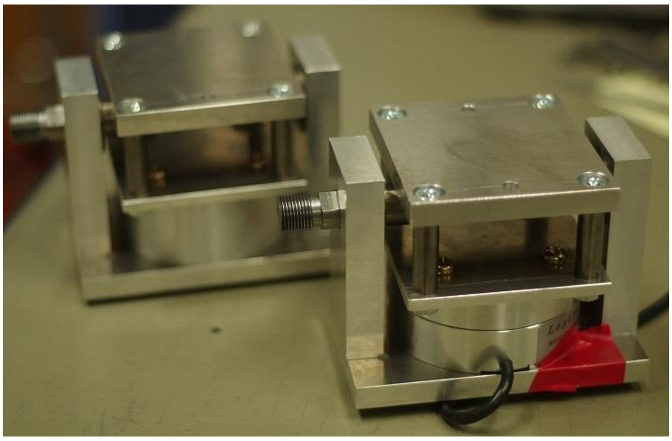
Internship Report :

Design of a pedal-type 6-axis sensor (Leptrino) destined to analyse the forces put at stake during the cycling movement



Supervisor: Kobayashi-sensei

6th April 2015 – 26th June 2015

Akita National Institute of Technology

I would like to thank the people who allowed me to make this internship in Japan in Akita National College of technology.

First of all, I would like to thank the director of Akita's Kosen to have welcomed me in his establishment for these three months. I also wish to thank Doctor Nishino for the organisation of this exchange, for his availability and his daily support.

My thanks also go to Ms Harumi Ito for her Japanese classes which allowed me to discover new things and improve my skills in this, at the same time complex and beautiful, language.

I would like to thank my workgroup, Akatasan and Kusakaisan, for all the accomplished things and for all the explanations and the exchanged advices.

A particular thanking to Kobayashi-sensei, my supervisor during this internship, who accompanied me for this three months in my researches, my realisations and the working method.

Finally I would like to thank all my friends of the Kosen for all the good moments together and for the good memories and stories that I won't stop reminding. Many thanks to Kaisan, Takerusan and Narasan for making me discover your culture and thank you Phil for the help you gave me to the everyday life and for the people I met thanks to you.

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Glossary

- Kosen: An abbreviation for "Koutou Senmon Gakkou" which means Institute of Technology

- 6-axis sensor: Device capable of measuring the forces and the torques on the 6-axis system

- Leptrino: The Japanese brand of the 6-axis sensor we used for our project

- FES: The acronym stand for Functional and Electrical Stimulation which is a field of biomechanics using muscle stimulation devices, for people suffering from spinal cords and other paralysis.

- Biomechanics: It is the study of the structure and function of any biological system such as humans by means of mechanics science.

- Rpm: round per minute

Introduction

I carried out my internship in Akita's National Institute of Technology (Kosen) from the 6th of April to the 26th of June 2015. During those three months I had the chance to become part of the mechanics laboratory specialised on cycling directed by Kobayshi-sensei. The theme of my internship was the study of the forces and moments put at stake when pedalling a road bike by the means of a 6-axis sensor (Leptrino). The goal of this study was to quantify and analyse the forces applied by the person riding the bike according to his position during the movement in order to determine an ideal position. For this to be possible, our workgroup had first to discuss about the design and the acceptable solutions for the realisation of our pedal containing the sensor. Once the conception was finished, Kobayashi-sensei was able to order all the necessary equipment for the machining and the assembly. Most of our work went on the design and the machining of the parts we needed to build our pedal-type sensor. We were able to test if it worked and if it could be used for further experiments after the assembly was finished.

My workgroup was composed by two 5th grade students, Akatasan and Kusakaisan, and myself, supervised by Kobayashi-sensei.

Presentation of the university:

The Akita National college of Technology is a college destined to prepare students for an eventual university after 5 years of studies. It is a college where students from 15 to 20 years old are prepared on theoretical and practical basis on several specialities:

- Mechanical engineering
- Computer science and electronics
- Civil engineering
- Chemistry

The lectures are composed on communication skills, languages (Japanese, English and German) and finally the subjects related to the chosen formation. For example, mechanical engineering students follow Material science, structure science, mechanics, and thermodynamics courses.

The campus is organised so that every speciality has its own building and laboratory. Moreover, the laboratories are equipped as more as possible in order to allow the students to learn and obtain as much skill as possible in the path they eventually want to take. The lectures usually begin at 8h50 in the morning and finish at 16h. Though, it is possible for students to stay in their laboratories to study or to make researches until 18h. Some of those laboratories are available for students during the weekend if they need to finish any work.

As an international exchange student, I had a different schedule compared to the other students. In fact, my only lecture was the Japanese language class which I attended three times a week. I could use the laboratory at any time and any day of the week. Though, my supervisor and I organised a schedule which I followed in order to work with my project team.

For the first four weeks, the schedule below was the one I followed:

<table>
<tr><th>Schedule</th><th>Monday</th><th>Tuesday</th><th>Wednesday</th><th>Thursday</th><th>Friday</th></tr>
<tr><td>8h50-10h20</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>10h30-12h</td><td></td><td></td><td></td><td>Japanese</td><td></td></tr>
<tr><td>12h50-14h20</td><td></td><td>Japanese</td><td>Japanese</td><td rowspan="2">Mechanics Lab</td><td></td></tr>
<tr><td>14h30-16h</td><td></td><td>Mechanics Lab</td><td>Mechanics Lab</td><td></td></tr>
</table>

In the beginning if may, this schedule changed because our team needed to use the workshop for our project. The workshop was available only on Wednesday and Friday from 13h to 16h30:

<table>
<tr><th>Schedule</th><th>Monday</th><th>Tuesday</th><th>Wednesday</th><th>Thursday</th><th>Friday</th></tr>
<tr><td>8h50-10h20</td><td></td><td></td><td></td><td></td><td rowspan="2">Workshop</td></tr>
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<tr><td>14h30-16h30</td><td></td><td></td><td>Workshop</td><td></td><td></td></tr>
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The workshop was available for any mechanical and civil engineering students. It was opened from 8h50 until 17h during the week. The standards rule were to wear a jacket anywhere inside the workshop, glasses while the machining process was in progress and clean the shaving after the use of the machines. I noticed that the last rule was the most important. In fact, many brushes, brooms and vacuum cleaners were arranged all around the place for the students to clean after their work is finished. The safety footwear were not imposed though.

Turning Machines

The lab offers a large choice of tools and machines. Most of them are traditional machines as the students in this Kosen use most of the time those kind of machines rather that the automatic-types. Even though, there are two automatic turning machines.

Such as the turning machines, the milling machines are almost all traditional. There is just one automatic-type. Next to those machines we can find some drilling machines with different diameters drill types available.

Milling machines

Other machines such as pipe cutters and a welding place were also available in the workshop.

The laboratory where we used to work was divided in two parts, the CAD and test part which was composed by many computer and all kind of tools and bicycle kit and finally a motion camera test place where several cameras were placed on a high structure all around the sector. We used to work mostly on the first part where the equipment we needed was available.

I. The 6-axis sensor (Leptrino):

1) Principle

When an external force acts on a sensor body, the sensor detects elastic deformation of the internal structure of the sensor and transforms the deformation to voltage or digital value and calculates the six components of the acting force. The elastic deformation is usually detected by means of strain gages. If the elastic deformation of the internal member in the sensor is within elastic limit, the relationship between maximum surface strain of the internal structure and the applied force on the sensor can be written as follows.

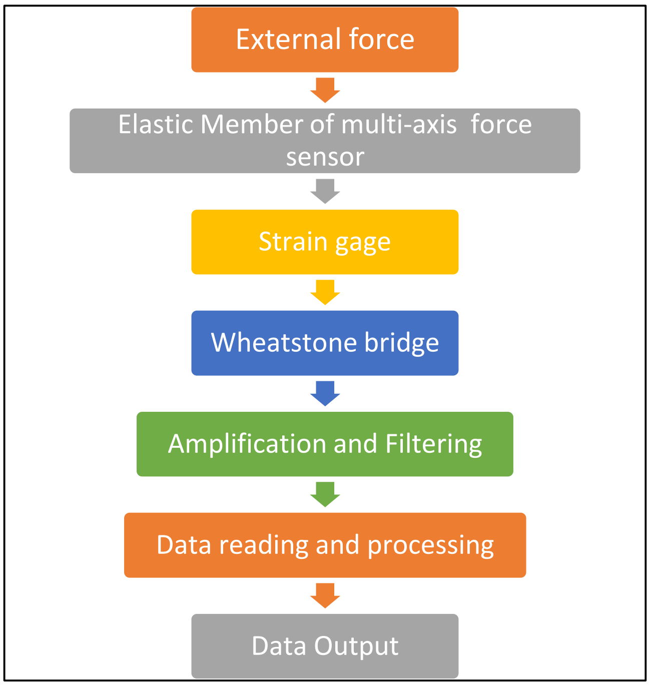
$$\varepsilon = C * f , \quad (1)$$

Where:

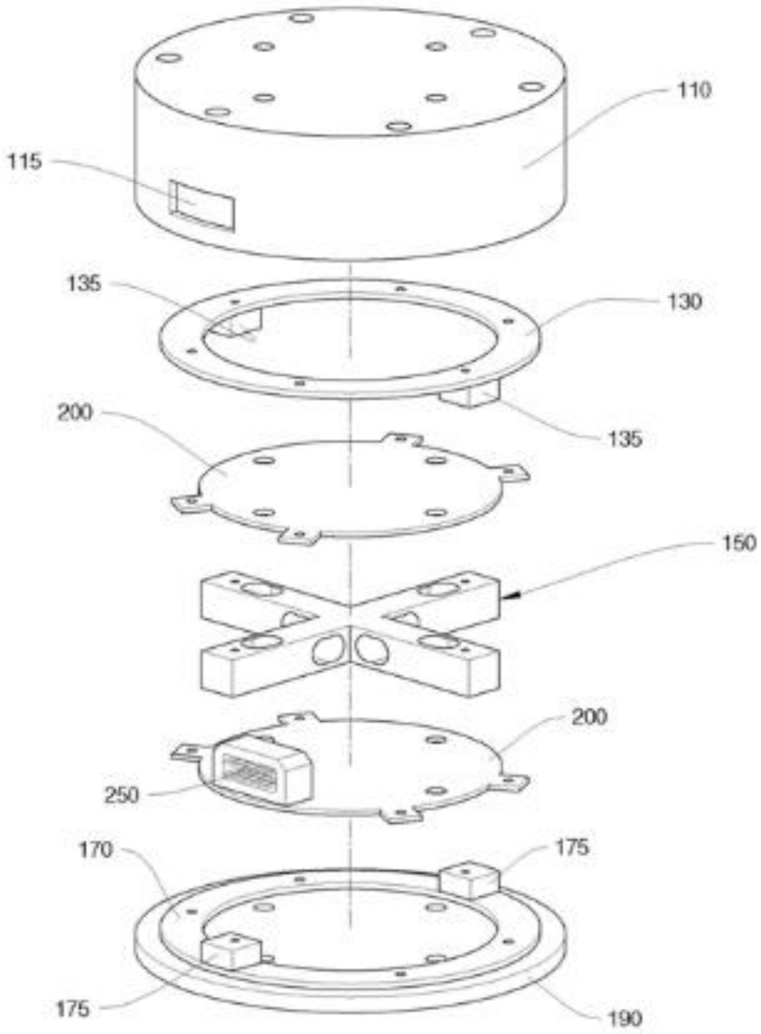
f is a measured force vector whose components are consisted of force components and/or moment components,

ε is a measured* strain vector whose components are consisted of m strain measurements of m points on the internal structure

C is a measured calibration matrix that is generated according to the forces and torques put at stake.



Functional steps of force-sensing



www.ijcas.com: Disassembled parts

The sensor in the picture is not the sensor we have used but the parts are almost the same since the functioning of this object is identical.

