain has be G = 100. To calculate the resistor for the gain, the formula from the datasheet can be used:

Given values:

$G = 100$

$[RG] = \Omega$ gain resistor

$$G = 4 + \frac{60k\Omega}{RG}$$

$$RG = \frac{60k\Omega}{G - 4} = \frac{60k\Omega}{100 - 4}$$

$\boldsymbol{RG = 625\Omega}$ **select value** $\boldsymbol{RG = 619\Omega}$

Calculation MC.6 microchip protection:

For the microchip input it is important that the level of voltage is less than 3.3V and the current should not be more than 2mA. Figure 49 shows the schematic.

Given values:

$U_{in} = 12V$	maximum output voltage from the instrumentation amplifier
$U_{out} = 3.3V$	maximum voltage for the input signal for the dsPIC
$I_4 = 2mA$	maximum current for the input signal for the dsPIC

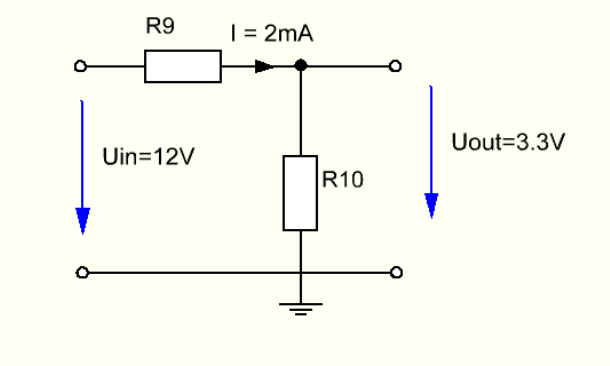


Figure 49: voltage divider / input protection

$$R_9 = \frac{U_{in} - U_{out}}{I_4} = \frac{12V - 3.3V}{2mA}$$

$\boldsymbol{R_9 = 4350\Omega}$ **select value** $\boldsymbol{R_9 = 4.42k\Omega}$

$$U_{out} = U_{in}\frac{R_{10}}{R_9 + R_{10}}$$

$$R_{10} = \frac{R_9 \cdot U_{out}}{U_{in}} \cdot \frac{1}{1 - \frac{U_{out}}{U_{in}}}$$

$\boldsymbol{R_{10} = 1676\Omega}$ **select value** $\boldsymbol{R_{10} = 1.69k\Omega}$

QEI_test_plant.c

```
#include <p33FJ256MC710.h> // QRI  HCTL2032

/*****************************************************************************
SPEED MEASUREMENT
*****************************************************************************/
// Config_QEI for speed measurement_____________________________________________

void QEIInit_speed(void)
   {
   // ConFigure I/O Ports
   AD1PCFGL = ADPCFG | 0x0038;      // Disable the A/D pins 3, 4 and 5
   AD2PCFGL = ADPCFG | 0x0038;      // Disable the A/D pins 3, 4 and 5
   TRISB = TRISB | 0x38;            // conFigure pins 3, 4 and 5 as inputs
   //QEI configuration register
   POSCNT = 0;                      // Set Current Position to 0
   MAXCNT = 360*2; //1000;          // Use QEI in 2x mode and 360 counts by roll
   DFLTCON = 0x0190;                // Digital filter set to on and 0 (3count), Count Error Interrupt
                                    Disable
   QEICON = 0;
   QEICONbits.QEIM = 5;             // x2 resolution and reset by MAXCNT pulse
   QEICONbits.POSRES = 1;           // doesn't Allow Index pulse to reset counter
   QEICONbits.SWPAB = 0;            // direction
   //ConfigIntQEI
   IEC3bits.QEIIE = 1;              // Enable QEI interrupt
   IPC14bits.QEIIP = 2;             // Interrupt priority level 2
   }     // QEIInit_speed
```

```
// Speed function_____________________________________________________________

double GetQEI_speed()
    {
    extern volatile int ct_turns;
    int count;
    int turn;
    count = POSCNT;
    POSCNT = 0;
    turn = ct_turns;
    ct_turns = 0;
    return (double)turn * MAXCNT + count;
    //return (double) POSCNT;
    }     // GetQEI_speed
//___________________________________________________________________________

/*****************************************************************************
POSITION / ROLL MEASUREMENT
*****************************************************************************/
// Config_QEI for position measurement_____________________________________

void QEIInit_roll(void)
    {
    // ConFigure I/O Ports
    AD1PCFGL = ADPCFG | 0x0038              // Disable the A/D pins 3, 4 and 5
    AD2PCFGL = ADPCFG | 0x0038;             // Disable the A/D pins 3, 4 and 5
    TRISB = TRISB | 0x38;                   // conFigure pins 3, 4 and 5 as inputs
    //QEI configuration register
    POSCNT = 0;                             // Set Current Position to 0
    MAXCNT = 360*2; //1000;                 // Use QEI in 2x mode and 360 counts by roll
    DFLTCON = 0b00000001100000;             // Digital filter set to on and 0 (3count), Count Error
                                            Interrupt Disable
    QEICON = 0;
    QEICONbits.QEIM = 5;                    // x2 resolution and reset by MAXCNT pulse
    QEICONbits.POSRES = 1;                  // doesn't Allow Index pulse to reset counter
```