- **110/190**: cover plates
- **130**: bolting plate
- **115/250**: connector part
- **135/175**: supporters for the cross-shape member
- **150**: Cross-shaped member

The assembly is made possible by several bolts. The cross-shaped member is the most important part of the sensor since it is the part that will make all measurements possible. As we said before, the sensor detects elastic deformation in the internal structure which is then converted into numerical results. The member will take this function in any kind of sensor. Of course, this member is calibrated so the sensor meet some of the specification guaranteed. The only difference with our sensor is that the connector part is a USB-type which we can easily plug into a computer.

2) Inconvenient:

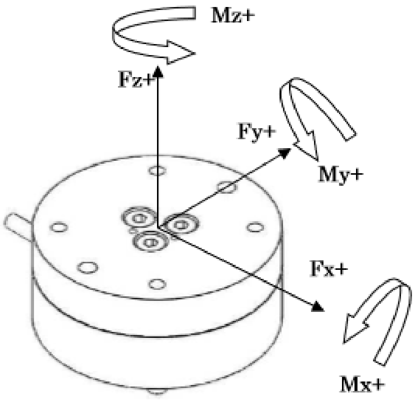
The performance of the sensor is affected significantly by an error signal that is included in the sensor signal. This sensor signal should be reduced appropriately to obtain an acceptable performance. Generally, for those kind of sensors, these errors may be classified into two categories: one is a structural error due to the shape of the elastic member and the inaccuracy of the sensor's body; the other is related to a noise signal existing in perceived information. Unfortunately, the structural error is hard to correct because of the specifications and the tolerance that are not possible to realize for a lack of accurate tools or simply a non-profitable marketing. Instead, the noise signal error can be slightly corrected by packaging all electronics inside the sensor body. Moreover, the analog signal which contains the measures is converted into digital numbers directly inside the sensor which is only after transmitted to the computer for analysing. We should though be aware of a certain percentage of error in all cases.

3) The Leptrino 6-axis sensor:

The sensor that you on the right is the sensor we will use during this project. The pedal that we should design must contain this sensor. Its functioning is the same as described is the subsection above. In order to analyse the data we collected, the Leptrino possess a USB-type output which can be plugged in any type of computer. For the analysis, a special software is needed. The latter was given with the Leptrino package.

The specifications related to this sensor are the following:

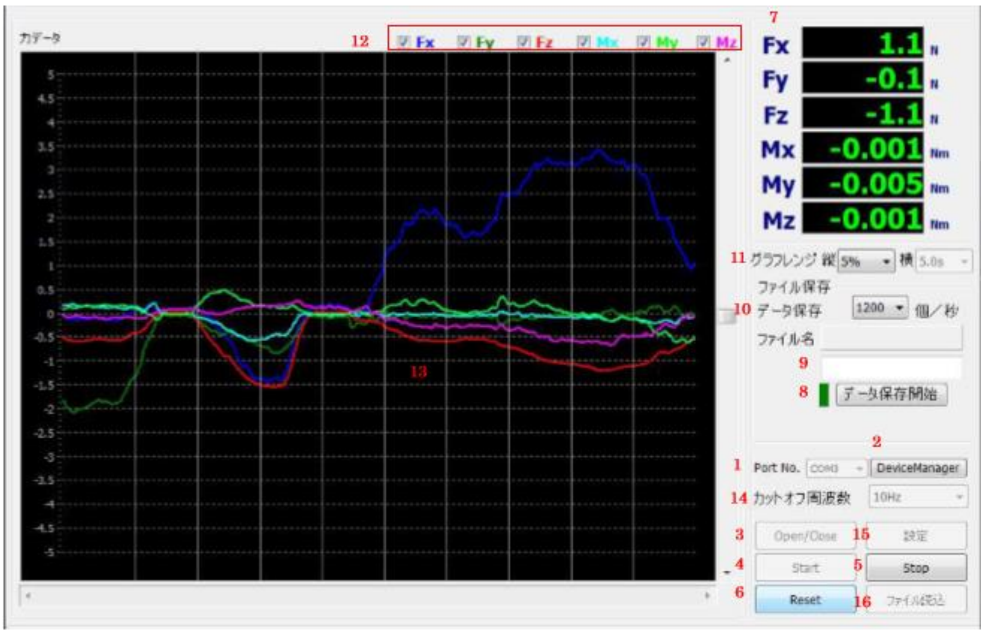
- Dimensions: Height: **3mm**
  Diameter: **80mm**
  Holes: **8-M6**, **4-Φ6 F7**
- Rating load: FxFyFz = **±500 N**
  MxMyMz = **± 20 Nm**



Leptrino instruction manual

The Leptrino cannot exceed a Load of 1000N otherwise it could break or at least it could start to have some dysfunctions. Moreover, if that is specified, the elastic member inside the sensor cannot bear more without having problems. There is of course a percentage of allowable overload but since these tools are very sensitive, the member could break anytime without being cautious. We can then say that the rating load are the limit load values that are guaranteed and that the allowable overland is the load that is not guaranteed by the producer after studies of the design, material and other mechanical calculations.

After the processing is done in the sensor, the data is output thanks to a USB. For the data to be read, the manufacturer gives a special software which can only be activated with the sensor's reference. It is a basic software which goal is either monitor or read the data file registered.



The graph showed in the previous picture correspond to the values of the different loads put at stake during time. Each force will have a different colour in order to compare and eventually highlight the one that kept our interest. We can of course save the data into a file so that we will be easily able to compare the results of different tests we could do with our pedal-type sensor.

Finally, this sensor will be used to extract the 6-axis loads data and help us understand when and in what kind of ground those will be highest. According to the position of the person riding the bike, the data could change, that is why another objective will be to find a position where the effort is at its minimum to avoid fatigue as much as possible. Since Kobayashi-sensei’s lab is also specialised is FES (functional electrical stimulation), one of the future objective is to find a utility for this pedal-type sensor in this biomechanics field.
For now, the tests will be done on a road bike and will only have the goal to check if the sensor works inside our pedal.

II. Design research:

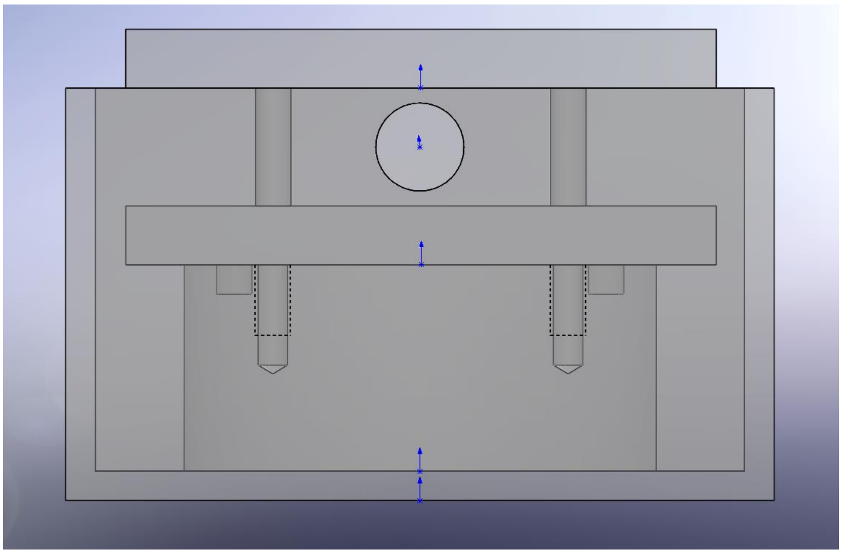
4) Discussed solutions

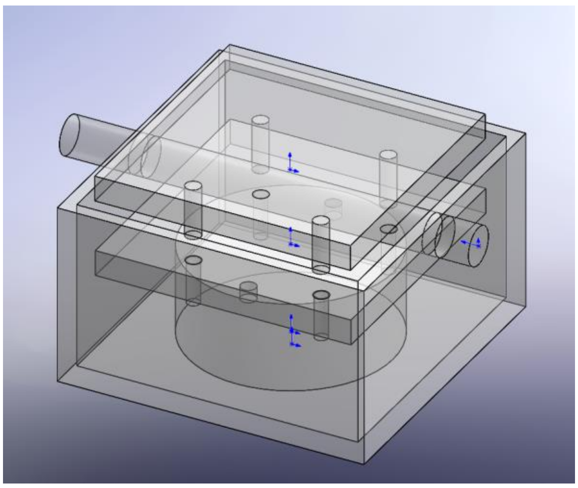
Our design specifications for the pedal were:

- The smallest possible (sensor Leptrino: D=8mm)
- The lightest possible for not interfering with the push-pull
- A bicycle drive axle of 15mm of diameter

Before approaching any calculation and designing, we discussed the shape that our pedal should have. One of the main criteria was the one to be able to join the sensor inside without interfering with the measures that we would have been made later.

The first solution that we talked about was to produce an empty box of 5mm of thickness were the sensor would be inserted as you can see in the picture. An upper board has the function to play the go-between with the middle board, the sensor and the foot allowing us to get the applied forces. We quickly noticed that our system was very likely to break because of the little thickness and the absence of some structure reinforcements.

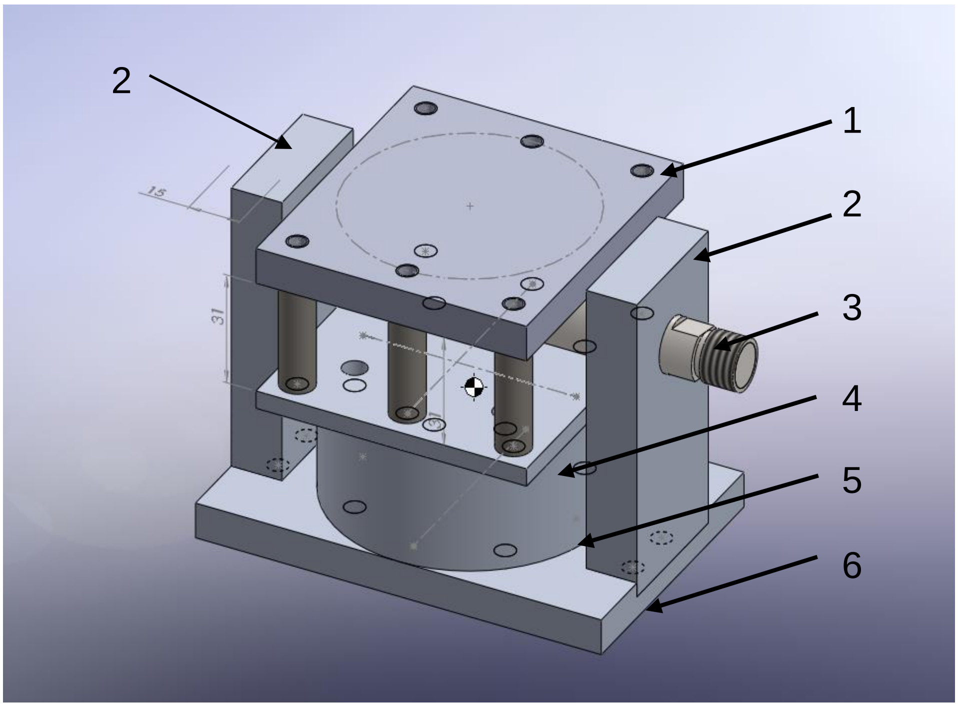




The second approached solution consist of a system which can totally be assembled, a system made up of spare parts completely intended to be assembled. Indeed, to guarantee a stable and less fragile structure than the first one, we thought of an assembly made up of screws and reinforcement of structure to obtain a light and easy to produce pedal.

Our assembly will have a rectangular shape. It will be made of several assembled boards.