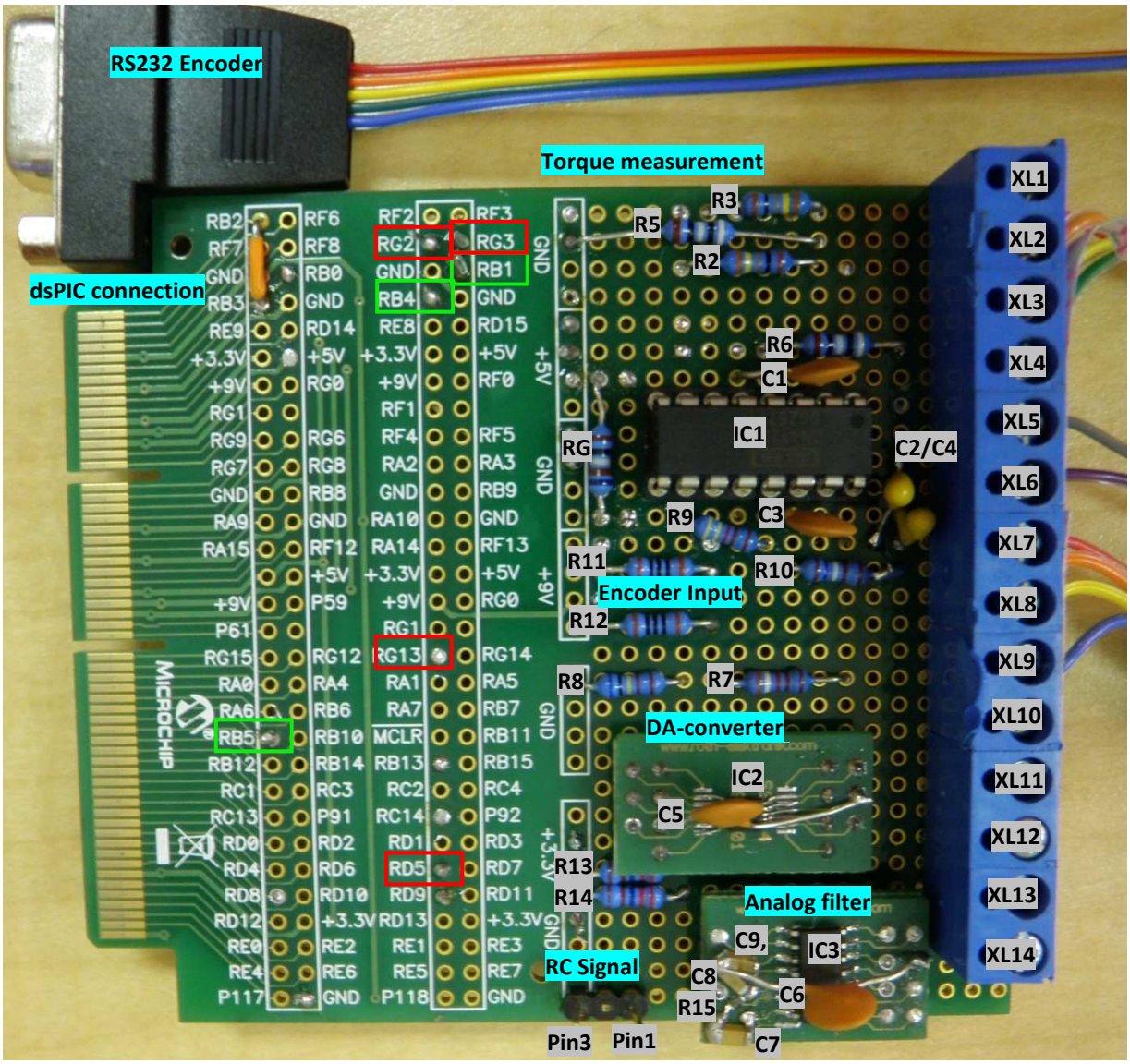
```
    QEICONbits.SWPAB = 0;                   // direction
    //ConfigIntQEI
    IEC3bits.QEIIE = 1;                     // Enable QEI interrupt
    IPC14bits.QEIIP = 2;                    // Interrupt priority level 2
    } // QEIInit_roll

// Roll function_____________________________________________________________

double GetQEI_roll()
    {
    extern volatile int ct_turns;
    return (double) ct_turns * MAXCNT + POSCNT;
    //return (double) POSCNT;
    }
//_____________________________________________________________________________
/* Interrupts----------------------------------------------------------------------------------------------------*/

void __attribute__((__interrupt__)) _QEIInterrupt(void)
{
    extern volatile int ct_turns;
    if (QEICONbits.UPDN ==  1)              // if it overflowed
    {
    ct_turns++;                             //  direction increment or decrement the roll counter
    }
    else
    {
    ct_turns--;
    }
    IFS3bits.QEIIF = 0;                     // clear the interrupt flag
}
```

In-Output circuit board



Connection terminal	
XL1	R1 / Strain gage
XL2	R1 / Strain gage
XL3	R4 / Strain gage
XL4	R4 / Strain gage
XL5	+12V
XL6	-12V
XL7	+5V / Encoder
XL8	CH A / Encoder
XL9	CH B / Encoder
XL10	GND / Encoder
XL11	Analog output A
XL12	Analog output B
XL13	GND / Analog
XL14	free

RS232 Encoder cable	
Pin1	A
Pin3	B
Pin5	Index
Pin8	+5V
Pin9	GND
Pin2/5/7/8 not used	

Connection RC Signal	
Pin1	Signal
Pin2	+ /not used
Pin3	GND

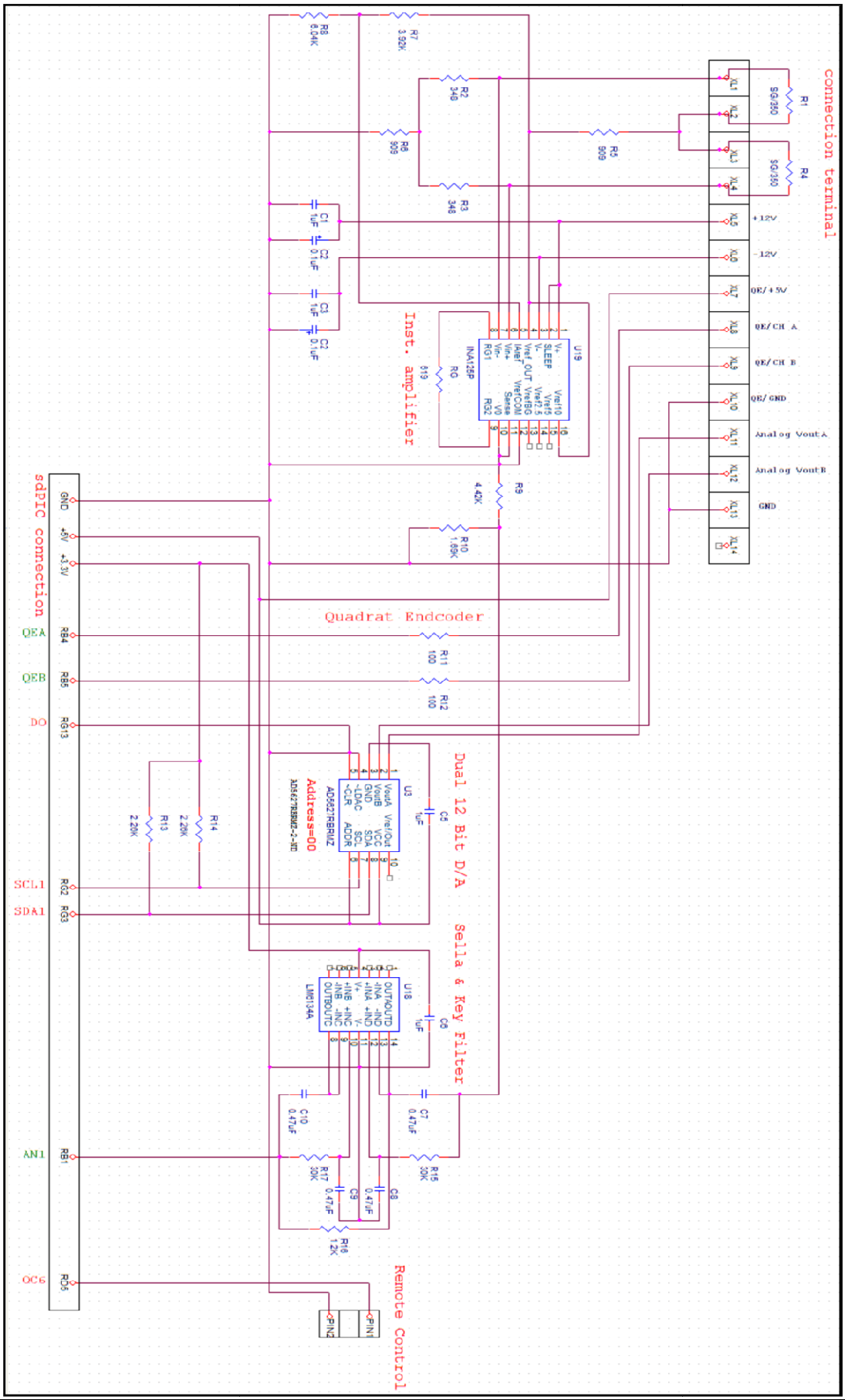
sdPIC - Inputs	
RB1	Torque M.
RB4	Encoder CH A
RB5	EncodeCH B