1. the upper tray
2. 2 rectangular pillars
3. the bicycle drive axle: the shaft
4. the middle tray
5. The Leptrino sensor
6. the bottom tray

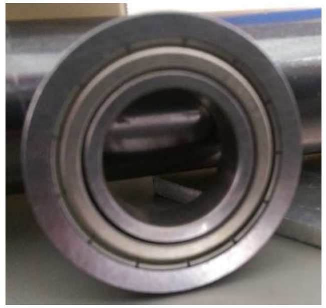
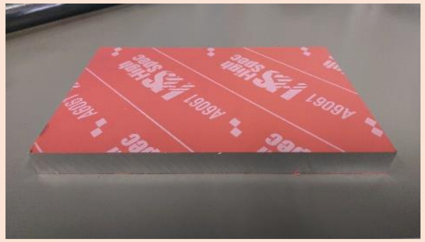


Those parts will be introduced in details in the following subsection. Their conception will be presented in the Applications section.

2) Available equipment:

As I previously said, our system will be composed of several parts. In this subsection, I will present each part that we decided to work with and that Kobayashi-sensei ordered for us:

Part/Ref	Dimensions	Material	Quantity	Description	Picture
Bottom tray	10x92x122 mm	aluminium 6061	2	This part will be used for the maintaining of the vertical pillars. In fact, for that to be possible, 2 compartment will be machined on each side of the bottom tray. Two drillings will be located on these compartments to guarantee the assembly by means of screws. Of course, the thickness of this tray will be reduced during the machining process to obtain 7mm.	
Pillars	15x92x42 mm	aluminium 6061	4	The pillars will be placed on each side of the bottom tray and will have the role of maintaining the bearings and the shaft.	

Shaft: *PSFRQ17-87-F40-P15-T15-Q15*	D=17mm d=15mm	steel	2	This shaft has been ordered in order to fit inside the holes we will make on the vertical pillars. The biggest diameter (17mm) will fit into those latter and the smallest diameter (15mm) will keep the bearings since we decided to use bearings of this kind.	
Ball bearings: *FL6902ZZ*	D=28mm d=15mm	Gcr15 (Chrome steel)	4	The bearings are the most import part for our pedals since they will allow the shaft to rotate. They have been ordered from a Japanese mechanical part producer (Misumi)	
Middle tray	5x82x92 mm	aluminium 6061	2	The middle plate will be put just upside the sensor. It will be linked to the upper plate with in order to provide the impulsions necessary for the sensor to calculate the several forces put at stake during the movement.	

Upper tray	10x82x92	aluminium 6061	2	This tray will essentially have the function for the person to place his foot.	
Screws	M6x1.0		25	Those are M6-type screws which will be used for the fixation of the sensor with the middle and the bottom tray as well for the fixation between the bottom tray and the vertical pillars.	
Spacer	Φ15x50	steel	1	This part will be cut in several smaller one that have the goal to maintain the upper tray stable in order to avoid any bending due to the foot position. A hole will be made in the middle in order to fit a long M6-type screw between the upper plate, the middle one and the sensor.	

3) Bearings calculations

Bikes are often settled with 15mm diameter shaft on their pedals. We chose to use this standard dimension. Therefore, we had to begin by searching a bearing which inside diameter was 15mm in order to realise our pedal. We then agreed on the following parameters:

- Outside Diameter, **D= 28 mm**
- Static charge, **C_0= 2,259 kN**
- Dynamic charge: **C= 4.321 kN**

The type **6902**

The following table summarise the model and the parameters chosen:

Référence pièce	d	D	B	D_1	C	r (min.)	Capacité de charge de base		Vitesse de rotation admissible (tr/min) (référence)	Dimensions relatives		Masse (g) (référence)	Prix unitaire
							Cr (dynamique) N	Cor (statique) N		Ds (min.)	R (max.)		
FL6900ZZ		22	6	25	1.5	0.3	2695	1273	34000	13.2	0.3	11.1	
FL6701ZZ	12	18	4	19.5	0.8	0.2	926	530	13000	12.4	0.2	3.4	
FL6801ZZ		21	5	23	1.1	0.3	1915	1041	33000	14	0.3	7.1	
FL6901ZZ		24	6	26.5	1.5		2836	1466	31000			13.2	
FL6702ZZ	15	21	4	22.5	0.8	0.2	937	582	11000	15.4	0.2	3.9	
FL6802ZZ		24	5	26	1.1	0.3	2073	1253	28000	17	0.3	8.3	
FL6902ZZ		28	7	30.5	1.5		4321	2259	26000			19.9	
FL6703ZZ	17	23	4	24.5	0.8	0.2	1000	658	9500	17.4	0.2	4.4	
FL6803ZZ		26	5	28	1.1	0.3	2233	1456	26000	19	0.3	8.9	
FL6903ZZ		30	7	32.5	1.5		4588	2565	23000			21.4	
FL6704ZZ	20	27	4	28.5	0.8	0.2	1041	729	8500	20.4	0.2	6.3	
FL6804ZZ		32	7	35	1.5	0.3	4015	2462	21000	22	[illegible]	19.8	
FL6904ZZ		[illegible]	9	[illegible]	2		6381	3682	19000			42.8	

We supposed the following parameters:

- The radial load, **F_R= 300N (30kg)** as far as we supposed that the average weight of a Japanese person was about 60kg and that this weight was equitably distributed of both right and left pedal.

- The axial load, **F_A= 100N (10kg)** as far as we supposed that the axial loads are rather unimportant in this type of system where the strength exercised on the pedal results from the person and from the ground (vertical loads).

We possess those several formulae for the bearing life calculations:

- The equivalent radial load applied is: P= 0.56.F_R + y.F_A if $\frac{Fa}{Fr} > e$

  P= x. F_R if $\frac{Fa}{Fr} < e$

- Bearing lifespan:
  - $L = \left(\frac{C}{P}\right)^3$ with L: basic rating life (10^6 revolutions)

    C: basic dynamic radial ration (N)

    P: Dynamic equivalent radial load (N)
  - $L_h = \frac{L}{60.n}10^6$ L_h: rating life (hours)

    n: speed (rpm)

- Calculations:

First of all we must find the coefficients **e** and **y**. For that we need the value of $\frac{Fa}{Co}$ and report it in the following table in order to find the associated coefficients:

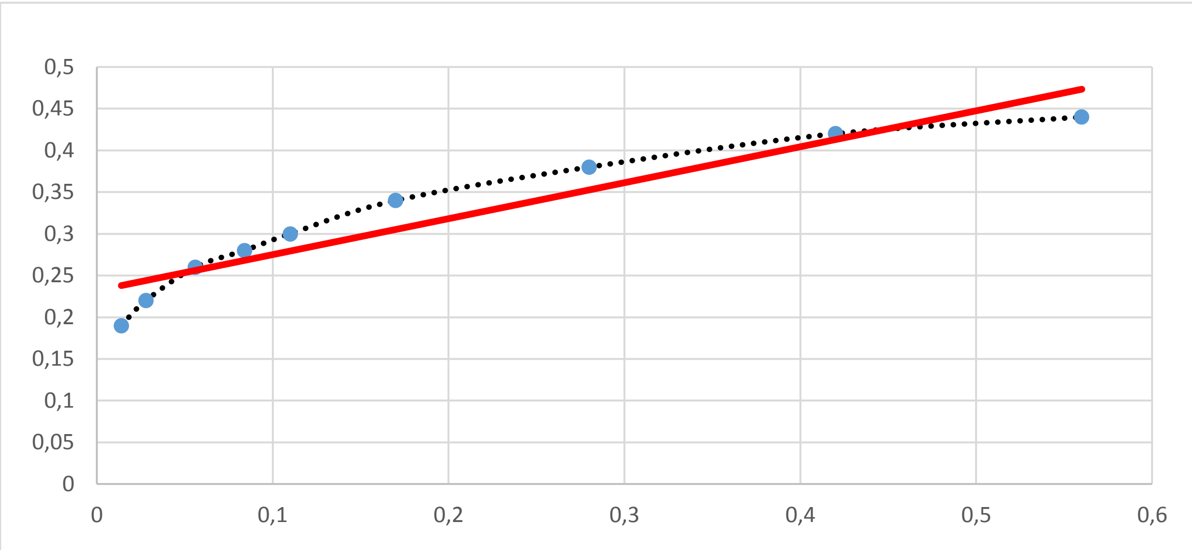
$\frac{F_a}{C_0}$	0,014	0,028	0,056	0,084	0,110	0,170	0,280	0,420	0,560
e	0,19	0,22	0,26	0,28	0,30	0,34	0,38	0,42	0,44
y	2,30	1,99	1,71	1,55	1,45	1,31	1,15	1,04	1,00

We have $\frac{Fa}{Co} = \frac{100}{2259} = \mathbf{0.045}$.

As we can see in the table above, $0.028 < \frac{Fa}{Co} < 0.056$ and 0.22< e <0.26

This graph corresponds to the values that are present in the previous table.

If we consider the linear graph (red line) we can approximately find the value or the coefficient "e".



The equation of this line will be similar to: $y = ax + b$ with

$$a(the\ slope) = \frac{0.26 - 0.22}{0.056 - 0.028} = 1.43$$

so $b(y - intercept) = y - ax = 0.056 - (1.43 * 0.26) = -0.3158$

For $y = \frac{Fa}{Co} = 0.045$, $x = e = \frac{(y-b)}{a} = \frac{0.045+0.3158}{1.43} = \mathbf{0.2523}$

We will use the same method to find the "y" coefficient we need:

We obtain: $y = \mathbf{1.70}$

Finally, $\frac{Fa}{Fr} = \frac{100}{300} \approx 0.3333 > e = 0.2523$ so P = 0.56*F_R + 1.70*F_A

$$P = 0.56 * 300 + 1.70 * 100 = \mathbf{338\ N}$$

$$L = \left(\frac{C}{P}\right)^3 = \left(\frac{4321}{338}\right)^3 = \mathbf{2089.10^6\ rev}$$

$$L_h = \frac{L}{60.n} 10^6 = \frac{2089.10^6}{60.120} = \mathbf{290138\ h}$$

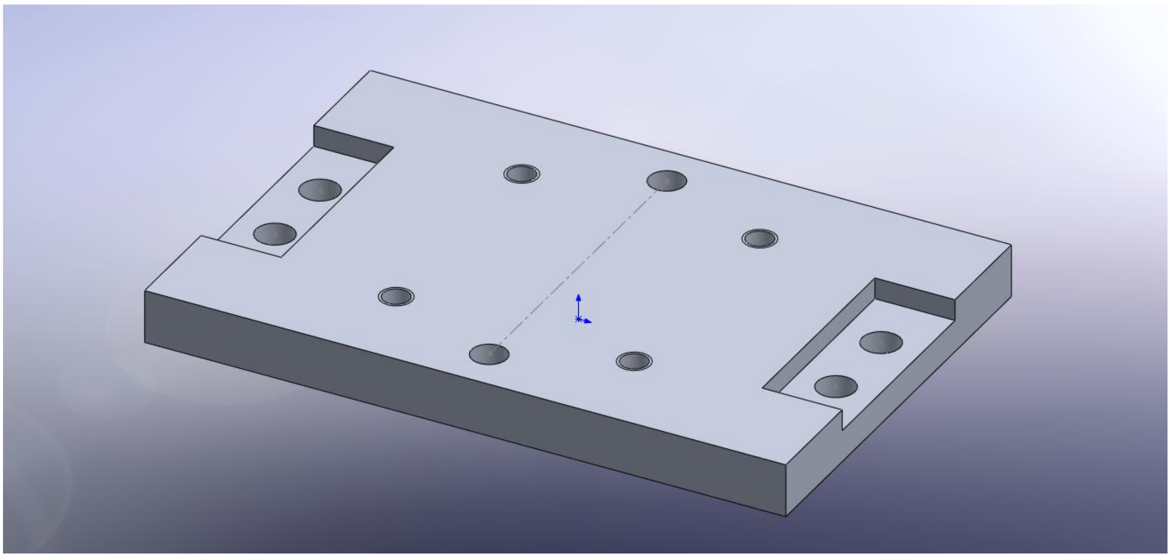
III. Applications:

1) CAD (SolidWorks)

Having decided on the shape and on the most suitable solution to produce our pedal, my workgroup and I started the CAD modelling.

I too much had no difficulties to become used to Solidworks software as far as the functions and the use are very similar to Catia which we used at the IUT. Furthermore, the chosen forms were squared-type and cylindrical-type, which reduced considerably the difficulty of handling of the software and the design difficulties.

We started from the bottom plate:

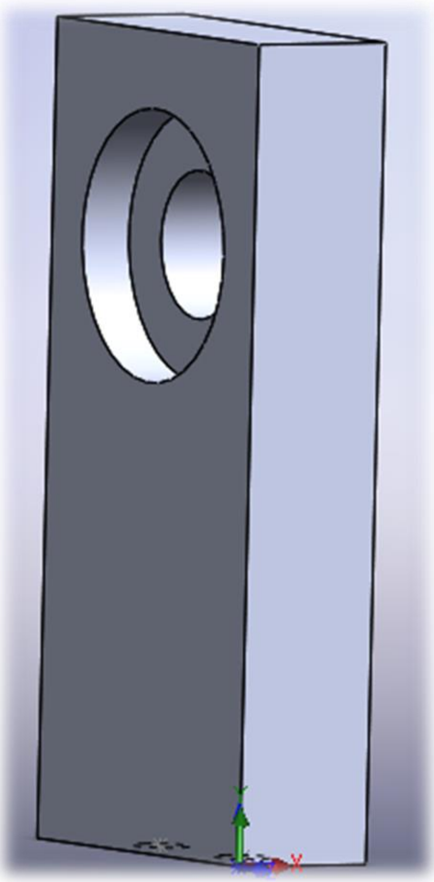


The latter was developed with a simple rectangular sketch and an extrusion followed by a removal of matter on each side to guarantee the assembly of both vertical pillars. The present drillings in the middle correspond to the present holes on the 6-axis sensor and which shall allow the fixation of the latter on the tray by mean of M6-type screws. The drillings placed on the pockets in the extremities of the tray will serve to assemble the vertical pillars.

The dimensions are the following:

- Length: **120mm**
- Thickness: **10mm**
- Width: **80mm**

The vertical pillars:

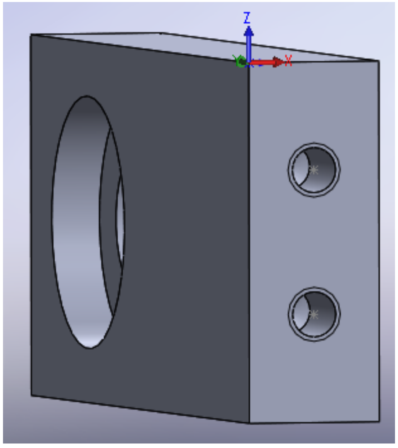


Those pillars are made from a simple rectangular sketch which has then been extruded for obtaining the necessary dimension. The hole present in the picture is the hole that will guide the crank arm axle (the shaft) to maintain the pedal. The bearings will also be placed inside the bore that has been made on this part.

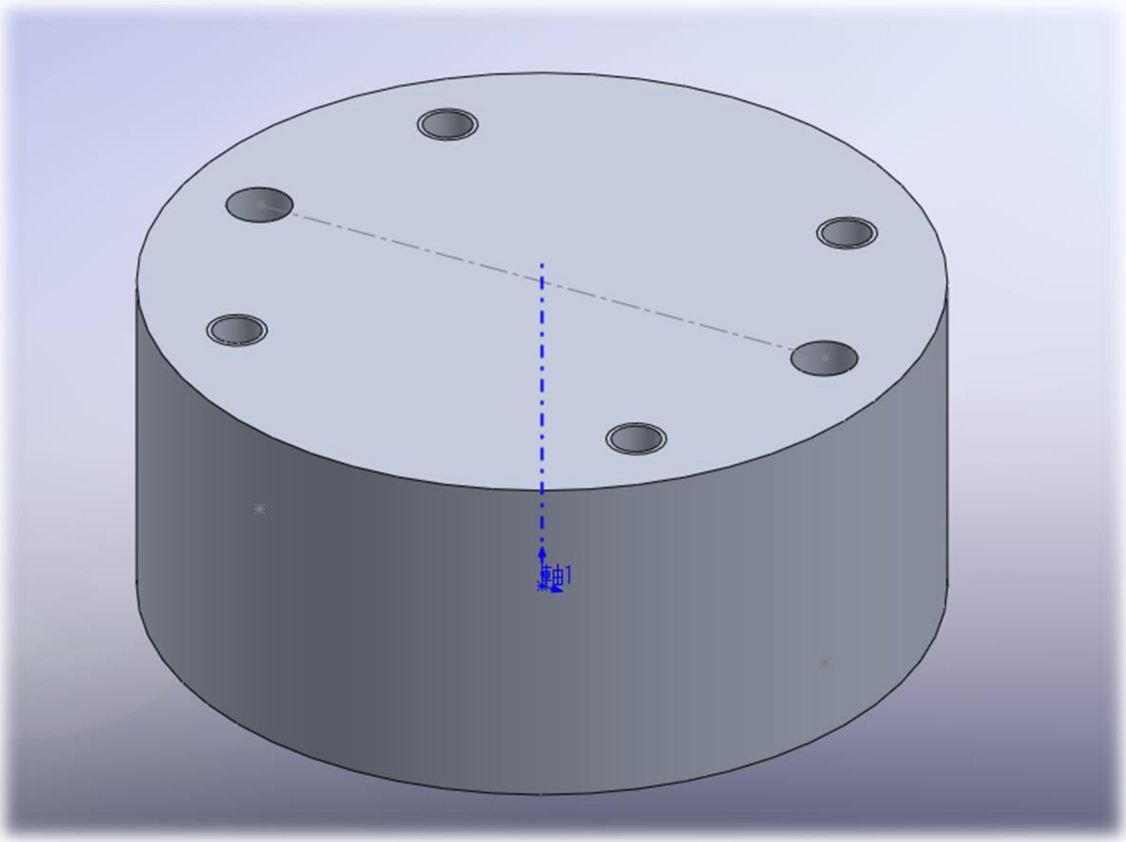
The dimensions are the following:

- Height: **84mm**
- Width: **40mm**
- Thickness:**15mm**
- Hole diameter: **17mm**
- Bore diameter: **28mm**
- Bore width: **5.5mm**

The holes on the picture on the right side are made to assemble those pillars to the bottom tray thanks to the M6-type screws. The hole has a diameter of **5mm** and a depth of **10mm**. The threading will be made at the end for the M6-type screws to be fitted.



The 6-axis sensor Leptrino:

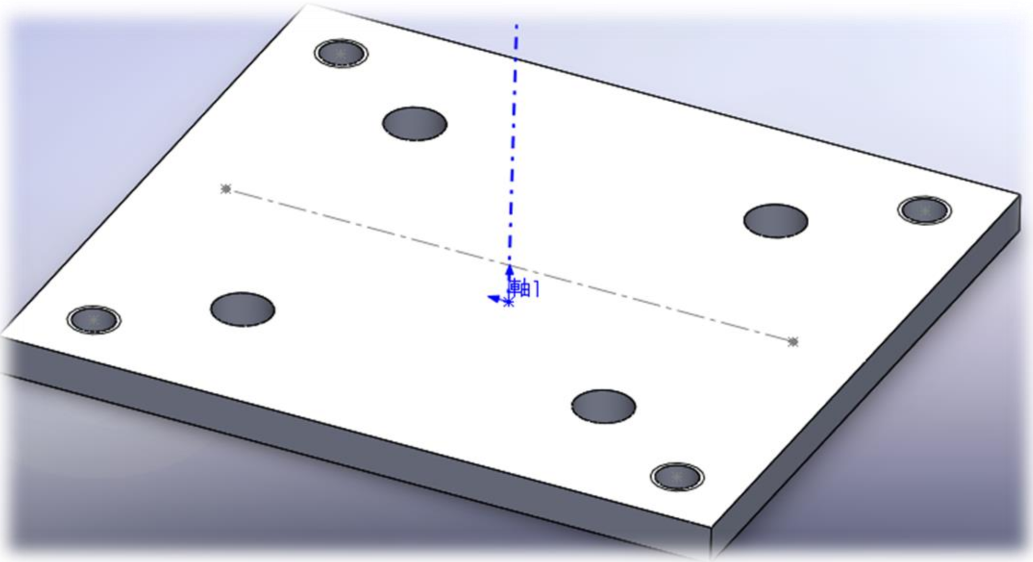


To design the shape of the 6-axis sensor we had to use for our project, was based upon the dimensions present in the user manual. A circular sketch and an extrusion was sufficient to mode this part. The sensor will be attached to the bottom plate by four M6-type screws. The same type of assembly will be made with the middle tray. We will need this part to build the second pedal for the road bike we will use to make the final tests.

The dimensions are the following:

- Diameter: **80mm**
- Height: **35mm**

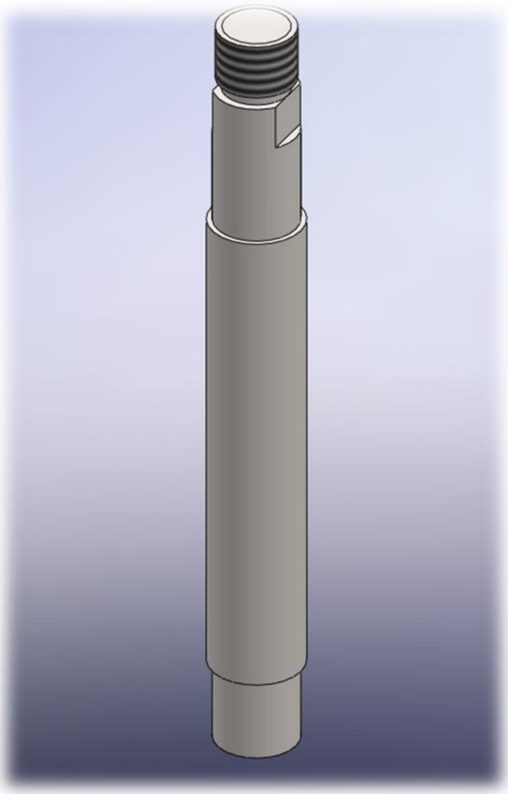
The middle tray:



This tray is made from a rectangular-shaped sketch which has been extruded in order to obtain the wanted thickness. As I previously said, this tray will be assembled with the sensor by means of four M6-type screws. The four holes will have a diameter of **6mm**. The four holes present on both extremities will be used to install the spacer between this tray and the upper tray.

The shaft:

The shape of the shaft is made from a revolution. The two extremities have a diameter of **15mm** and the central part has a diameter of **17mm**. In order for the bearings to fit, we had to choose this solution of a double-diameter shaft. The threading made at the top extremity as you can see in the picture will be screwed in order to complete the assembly with the bike.



The upper tray:

This tray is very similar to the middle tray. It has three holes on each extremities which diameter is **6mm**. On four of them, situated on the corner, bores of **10mm** of diameter and 5mm of depth are made in order for the head of the screws to fit inside the tray. Those two trays will be fixed by means of four spacer containing four screws assuring the fixation between them with nuts.

2) Machining

All the machining process have been made by traditional machines. The several processes for the different parts combined four types of machines: a pipe cutter, a milling machine, a turning machine and a drilling machine.

The following parameters apply for all the machined trays: the bottom tray, the middle tray, the upper tray and the vertical pillars:

We used a milling machine with a diameter of **160mm** and **7 teeth**. Since the machined material was aluminium we selected a rotating speed of **9000 rpm** and a feedrate of **180 mm/min**. The several holes were made with a drilling machine set with a rotation speed of **1420 rpm.** A previous works had been done before the drillings. In fact, we marked, thanks to measurements tools and a marker the spots where the holes had to be made. This method helped us finding the centre of each drilling and to obtain an accurate product without using an automatic-type machine.