sdPIC - Outputs	
RD5	Remote Signal
RG2	I²C / SCL1
RG3	I²C / SDA1
RG13	Reset / AD5627R

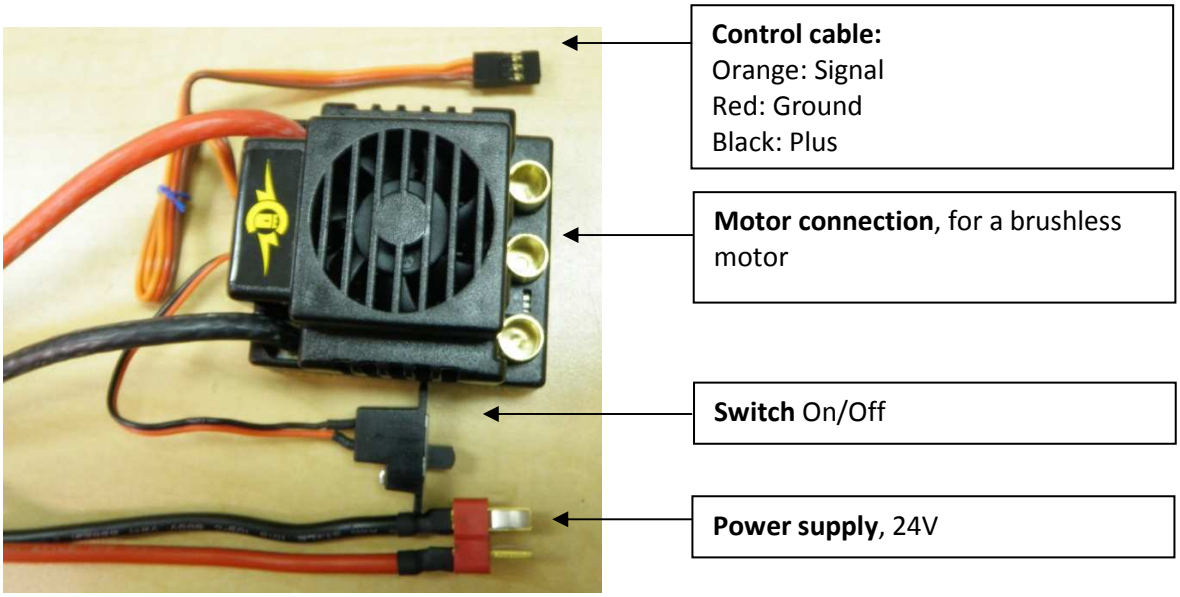
Filter Components/SMD	
Top layer	
C7/C8	0.47µF
C9	0.47µF
R15	30k
Bottom layer	
C10	0.47µF
R16	1.2kΩ
R17	30kΩ

Components	
R2/R3	348Ω
R5/R6	909Ω
R7	3.92kΩ
R8	6.04kΩ
R9	4.42kΩ
R10	1.69kΩ
R11/R12	100Ω
R13/R14	2.26kΩ
RG	619 Ω
IC1	INA 125P
IC2	AD5627R
IC3	LM6134
C1/C3	1µF
C2/C4	0.1µF
C5/C6	1µF

Schematic plan In- Output circuit board



Mamba Monster controller



Mamba Monster, amplifier controller