In order to obtain the final bottom tray, two dressing operations were necessary in order to obtain the decided dimensions. In fact, we had to cut **1mm** on each side of the length and **6mm** on each side of the width. After those operations were finished, we started the drilling operations. We had a little problem for the machining of the two side pockets because of the high precision we needed. For this reason, Kobayashi-sensei asked the technician for completing the machining of this part which he accepted

Concerning the vertical pillars, they were first cut by the mean of a pipe cutter because we would have wasted time by doing this operations on the milling machine. We had to cut **4 mm** and then cut **2 mm** on each side of the length and **1 mm** on each side of the width with surfacing operations. After those operations, we prepared the spots where the drillings and the reaming will be machined. We started by doing the two **5mm** holes on the bottom of the pillars with the drilling machine and the threading and we continued on the milling machine to complete the **15mm** diameter hole and the **28mm** diameter bore. For the last two operations we used a drill of D=**15,2 mm** and a reamer of D=**28mm**. They were set at a speed of **800 rpm**.

Final vertical pillar

Final middle tray

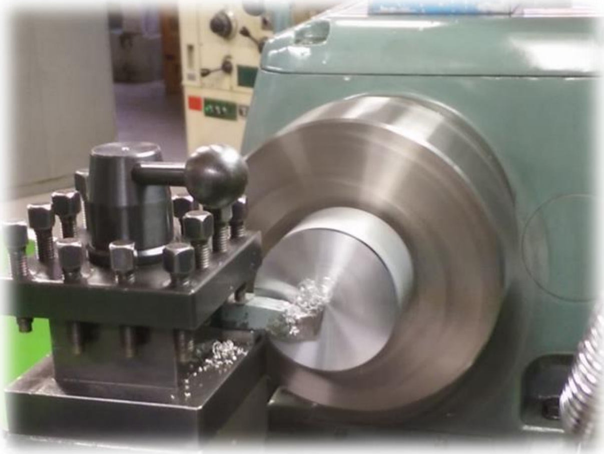
In order to have the right dimensions of the middle tray, we had to cut **2 mm** on each side of the length and **1mm** on each side of the width with surfacing operations. After that, we prepared the spots for the drillings and we used the drilling machine. For the holes that are used for connecting this tray to the upper tray, no problem emerged. They were machined with a 5mm drill and threaded manually for the M6 screws. Unfortunately, the holes in the middle section of the tray raised us some problems for the assembly. Those holes have a diameter of **6.5mm** and since the distance between the centres of the holes is inaccurate and the alignment between them is not perfect we had to find a solution for this tray to fit on the sensor. We filed a little bit every hole in order to spread the diameter for the screws to be screwed without strain.

The upper tray was obtained in the same way as the middle tray except that four **10mm** diameter and **6mm** deepness bores were made on the extremities holes in order for the M6-type screws' heads to fit in.

Final spacer

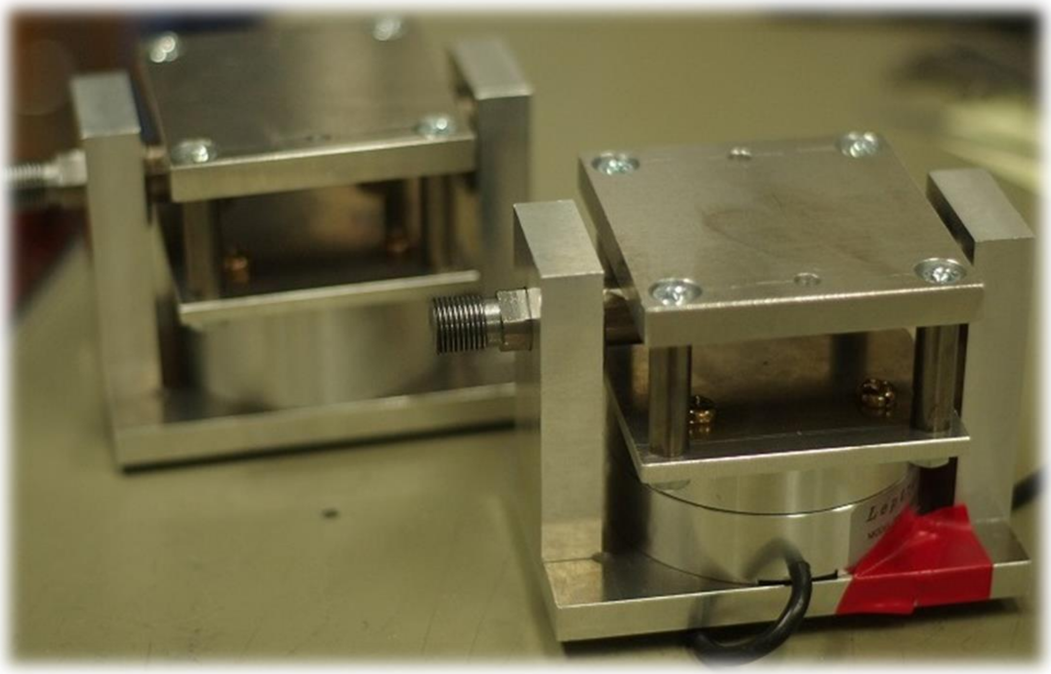
For the spacer to be made, we started by cutting a round-shaped bar into eight **33mm**-length parts. A turning machine settled at **1500 rpm** was needed to cut **2mm** of the diameter and to make the **6mm** hole in the spacer

The copy of the sensor destined to be mounted on the other pedal with the goal to have the same weight and balance the pedalling movement was made from a long aluminium cylinder (Φ88mm and L=400mm) which was cut at first with a pipe cutter to obtain a length close to the original sensor. The finishing was then made with a turning machine settled at **500 rpm** to obtain a diameter of **80mm** and **35mm.** The drillings were made on the drilling machine we used for the trays. Furthermore, the part was about 100 grams heavier that the original sensor. We had to do some useless drillings in order to reduce and obtain a similar weight.



Machining of the sensor

Finally, after filing some holes on the trays which centres were not aligned we were able to mount both pedals with our M6-type screws and nuts. Each pedal was **120mm** wide, **80mm** long and **84mm** high and **1.5kg** heavy which seems a little bit too much but we were confident for the tests to work. At this point we were able to start our experiments



Final pedals

3) Tests

The tests will be made on two different persons. The parameters that will differ are: the weight, the person height and the saddle height. The gear conditions will also vary. In fact, according to the gear, the person will have to push more or less harder to make the cycle move. At the contrary, there are some parasite parameters that we won't have to include during our test. Since the bike used is the same for both test, the type and the pressure of the tyres remain unchanged as well for the bike's weight.

According to those parameters, our goal is to find out if the range of the loads tested thanks to our pedal-type sensor are in accordance with the sensor specifications. If the loads exceed the maximum load possible, a totally new system will have to be designed.

- **Preparing the tests:**

For the preparation of our test, we had to proceed according to the three following steps:

First of all, we had to mount our pedal-type sensor on the bike. We have chosen to put our 6-axis sensor on the right pedal and the other round-shaped block we machined on the left pedal. We had some trouble by fixing the left pedal on the crank arm due to a little scratch on the treaded part of the shaft. Finally, everything went well since we tried many times and forced a little bit without breaking anything.

Moreover, since the Leptrino was only useful if plugged directly into the computer during the tests, we had to put the bike on a system allowing the back wheel to rotate. All the equipment for this matter was already available in the laboratory.

Once the equipment settled, we were able to begin the tests: to highlight the loads put at stake according to the person who was riding the bike, it was necessary to fix parameters. The road bike possessed many gears, twelve to be more accurate, we chose to operate our tests on two different combination of gears and we chose to fix the speed of the cyclist so the frequency of pedalling would also remain the same.

Where from the presence of a speedometer, to fix the speed during the realisation of our tests. We chose to operate at 60rpm which is equal to more or less 25km/h. This is a normal speed considering the type of bike, its purpose and its weight (7kg). Concerning the gears, we have chosen a light combination of 50/21 teeth and an intermediate heavy combination of 50/15 teeth.

Those tests will last one minute each and the saddle height will be settled at 890mm from the ground.

- **Parameters and Cyclists profiles:**

Tester A: Akatasan
- Height: 174 cm
- Weight: 64kg
- Saddle height: 890mm

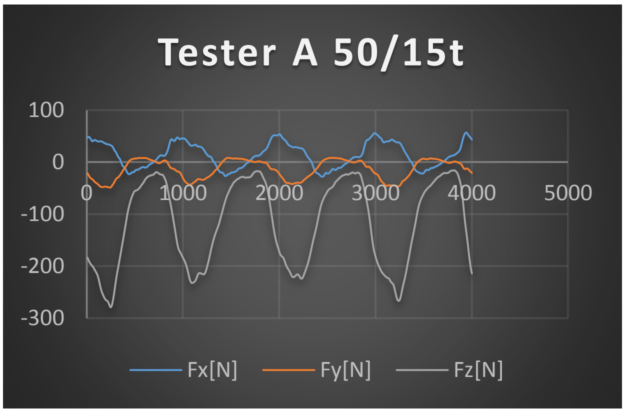
Tester B: Kobayshi-sensei
- Height: 167 cm
- Weight: 71kg
- Saddle height: 890 mm

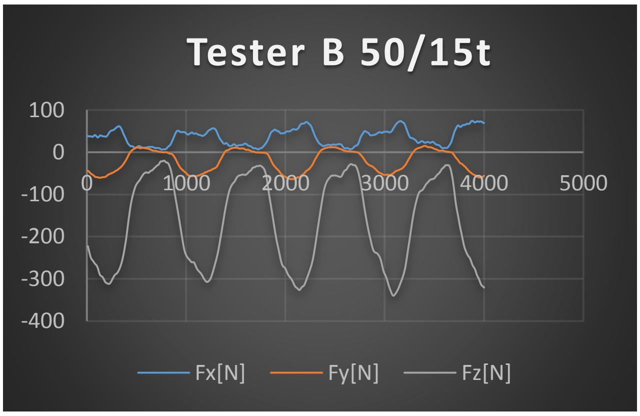
Tester C: Me
- Height: 175cm
- Weight: 72 kg
- Saddle height: 890 mm

- **Test results and interpretations:**

Before starting every experiment every tester had to ride for one minute at the 50/15 gear combination in order to calibrate the sensor. One minute passed the tester released his feet and started pedalling again for one minute for the loads to be registered.

Let us take the example on Tester A and Tester B ride. The following graphs represent the loads put at stake during this minute of cycling:





The most interesting load to analyse and compare is the one following the z axis. In fact, we notice that the grey line on the graph is the widest between the three lines. The F_x and F_y loads are really scarce because the force transferred from the feet to the pedal is mostly a vertical one since the low part of the leg is almost in a vertical position. The easiest characteristic that can be noticed is the negative value of F_z. In fact, during the bike movement, the pedals are pushed by the leg and feet which means that the loads put at stake are in the opposite direction of the z axis.

The graphs shown above are the one obtained with a heavy gear combination. In fact, the maximum load perceived is around 290N for Tester A and 325N for Tester B. The Tester A is about 8kg less heavy than Tester B which could explain the slight difference between the maximum vertical loads (F_z).

Furthermore, we can notice that the pedalling load pattern of the grey line for Tester B is more regular than Tester A. After some thinking I made the conclusion that this pattern difference is caused by the speed parameters which we settled at 60rpm. To maintain this speed, the pedalling must be regular for at least one minute, the time our experience last. When the speed goes lower than the settled parameters the cyclist has to accelerate his pedalling frequency to reach it. Since the acceleration is possible only if the cyclist pushes harder on the pedal that explains the spikes reaching 290N for Tester A. Otherwise, the regular load seems to be around 225N

Concerning the light gear combination graphs (ref: Appendices), the maximum loads values are lower. Those loads reach 130N for Tester A and 195N for Tester B. The reason for that considerable decrease is the gear combination. Of course, if the pedalling movement is easier to realise then the loads put at stake need to be lower that a heavier gear combination which make the pedalling movement harder.

Finally, these experience allowed us to confirm the functioning of our pedal-type sensor which seemed to show predictable results according to the person who was riding the bike. However, we noticed in the first place that this pedal-type sensor was heavy (1.5kg each). This weight should be reduced for further experience to obtain more accurate results and reduce the pedalling efforts in particular on heavy hear combinations. This should be possible by reducing the shaft diameter and probably using a different and lighter material. Moreover, for further results, other kind of tests need to be made. For example, the saddle height should be taken at two different positions for a single person in order to realise the importance of this parameter. Moreover, the tests should be done on flat and sloping ground combined with the saddle height parameters to obtain more comparison elements. Since our sensor needed to be connected to a computer this last test could not be realised. The future goal for Kobayashi-sensei's laboratory is to build another type of pedal-type sensor using a smaller shaft diameter and a different type of sensors. Those sensors will be squared-shaped, thin and light which will considerably reduce the weight and the dimensions.

Conclusion

Thanks to Kobayashi-sensei's laboratory and his students, I was able to take part in their project. We started by discussing about different possibilities for designing our pedal-type sensor which was very useful for taking a decision that looked more or less possible. When the decision was taken, the equipment that we needed was ordered by our supervisor. While waiting for the equipment it has been possible to start the computer aided design on Solidworks. After making the arrangements for the availability of the workshop we could finally start the machining of every part before coming to the assembly and the tests three week later.

This project allowed me to discover a new CAD software that I never used before. Since I already used Catia in my formation, this software was very easy to understand and to use. Furthermore, I had to rely on my knowledge about the bearing life span calculations because of the four bearings in our pedal. Concerning the technical part, the technical formation that was given to me in the last two years was very useful for the use of the several machines in the workshop. It helped me remember how to use the traditional milling and turning machines that I didn't touched since last year. Moreover, it made me discover some cycling equipment I had never known and used before. Finally, this project allowed me to work with a serious and kind team which was always here to explain me anything I did not understand. Even if the communication was hard because of the language issues, I managed to work and have fun with a great team and I would not hesitate to do this enriching experience again.

In a personal context, I liked this project very much because it mixed all kind of knowledge and technical abilities that I have been learning in the past years. I discovered a new field that is called the biomechanics which has been explained to me by a careful and interested professor such as Kobayashi-sensei. Not only had it kept my interest but it even made me think about other possibilities for my career.

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A.6-axis sensor (Leptrino) specifications:

Leptrino

6-axis force sensor **Specifications**	1/3 Model **PFS080YA501U6**

Ⅰ. General description

6-axis force sensor detects the moment around each axis and XYZ axis 3 direction of the force.
The sensor outputs the power of the signal directly via USB.

Ⅱ. Spec

- ◆ Machine characteristic
  - ・Rating load FxFyFz : ±500N
    MxMyMz : ±20Nm
  - ・Allowable overload F system ±400%R.C. M system ±200%R.C.
  - ・Hysteresis ±0.2%R.O.
  - ・Stiffness property F : under 20 μ m
    M : under 150 μ m
  - ・Weight about 400g
  - ・Material aluminum

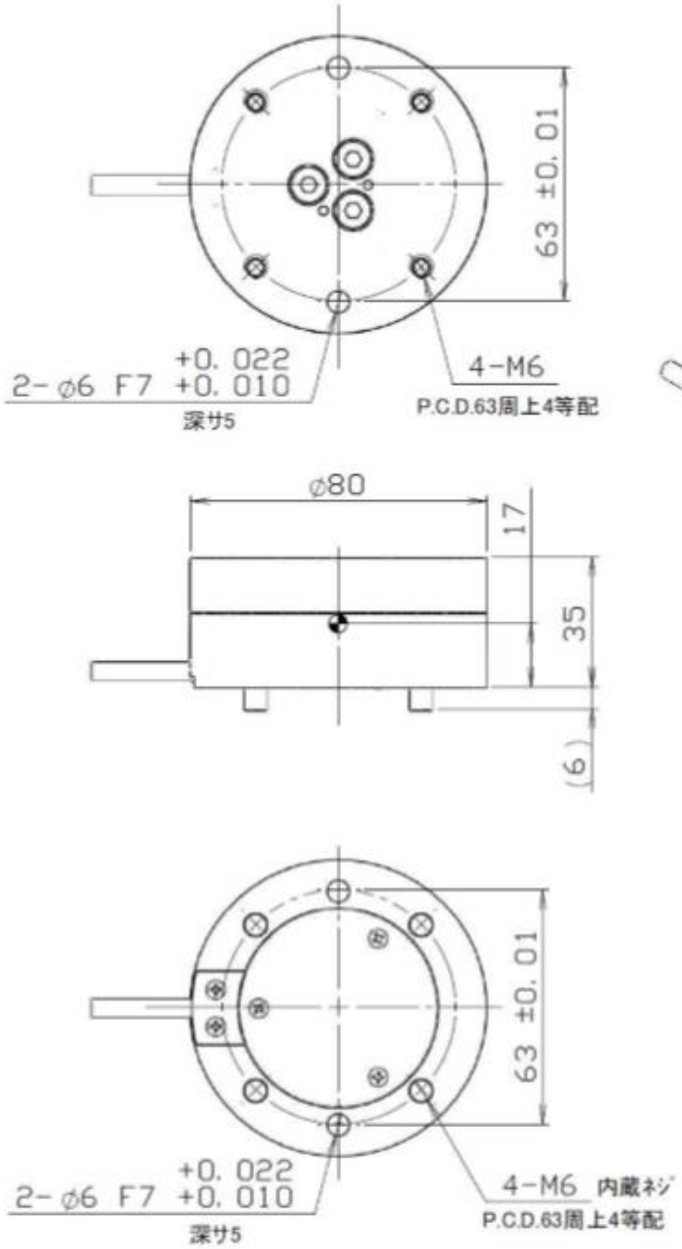
- ◆ Electric character
  - ・Output 6-axis force data : ±100.00%(At the rated output)
    Abnormal signal
  - ・Non-linearity ±1.0% R.O.
  - ・The other axis interference ±2.0% R.C.
  - ・Resolution ±1/4000
  - ・Output frequency 1.2kHz
  - ・Response frequency fc = 10Hz or 100Hz or 200Hz or OFF
    (It is possible to change in the supplied software)
    FIR digital filter
  - ・Interface USB2.0
  - ・Consumption current 180mA Typ

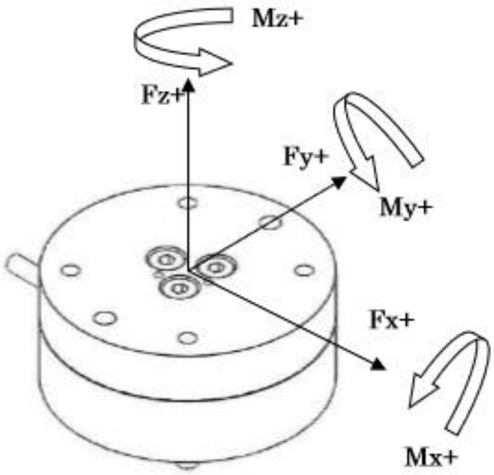
No.S080P003A

Leptrino

6-axis force sensor **Specifications**	3/3 Model **PFS080YA501U6**

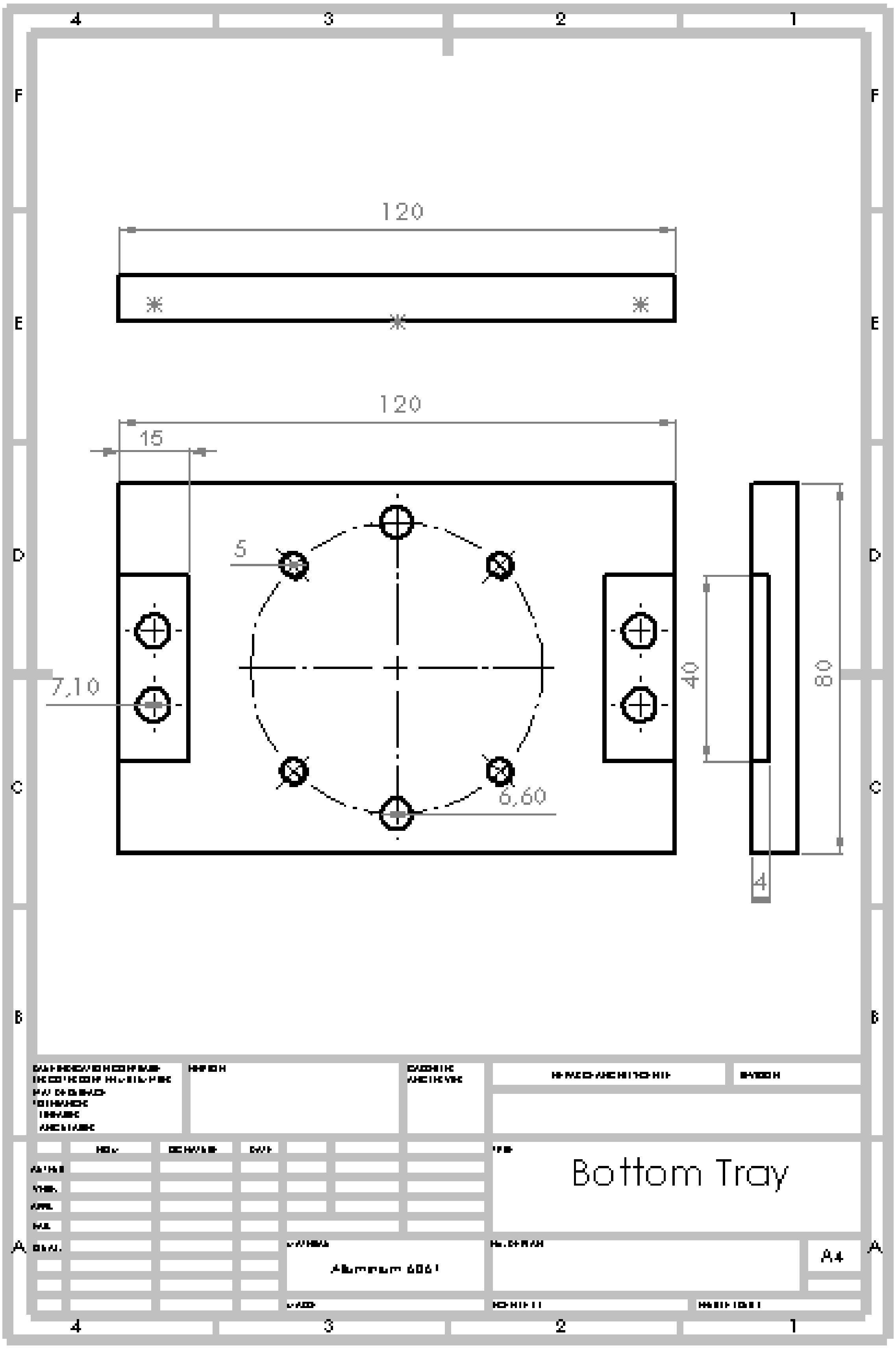
Ⅲ. External form



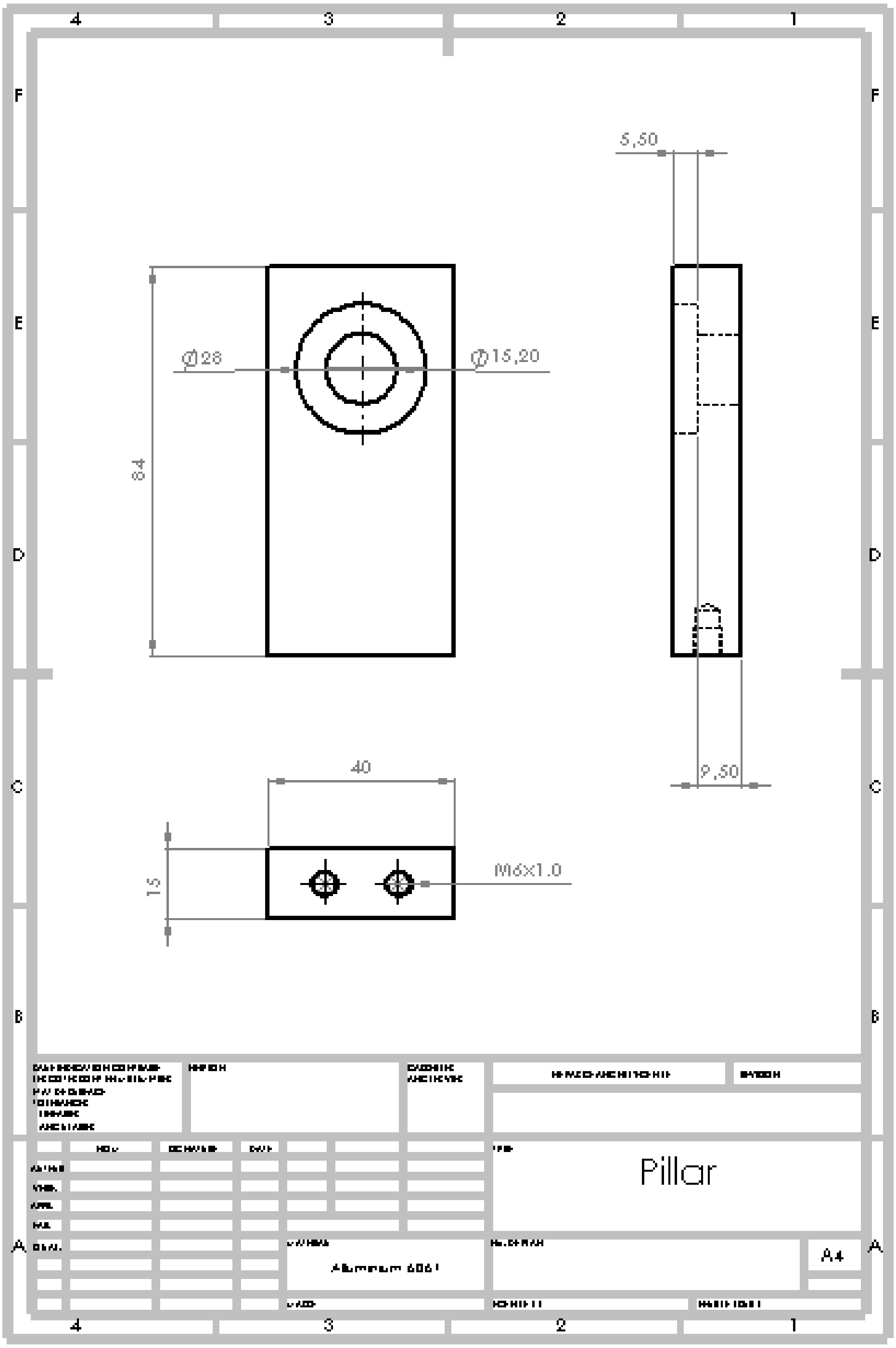


No.S080P003A

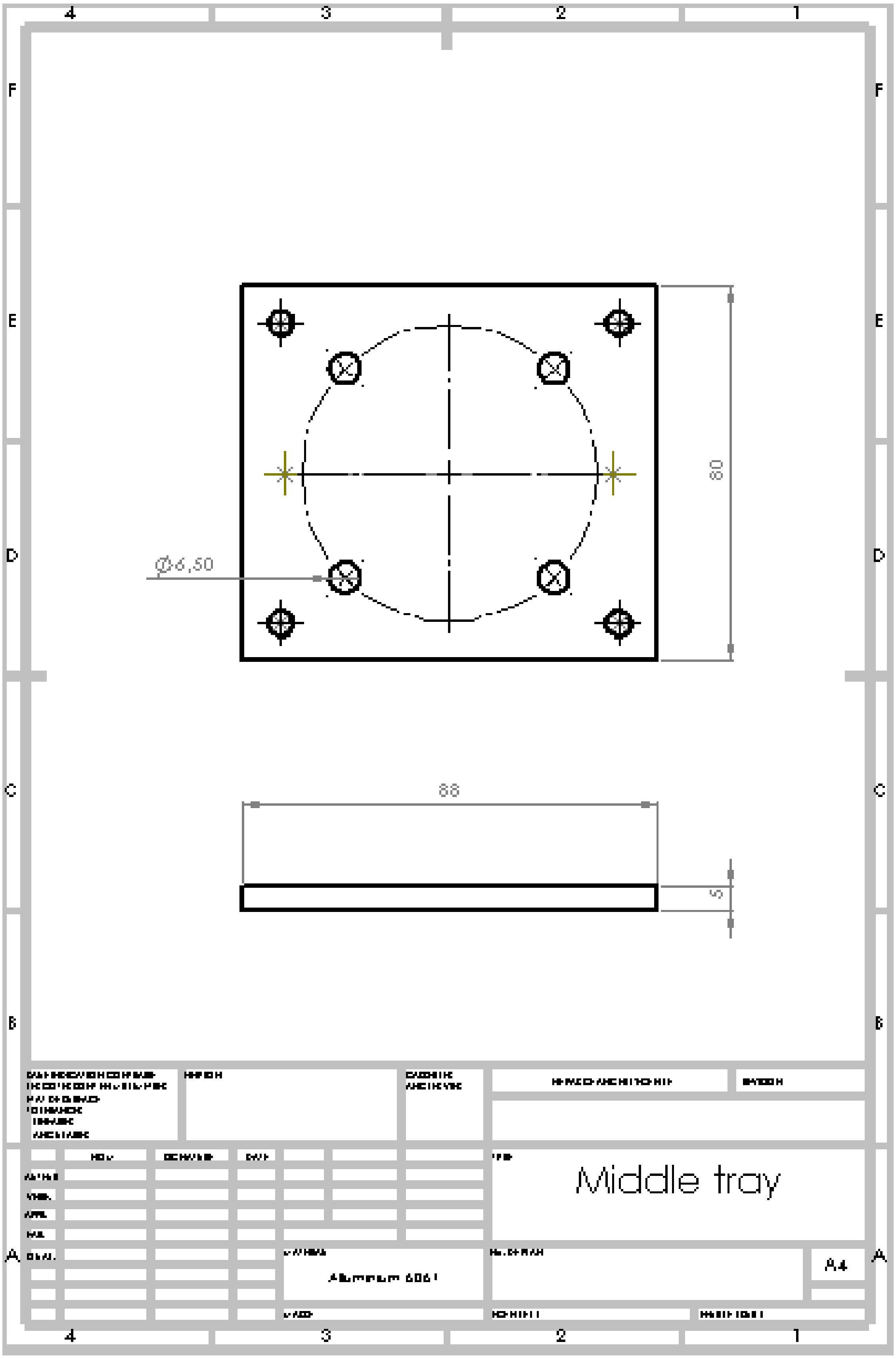
B. Bottom tray drawing:



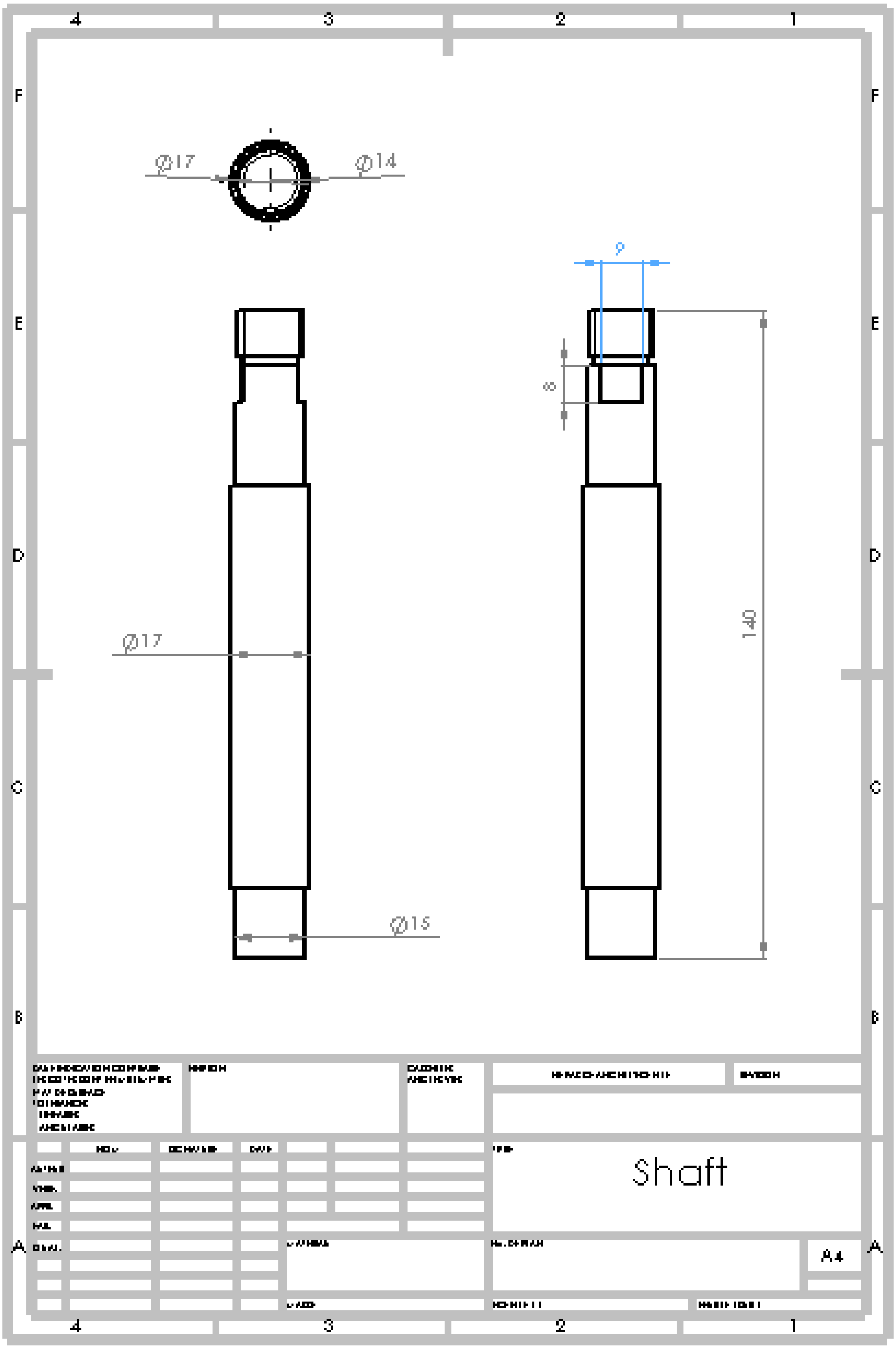
C.Vertical pillar drawing:



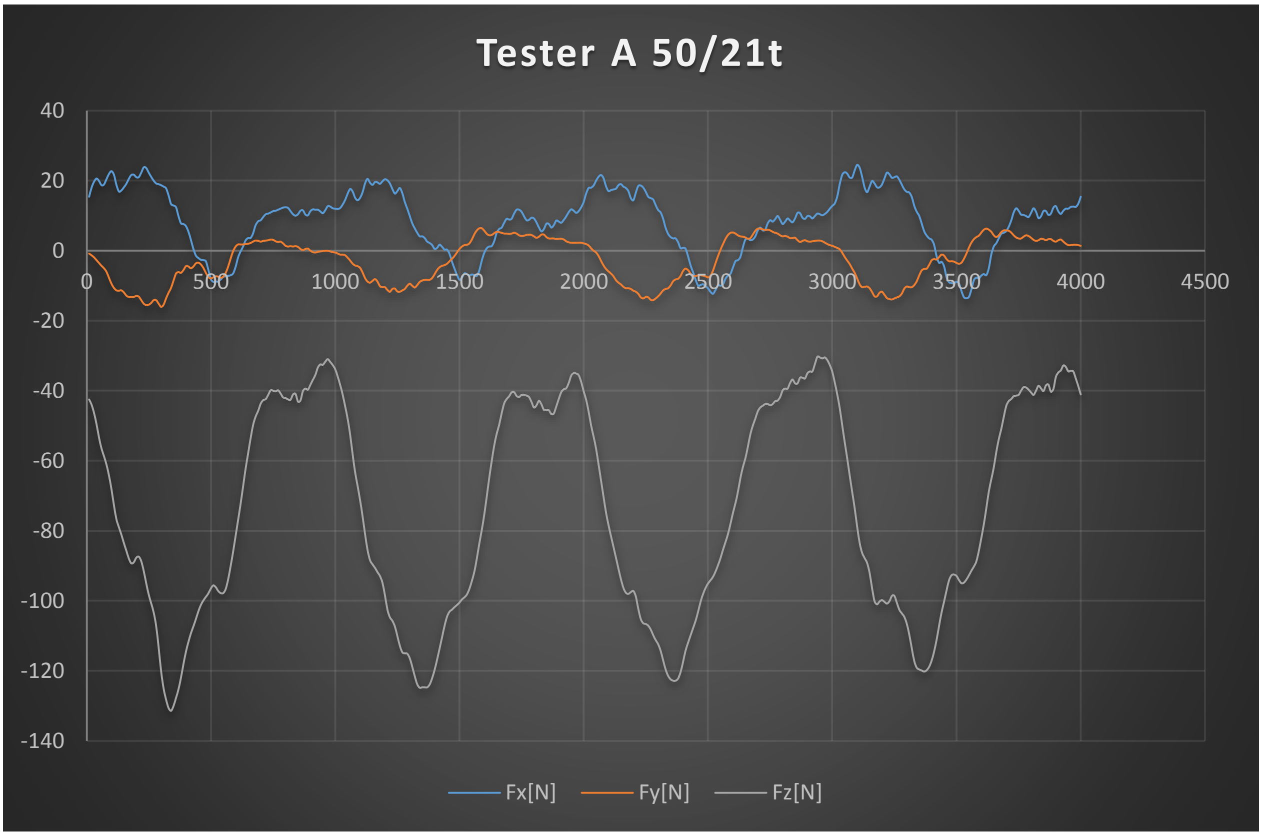
D.Middle tray drawing:

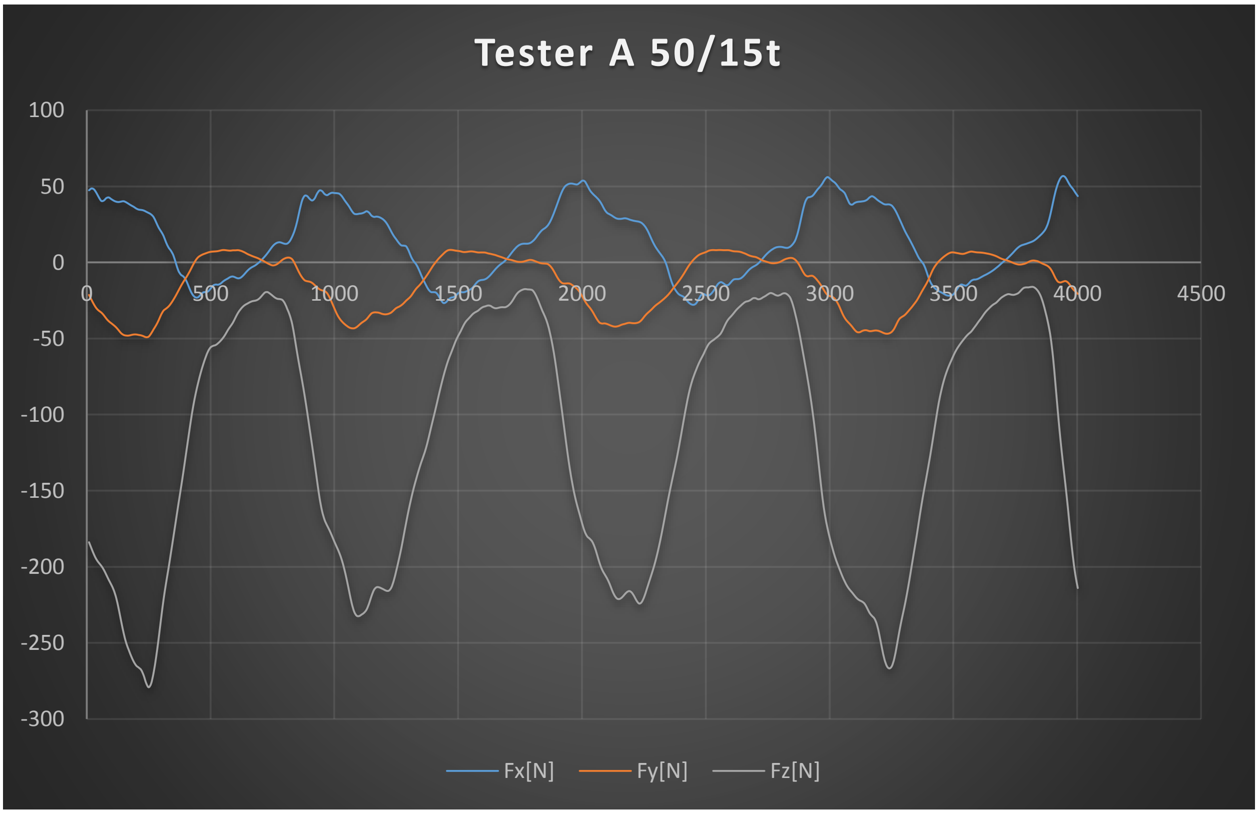


E. Shaft drawing:

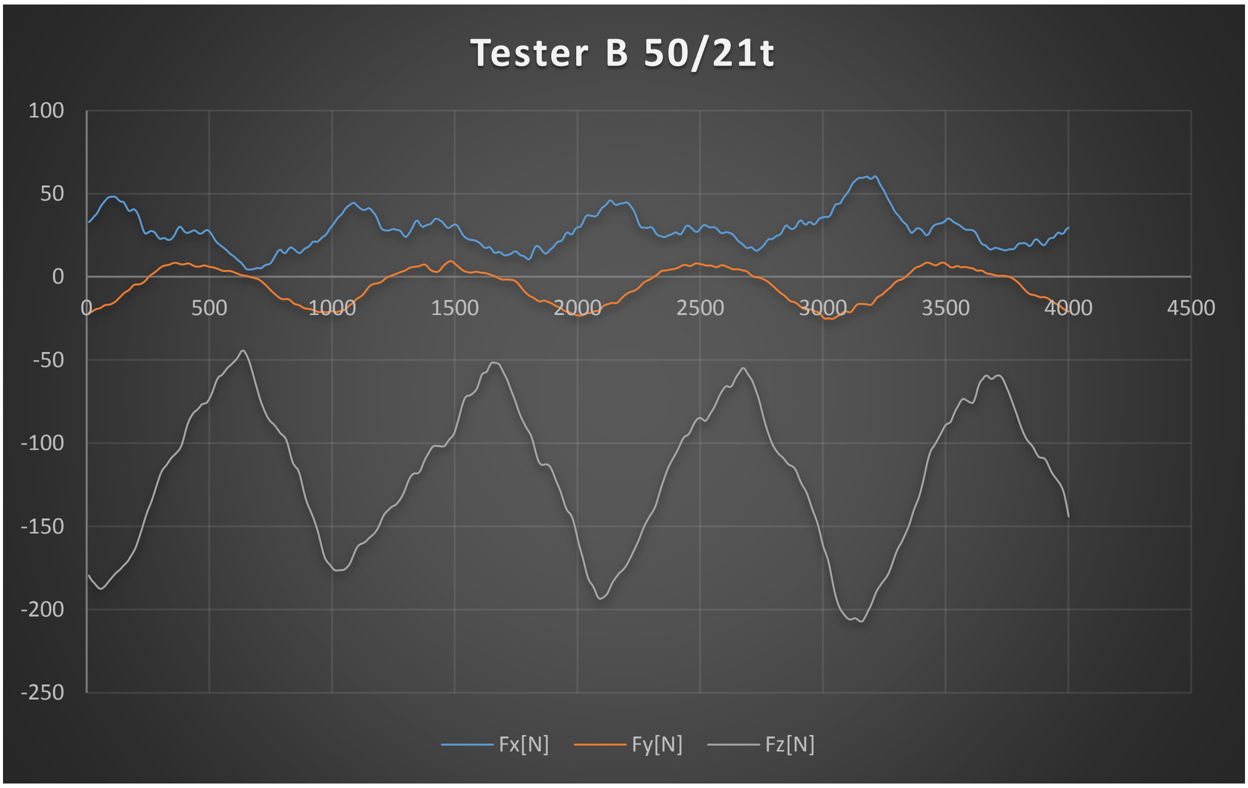


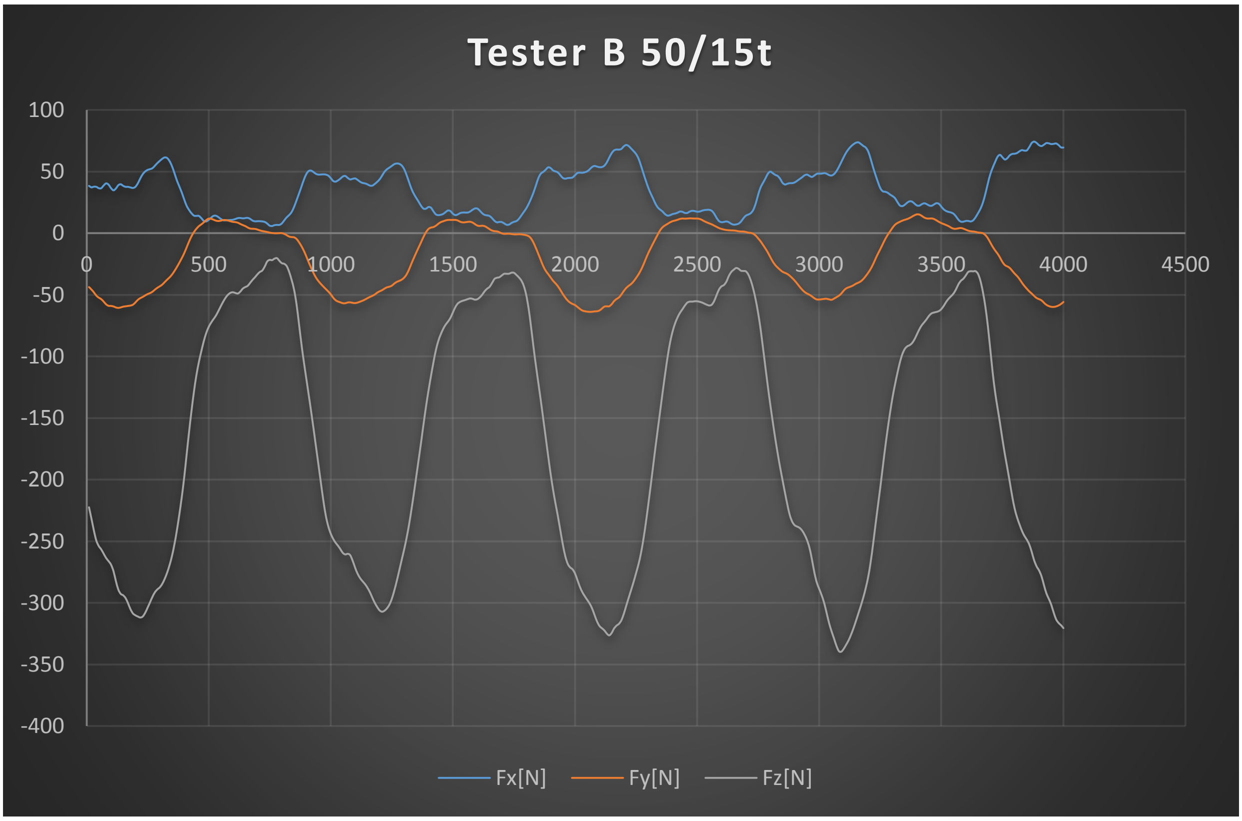
F. Loads registered from Tester A:





G. Loads registered from Tester B:





H.Loads registered from Tester C: