Compressed Air Energy Storage- A Completion Plan for a Lab-Scale Model

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1 Abstract

This report presents the technology of compressed air and thermo energy storages. The project is made by the EPS group of autumn and spring.

The Project Owner and Novia European Project Semester (EPS) Program gives the EPS team working on a project in Spring Semester a straight goal which was to finish off a lab-scale CAES demo for students that was started by a previous EPS Autumn Semester team. The demo would enable students to do measurements and get an insight into Compressed Air and Thermal Energy Storages thus expanding their competence in the field of energy storage.

Project Management is vital in this project and is explained discussing; work breakdown structure, problem analysis (WBS) and explanation of different WBS topics, problem analysis, quality management, cost management, human resource management, team dynamics, S.W.O.T., communication management, risk management, time management and change management.

Due to unforeseen circumstances, the scope of the project was redefined and made the project more theoretical and analysis of lab results for tests carried out earlier in the project. The report focuses on laying out completion plans that will enable the completion of the demo by another party. Some of the focus areas are redesigning solutions for gears and bracket for expander holder and the digitalisation plan, with LabView as a chosen platform. The report ends with a discussion of the carried-out tasks and recommendations for the continuation work on the demo.

2 Table of content

3 Abbreviations

Abbreviation	Meaning
T.E.S.	Thermal Energy Storage
C.A.E.S.	Compressed Air Energy Storage
BCWS	Budget Cost of Work Schedule
ACWP	Actual Costs of Work Performed
BCWP	Budget Cost of Work Performed or Earn Value
RPM	Rotations per minute
LabVIEW	Laboratory Virtual Instrument Engineering Workbench
CAD	Computer Aided Drawing
PLA	Polylactic acid (plastic)
ABS	Acrylonitrile butadiene styrene (plastic)
CAT	Compressed Air Tank
Q	Energy joule (J)
C	Heat capacity ($\frac{J}{kgK}$)

Table 1 Abbreviations

4 Figures

5 Graphs

6 Tables

7 Introduction

The high dependency on fossil fuels has let to high global greenhouse gas emissions which has had a negative impact on the environment. In order to reduce these emissions, focus has moved to renewable energy sources for cleaner energy. The intermittent behaviour of major renewable energy sources makes it difficult to use with the traditional energy systems, but this can be changed with energy storage. The storage of sustainable energy is the next big thing in the world. By using energy storage, it is possible to gain the maximum capacity of renewable energies. If the storage is optimal then it becomes easy and feasible to expand the capacity of the renewable energy share and reduce on fossil fuels. By doing this it is possible to reach the goals that the European Union has set up for each country. The reason why the goals are not reachable at this moment is because renewable energy is uncertain and highly fluctuating. This is because in most countries, renewable energy comes from solar and wind. Solar power is most of the times only available during the day and wind is predictable but also not changeable. This means that without an energy storage the renewable energies cannot be relied to provide the demand at any given time. Therefore, energy storage systems are important.

This project is about a lab scale Compressed Air Energy Storage demonstration (with a possibility to include the Thermal Energy Storage) to be implemented in educations, research, and demonstrations system for students. The CAES demo is located in the Technobothnia Education and Research Centre and how efficient it can be to store the renewable energy in compressed air. This document gives a theoretical look into the components, process redesign for efficiency improvement and how to enable the students to work easily, safely and collect accurate data by use of LabView.

7.1 European Project Semester

Every region of the world is getting more connected to each other. There is a lot of technology and cultural exchange in the work field therefore it is important that young people know how to cooperate with different cultures. This will make it easier for the new generation to do business with other cultures and with the new cultural experience, the students can adapt better in various cultural situations. If Europe wants to build one big family the residents needs to understand each other.

Figure 1 EPS.

(europeanprojectsemester, sd)

7.2 C.A.E.S.

The EPS group of autumn build the system, this information is in a different report that can be accessed from the Project Owner at Novia Univiversity of Applied Sciences titled, “Energy Storage Demo Environment in Technobothnia. Adiabatic Compressed Air Energy Storage Demo, 2019”. The

The compressor compresses air to 150 bar and is stored in a tank (CAT). The pressure regulator reduces the storage pressure to around 6 bar in readiness for the expander which has a maximum operating pressure of 6 bar. The Thermal Energy Storages (T.E.S.) collects the heat from the compressor with water as the medium during the compression process. The T.E.S. is a heat exchanger with a copper spiral tubes for the compressed air submerged in the heated water from the compression system. The T.E.S. facilitates for the reheating of the compressed air during expansion.

Some of the focus points for the demo performance are the impact of the T.E.S on the performance of the expanders and which expander gives better performance for the demo. An accurate data collection method is required in order to get true values to execute the calculations. Manual registration of data is exhausting and poses a risk of inaccuracy. A program will be written in LabVIEW that will collect the data. The Power output measurement will be exported in a excel file where it is possible to make graphs and see the power output in time.

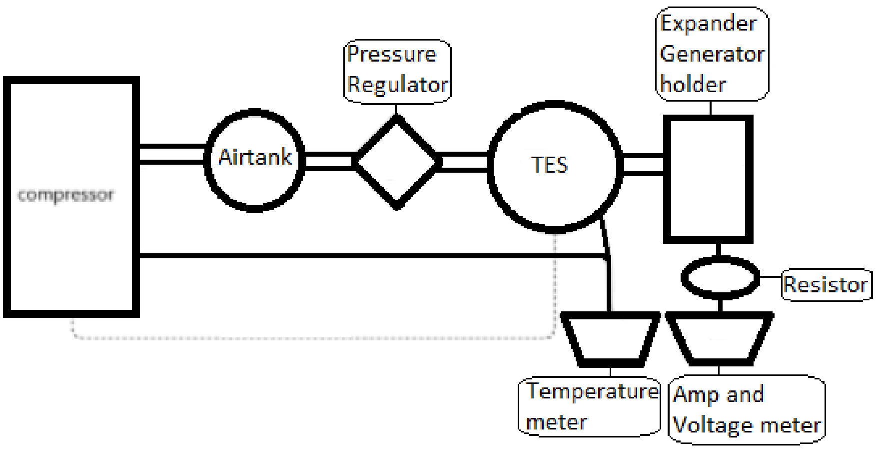


Figure 2 System C.A.E.S.

7.3 Project Goals

The goal of this project is to build a demo setup to store compressed air and which can be used by students. By using this demo setup, the students can see what the impact is of a thermal energy storage (T.E.S.) on the performance of the system and which expander has better performance for this lab-scale model.

Finding an efficient way to store and recover energy from compressed air. The team is focused on finding theoretical solutions for increasing the performance while the Project Supervisor does the practical work in the lab and gives the results. The performance can be increased by better design of gears and fixing leaks in the system. Explanations and more solution can be found in this document.

8 Project Management

8.1 Cost management

Cost management structure is the backbone of the project. It gives a vision of the costs and a timeline of the expenses.

The budget of this project is theoretical, since the team members are not getting paid for their work. However, there is a budget for material and software of €3000. In order to carry out an Earned Value Analysis.

Work hours

The number of work hours need to be included in the cost management to obtain the earn value analysis. To study it some parameters have to be established.

- four members
- Team member work 30 h/week
- The project has a time frame of 14 weeks.
- 10 €/hour.

Work material

The materials needed till the end of the project this semester is defined in a table estimating when these materials will be bought (Table 2). Due to COVID-19 some changes had to be done and the practical work was cancelled and some of the materials were not bought.

Week	Name	Category	Price(€)
1	Connection broken part	Mechanical	3
	Drill	Mechanical	11,9
	Pressure measurement	Mechanical	24,32
	Drill	Mechanical	15,9
	Autodesk inventor	Software	557
	Total		612,12

Table 2 Work materials week 1.

Week	Name	Category	Price(€)
3	LABVIEW	Software	3350
	Total		3350

Table 3 Work materials week 3.

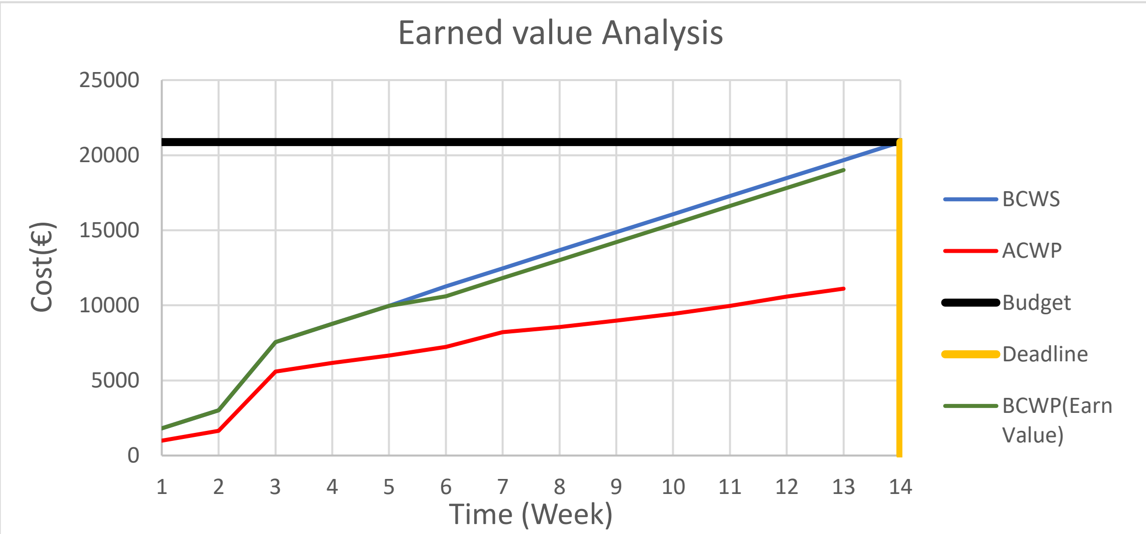
Week	Name	Category	Price(€)
6	Mild steel 200x300x5(or4)	Mechanical	4,71
	M8 bolts(8pieces)	Mechanical	2,6592
	M8 nuts(8pieces)	Mechanical	0,88
	Nylon 3D printer	Mechanical	32,95
	arduino	Electronical	25
	Bidon 12L	Mechanical	17,23
	resistor	Electric	3
	sensors	Electric	30,4
	Totals		116,8292

Table 4 Work materials week 6.

Week	Name	Category	Price(€)
8	90º insulation (22mm)	Mechanical	10,8
	pipe insulation (22mm)	Mechanical	8,1
	Isolation pipe tape	Mechanical	6,9
	Isover SK-C(rol)	Mechanical	28
	Total		53,8

Table 5 Work materials week 8.

The graph illustrates curve BCWS (Budgeted Cost of work schedule), the ACWP (Actual Costs of Work performed) and BCWP (Earn Value). These curves explain the accumulated labour and material costs of the project over the duration of the project. If ACWP is behind BCWS it means that maybe the work materials have not been ordered yet and show a cost variance. This means that the group is working behind schedule but with a cost variance. However if the ACWP is above BCWS it means that the schedule is being followed, however if the budget has risen the group would need additional founding. Also if the BCWP lies below BCWS, the group work fewer hours for the project that was first thought but if the BCWP is above BCWS the team needs to work many hours in the project that it was estimated it.



graph 1 Earn value analysis

After the curves of earned value analysis were plotted many important parameters were registered (Table 6).

Budget at completion	20933€
Planed Value	19733€
Actual Cost	11112€
Earn Value	19021€

Table 6 Earn value parameters.

As illustrated in the graph 1, the ACWP is behind BCWS this means that the project is underlying a cost variance. Also, BCWP (Earn value) lies below BCWS shows that the project had a schedule variance (Table.7).

Cost variance (CV)	7908€
Schedule variance (SV)	-712€

Table 7.Earn value variance.

After a thorough analysis of our project, the variances could be reattributed to some aspects.

The cost variance is positive because due to COVID-19 the university was closed our scoped were changed by the supervisor because any practical work was being done by us. This means that all work materials needed between weeks six to week fourteen were cancelled this caused a reduction in our budget.

Also, for the schedule variance, the group work less hours in the project that was planned because our scoped was changed by the supervisor and the laboratory and workshop hours were cancelled.

8.2 Team dynamics

A team is just a start, for having a high-performance team there needs to be a good team dynamic. It is possible to work on the team dynamic. The team focusses on five different fields.

Trust & belief: The team trusts different team members on their tasks. Each team member has a field of expertise with trusts and beliefs. The team member will bring high value to the team. This results in project having more depth.

Define roles: With a clear structure everybody knows their position in the group and knows where to go if they need extra help to tackle a problem.

Co-operation: Work together and work in different sub teams, even outside comfort zone in order to get new look on different parts of the project.

Shared goals: Create the same expectations in the group so everybody works at the same goal.

Clear communication: Start with clear rules. These are written in the team contract. Also, the team communicates outside the project hours to keep each other updated.

Fields	Action taken
Trust & belief	Start of the project. Small talks to get to know each other. Do some small things together like eating dinner.
Define roles	Be sure that nobody is forest in a role that he doesn't like. Therefore the "Axenroze" is used is used for it. Explanation under this table.
Co-operation	Getting a good group atmosphere. Telling stories about yourself and be interested in the author person.
Shared goals	Creating same expectations and goals. Enjoying our time on Erasmus but it is not only partying. Make realistic goals and create a creative environment to achieve our goals.
Clear communication	Besides direct communication within the team there is a messenger group in Facebook for communication

Table 8 Fields of dynamics

The Axenroze gives for each person the position in the group. The tool is dynamic because group members can change roles during the project

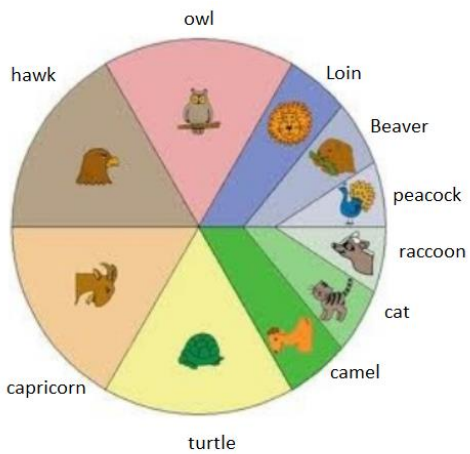


Figure 3 Axenroze

Team member	Role	Impact
Arne	Loin/hawk	Arne is critical around everything that comes as an idea from the group. Alejandro (raccoon) feels a lot of pressure from Arne. Arne created high expectations for the group. He wants a good result.
Dean	Beaver	Works hard on the project. He is active in meetings. He listened to the project leader and to his parts.
Mateusz	Beaver	Mateusz finds many solutions on the mechanical aspect of the group. He has high expectations of him self.
Alejandro	Raccoon	Alejandro looks up to Mateusz and embraced him. The duo works perfect together.

Table 9 Team dynamics

8.3 Covid-19 impact

Convid-19 has a considerable impact on the project which is largely practical. Making progress form home is challenging with the current scope.

The project leader focusses on every aspect of the project and must be open-minded and assist every group member in this situation.

The following steps were taken:

1: Emergency meeting: Organize a meeting and discus the different solutions for the new situation.

2: Risk management: Be critical for every solution and take the best steps for the current situation.

3: Implementing: Assisting the team members to adapt to the new situation.

8.3.1 Emergency meeting

Project coordinator and project leader organized an emergency meeting to discuss the different options:

Option 1:

> Changes to the scope from practical to theoretical and work everything out on paper. Describe all the steps that need to be made in detail. In this way the team has a plan of action when they are allowed to enter school again. If the school remains closed for the whole semester, there is a report out for the next EPS-students.

Option 2:

> If only a part of the team is allowed to enter the lab they have to discuss the lab work thoroughly with the other team members. The team members who are not allowed to work in the lab assist the team in the lab on theoretical level. Only the main parts of the scope can be achieved.

Option 3:

> If only the project coordinator is allowed to the lab, she will take over the practical work in the lab. The team will inform and support the lab work. The project coordinator gives feedback on regular basis on the lab work. Students can work safely from home.

8.3.2 Risk of the new situations

For every situation, the team noted the possible risks.

		Impact		
		Low	Medium	High
possibility	High			
	Medium			
	Low			

Table 10 Covid-19 matrix.

Option 1: Nobody is allowed to enter the school. Changes the scope from practical to theoretical work.

	Risk	Probability	Impact	Risk Assessment	Plan of Control
1	Guess work	High	Medium	High	Checks of the results
2	Uncompleted work	High	High	High	No solution Safety>Project
3	Running out of time	Low	Medium	Low	Time Management

Table 11 Convid-19 option 1

1. Because of the lack of information there is a possibility that the team needs to do some guess work. It is important that the results are checked by different team members to minimize the mistakes.
2. In this option safety is the priority. There will be unfinished practical work.
3. Theoretical work in the project is a minority to the practical work.

Option 2: Some team members are not allowed to go to school anymore form their home university.

	Risk	Probability	Impact	Risk Assessment	Plan of Control
1	Guess work	Medium	Medium	Medium	Focus on the essential part of the scope
2	Uncompleted work	Medium	High	High	Focus on the main goals
3	Running out of time	Medium	Medium	Medium	Time Management
4	Novia closed	High	High	High	Change of scope

Table 12 Convid-19 option 2.

1. The missing information will be provided by the team members that can enter the lab. With less manpower this can take more time than projected.
2. With less working power in the lab, only the essential parts of the scope will be finished.
3. There is still a high expectation of the result although there is less working power in the lab. This created pressure on the team members that are working in the lab to finish to project on time.
4. With closing the university “Novia”, no team member is allowed anymore to go to the lab. This sets the lab work on hold and the project is not able to be completed.

Option 3: Project coordinator will do the lab work. No risk for students to be expelled from school.

	Risk	Probability	Impact	Risk Assessment	Plan of Control
1	Guess work	Medium	Medium	Medium	Focus on the essential part of the scope
2	Uncompleted work	Low	Medium	Medium	Focus on the main goals
3	Running out of time	Medium	Medium	Medium	Time Management
4	Coordinator is not able to work	low	High	Medium	Asking extra help for lab support

Table 13 Convid-19 option 3

1. The missing information will be provided by the team coordinator who can enter the lab. With one person in the lab it will take more time than projected.
2. With less working power in the lab, only the essential parts of the scope will be finished.
3. With the coordinator closer to our project the scope can be changed because she has a clear picture of the project. The coordinator can help to make an achievable scope.
4. Coordinator can get sick or can be no longer allowed to work on the project (family, accident, not allowed in the lab). The team coordinator has connections in the university that can take over the work if necessary.

Option three is chosen. This option is the most reliable till the end of the semester. There is no high risk on failure. The essential practical work can be finished. The project has a deadline and needs to be met.

8.4 Time Management

8.4.1 Project planner

The project started with some small tasks. The tasks were focussed on making a working demo and getting familiar with the system.

ACTIVITY	PLAN START	PLAN DURATION	ACTUAL START	ACTUAL DURATION	PERCENT COMPLETE
Broken part	1	2	1	2	100%
check pump and compressor	2	1	1	1	100%
WBS	1	3	1	3	100%
Cost management	1	13	1	13	100%
Buy parts to fix the demo	2	1	2	2	100%
Check T.E.S.	2	1	3	1	100%
Testing demo	3	1	3	1	100%

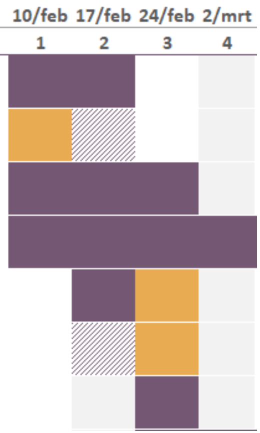
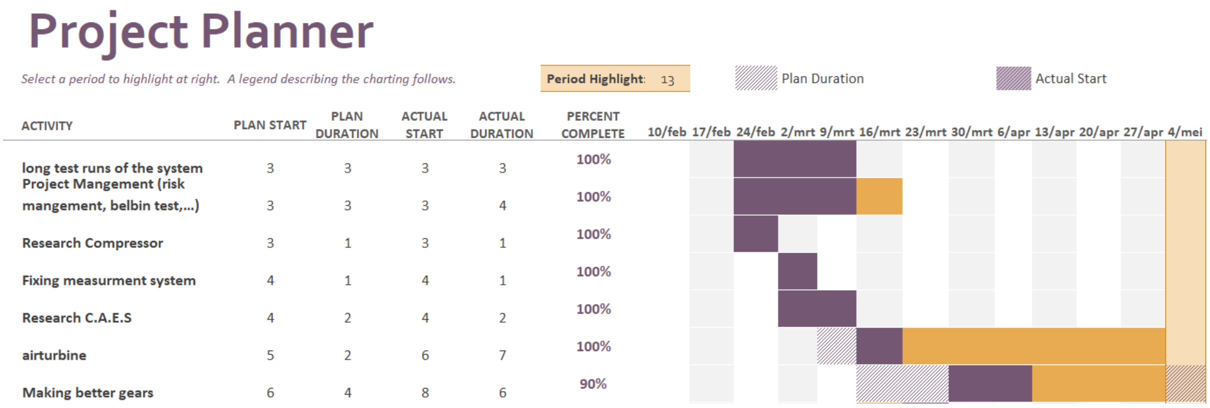


Figure 4 Project planner 1.

In weeks 4, 5 and 6 the team collected information around the system. At that time the test runs were performed to see the quality and possible errors in the system. Tasks are getting more complex like designing gears, calculating performance of the compressor.



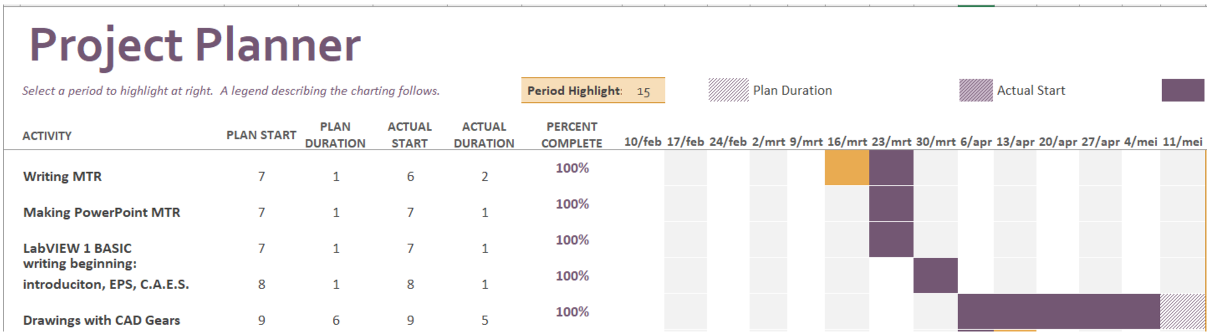
Project Planner

Select a period to highlight at right. A legend describing the charting follows. **Period Highlight:** 13 Plan Duration Actual Start

ACTIVITY	PLAN START	PLAN DURATION	ACTUAL START	ACTUAL DURATION	PERCENT COMPLETE
long test runs of the system	3	3	3	3	100%
Project Mangement (risk mangement, belbin test,...)	3	3	3	4	100%
Research Compressor	3	1	3	1	100%
Fixing measurment system	4	1	4	1	100%
Research C.A.E.S	4	2	4	2	100%
airturbine	5	2	6	7	100%
Making better gears	6	4	8	6	90%

Figure 5 Project planner 2.

Around the midterm report the work speed decreased due the deadline of the midterm report and covid-19. The changes of our way of working style was a slow process in our team (practical focus too theoretical focus).



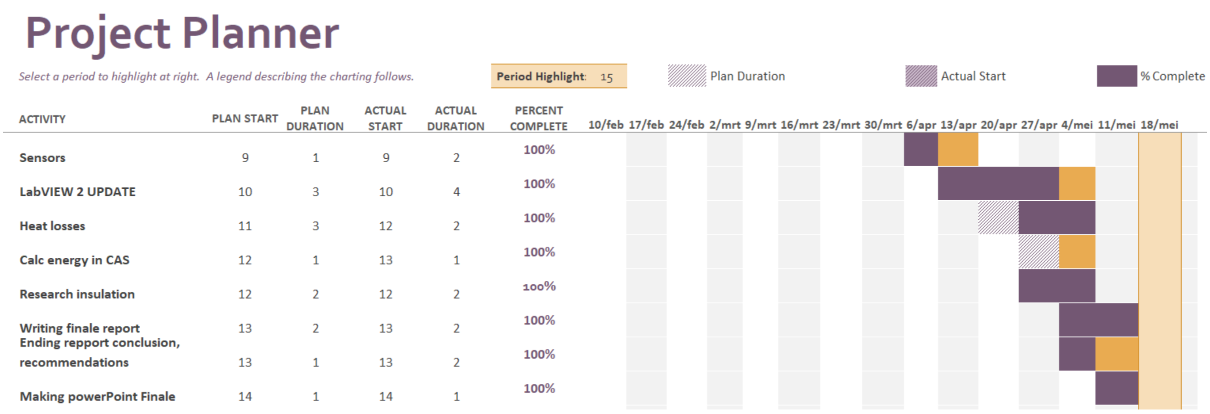
Project Planner

Select a period to highlight at right. A legend describing the charting follows. **Period Highlight:** 15 Plan Duration Actual Start

ACTIVITY	PLAN START	PLAN DURATION	ACTUAL START	ACTUAL DURATION	PERCENT COMPLETE
Writing MTR	7	1	6	2	100%
Making PowerPoint MTR	7	1	7	1	100%
LabVIEW 1 BASIC	7	1	7	1	100%
writing beginning: introduciton, EPS, C.A.E.S.	8	1	8	1	100%
Drawings with CAD Gears	9	6	9	5	100%

Figure 6 Project planner 3.

With the change of the scope some new tasks were developed. The project has enough tasks around 27 of April to get back on a normal speed of the project. With the final report beginning, the team assembled the information in one report.



Project Planner

Select a period to highlight at right. A legend describing the charting follows. **Period Highlight:** 15 Plan Duration Actual Start % Complete

ACTIVITY	PLAN START	PLAN DURATION	ACTUAL START	ACTUAL DURATION	PERCENT COMPLETE
Sensors	9	1	9	2	100%
LabVIEW 2 UPDATE	10	3	10	4	100%
Heat losses	11	3	12	2	100%
Calc energy in CAS	12	1	13	1	100%
Research insulation	12	2	12	2	100%
Writing finale report	13	2	13	2	100%
Ending repport conclusion, recommendations	13	1	13	2	100%
Making powerPoint Finale	14	1	14	1	100%

Figure 7 Project planner 4.

8.4.2 Individual time schedule

Week schedule before covid-19

Day	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Task	Lecture	Lab work	Lab work	Lab work	Meeting	Prepare lab work	Prepare lab work
	Lab work		Homework		Lab work		

Table 14 Week schedule before covid-19.

In first schedule our meeting with Cynthia was planned on Friday. This setup gave the team the opportunity to prepare the lab work during weekend. Monday, Tuesday, and Thursday were our main working days in the lab. Wednesday was the day where team members had the opportunity to work with less people in the lab. This gave the possibility to do some big changes on the system without interrupting the rest of the team members.

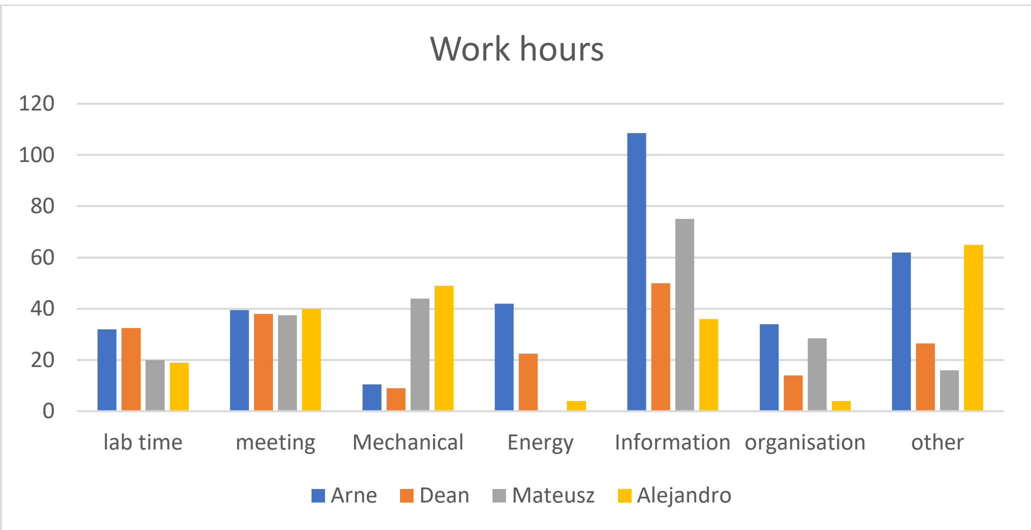
The schedule changed due to covid-19.

Day	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Task	Work from home	Group meeting	Work from home	Meeting	Work from home	Prepare lab work for Cynthia	Prepare lab work for Cynthia
				Work from home			

Table 15 Schedule changed due the covid-19

As shown in table 17, the new schedule focussed on working from home. Moreover, the group decided to organize group meeting for work together and help each other. The meeting with Cynthia was rescheduled on Thursday for sharing the progress of the project of every week, prepare the plan for the next week and help Cynthia in the problems or questions about the lab work.

The lab time is lower than expected due the school being closed for the second half of the project. The team has two persons for energy (Dean and Arne) and two persons for mechanical (Mateusz and Alejandro). The tasks of energy where more lab connected that is the reason that they have more lab hours. Arne was project leader in the first half of the semester for organisation. As he prepared the tasks and meetings. The time slot other is work hours that are not specified. It can be buying components, a lot of small things spread out over different fields, … .



graph 2 Work hours.

9 Gears

Energy can be stored by compressing air and storing that compressed air in tanks. When the energy is needed again it can be retrieved by expanding it with an air motor or turbine. These will drive a generator, that will convert mechanical energy, into electrical. For the transmission of the mechanical energy a system transmission is needed, there are many options on transmission but gears transmission was the option tried by the team because gears allow large velocity ratio with minimum space, mechanically strong and higher loads can be lifted, long life and require only lubrication.

9.1 The law of gearing

When two mechanisms have contact between them the angular velocity was inversely proportional to the segments that describe the contact point, this is supported by the Aronhold-Kennedy theorem.

$$i = \frac{\omega_2}{\omega_1} = \frac{r_1}{r_2} = \frac{\overline{O_1P}}{\overline{O_2P}} \quad (1)$$

With:

ω_1: *speed for pinion*

ω_2: *speed for gear*

r_1: *radius for pinion*

r_2: *speed for gear*

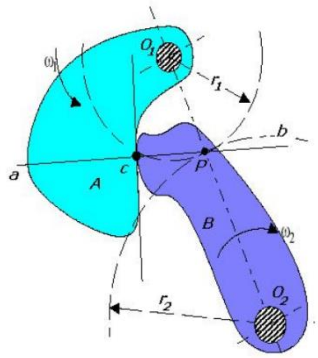


Figure 8 Law of gearing.

The law of the gear could be announced as follows.

"The relation transmission between two profiles must remain constant, as long as the normal to the profile at the contact point passes at all times through a fixed point on the centre line."

(A.Bhatia, 2018)

9.1.1 Parameters for gear design

The gears can be defined in terms of its pressure angle, pitch and number of teeth. Introduce important terms:

The Pitch Diameter (d) is the circumference where the two gears mesh.

Outside Diameter (OD) is the distance between the centre of the gear and the end of the teeth. This number will be important in the design to know the exact magnitude of the gear

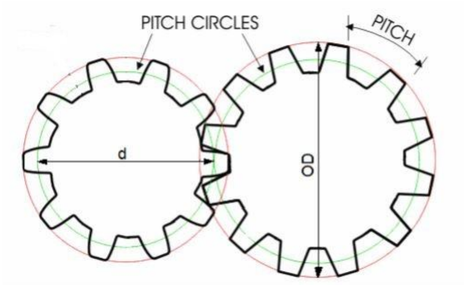


Figure 9 Gear Parameters.

Diametral Pitch (P_d) is the quotient between the number of teeth and pitch diameter

$$P_d = \frac{Z}{d} \quad (2)$$

With:

P_d: diametral pitch.

Z: number of teeth.

d: pitch circle diameter.

Module (m) is the quotient between the pitch diameter and the number of teeth. It is the reference for the calculations for the different parameters of the gear, the module must be the same in both gear for mesh it. The module has been normalcies and follow the rule UNE 18005-84.

$$m = \frac{d}{Z} \; (3)$$

With:

m: module.

d: pitch circle diameter.

Z: number of teeth.

I	1	1,25	1,5	2	2,5	3	4	5	6	8	10	12	16	20	25	32	40	50
II	1,125	1,375	1,75	2,25	2,75	3,5	4,5	5,5	7	9	11	14	18	22	28	36	45	

Table 16 Module UNE 18005-84.

Pressure angle defines the direction in which the power transmission between the two profiles takes place. If the angle fluctuated, the transmission power direction changes and this is damaging the point of view of the dynamics. The ideal point is to have a straight mesh line because the angle of pressure will be constant. The standard pressure angles are 14.5°, 20° and 25°. The pressure angle in use today is 20°; a good compromise for power and smoothness.

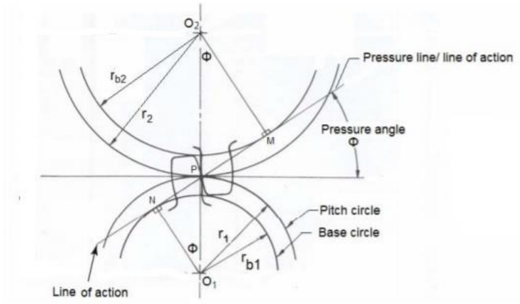


Figure 10 Pressure angel

(A.Bhatia, 2018)

9.1.2 Power transmission

The power transmission in the system is the transfer of the energy between the air motor and the final location of our generator. There are many mechanical options for the transmission of power for example belts, ropes, chains or gears.
The power is given by the amount of work that is executed in a certain increment of time:

$$P = \frac{W}{\Delta t} \quad (4)$$

With:
P=Power

ΔE= Change Energy

Δt= change time

The amount of work for a rotational power transmission is it defined by the equation:

$$W = T \cdot \Delta\theta \quad (5)$$

With:
T: Torque

Δθ: Angular displacement

The angular displacement is related by the angular speed and the increment of time.

$$\omega = \frac{\Delta\theta}{\Delta \mathrm{t}} \quad (6)$$

If Equation (5) and Equation (6) are introduced in the Equation (4), the equation for the power in a rotary machine is defined.

$$\mathrm{P} = \mathrm{T} \cdot \omega \quad (7)$$

(A.Bhatia, 2018)

9.2 Gear Design

9.2.1 Gear materials

One important point for gear design is materials. Materials can change some aspects of transmission, for example, the weight or strength, is why the group need to be accurate in selecting the right ones. Due to, that in our university the 3D metal printer is not available right now, the only option is to use a plastic for print our gears.

Plastic materials for 3D printer:

Nylon is the first choice for durable gears, especially for running without lubrication. Nylon has the strength, flexibility required to generate a durable plastic gear and low friction coefficient, high inter-layer adhesion and high melting temperature. Given that nylon is very hygroscopic, pre-drying is always recommended before printing. Inside Nylon materials some can be designate for example Taulman PCTPE, Bridge or 910 filaments.

(Pechter, 2018)

PLA is a biodegradable thermoplastic that offers good tensile strength, resistance to heat, surface and has a low cost.

ABS (acrylonitrile-butadiene-styrene) is a low-cost engineering thermoplastic that is easily machined, fabricated and thermoformed. This thermoplastic provides rigidity, resistance to chemical attacks and high-temperature stability as well as hardness and toughness at any temperature

(Pechter, 2018)

PEEK is a semi-crystalline thermoplastic with excellent properties. PEEK offers excellent strength, stiffness, resistance to deformation with a continuous load and weariness properties. Also can safe their properties in different temperatures situations. The only bad point is the price as could see in Table 17.

Polycarbonate (PC) is a thermoplastic rigid, with a big resistance into impacts, resistance to fire. Also support the possibility of lubrication with oil or dissolvent. PC support temperatures around 100 ℃ without deformation.

(Symplify 3D, 2020)

Gears							
Material	Cost		Availability		Strength		Total Weight
ABS	3	9	5	25	4	8	42
Nylon	2	6	5	25	3	6	37
PEEK	1	3	5	25	5	10	38
PC	2	6	5	25	3	6	37
PLA	4	12	5	25	4	8	45
	3		5		2		

Table 17 Materials selection table

9.2.2 Calculation gear train

As the chapter 9.1.2 power transmission shows with the equation (7), if the generator turns faster the more energy is produced.

To calculate the speed output and the number of teeth for the gear the equation below can be used. This equation shows that there is a correlation between the number of teeth on the gears and the speed of those gears.

$$i = \frac{z_{Input}}{z_{output}} \qquad (8)$$

$$i = \frac{N_{output}}{N_{input}} \qquad (9)$$

Z being the number of teeth.

N being the speed in revolutions per minute (rpm)

i gear ratio.

Taking the number of teeth on each gear (50 on gear 1 and 10 on gears 2) and knowing the input speed (gear 1) that the system has (300 rpm), the output speed can be calculated by the equation (9) derived from equation (8).

$$i = \frac{50}{10} \qquad (10)$$

$$i = 5$$

Using equation (11) from equation (9) to calculate speed on gear 2

$$N_{output} = 5 * 300rpm = 1500\ rpm \qquad (11)$$

The speed can be increased, the only limitations are the physical components, in this case the generator used can withstand speeds of up to 3000 rpm (see appendix 17.2). Using equation (12) from equation (8), the gear ratio is going to be calculated for increasing the speed to 3000rpm

$$i = \frac{3000\ rpm}{300\ rpm} = 10 \qquad (12)$$

If the speed want to increase with the current transmission of two gears, there are two options.

Using equation (13), the number of teeth is going to be calculated for the new output gear (gear 2) in the current transmission.

$$Z_{output} = \frac{50\ teeth}{10} = 5\ teeth \qquad (13)$$

Also, Using equation (13), the number of teeth is going to be calculated for the new input gear (gear 1) in the current transmission.

$$Z_{input} = 10\ teeth * 10\ = 100\ teeth \quad (14)$$

As can see the current system have two options for double the speed:

- $Z_1 = 100$ and $Z_2 = 10$; a hundred teeth gear it could be a problem for the dimension, the gear when try to turn, it will touch the bracket.
- $Z_1 = 50$ and $Z_2 = 5$; five teeth gear it could be a problem because with the high speed and the high pressure, the gear could break down.

So the group decided to create a gear train therefore doubling the speed from 1500 rpm to 3000 rpm.

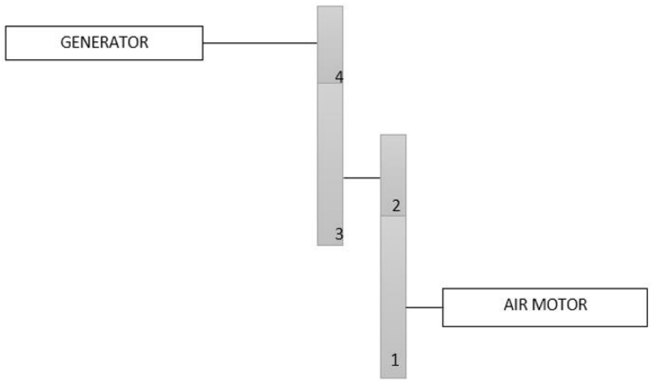


Figure 11 Scheme gear train

Z_1=50

Z_2=10

Z_3=?

Z_4=10

z_3 must be calculated by the equation (8) and (9). Knowing that the gear 4 has to have a speed of 3000 rpm and gear 3 has speed 1500 rpm as it is attached to gear 2 as shown in above figure 11.

$$i = \frac{N_{output4}}{N_{input3}} \qquad (15)$$

$$i = \frac{3000}{1500} = 2 \qquad (16)$$

$$z_3 \ = \ 10\ teeth * 2 = 20\ teeth \qquad (17)$$

Gear three should have 20 teeth thus allowing the gear train to produce the maximum theoretical speed and be above 10 teeth on each gear.

Also, the increase of the speed produces changes in the torque. This must be calculated and compared with the maximum torque that the generator can support. The generator can support a maximum of 0,2 Nm (See Appendix 17.2).

With the equation (7), a calculation of the torque is being done:

$$T = \frac{60W}{3000rpm * \frac{2\pi\, rad}{60\, s}} = 0,19\ Nm\ (18)$$

It is noticed that the torque that the system requires for increasing the speed is below the maximum that the current generator needs. Also, the calculation are theoretical since any friction losses are not analysed.

9.2.3 Old vs new

While testing the demo it was noticed that the gears had too much friction because of misalignment and inaccuracy.

Also gear system has an air motor attached to fifty teeth gears and the other gear attached to the generator with ten teeth.

$$i = \frac{z_1}{z_2} = \frac{50}{10} = 5 \qquad (19)$$

The system has a gear ratio of five this means that the angular velocity is increasing 5 times more in the gear system, but the group decided to increase the output speed and therefore the system will have a higher performance.

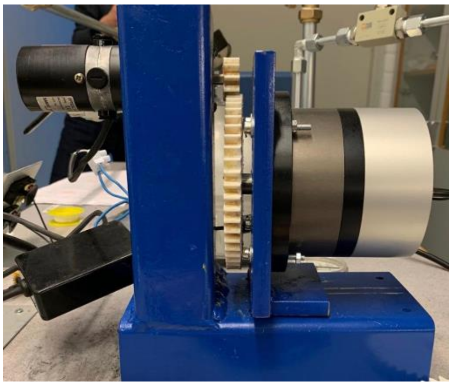


Figure 12 Old gears design.

The new gear train was done by the software Solid Works using an option inside called Toolbox. In this one the designer has to choose the important parameters in a gear design. This one includes four gears one of with fifty teeth one of twenty teeth and the other two ten teeth. The four gears were designed by a DIN profile with a module of two for their perfect engaged and also with pressure angle of 20º.

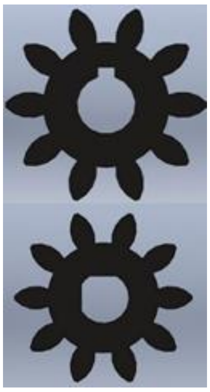


Figure 13 Ten teeth gears

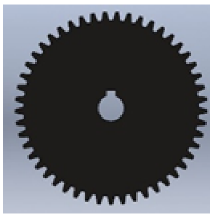


Figure 14 Fifty teeth gears

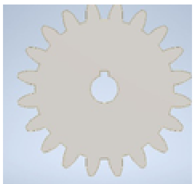


Figure 15 Twenty teeth gear

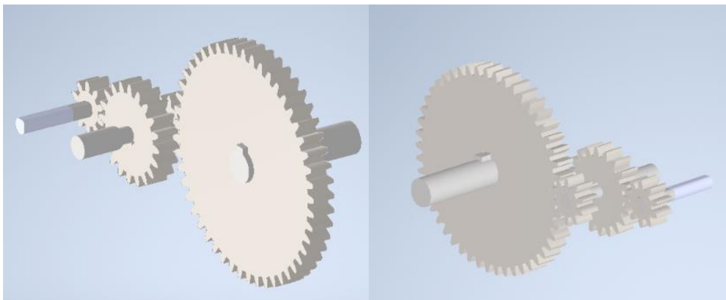


Figure 16 Gear train

9.2.4 Gear train bracket.

Due to the new gear train and that the old bracket is not designed correctly for change of the air turbine between air motor. The group decided to create a new design to make the changes easier and quicker for the students, so two different brackets were designed by the group. The small bracket is designed for the air turbine (Figure 17) and air motor (Figure 18) thinking in the possibility of a fast change only changing four bolts.

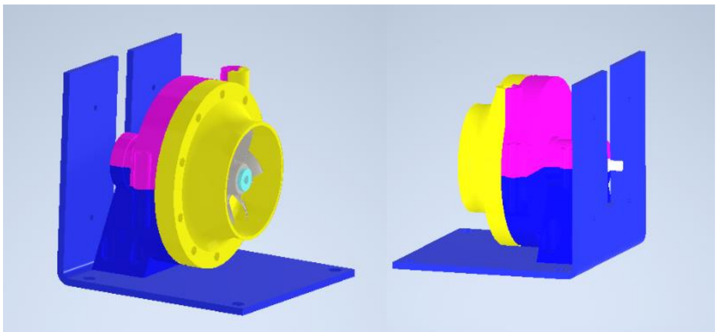


Figure 17 Bracket for air turbine.

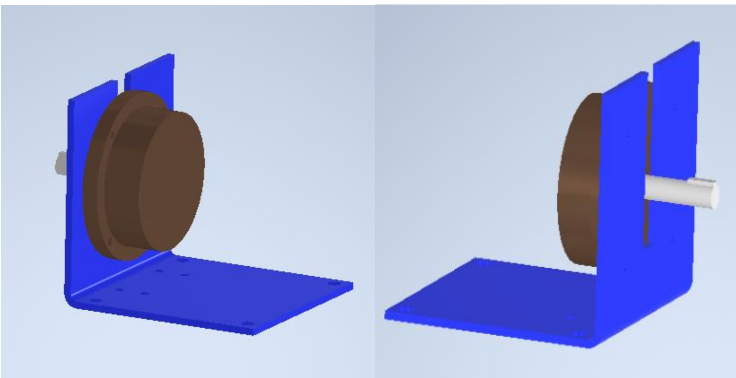


Figure 18 Bracket for air motor.

The second bracket is designed to hold a shaft with the two new gears for the gear train and the generator (Figure 19).

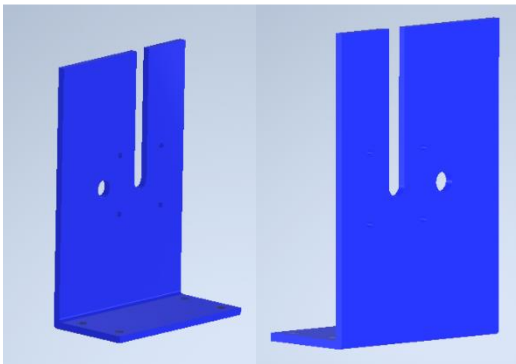


Figure 19 Bracket for generator and new gears.

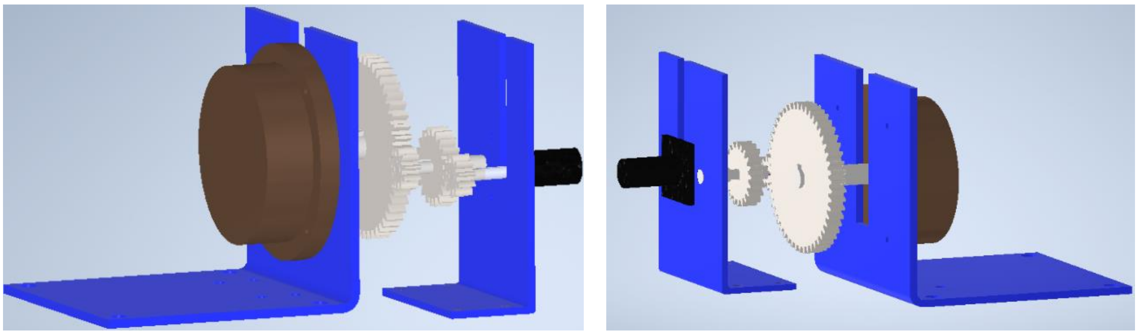


Figure 20 Final assembly.

9.3 Manufacture

9.3.1 Printing Gears

Producing gears in-house saves lots of time as well as money compared to obtaining them from outside although 3D printed objects have larger fatigue and are typically weaker than injection moulded ones. The gears used in this project will be created using a 3D printer as this will have all the benefits mentioned above and even though they will be weaker they have proven to be reliable throughout continuous use.

To 3D print them there is a seven step procedure; producing a 3D model using CAD software, converting the model to an STL(standard tessellation language) format, sending the STL file to 3D printer computer, machine setup, 3D printing process, removal, and post processing.

A 3D model for the gears was created using Inventor as it is available to the students and also using inventor the model was converted to an STL file. Using a USB stick the file can transported to the 3D printer which after a set up will be ready to print. Next the print needs to be safely and carefully removed and given time to cure before put in use. Curing will give the printed material better strength.

(howstuffworks, 3-d-printing4, sd)

9.3.2 Bracket for Gears

Since the needed dimensions of the bracket are outside the sizes of the 3D printers that are available to the team in might not be possible to use 3D printers and therefore the brackets will have to be build using a metal sheet and metal working processes.

Steps for making the bracket in the workshop:

1. Cut out the need dimensions from the metal sheet using hack saw.
2. Mark out the holes that are needed to be drilled.
3. Drill the holes using a metal drill.
4. Make the slots by marking out the slot with a metal scribe then drilling a hole every 10 mm and then by drilling again where the metal pieces are still left.
5. Mark on the sheet where the metal will be bend and then secure the sheet in a vice at that level.
6. Start bending the metal using hands and finish using hammer.
7. Finish by making the edges smooth with a metal grinder.

Figure 21 Generator Bracket

10 Energy

In this chapter includes compressor, insulation and thermodynamics.

10.1 Compressor location

Place the compressor as close as possible to the compressed air tank (central). This gives a better performance of the installation. It also lowers the chance of leaks. The system needs less pipes and short pipes reduce pressure losses in the system

The location of the compressor is important. It needs to be easily accessible for maintenance and protected against unauthorized access.

The compressor inlet air must be as clean as possible (as little (exhaust) gas as possible) and free of solid particles. The compressor needs to be in a cool place if possible.

A compressor generates a lot of heat. The compressor needs to be cooled. There are different ways to cool the compressor with air or water. The heat in the medium can be used in different processes. If you reuse the heat the overall performance of the system increases.

Cooling down compressor:
Currently the compressor gets too hot. With the heating problem the compressor needs to be shut down around 100 bar. This is the reason that the compressor is not reaching 150 bar. The compressor is located in a closed room without proper ventilation.

10.2 Insulation

10.2.1 Insulating pipes

Insulating pipes is important for transporting the heated water from the compressor to the T.E.S. By insulating, the heat remains in the pipes and losses to the surroundings are reduced. During expansion of air from 150Bar to 6Bar, there is a drop in temperature to cryogenic temperatures as shown in the report made by the EPS Autumn Semester Team, 2019. The cryogenic temperatures are just as dangerous as the hot temperatures as they can cause cold burns, and the end user needs to be protected from both hot and very cold surfaces.

For the isolation there is recommended to use polyethylene that is available in the shop Biltema. The isolation needed are 6 X 90-degree isolation corners with thickness 13mm and for 22mm pipes. And 3X straight isolation pipes with the same measurements as the corners.

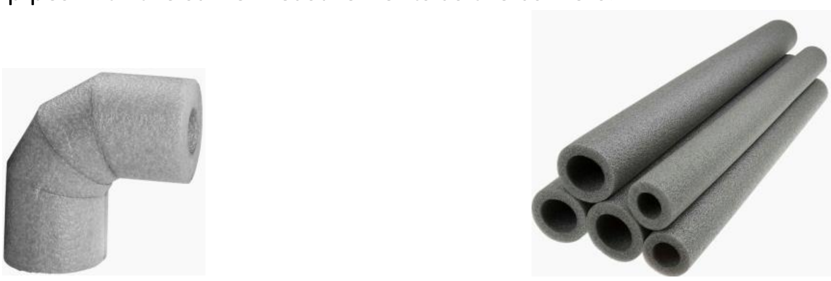


Figure 22 Isolation corners and isolation pipes.

10.2.2 Heat losses pipes

Determination of the equivalent thickness of the pipe

$$d_{eq} = r_2 * ln(\frac{r_2}{r_1}) \qquad (20)$$

with:
d_{eq} = equivalent thickness
r_2 = outside radius = 10,67mm
r_1 = internal radius = 7,5mm

$$d_{eq} = 10{,}67mm * \ln\left(\frac{10{,}67mm}{7{,}5mm}\right) = 3{,}762mm = 0{,}0038m \qquad (21)$$

Calculating heat losses pipes

$$P_W = \mathrm{U} * \mathrm{A} * \Delta\mathrm{T} \qquad (22)$$

With:
P_W = total heat loss
U = Thermal transmittance (rate of heat transfer through a material)
A = total surface of the pipes
ΔT = total temperature difference

Calculate U without isolation

$$U = \frac{1}{R} => R = \frac{d_{eq}}{\lambda} + R_i + R_e \qquad (23)$$

With:
U = Thermal transmittance
R = thermal resistance
d_{eq} = equivalent thickness
λ value of stainless steel = 17 W/mK
R_i = 0,13 m^2K/W
R_e = 0,0008 m^2K/W

$$U = \frac{1}{R} = \frac{0{,}0038m}{17\frac{W}{mK}} + 0{,}13\frac{m^2k}{W} + 0{,}0008\frac{m^2k}{W} = \frac{1}{0{,}131\frac{m^2k}{W}} = 7{,}63\ \frac{\mathrm{W}}{\mathrm{m^2K}} \qquad (24)$$

Calculate U with isolation

$$U = \frac{1}{R} => R = \frac{d_{eq}}{\lambda} + \frac{d_{PE}}{\lambda_{PE}} + R_i + R_e \qquad (25)$$

With:
U = Thermal transmittance
d_{eq} = equivalent thickness
λ value of stainless steel = 17 W/mK
R_i = 0,13 m^2K/W
R_e = 0,0008 m^2K/W
$\lambda_{PE\ polyethylene}$= 0,26 W/mK thickness of 13mm

$$U = \frac{1}{R} = \frac{0{,}0038m}{17\frac{W}{mK}} + \frac{0{,}013m}{0{,}26\frac{W}{mK}} + 0{,}13\frac{m^2k}{W} + 0{,}0008\frac{m^2k}{W} = \frac{1}{0{,}181\frac{m^2k}{W}} = 5{,}52\frac{\mathrm{W}}{\mathrm{m^2K}} \qquad (26)$$

Calculate the total surface of the pipes

$$A = 2\pi * r * l_{totale} \qquad (27)$$

With:
A = Surface
r = outside radius
l_{total} = total length of the pipes

$$A = 2 * \pi * 10{,}67mm * 2730{,}50 = \ 183\ 057{,}451mm^2 = 0.183m^2 \qquad (28)$$

Calculate total heat loss

$$P_W = \mathrm{U} * \mathrm{A} * \Delta\mathrm{T} \qquad (29)$$

With:
P_W = total heat loss
U = Thermal transmittance
A = total surface of the pipes
ΔT = total temperature difference = $38.9°C(Tempature\ after\ running) - 20°C\ (room)$

With no isolation:

$$\mathrm{Pw} = 7{,}632\left(\frac{\mathrm{W}}{\mathrm{m^2K}}\right) * 0{,}183m^2 * (312{,}05K - 293{,}15K) = 26{,}398\,W \qquad (30)$$

With isolation:

$$\mathrm{Pw} = 5{,}52\left(\frac{\mathrm{W}}{\mathrm{m^2K}}\right) * 0{,}183m^2 * (312{,}05K - 293{,}15K) = 19{,}1W \qquad (31)$$

Conclusion:

With insulation around the pipes there is a heat recovery of 7,3W with the current temperature. Therefore, just for insulating to lower the heat loss is worth it. Since, there is another aspect for the insulation for safety, these two combined aspects would make it be ideal to isolate the pipes.

10.2.3 Insulating T.E.S.

Insulating the T.E.S. will help to minimalize the heat losses of the T.E.S. It is an important part to isolate for the reason being it is a large object that is just made from aluminium, so it has not so much thermal transmittance. In the industries it is also one of the most isolated items for the reason being the water/fluid is most of the times in large amounts there. Therefore, if not isolated and the efficiency of the thermal storage system is reduced. There for it is important to insulation the T.E.S. to get a higher efficiency.

The isolation that is recommended to use for the demo is available at STARKKI. And the measurements of insulation are 20x140 mm and a length of 14 m.

Figure 23 Insulation isover (STARK).

10.2.4 Heat losses T.E.S.

Calculating heat losses T.E.S.

$$P_W = U * A * \Delta T \qquad (32)$$

with:
P_W = total heat loss
U = Thermal transmittance
A = total surface of the pipes
ΔT = total temperature difference

Calculate U without isolation

$$U = \frac{1}{R} => R = \frac{d}{\lambda} + R_i + R_e \qquad (33)$$

With:
U = Thermal transmittance
R = thermal resistance
d = thickness aluminum
λ value of aluminum = 160W/mK
R_i = 0,13 m^2K/W
R_e = 0,0008 m^2K/W

$$U = \frac{1}{R} = \frac{0.0025m}{160\frac{W}{mK}} + 0{,}13\frac{m^2k}{W} + 0{,}0008\frac{m^2k}{W} = \frac{1}{0{,}130816\frac{m^2k}{W}} = 7{,}644\ \frac{\mathrm{W}}{\mathrm{m^2K}} \qquad (34)$$

Calculate U with isolation

$$U = \frac{1}{R} => R = \frac{d}{\lambda} + \frac{d_{PE}}{\lambda_{PE}} + R_i + R_e \qquad (35)$$

With:
U = Thermal transmittance
d = thickness aluminum
λ value of aluminum = 160 W/mK
R_i = 0,13 m²K/W
R_e = 0,0008 m²K/W
$\lambda_{mineral\ wool}$= 0,039 W/mK thickness of 20mm

$$U = \frac{1}{R} = \frac{0{,}0025m}{160\frac{W}{mK}} + \frac{0{,}020m}{0{,}039\frac{W}{mK}} + 0{,}13\frac{m^2k}{W} + 0{,}0008\frac{m^2k}{W} = \frac{1}{0{,}644\frac{m^2k}{W}} = 1{,}554\frac{\mathrm{W}}{\mathrm{m^2K}} \qquad (36)$$

Calculate the total surface of the T.E.S.

$$A = 2 * \pi * r^2 + 2 * \pi * r * h \qquad (37)$$

With:
A = Surface
r = outside radius
$l_{T.E.S.}$ = Length of the T.E.S.

$$A = 2 * \pi * 150^2 mm + 2 * \pi * 150mm * 340mm = 461\,814{,}12mm^2 = 0.461m^2 \qquad (38)$$

Calculate total heat loss

$$P_W = \mathrm{U * A * DT} \qquad (39)$$

With:
P_W = total heat loss
U = Thermal transmittance
A = total surface of the T.E.S.
ΔT = total $\text{temperature difference} = 38.9°C(Tempature\ after\ running) - 20°C\ (room)$

With no isolation:

$$\mathrm{Pw} = 7{,}644\left(\frac{\mathrm{W}}{\mathrm{m^2K}}\right) * 0{,}4618m^2 * (312{,}05K - 293{,}15K) = 66{,}722\ W \qquad (40)$$

With isolation:

$$\mathrm{Pw} = 1{,}554\left(\frac{\mathrm{W}}{\mathrm{m^2K}}\right) * 0{,}4618m^2 * (312{,}05K - 293{,}15K) = 13{,}561W \qquad (41)$$

Conclusion:

With isolation around the T.E.S. it is possible the get the heat loss from 66,72W down to just 13,56W. The isolation reduces the heat losses by around 53 watts.

All done with (Jan, 2017)

10.3 Thermal energy in T.E.S.

The information under following table is collected from test results. The charge time of the compressor is 20 min. The pressure inside the C.A.T. was 90 bars.

Temp comp start	23,2	°C
Temp T.E.S. start	24,6	°C
Comp power(kwh)	0,53	kWh
Time of Air mot	12,2	minutes
Temp comp after	77,2	°C
Temp T.E.S. after	38,9	°C
Time comp	20	minutes
End pressure	90	bar
Amount of water	6	litre

Table 18 Information 20 min test

From degrees Celsius to Kelvin:

$$TK(K) = 273.15 + \Delta T\ (°C) \qquad (42)$$

$$Q\ (J) = m\ (kg) * c\ \left(\frac{J}{kgK}\right) * \ \Delta T\ (K) \qquad (43)$$

With:

Q = Energy

M= masse

C= Heat capacity

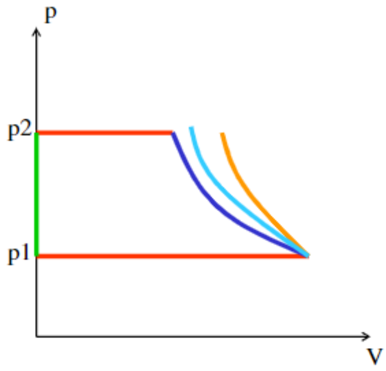
ΔT = Different in temperature

$$Q\ (J) = 6\ (kg) * \ 4186\ \left(\frac{J}{kgK}\right) * \ (312.05 - 297.75)(K) = \ 359158{,}8\text{J} \ = \ 0{,}09998\text{kWh} \qquad (44)$$

In total the system collected 0,1kWh thermal energy in the T.E.S..

10.4 Compression energy

With an isothermal compression the temperature is constant. The dark blue line is the isothermal process. In graph 3 it is clear that isothermal compression needs the least amount of energy.



graph 3 P/V graph compression

$$W_t = G(kg) * R\left(\frac{J}{kg\ K}\right) * T\ (K) * \ln\left(\frac{P2}{P1}\right) \qquad (45)$$

With:

W_t = Isothermal compression (dark blue line)

R = Gas constant = 288 $\frac{J}{kgK}$

T = Temperature of the air = 20°C = 293K

P_2 = End pressure of 90 bar

P_1 = Starting pressure 1 bar

G = Enclosed gas mass

$$G = \frac{\mathrm{V}_{\mathrm{AirExpander}}}{\text{Masse density of air}} * t \qquad (46)$$

With:

$V_{\text{Air Expander}}$ is the air volume flow through the expander, what equals to $5 * 10^{-3}$according to the datasheet.

Masse density of air is 0,775 m³/kg

t= time (s) the time of the expansion is 12,27 minutes (736 seconds)

$$G = \frac{5\ x\ 10^{-3}\ \frac{m^3}{s}}{(0{,}775\frac{m^3}{kg})} * 736\ s\ = 4{,}75\ kg \qquad (47)$$

$$Wt = 4\ {,}75\ kg * \ 288\frac{J}{kgK} * \ 293{,}15K * \ln\left(\frac{90}{1}\right) = \ 1804555{,}7\mathrm{J}\ = 0{,}501\mathrm{kWh} \qquad (48)$$

$$h\ = \frac{Wt}{P_{compressor}} * \ 100 \qquad (49)$$

$$h = \frac{0{,}501}{0{,}53} * \ 100 = 94{,}53\% \qquad (50)$$

With the water cooling the compressor is coming close to the isotherms process.

10.5 Isothermal storage

In an isothermal storage the temperature is constant. The exchanges of heat with the compressed gas is necessary. Otherwise the temperature will be rising during the charging and the temperature will drop during discharge.
For getting an estimation for compression and expansion, the ideal gas law will be used.

P = pressure
V = volume
n = amount of substance of gas (moles)
R = gas constant
T= temperature

$pV = nRT = constant$

The work output of a compression is negative and expansion positive.

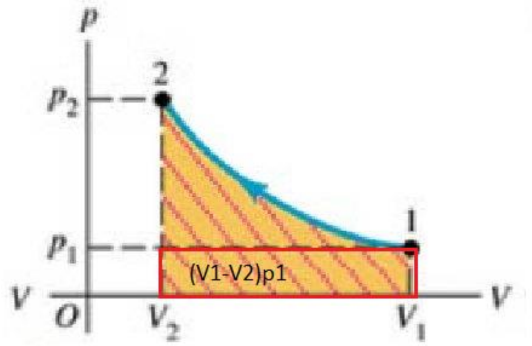
$WA \rightarrow B =$ Necessary energy for changes from situation A to B

$$WA \rightarrow B = \int_{V1}^{V2} p\, dV = \int_{V1}^{V2} \frac{nRT}{V} dV = nRT * \int_{V1}^{V2} \frac{1}{V}\, dV \qquad (51)$$

$$= \; nRT * \; (\ln V2 - \ln V1) = nRT * \ln\left(\frac{V2}{V1}\right) = nRT * \ln\frac{V2}{V1} = pA * VA * \ln\frac{p1}{p2} = pB * \; VB * \ln\frac{p1}{p2} \; (52)$$

If the outside pressure is the same as the starting pressure, this is positive effect for compressing air.

$$Wt\ A \rightarrow B = \; p1 * V1 * \ln\left(\frac{p1}{p2}\right) + (V1 - V2)p1 = \; p2 * \; V2 * \ln\frac{pA}{pB} + (p2 - p1)\, V2 \qquad (53)$$



graph 4 P/V energy safe outside pressure

P1 is atmospheric pressure (1bar). Since to the fact that the starting pressure is 1 bar, the system doesn't have to put energy in the system for achieving a pressure of 1 bar.

Energy for compression:

$$WtA \rightarrow B = 9\ MPa * \; 0{,}012m^3 * \; \ln\frac{1\ bar}{90\ bar} + (9MPa - 0{,}1Mpa)\ 0{,}012m^3 = \; -0{,}379\ MJ = -379KJ \qquad (54)$$

Energy for expansion:

$$WtA \rightarrow B = 9MPa * \;\; 0.012m^3 * \; \ln\frac{90\ bar}{5\ bar} = 0{,}312\ MJ = 312\ KJ \qquad (55)$$

(CAES, 2020) (Moonen, 2020)

11 System Repair

11.1 Failing of the Compressor

The compressor failed a couple of times in the project and by the end of this project, it was totally out of function.

This phase of the project started with a faulty compressor which had occurred during a testing by the first group. The connection between the compressor and the C.A.T. was non-functional due to weak threads that could not withstand high pressure (green box). According to the previous team, the connection gave away at 100 bar.

The process of making the part is explained in the next chapter.

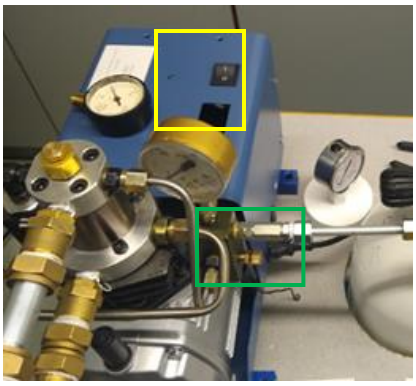


Figure 24 Compressor broken part

Secondly, during this phase of the project, the starting cables where broken by the ventilator of the compressor (yellow box inside the compressor). The solution was to rewire everything every part that was damaged by the ventilator.

During a test the compressor was overheated. Due to that the plastic filter melted away. This happened at the same time with the beginning of the global pandemic Covid-19 and made it impossible to fix the filter or buy a new compressor. The temporary solution was to connect the system to the compressed air net of the school.

The project coordinator gives the team advise to wait with buying a new one. Looking for a bigger budget for buying a better compressor that will increase the efficiently of the system.

11.2 Broken part

In previous demo test high pressure from compressor and weak connection due to short thread resulted in failure. Current team decided to make a new thread by increasing the diameter size of the female thread as the thread was damaged. In addition, using the depth of the hole to have a stronger hold. A new connection was used between the compressor and the pipe DP 701 (Fig 25.) this was a suggestion from the expert in the workshop.

Figure 25 DP701.

11.3 Leakage

Leaks are a big problem in installations because it will lower the efficiencies and cost lots of money. Currently when the C.A.E.S. runs the leakages are minimum. By using a tape that's made from Teflon it is possible to make the connection more airtight.

Figure 26 Teflon tape (Teflon)

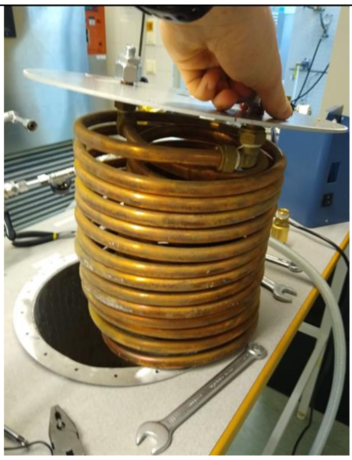
Measuring the air leaks:

By measure the air leaks with an ultrasonic meter it is possible to find leaks that aren't hearable with the ear. By doing this the efficiency of the system goes up and there will be a cost safe on the otherwise wasted air through leaks.

Figure 27 Ultrasonic meter (sonocheck).

11.4 Oxidation

T.E.S. is built from copper tubes. Copper in contact with water causes oxidation. Checking the T.E.S. there was an encounter of brown water with solid particles. The colour can be explained from the copper tubes in the T.E.S.. This water affects the performance of the pump and changes the heat capacity of the water. This polluted water has a negative impact on the overall flow of the water in the system. The solid particles can create corrosion in the pipes.

 Figure 28 T.E.S. tubes	 Figure 29 T.E.S. inside	 Figure 30 Tubes
Coper and water give oxidation. This changes the color of the water and might give solid particles in the water.	Solid particles and minerals settle in the T.E.S..	Solid particles damage the tubes and the water pump. This decreases the flow of the water in the system.

There are different possible solutions to prevent the oxidation:

- Coating by giving a protective paint or lacquer layer around the metal.
- Galvanize: Due to a chemical reaction zinc and steel melt together to form an alloy. This creates a strong bond between the base material and the coating.
- Refresh the water on a regular basis. The T.E.S. should be refilled with fresh water before the test and emptied after the test.
- Coating needs know how for achieving the requested quality. Galvanizing is the most expensive solution.

Refreshing the water is a straightforward solution with can be performed by students.

(tosec, 2017)

12 LabView

12.1 LabVIEW program

While doing measurements students also learn about the compressed air and thermal storage system.

The students need to collect data to get information about the system. The information that can be measured is temperature, pressure and power. It is important that they collect correct data in a safe way.

A program is being developed to collect data. Use software for collecting data is more accurate than manual colleting. The students can hold a safe distance between themself and the demo . Software is accurate for collecting data because software can collect correct data with small time intervals and without reading mistakes.

The program needs some Inputs for calculating the outputs.

Inputs	
Temperature	Start and ending temperature T.E.S., for thermal energy calculation Temperature Compressor
Amount of water in T.E.S.	How much water is added in the thermal energy storages
Voltages	Voltages in the electrical circuit
Current	Current in the electrical circuit
Power	Power output of the generator
Power used by the compressor	Electrical consumption of the compressor, for calculated overall performances.

Table 19 LabVIEW inputs

Outputs	
Electrical performances	Efficiency electrical energy
Electrical + thermal performances	Efficiency electrical energy + thermal energy from T.E.S.
Power output graph	Power output graph in excel for calculation and the data that's been collect from the generator output.

Table 20 LabVIEW outputs

12.2 Starting program

Start by understanding what the inputs and outputs are from the system. Then get a visual idea which measurement need to be digital.

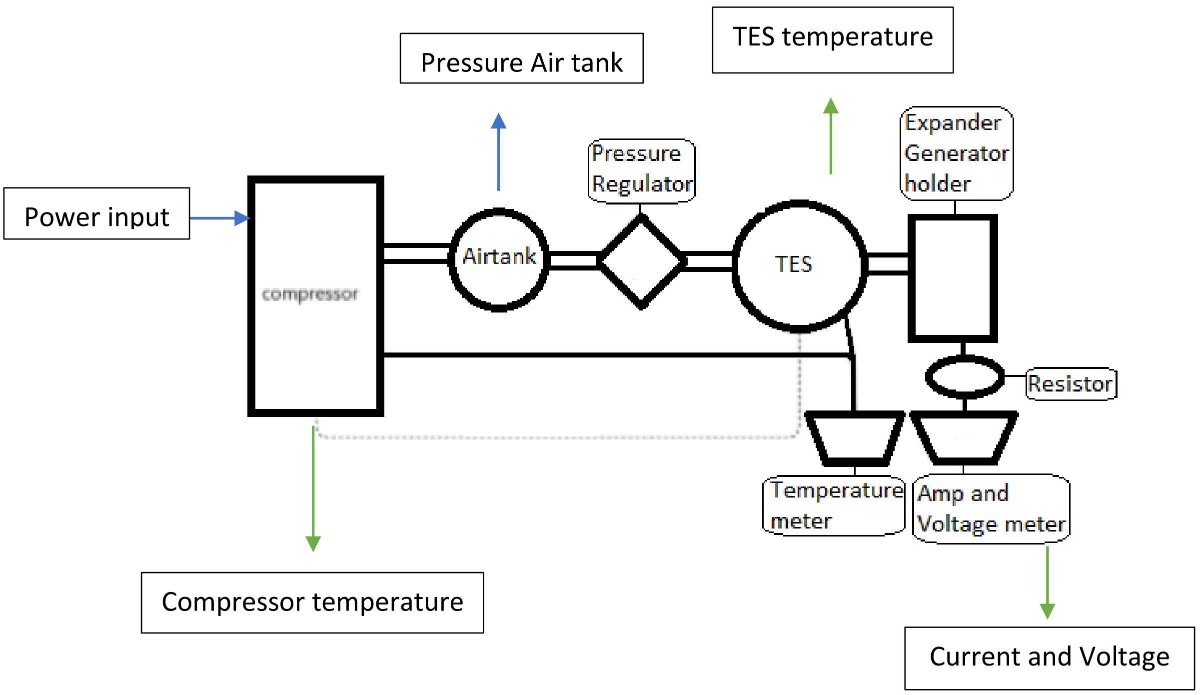


Figure 31 System input and outputs

The blue arrows are manual measurement devices.
The green arrows are digital measurement devices. The Arduino has an analog input that can read signals. With the input of the measurements the program can do the calculations.

The power output of every second will be calculated and uploaded to an excel file. A digital way for collecting data will be more accurate than manually writing it down.

12.3 User manual program

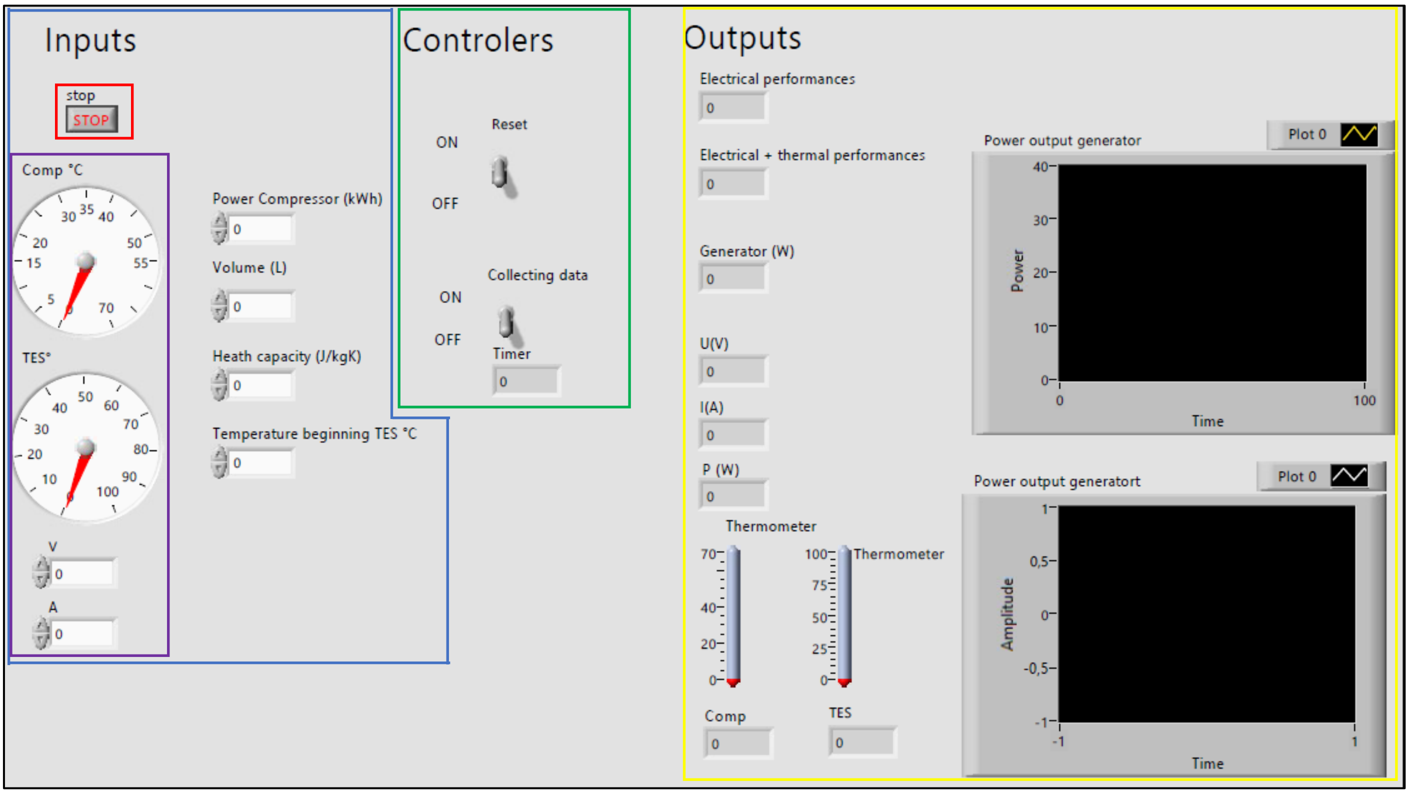
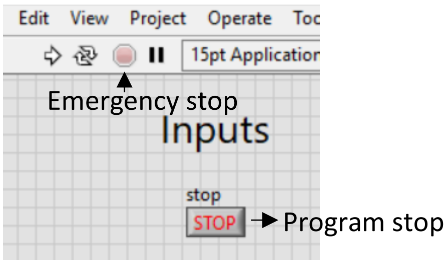


Figure 32 User manual program.

Red box	Program stop: with this stop the program stops safely and there are no chances that the data will be corrupted. Emergency stop: this shuts down the program immediately. There is a possibility that the programme will lose data or give an error when trying to restart the program.  *Figure 33 Stops*
Blue box	Input system collects data out of the compressed air system. Purple box can be changed with real input of the system. The other data needs to set manually by the user. Power compressor: read it out of the energy meter. Volume (L): How much water is added in the thermal energy storages (T.E.S.) in litres. Heat capacity: For water it is 4186 J/kgK Temperature beginning T.E.S. in degrees Celsius.

Green box	The reset switch resets the collected data and the timer. Collecting data switch on: Starts collecting the data and activates the timer. The switch needs to be used when the generator starts generating power. Timer in seconds gives how long the system is collecting data and the generator is running.
Yellow box	Electrical performances (%): what are the overall performances of the system with electrical energy. Electrical + thermal performances (%): The overall performance of the system with electrical and thermal energy. Generator (W) total power output of the generator. P (W) live power output of the generator. U (V) and I (A) are values of the electrical circuit. Temperature of compressor and T.E.S. is displayed on a thermometer and a digital display. The power output is displayed on the graphs.

Table 21 User manual LabVIEW

12.4 Code

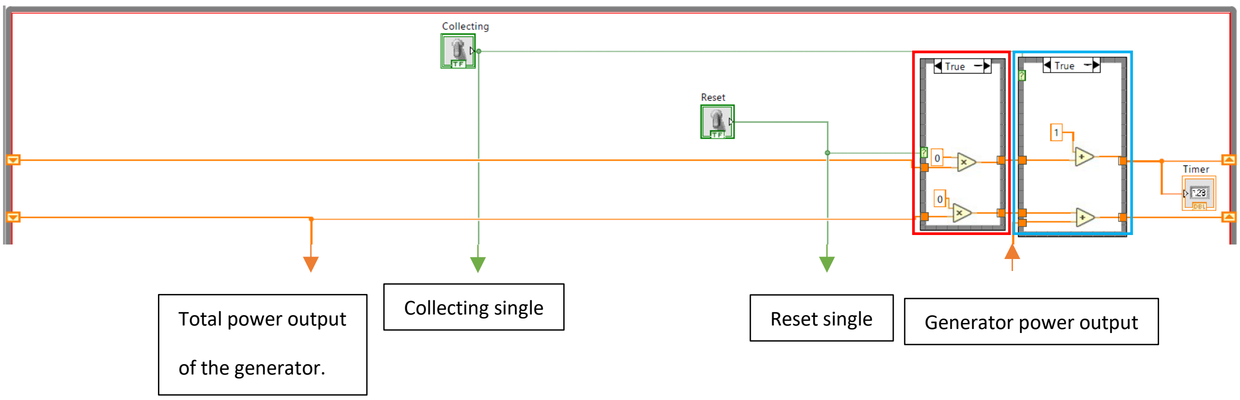


Figure 34 Code timer and add power

The total power output is the power output of the generator counted up every second.

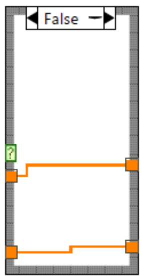


Figure 35 False

The red box is activated when the reset switch is True. Multiply the timer and power values with zero to start from the beginning.
When the reset switch is False nothing happenes to the data. The data flows around the program.

The blue box counts every second one up. The delay of one second is situated where the data is collected to write it down in the excle file. Every second the power output of the genertor will be counted up.

When the collecting data swicht is false there the timer will stop (adding zero every second) and no power output will be counted.

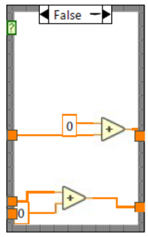


Figure 36 False

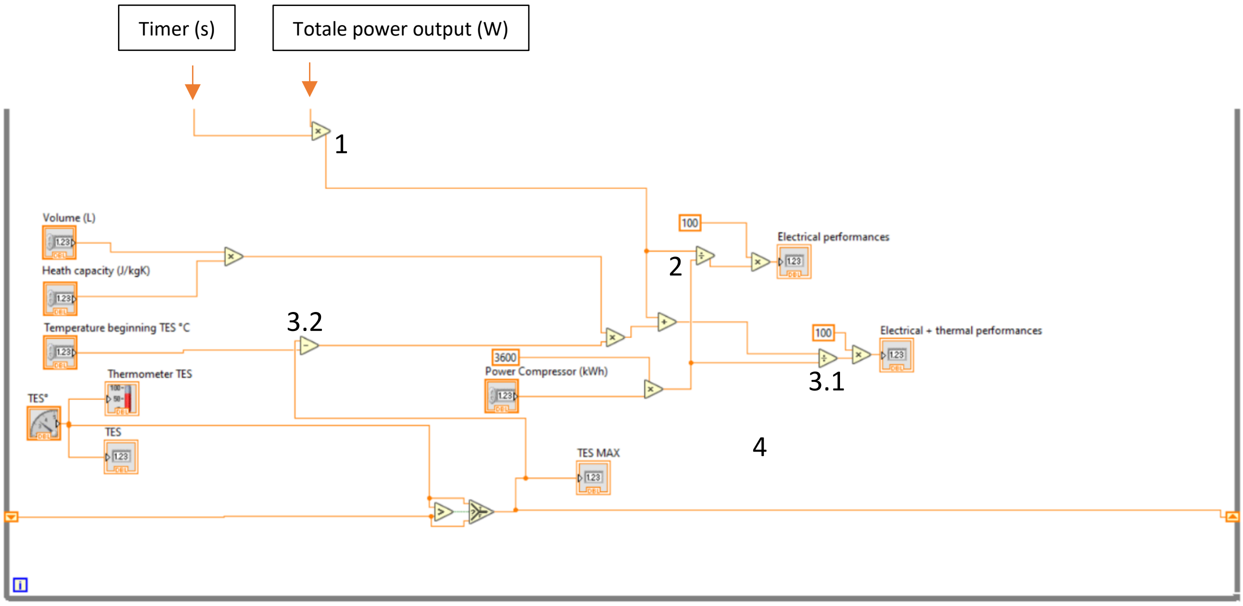


Figure 37 Code calc.

1. $Q_{generator}\ (J) = P\ \left(\frac{J}{s}\right) * t(s) \quad (56)$
   Total power output of the generator to joule.

2. $\eta_{elektricy}\ (\%) = \frac{Q\ generator\ (J)}{Qcompressor\ (J)} * 100 \quad (57)$
   Efficiency electricity = Output energy / Input energy. This is the performance only with the electrical energy flow of the system.

3. 3.1 $Q_{T.E.S.}(J) = m\ (kg) * c\ \left(\frac{J}{kgK}\right) * DT\ (K) \quad (58)$
   Total energy collected in the T.E.S..
   3.2 $\Delta T = T_{T.E.S.\ max} - T_{TES\ beginning}$
   $T_{TES\ max}$ is the maximum temperature that the T.E.S. reach in the test.

4. $\eta_{electical\ +thermal} = \frac{Qgenerator+QT.E.S.}{Q\ compressor} \quad (59)$
   Performance of the system with both energy flows.

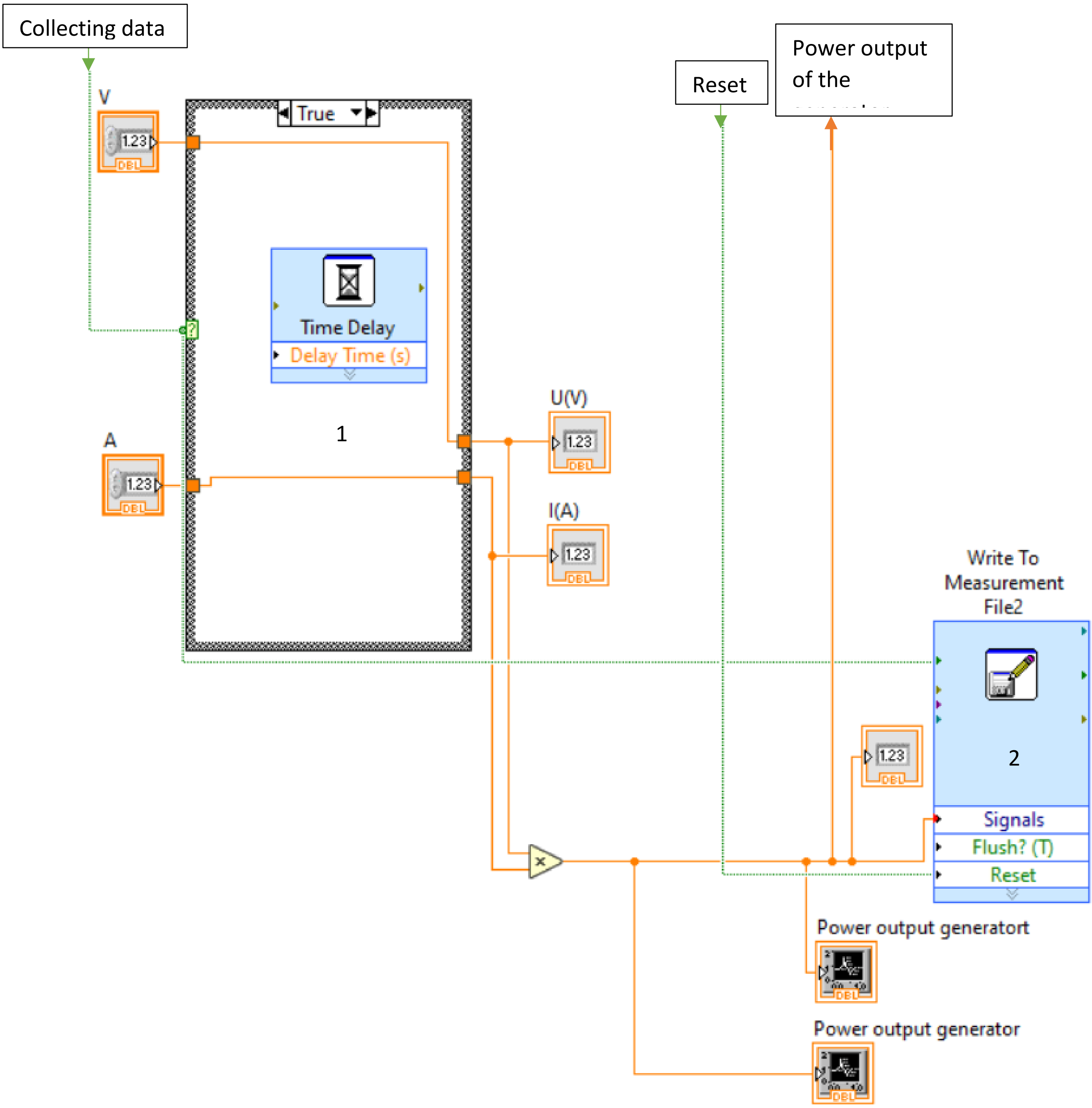


Figure 38 Code excel file.

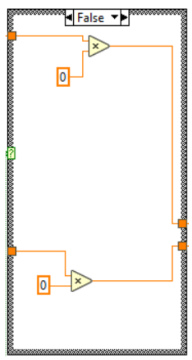


Figure 39 False

1. When data colleting is true the case will let the data flow through the measurement.

   When data colleting is false the data will be multiplied by zero. To set all new data on zero.

2. Collecting data in excel file.

   $$P = U * I \qquad (60)$$

   The power (P) is connect to "Write to measurement file2"
   Collecting data is connect to the enable function of "Write to measurement file2"
   Reset switch is connected to the rest of "Write to measurement file2" and specifies when to reset the data file.

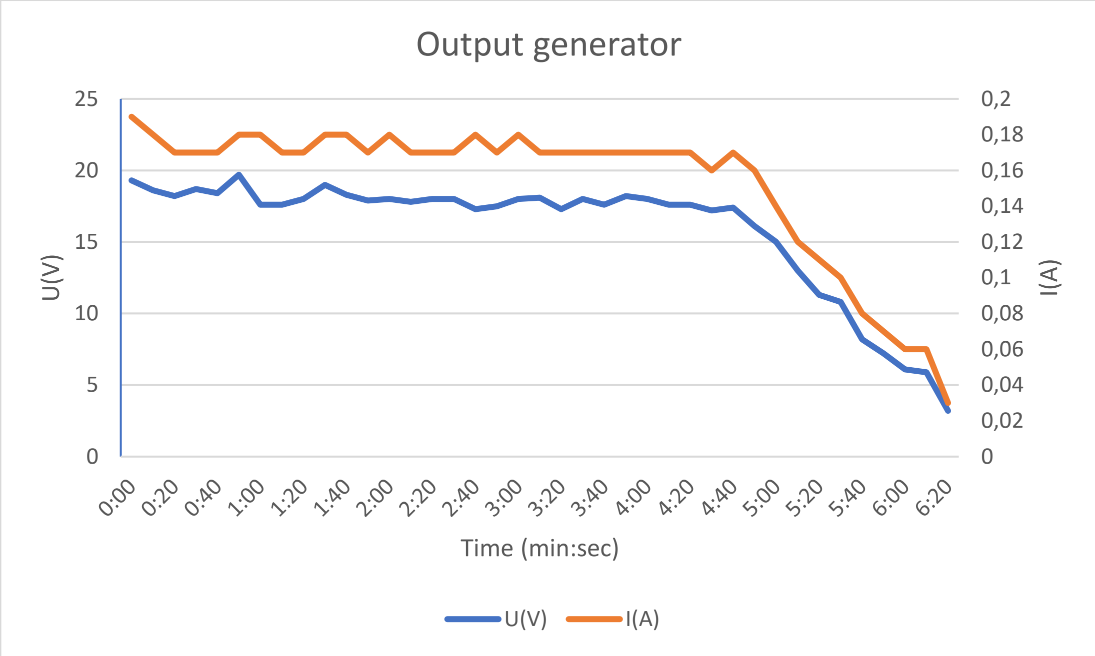
12.5 Single analyzes

The output of the program is a visual indicator of the temperature. The power output is logged in a excel file. This is an import file for doing calculations. Example power out put in excel.

Time	Power(W)
24/03/2020 19:46:53,145	5
24/03/2020 19:46:54,399	5
24/03/2020 19:46:55,821	5
24/03/2020 19:46:57,378	5
24/03/2020 19:46:58,832	5
24/03/2020 19:47:00,459	10
24/03/2020 19:47:02,073	10
24/03/2020 19:47:03,552	10
24/03/2020 19:47:04,972	10
24/03/2020 19:47:06,818	10
24/03/2020 19:47:08,211	10
24/03/2020 19:47:09,612	10
24/03/2020 19:47:10,997	10
24/03/2020 19:47:12,510	8
24/03/2020 19:47:13,914	8
24/03/2020 19:47:15,288	6
24/03/2020 19:47:16,684	6
24/03/2020 19:47:18,211	6
24/03/2020 19:47:19,668	6

Table 22 Output LabVIEW.

The document contains the information of the power output of the generator. There is a date and time connected to the power output.



graph 5 Output voltages and current.

The first five minutes the graph is stable. In graph (5) there is a slow decrease in the last two minutes. The decrease is due to the less pressure from the system. The pressure slowly decreases at the end of the test. Due to the less pressure there is less power, and this means that there is less power output of the generator.

The voltages and current signal are the same only the value changes between them. The value of the current is 100 times smaller than the voltages value.
The relation between voltage and current is given by the law of Ohm:

$$U = I * R \qquad R = \frac{U}{I} \quad (61)$$

The ratio between voltage and current is the resistor. In the test measurement the resistor was 100Ω. Therefore, for the value ratio between the values is 100.

This is a trend that has been analysed in different tests.

The generator produces 3W when the graph is stable. There is a possibility to change the resistor to get different values of the voltages and current.

$$P = U * I \qquad\qquad I = \frac{P}{U} \quad (62)$$

U(V)	I(A)	P(W)
18,6	0,18	3,348
5	0,67	3,348

Table 23 Changing resistor

Changing the resistor changes the voltages and current values. For example, 5V can be used for charging a phone.

13 Results

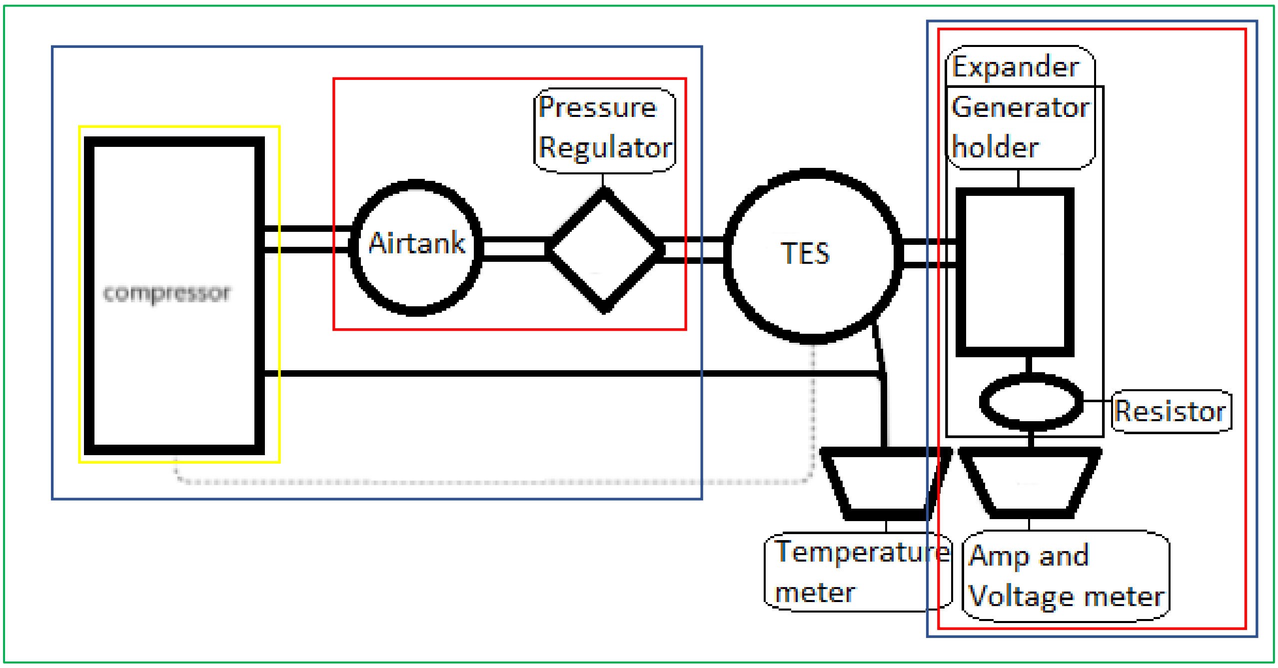


Figure 40 System performances

Data sample used for the calculations:

End pressure: 90 bars

Charge time compressor: 20 minutes

Temperature T.E.S. start: 24,6 °C

Temperature T.E.S. after the test: 38,9°C

Compressor power use: 0,53 kWh

Amount of water in T.E.S.: 6 litters

Generator produced power: 0,000612kWh

The calculations of the energy are calculated in chapter 10.

Green box	Performance of the entire system. $Q\ (J)$ =0,0999766 kWh $P_{generator}$ = 0,000612kWh $P_{compressor}$ = 0,53 kWh $\eta\ = \frac{P\ T.E.S.+P_{generator}}{P\ _{compressor}} *\ 100 = \frac{0,099+0,000612}{0,53} *\ 100 =\ 18,939\% \quad (63)$
Yellow box	Performance of compressor. How much energy is converted in compressed air energy. $P_{compressor}$ = 0,53 kWh Compression energy in compressed air tank = 379KJ = 0,105kWh $\eta\ = \frac{P_{Compressor}}{P_{generator}} * 100 = \frac{0{,}105kWh}{0{,}53kWh} * 100 = 19{,}8\% \quad (64)$
Expander/ air motor	Efficiency of the air motor $W_{Airmotor}\ = P_{Airmotor} * t\ (cycls) = 75W\ *\ 732 = 54900W\ = 0{,}01525kWh \quad (65)$ Expansion energy = 312 $KJ = 0{,}086667\ kWh$ $\eta\ = \frac{P\ _{Airmotor}}{P_{expansion\ energy\ C.A.T.}} * 100 =\ 100 = 17{,}6\% \quad (66)$
Black box	Gear and generator $P_{Airmotor}$ = 0,01525kWh $P_{Generator}$ = 0,000612kWh $\eta\ = \frac{P_{Generator}}{P_{Airmotor}} * 100 = \frac{0{,}000612kWh}{0{,}01525kWh} * 100 = 4{,}013\% \quad (67)$
Blue box	Performance of the system only with electrical energy. $P_{generator}$ = 0,000612kWh $P_{compressor}$ = 0,53 kWh $\eta = \frac{P_{generator}}{P\ _{compressor}} *\ 100 = \frac{0{,}000612}{0{,}53} *\ 100 =\ 0{,}11547\% \quad (68)$
Red box	Performances of the system with the energy of the air tank. Expansion energy = 312 $KJ = 0{,}086667\ kWh$ $\eta\ = \frac{P_{generator}}{P_{expansion}} *\ 100 = \frac{0{,}000612}{0{,}0867} *\ 100 = 0{,}706\% \quad (69)$

Table 24 Performances calc from test 90 bars

The maximum power output of the generator is 60W. When the system will run for the same time on a power output of 60W the total power out will be 0,0121 kWh. The same performances will be calculated. This stays a theoretical performances calculation.

Green box	Performance of the entire system. $Q\ (J)$ =0,0999766 kWh $P_{generator}$ = 0,01212kWh $P_{compressor}$ = 0,53kWh $\eta\ = \frac{P\ T.E.S.+P_{generator}}{P_{\ compressor}} *\ 100 = \frac{0,099+0,0121}{0,53} *\ 100 =\ 20,962\% \quad (70)$
Blue box	Performance of the system only with electrical energy. $P_{generator}$ = 0,0121kWh $P_{compressor}$ = 0,53 kWh $\eta\ = \frac{P_{generator}}{P_{\ compressor}} *\ 100 = \frac{0,0121}{0,53} *\ 100 =\ 2,28\% \quad (71)$
Red box	Performances of the system with the energy of the air tank. Expansion energy = $312\ KJ = 0,086667\ kWh$ $P_{generator}$ = 0,01212kWh $\eta\ = \frac{P_{generator}}{P_{\ expansion}} *\ 100\ = \frac{0,0121}{0,086667} *\ 100 = 13,96\% \quad (72)$

Table 25 Performances compressor 60W output power

Different tests were running with different run times of the compressor.

T.E.S. was filled with 12,6L of water.

Efficiency electricity = $\frac{P_{generator}(kWh)}{P_{compressor}(kWh)}$ (73)

$$\eta_{\text{Efficiency electricity + Thermal energy}} = \frac{P_{generator}(kWh) + (Cw\left(\frac{J}{kg\,K}\right) x\, m(kg) * \Delta T\,(K)}{P_{compressor}(kWh)} \quad (74)$$

Run time comp. (min)	5	7	9	10
Electricity	0,079228%	0,098189%	0,091161%	0,071925%
Electricity + Thermal energy	18,11123%	**15,56313%**	19,20116%	26,98888%

Table 26 Result electricity

The 7 min test result (electricity thermal) is not in line with the other ones. The starting conditions were different in this test as the temperature in the T.E.S. was 25.3°C

T.E.S. was filled with 6 litres of water. Impact with and without water in the T.E.S.

Run time comp. (min)	20 (Water in the T.E.S.)	20 (No water in the T.E.S.)
Electricity	0,115435%	0,114413%
Electricity + thermal energy	18,93927%	/

Table 27 Result without and with T.E.S.

Less water in T.E.S. mains hotter water. ΔT is smaller at the end of the test, due the hotter water. This means that less energy can be transferred in the heat exchanger of the compressor.

14 Conclusions

Continuing the project from mid term the project plan was to continue with upgrading the CAES. The system which was delayed as part of the compressor overheated causing damage. Covid-19 happened the team get restricted from the lab and so slowing the project down. Because of that the team had to adapt by creating a new time plan resulting in a new project goal.

Although the issues, the project coordinator had access to the lab allowing some work to occur including connecting the CAES to the university compressor thus allowing the system to continue working. The team had continued making calculations regarding insulation, performances and gears. Also, designing components and operation procedure for the next team. In addition, the team has completed a simulation LabVIEW program. Overall the project was a success even though the situation it has faced, by making a working demo supported by the university pressure grid.

14.1 Performances

The performances of the system can increase because there is more power out possible by the air motor (75W) and generator (60W). For more power output the speed needs to increase to the optimal working speed of the generator (3000rpm). The potential increase of the system is 2,1% electrical energy. 13% increase of the performances is reachable from air tank to the electrical power out.

14.2 Project Management

The unusual situation was hard for project leader. Nobody has experience in this long-term crisis. The team adapt slowly and after a time the basic of the team was back. The focus the project was to finish the basic goals. This vision on the project left some team members disappointed because they were practical minded.

14.3 T.E.S.

According to calculated data The impact of T.E.S. is minimal. The performances of the system increased by only 0,001%. The manual way of collecting data of the system is not accurate. The conclusions of the T.E.S. is that the impact on electrical performances is neglectable.

T.E.S. collects thermal energy that can be used for heating up compressed air (reducing water in the air). The thermal energy can be used for other applications that needs hot water. But this is not implanted in the project.

14.4 Gears

The gears in our system are giving (1500rpm) at the output speed however the generator can support (3000rpm), the current gear system consist of two gears, it could be possible to increase the speed only with the two gears but the reason that the group decided to make a gear train is that the gears that there are needed were so small or too big. After some calculations the train gears have to be composed for (z_1=50 z_2=10 z_3=20 z_4=10).

14.5 Isolation

Isolation will protect the students against the heat. The isolation will reduce the heat losses by 60W thus T.E.S. will stay warmer for a longer period and might be more efficient.

14.6 Achievement in the project

The project Management part is finished, with the necessary changes due covid-19. The project leaders have made the necessary support for the team.

Mechanical engineering task have not been completed, they are; noise cancelling box for the compressor, different gear train and a bracket. Noise cancelling box have been ignored for now. Gears and bracket are designed.

Electrical measurement system works but is not connected to software. The software that is made in LabVIEW is a simulation software. The software is made in a way that it is easy to changes to real life date input from the system with an Arduino. The calculations for thermo energy are made for isolation. Only basic test of the performances of the system are done.

15 Recommendations

15.1 Bracket system

The current bracket system takes a long time to change components for example changing from air motor to air compressor. It is also difficult to work with as the bolts and nuts are hard to access. Therefore, a simpler bracket system was design for easier and faster access. Manufacturing a new bracket system is shown in design and the operation procedure is in manufacture section of this report.

15.2 New system

If the compressor is still water cooled then piping network should be redesigned so that the pipes are under an angle of 1-2 degree and a tap point to realise the water. This so that the water never stands still in the pipes and to slow down oxidation in the pipes.

15.3 Insulation

Covering the pipes with insulation to reduce heat loss thus increasing efficiency as well as to protect the users from the hot and cold temperatures of the pipes. More information can be found in chapter about insulation.

15.4 Gears

To update the current gear system from two gears to a new system of four gears as presented in above gear section discussing the theoretical calculations and presenting the CAD drawings. This will theoretically increase the energy generated. Furthermore using a motor connected directly to the gears can calculate the efficiency of the gears by measuring difference of power put into the motor and the power measured with the sensors from the generator (Only issue with that is how to connect the motor with the gears which is a small challenge to be resolved).

15.5 Compressor

The new compressor should be water cooled and should have high efficiency. If a noise or vibration shield is not included in the original compressor package, it should be bought or manufactured to reduce those issues.

15.6 LabVIEW

The program is a simulation software. There is an option to buy a sensor and get real time data in the software. LabVIEW supports Arduino, on the website of national instruments there is a manual on how to connect Arduino to LabVIEW.
This code needs to be added in the program.
settings:

Comp port check in Device Manger on PC
baud rate 115200
Bord type (Arduino) uno
Connection type USB/Serial

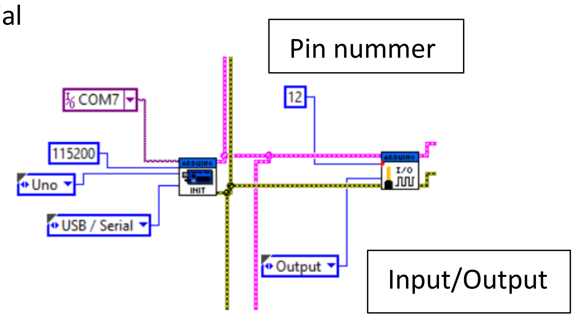


Figure 41 Code Arduino

(knowledge, sd)

The next sensor can be bought to digitalize the system. Be aware that the maximum voltages input of an Arduino is 5V on the analog pin. The simulator software will be available to change.

15.6.1 Temperature sensor

Buying the correct sensor and micro control is important. The accuracy of the sensor needs to be acceptable. For temperature +/- 0,5°C is acceptable.

The water-resistant temperature sensor from Robomaa has a temperature ranges from -10°C to 85°C. The accuracy of the measurement +/- 0,5°C. The cable is 1,8 meters long. This length is long enough for connecting the sensors in the T.E.S. and in the compressor.

Figure 42 Temperature sensor

15.6.2 Arduino

Arduino is an opensource-software. For opensource-software there is free information on the internet. The platform is accessible for everybody who as an interested in programming. LabVIEW supports Arduino, there is an easy way to connect them to each other.

Figure 43 Arduino

15.6.3 Voltages measurement

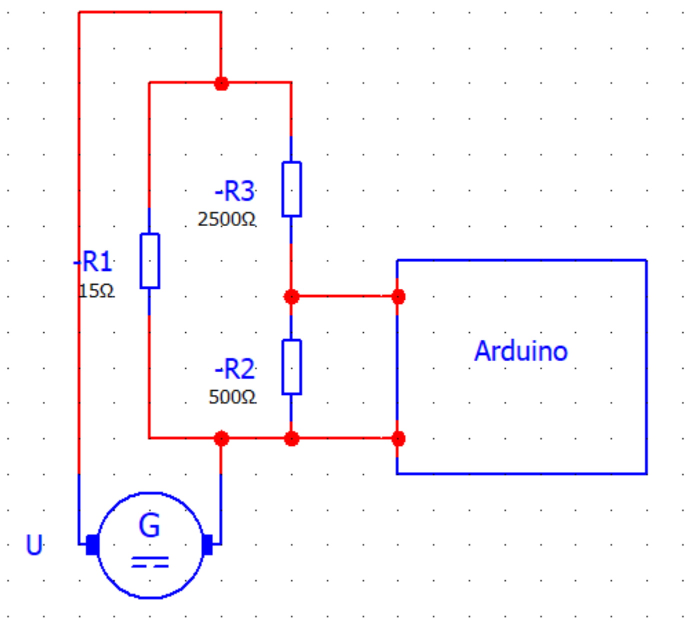


Figure 44 Voltages measurement

Calculating total resistance of the circuit.

$$R_{total} = \left(\frac{1}{15} + \frac{1}{2500 + 500}\right)^{-1} = 14{,}925\ \Omega \quad (75)$$

Generator generates a maximum voltage of 24V. Voltages divide by resistor gives us the current.

$$I = \frac{24V}{14{,}925\Omega} = 1{,}608A \quad (76)$$

Current through R2 and R3

$$IR_{2,3} = \frac{24V}{500\Omega + 2500\Omega} = 0{,}008\,A \quad (77)$$

Voltages over the resistor R2

$$UR_2 = 500\,\Omega\,x\,0{,}008A = 4V \quad (78)$$

Voltages division $=\frac{500\Omega}{500\Omega+2500\Omega}$ = 0,167 =>16,67% of the total voltages stand over R2. (79)

The maximum input voltages of the Arduino is 5V.

$$U\,maximum\,voltages\,in\,the\,circuit = \frac{5V}{0{,}1667} = 30V \quad (80)$$

If the voltages in the circuit is higher than 30V the Arduino anagoge input will be damaged. The maximum generator voltages is 24V.

From analog reading to true value of the circuit.
U measured by the Arduino is only 16,667% of the true value. Calculating the true value of the circuit as followed.

$$U = \frac{2{,}5V}{0{,}1667} = 15V \quad (81)$$

The maximum voltages output of the generator is 24V.
Generator 24V output:

$$U_{Arduino} = 24 * 0{,}1667 = 4V \quad (82)$$

When the generator produces 24V there is a voltage over the analogy pin of the Arduino of 4V.

15.7 Oxidation in the water

The solid parts in the water has a negative effect on the system. The recommendation is to refresh water in the beginning of each test.

The water tube under the T.E.S. is too long to empty. It should be made shorter so there is no possibility that the water stays in the water tube and would be spilled on the ground.

15.8 Operations Procedure

Operation procedure will explain step by step how to operate this system. Since few activities and tests can be performed on this system there will be manuals for each activity including charging and discharging of C.A.T., using T.E.S. and without T.E.S. and installing air motor or air turbine.

Charging C.A.T.

Check the oil of the compressor before test start. There is a window to check oil level. Refilling can be done with opening the black cap.

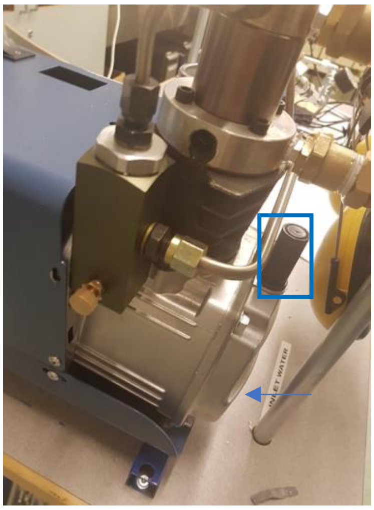


Figure 45 Compressor oil level

The compressor will pressurize air in the C.A.T. there are two possibility reaching end pressure or an amount of charging time. The water pump will circulate the water from T.E.S. to the compressor for cooling. In this stage variables that will be measured are pressure of the C.A.T. (Bar), total running time (seconds) and the water temperature in T.E.S. (°C) at the end of the test.

1. Fill T.E.S. between 6 - 12 litres of water
   Less water: higher end temperature
   More water: better cooling lower end temperature
2. Switch on the water pump
3. Switch on power meter and thermometer
4. Open valve of the air tank
5. Switch on compressor
6. When pressure of C.A.T. reaches the requested pressure of the amount of rune time switch off compressor
7. Close valve of the C.A.T.
8. Switch off power
9. Collected information of the energy meter

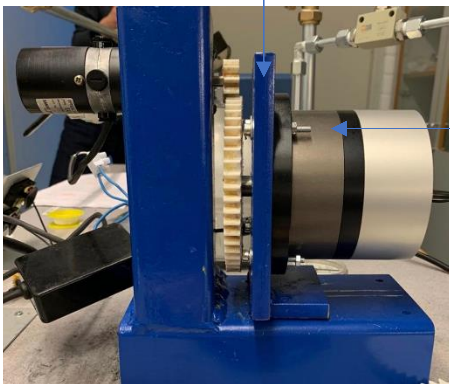
Discharging C.A.T. with/without T.E.S.

Expanded through the compressed air of 5 bars through the air motor or the air turbine. During this stage variables that will be measured are:

Running time air motor (seconds)
Power output of the generator (W)
End pressure of the C.A.T. (bar)
highest temperature of the T.E.S. (°C).

Installing air motor

Air motor can be used to generate electricity when connected to a generator through gears. This is a reliable technology and has been used for a long time. Using air motors will show how efficient it is which then can be compared to air turbine.



1. Connect the air motor in the smaller L plate and fasten wit M8 bolts.
2. Place an appropriate gear on the metal shaft of the air motor and connect it on.
3. Slide on the second gear on the generator.
4. Place the smaller L plate (with the air motor) onto the blue metal fixture on the table and fasten lightly using M10 bolts.
5. Make sure that both gears are straight, by moving the L plate if needed, once straight properly fasten the M10 bolts.
6. Connect the air pipe from T.E.S. by screwing on the threaded end to the air motor.

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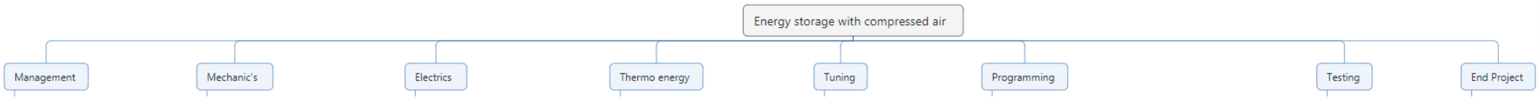
17 Appendix

17.1 Project Management

17.1.1 Work Breakdown structure

The Work Breakdown Structure (WBS) is a planning tool that shows various stages within a project that need to be carried out under the project. The project team has lots of initial questions such as has: what, how, when, where, how much, etc but the WBS only give an answer to that. The main goal of the WBS is to identify all the work that has to be done to achieve the set goals.

This Holl of structure of the WBS can be find in the additional documents.



17.1.2 Project Management and Financially

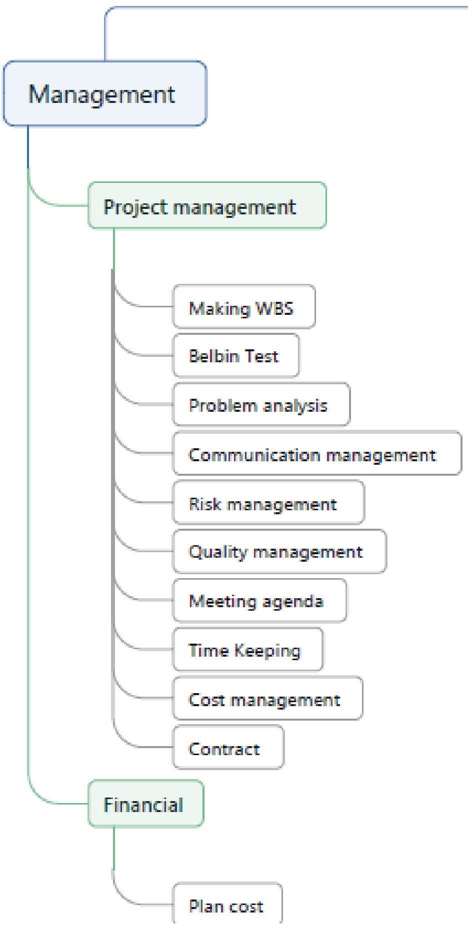


Figure 46 Project Management and Financially

17.1.3 Project Management

Project Management is the drive in a project. It gives the project a flow. With good Project Management the team is capable to bring more quality into the project.

Short explanation of some points of Project Management. The full documents can be found in the final report of Compressed air and energy storage.

- WBS (work breakdown structure)
  Identify the tasks of the project.
- Belbin test
  Gives information over the team members
- Risk management
  This chapter gives answers on the question: What are the risks of the project?
- Contract
  Team agreements and expectation from each other

17.1.4 Financial

Log the expenses carefully in the project. So when there is a need to build a new one, there is a detailed guideline on costing. The cost management in detail can be found in chapter 8.1

17.1.5 Mechanic's, Electrics, Thermo energy

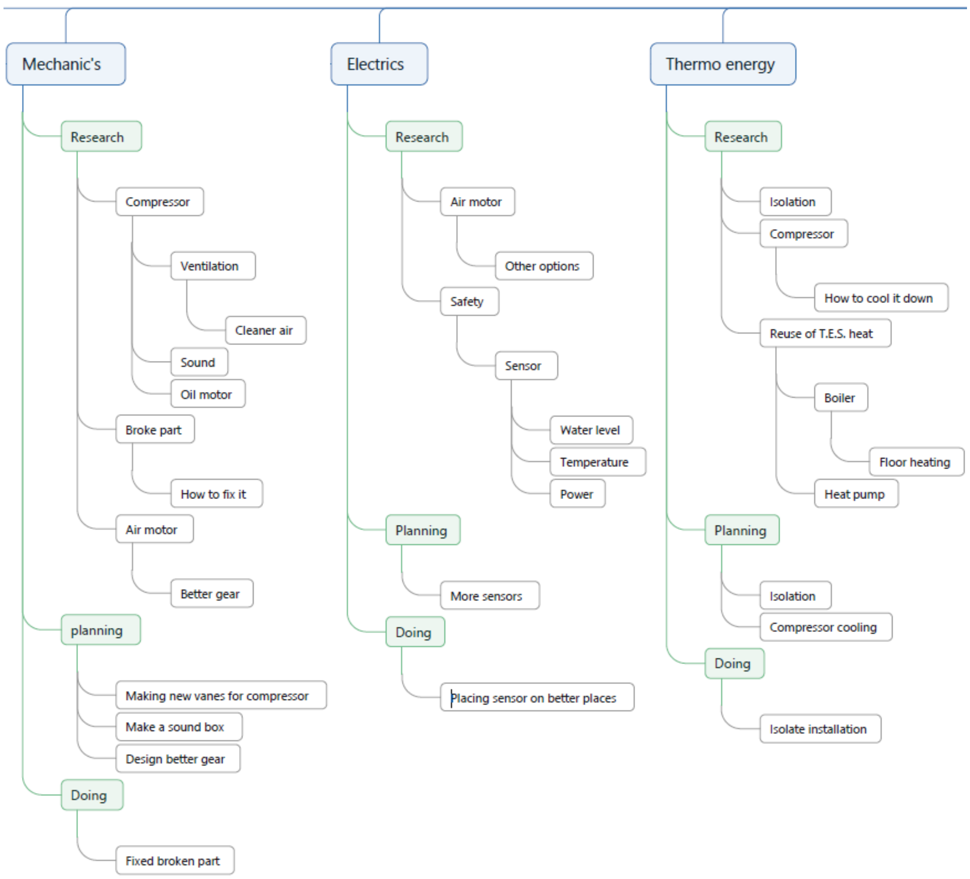


Figure 47 Mechanic's, Electrics, Thermo energy.

17.1.6 Mechanic's

Before the tests can be run the broken part needs to be fixed.
The plan is to make the hole bigger and tap it again. There must be a good connection between the compressor and the pipe for preventing the same failure.

The air motor's gear is not optimal. The hole was not centred and created a lot of friction between the gears. Making new gears to increase the speed. With increasing the speed to power output will increase and therefore the system has a higher performance.

The compressor makes a lot of noise. For a demo system for students is this not optimal. Possible solution is to place a noise reducing box around the compressor.

17.1.7 Electrical circuit

There are two ways available to drive the generator either with the air motor or the air turbine. One of the tasks is finding out which has the best performances. It is interesting to do some test around it.

Fixing the electrical circuit there is an error in the current measurement system.

Include more safety futures in the demo. For example, use two sensors in the T.E.S. that gives an alarm when the water level is too low or too high as show in figure 48.

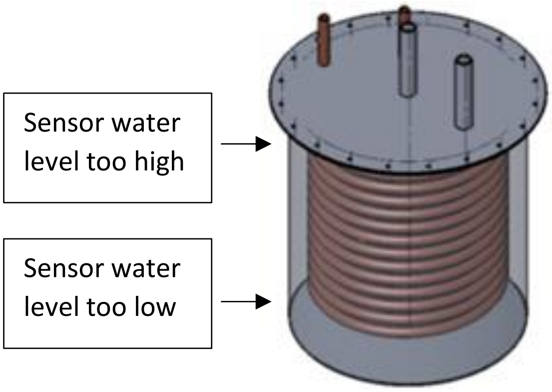


Figure 48 T.E.S. sensors

17.1.8 Thermo Energy Storages

There is a lot of heat production during the compression process which would otherwise go to waste. Collecting this heat will increase the overall performance of the demo by reusing the heat to warm the compressed air. The heat is collected in the T.E.S. the inside structure is visible in figure 48. Warm water losses heat over time. To decrease the heat losses, you can isolate the water storages and pipes.

The next question is: What are the losses of electrical and thermal energies and how to prevent them?

17.1.9 Tuning and programming

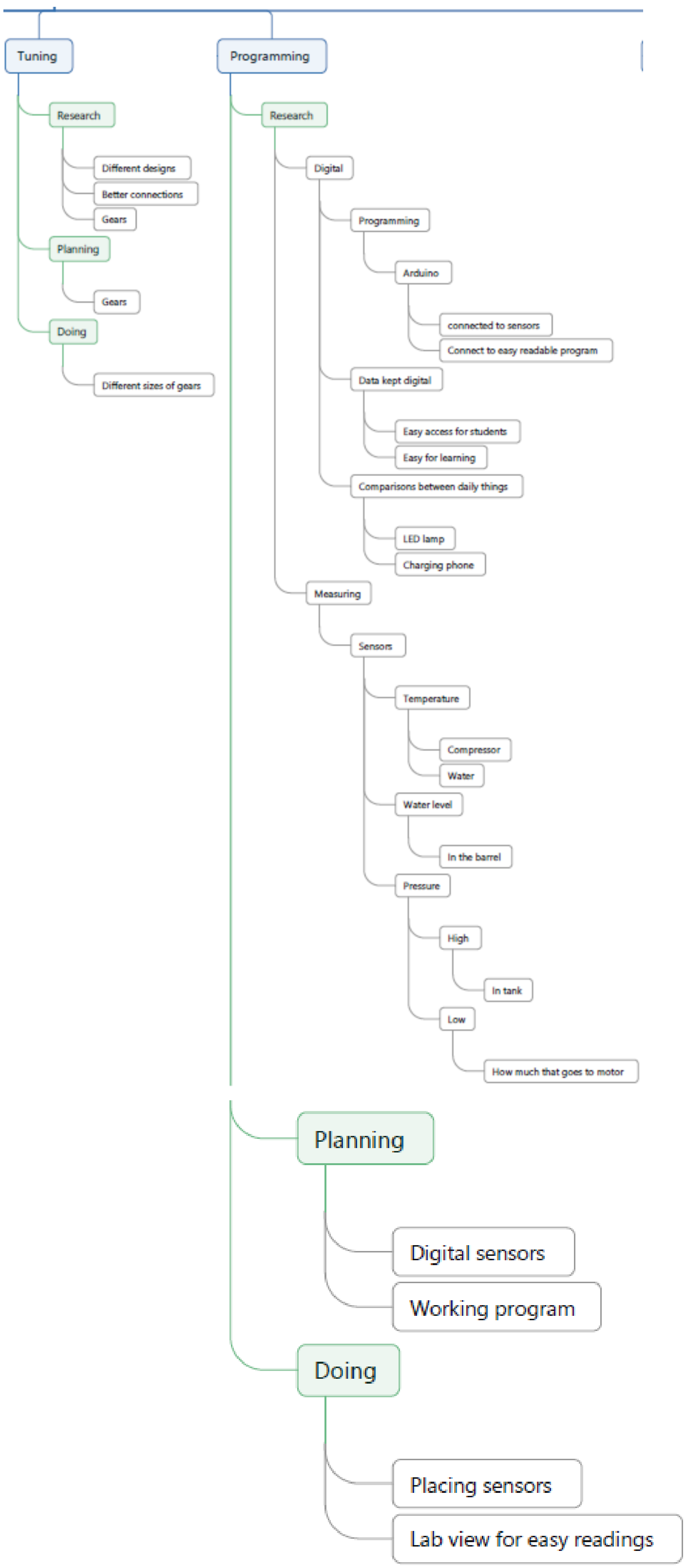


Figure 49 Tuning and programming

17.1.10 Tuning

For redesigning the demo there can be less pipes used, but the demo system is getting more complex.

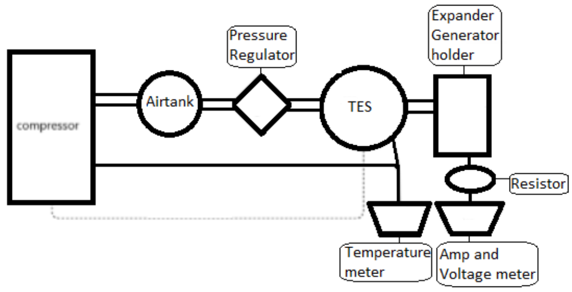
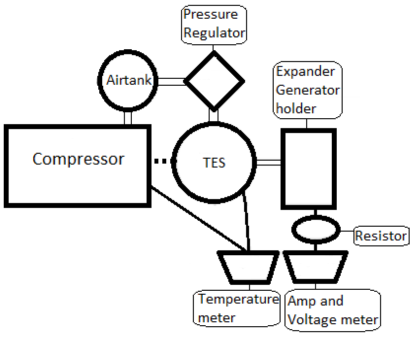
Before	After
 *Figure 50 System*	 *Figure 51 New system*
Clear flow of the air and water. Maintenance is easier as there is a lot of space between the components.	Takes less space. Better efficiency because less connections and tubes.

Table 28 Redesign C.A.E.S.

17.1.11 Programming

The students can do measurements and get an acquainted with Compressed Air and Thermal Energy Storages.

As the demo is meant for use in education, students have to carry out tests and take measurements which can then be analysed. It is important that they collect correct data in a safe and accurate way.

A program is developed to collect information safety. Students can hold a safe distance between themselves and the demo. The software is accurate for collecting data. The benefits of software are that you can collect correct data with small time intervals without making reading mistakes.

The software that will be used is LabVIEW which is a visual programming language. The power of LabVIEW is that there is a big library inside the program. It is user friendly and it is internationally used. Some company’s use LabVIEW in their production so it is nice to get students early in contact with LabVIEW.

More information can be found in chapter 12 LabVIEW

17.1.12 Testing and end project

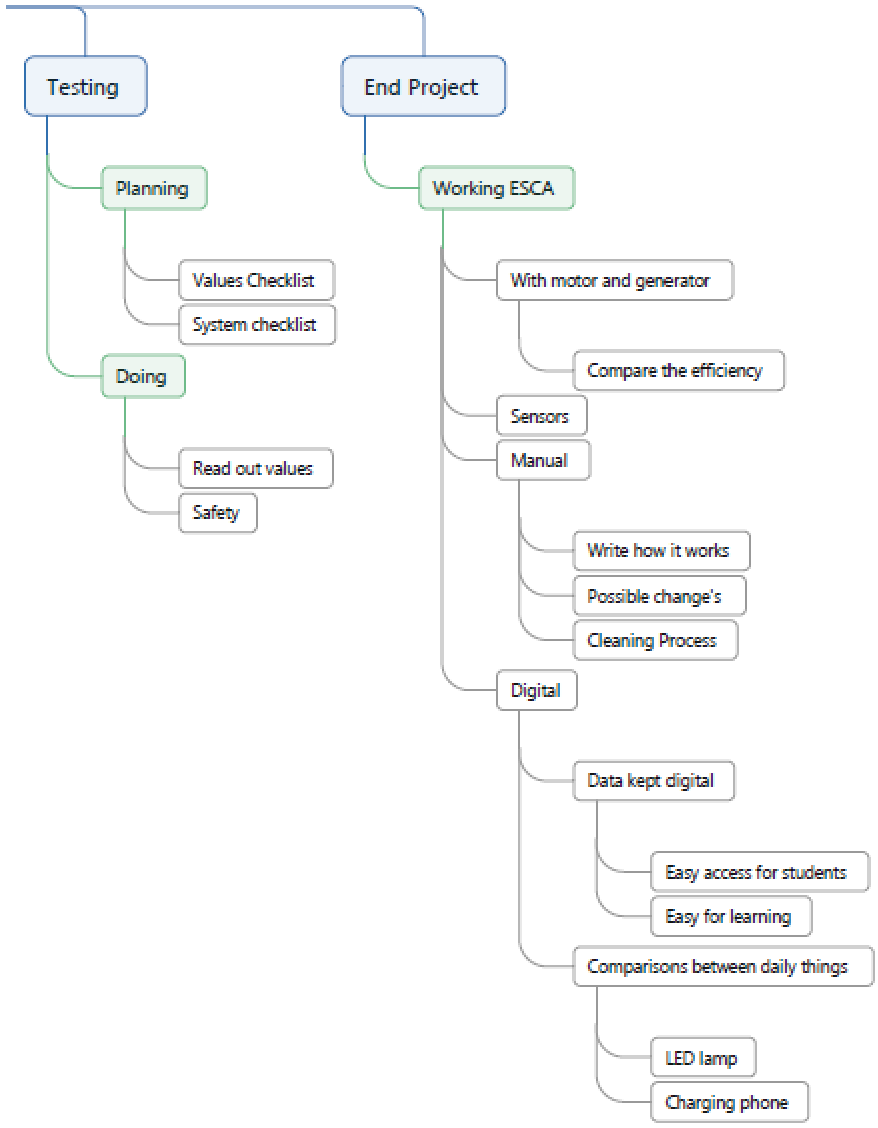


Figure 52 Testing and end project

17.1.13 Testing

During the project testing it is important to make it more efficient. Therefore, there needs to be a planning and this planning must have following items:

- Values checklist (starting conditions)
- Manual for operating the system
- System checklist (safety)

The testing needs to be done

17.1.14 End project

The final goals overall in the project are:

Deliver a working demo.

A full detailed report on how to carry forward the project.
Read out the sensors.
Writing a manual.
Easy access to information of the demo.

17.1.15 Problem Analysis

The energy storage in Our Low Carbon Society project has an objective of building an energy storage demonstration in Technobothnia Education & Research Center.

The aim is to promote energy storage know-how by bringing the practical aspect of energy storage to education.

The goal of this EPS-group was repaired and end the project, due to COVID-19 end the project was not possible.

The following requirements and conditions need to be considered:

- The demo must be suitable for learning purpose, so there must be a manual so students can work independently with the experiment set-up.
- The system should have some changeable parameters, so students can research the influence of the variables on the efficiency of the system.
- The experiment with the demo must be finished within three hours.
- The demo has to be safety, cannot produce too much noise because other students have to work in the same laboratory.
- The set-up cannot by higher than 4,5 meters because physical restrictions in the energy lab of Technobothnia.

The project will start at 10-02-2020 until 18-05-2020 and the budget for done the project is 3000€. Novia UAS is responsible for the EPS-group, so the group will work further on the research already done by this university and from the other EPS autumn group.

17.1.16 Quality Management

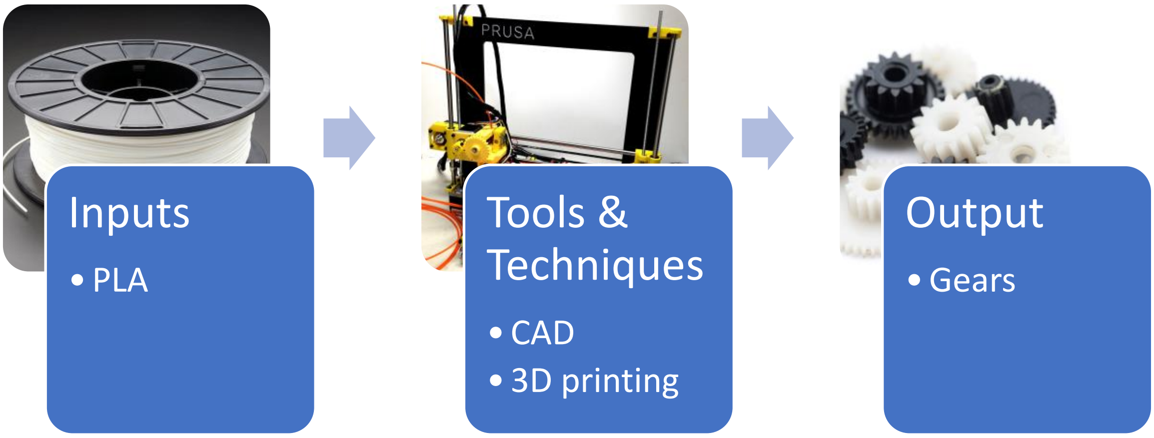
Definition of quality is how good a product is according to specifications given. Quality management is controlling of processes that contribute to making a product within the specifications, this also helps minimise risks to the project and can save time and resources.

Plan, do, check, act cycle, as shown in figure 53, arguably this step by step process helps keep the quality up to specifications and is used every time a new project is created. It can also be used when continuing a project and can be started with checking, then acting the planning then doing.

Figure 53 Plan do check act

In a quality triangle factors which includes time, resources and quality, only two factors can be picked at a time. For this project time is limited and even cost up to 3,000 Euros, this means that final quality of the product might be sacrificed. However, since resources also include human resources that means if the working team works extra hard the quality of the project can be increased.

Inputs are the resources used these include raw materials or already bought parts, better the input better the output if tools and techniques used are correct. Tools and techniques are the way an activity is performed or objects used to create the output. How good they are is based on precision and speed. Output is the result of input with tools and techniques above, this include the finished product.



Input	Tools and Techniques	Outputs
PLA filament	CAD + 3D printer	Gears
Excess renewable energy	CAES	Thermal and electrical energy
Thermal and electrical energy flow in the system	LabVIEW and sensors	Data in excel file
Project specifications	Machines and engineering knowledge	Successful project

Table 29 ITTO in the project

Ishikawa is a diagram otherwise known as fishbone diagram or cause and effect diagram which helps identify issues taking eight headings into account: machines, Mother Nature, management, manpower, money, materials, measurement and method. Issues found under those topics are then analysed to help in finding a solution. Below four topics are observed to identify the problem of low efficiency.

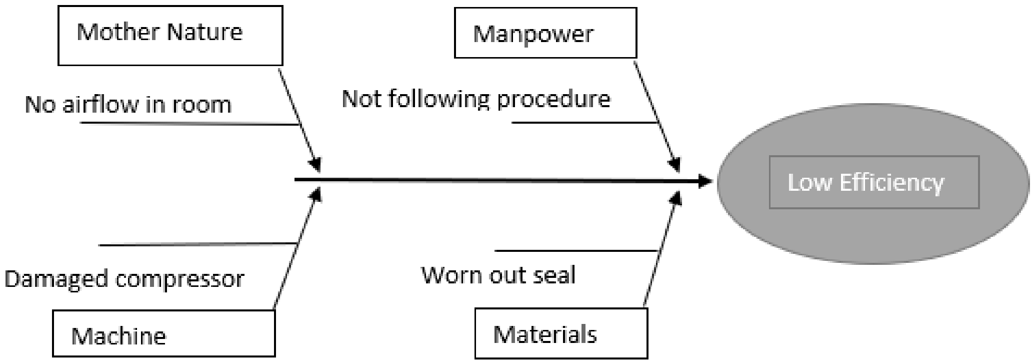


Figure 55 Ishikawa

17.1.17 Human Resource Management

For project management it is important that the project leader has an idea of the character of the team members. For a continuous flow in the project, he manages the tasks and the people on a correct way. Everybody is different and needs another way of management. The foundation of a good functioning project team is that team members know their strengths and weaknesses. Each member has a different skillset. Members can help each other on different aspects. To find out where a team member has excellent skills or might be lacking in, the Belbin questionnaire was developed. The result of this questionnaire is a so-called role within the team. If many members appear to have the same personality, the project might fail because some crucial skill assets could be missing.

17.1.18 Different roles

Team Role	Contribution	Allowable Weaknesses
Plant	Creative, imaginative, free-thinking. Generates ideas and solves difficult problems.	Ignores incidentals. Too preoccupied to communicate effectively.
Resource Investigator	Outgoing, enthusiastic, communicative. Explores opportunities and develops contacts.	Over-optimistic. Loses interest once initial enthusiasm has passed.
Co-ordinator	Mature, confident, identifies talent. Clarifies goals. Delegates effectively.	Can be seen as manipulative. Offloads own share of the work.
Shaper	Challenging, dynamic, thrives on pressure. Has the drive and courage to overcome obstacles.	Prone to provocation. Offends people's feelings.
Monitor Evaluator	Sober, strategic and discerning. Sees all options and judges accurately.	Lacks drive and ability to inspire others. Can be overly critical.
Teamworker	Co-operative, perceptive and diplomatic. Listens and averts friction.	Indecisive in crunch situations. Avoids confrontation.
Implementer	Practical, reliable, efficient. Turns ideas into actions and organises work that needs to be done.	Somewhat inflexible. Slow to respond to new possibilities.
Completer Finisher	Painstaking, conscientious, anxious. Searches out errors. Polishes and perfects.	Inclined to worry unduly. Reluctant to delegate.

Figure 56 Roles.

17.1.19 Mateusz

	Coordinator	Shaper	Plant	Monitor	Implementer	Resource investigator	Team worker	Finisher
1	0	2	4	0	0	2	1	1
2	2	3	3	0	1	1	0	0
3	2	0	1	1	0	2	4	0
4	1	1	3	1	0	3	1	0
5	0	1	2	0	4	3	0	0
6	3	1	0	1	1	2	1	1
7	2	3	1	0	2	1	0	1
Tot	10	11	14	3	8	14	7	3

think act

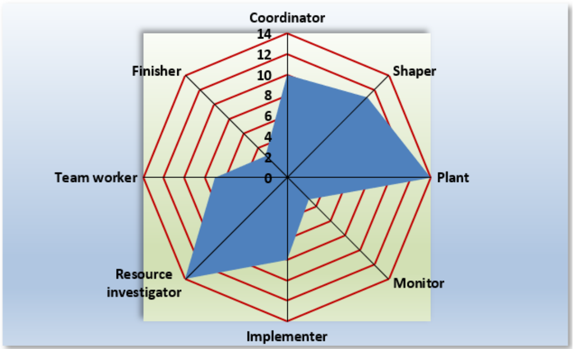
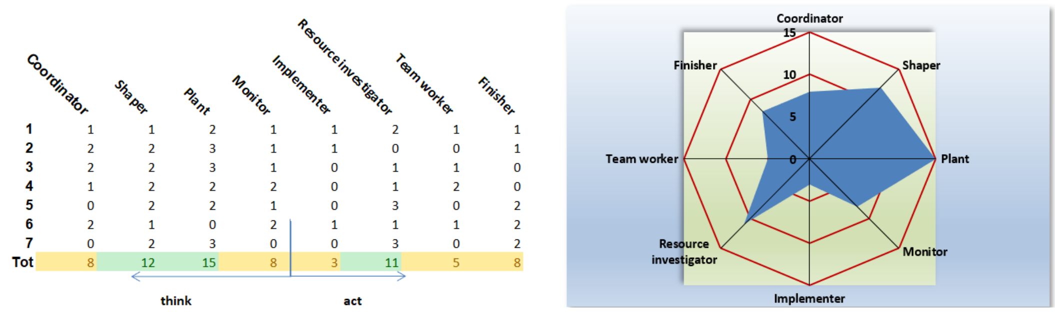


Figure 57 Belbin Mateusz.

Mateusz is a Plant and Resource investigator. He can work independently and find solutions wherever he is. When the solution is found there is a clear view that needs to be happened. Other team members with not the same background as Mateusz, might have a hard time in following his way of thinking as Mateusz is so driving in his project that he forget to explain his way of working in an easy way so everybody understands him Mateusz scores low on the finisher role. Mateusz loves to keep making changes on his tasks to make it better. With a hard focus on his tasks, he loses sometimes the overall view of the project.

Strengths	Weakness
Focus on the tasks	Easy way of explaining his solutions
Finding solutions	Finishing his tasks
Work outside of project hours	

17.1.20 Dean



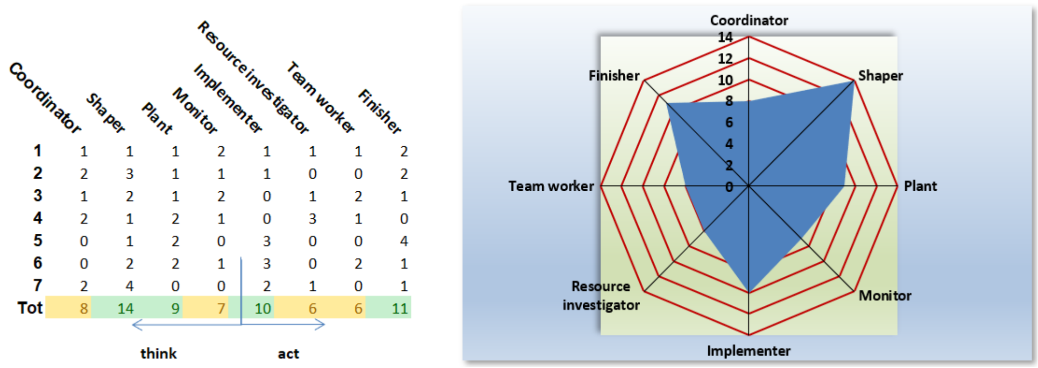
	Coordinator	Shaper	Plant	Monitor	Implementer	Resource investigator	Team worker	Finisher
1	1	1	2	1	1	2	1	1
2	2	2	3	1	1	0	0	1
3	2	2	3	1	0	1	1	0
4	1	2	2	2	0	1	2	0
5	0	2	2	1	0	3	0	2
6	2	1	0	2	1	1	1	2
7	0	2	3	0	0	3	0	2
Tot	8	12	15	8	3	11	5	8

Figure 58 Belbin Dean.

The test result for Dean is a main role Plant. This means that he is creative and good at solving problems in unconventioanal ways. As a resource investigator he thinks out of the box for solving problems. Dean is really focused on the project and has a background knowlegeds in compressed air. He works hard for the project and does not care if he needs to work longer. He communicates always what his plans are and where he is in his task. He has a great idea where he wants the project to go.

Strengths	Weakness
Background knowledge	Too direct
Hard worker	Focus on own idea's
Communication	

17.1.21 Alejandro



	Coordinator	Shaper	Plant	Monitor	Implementer	Resource investigator	Team worker	Finisher
1	1	1	1	2	1	1	1	2
2	2	3	1	1	1	0	0	2
3	1	2	1	2	0	1	2	1
4	2	1	2	1	0	3	1	0
5	0	1	2	0	3	0	0	4
6	0	2	2	1	3	0	2	1
7	2	4	0	0	2	1	0	1
Tot	8	14	9	7	10	6	6	11

Figure 59 Belbin Alejandro.

Alejandro is a shaper, he is quiet in the group but he takes his task very serious. If he is working alone, he find solutions for problems. Alejandro has an eye on the finished project. All the work that he does is focused on getting results. A good combination of a person is a resource investigator and monitor. With the information that Alejandro gets of the person, he can create a good end result.

Strengths	Weakness
Hard worker	Quiet
Independent	Less input during discussions
Adapt fast	

17.1.22 Arne

	Coordinator	Shaper	Plant	Monitor	Implementer	Resource investigator	Team worker	Finisher
1	1	1	1	1	1	2	2	1
2	2	2	1	2	1	1	0	1
3	3	0	1	1	0	1	2	2
4	1	2	1	1	2	1	2	0
5	0	1	2	0	2	2	0	2
6	2	2	0	1	0	2	2	1
7	1	1	2	1	1	1	2	1
Tot	10	9	8	7	7	10	10	8

think act

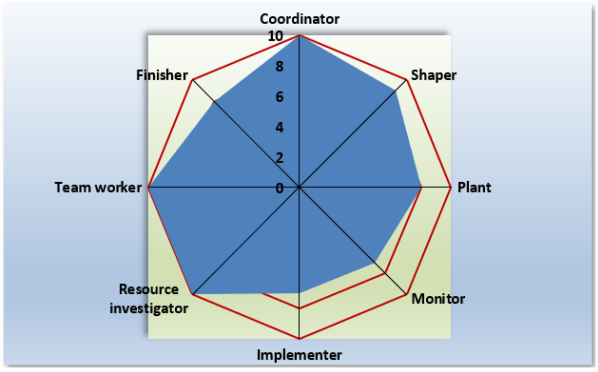


Figure 60 Belbin Arne

The test result shows that Arne is a coordinator, team worker and Resource investigator. He coordinates the group and makes the plans for getting the deadlines. As a team worker he trusts his team members on their tasks. If needed he will help where help is need. As shaper and resource investigator he loves to find new solutions but get easily distracted when he needs to do routine work.

Strenghts	Weakness
Coordinator	Easily distracted
Background knowlegeds	Question everything
High expectations of oneself	

17.1.23 Team score

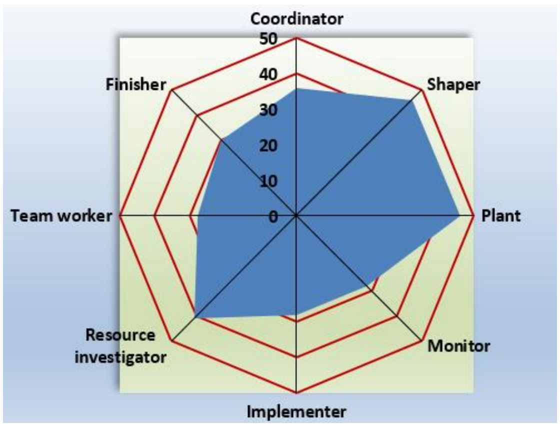


Figure 61 Belbin Team

In the team result there is a high score for resource investigator. This is great for getting new trends in the project. Combined with high score of shapers the trends get fast a shape. The lower score in implementer can make it hard to get all the new trends in the project and fitting together.

The plant score is higher than the team working score this means that the team like to do work individually. A good coordination is important for the communication in the team.

The lower score of monitor and finisher can be a struggle in the project. With no monitor the team will be doing everything and do not make a selection. The danger of a lower point in finisher is that the project will never be fully finished because the team like to work more and more on the project.

As a team leader you see the obstacles and adapt you style of leadership. It is important that you are aware of the potential struggles in the project.

17.1.24 S.W.O.T.

Strengths	- A team with different backgrounds and nationalities allows to give a bigger look at the project. -Background knowledge (theoretical energy and mechanical)
Weaknesses	- Lack of experience -Limited time - Lack of programming knowledge
Opportunities	-Helping stabilize the grid -New technology -Higher overall efficiency of the demo
Threats	-High pressure can be dangerous -Sickness (every team member is important for the team) -Overall efficiency to low -Different solutions with higher efficiency for storages of energy

Table 30 SWOT.

17.1.25 Risk Management

For health and safety reasons as well as success of the project it is important to reduce risks to minimum or eliminate them if possible. This is done by first identifying the risk then analysing how much of an impact it can have and how likely it is to happen, afterwards to apply safety measures to reduce the risk. To avoid accidents happening it is important to be proactive about risk management therefore steps mentioned must be repeated for every risk identified.
Below is a risk matrix which shows how high of a risk an activity is:

		Impact		
		Low	Medium	High
possibility	High			
	Medium			
	Low			

Figure 62 Risk Matrix

Risk matrix above can be used to make a control plan for risk management which is as follows:

Figure 63 Control plan steps

To identify a risk it is important to realize what activity can damage someone's health, be a threat to life, can negatively impact the success of a project or be a danger to environment.
Estimation probability of a risk can be calculated using data from a control safety test. A test needs to show how likely an accident is to happen for example once a day or once every few years.
Estimation of impact shows how dangerous a risk can be, which can be either lethal or long lasting as well as a minor. This can be analyzed by research or by simple logic for example: working at a height or with explosives.

Risk assessment determines the importance of the risk and defines how important plan of control for that risk is. This can result in a low-level risk where action is minimal to a high-level risk where lots of preparation needs to be done before an activity.
Plan of control includes countermeasures which help reduce the risk. Countermeasures can include wearing PPE (Personal Protective Equipment), creating risk awareness signs, making an operation manual on dangerous equipment, and implementing safety procedures etc.

	Risk	Probability	Impact	Risk Assessment	Plan of Control
1	Virus	High	High	High	Minimize physical contact/ covid-19 impact
2	Lack of access to lab	Medium	High	High	Covid-19 impact
3	Losing information	Low	Medium	Low	Saving information securely
4	Failure of Gears	Low	Low	Low	3D print new
5	Inaccurate data	Medium	Medium	Medium	LabVIEW

Table 31 Control plan

1. Virus probability is changed to high since the effects of it have reached Finland placing restrictions on schools, the impact remains high as working in a lab has been limited greatly. Avoiding contact with contained person is the best measure available, this can be done by communication online. Risk assessment is rated high. Working in lab will be on hold in this period.
2. Lack of access to the lab is rated medium for probability since lock down has come into place, although the project coordinator still has access. Impact is rated high as this greatly limits what can be done thus risk assessment is rated high. Details of plan of control are in Covid-19 impact section.
3. Losing information from computers like data or the whole report has a negative impact on the project as it can be time costly to say briefly. It was rated low for probability as chances are low it can still happen. Impact is rated medium as it will cost the team members time to make a new set of data or writing report from beginning thus risk assessment is low. Plan of control is to save data in the cloud as those services have a very good reputation.
4. Failure of gears has a low probability as minimum damage has been done to them in testing. Impact of failure is low as new gears can be produced within a day thus risk assessment is low and the plan of control is to make new ones and investigate the reason of failure.

17.1.26 Communication Management

In order to achieve a good productivity and avoid misunderstandings between the team members and stakeholders, a good exchange of information is necessary. For communication outside the project there is a messenger group. Documents and reports can be accessed in Teams.

For updates the Team and Cynthia meet weekly. In meeting solutions are discussed and feedback is made on the work that's done. There is also a briefing for next week with goals.

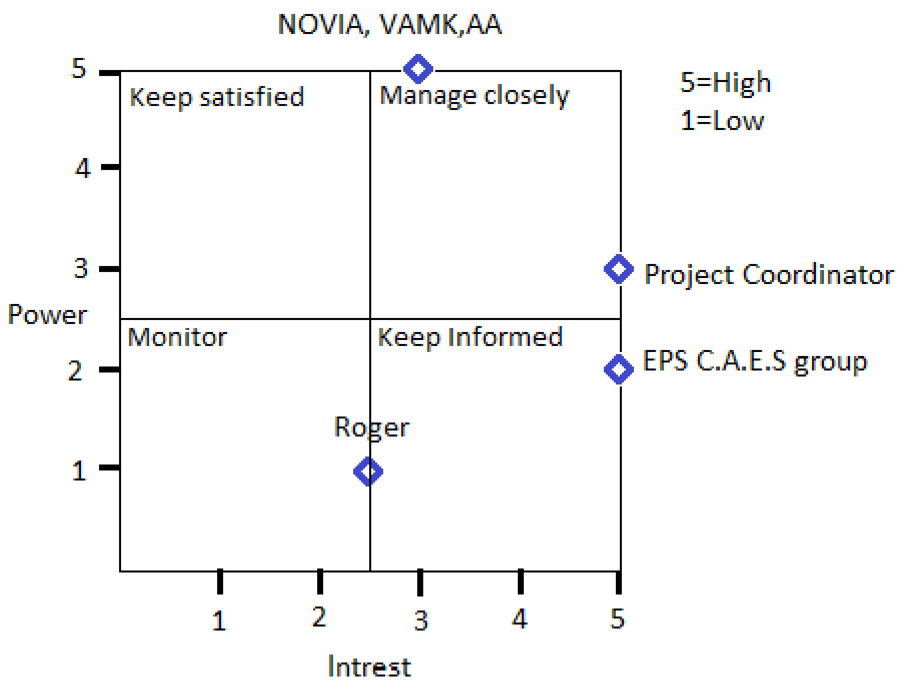


Figure 64 Stakeholders

Manage closely

-Cynthia is the coordinator. She has a lot of power, she gives feedback and helps to set the right focus points.

-EPS flow group C.A.E.S. are the working persons in the group. Communicate is important for a good project.

Monitor

-Roger is the EPS-coordinator. He has no direct impact in our project although he needs to be informed with a midterm report and presentation as well as for end of the term. With big problems he will help to solve them.

Keep informed

-EPS C.A.E.S. group and Lab teachers have a lot of knowledge. They can help us, but they have small power in the project.

Stakeholder	Information	Frequency
EPS group C.A.E.S.	Share constantly information of the project.	Daily
Cynthia	Updates on progress of the work She gives the team information about the lab. There is an information flow between the group members and Cynthia.	2 week/ Daily
The schools	Cynthia update the schools. Two times presentation by the team	Twice
Roger	Information in form of a report Mid-term report and Final report.	Twice
Lab teacher	Give them a verbal update when they are interest to listen.	Spontaneously

Table 32 Stakeholders

17.1.27 Change Management

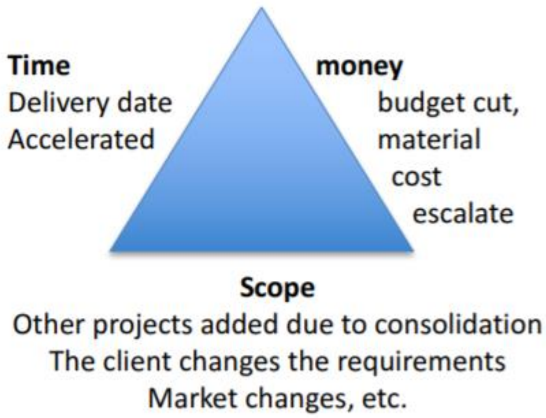


Figure 65 Changes management triangle (Project management)

Time: The project has a time limit. Big changes in time can have a big impact on the project. If the project has a big delay it can be fatal.
Money: The project has a budget. The budget is big enough to cover whole the project.
Scope: The project goals are set by the school and are hard to change

If the changes happened unexpected the impact can be huge.

Changes	Impact
Leaks **Tubs, parts of the compressors, connections**	Small Time: There is sometime time lose. But with great planning it is possible for getting around the change. Money: Low money spend Scope: Is in line with the project goals the get a better overall performance
Failing compressor (small) **Noise, connections between compressor and the tubes, cable damages**	Small/medium Time: Can delay working time in the lab with one day. Money: Low there is a lot of material in the lab that is available. Scope: Noting
Failing compressor (Big)	Big Time: Worst case scenario buys a new compressor with a long delivery time or use pressure system of the school. Money: Buy a new compressor. Scope: With the time loss the scope needs to be changes for a small time. Because the compressor is the hearth of the system.
Group member get sick	Small/big Time: More work for the other team members. Furthermore, working on mechanical part of the project can be extra difficult for non-mechanical engineers. Money: No loss of money Scope: Depends how long the group member is sick. The group member can work from home so the impact can be reduced.
Error in measurement system	Medium Time: Debug can cost a lot of time. Work together with another team member to get different vision on the problem. Money: Buy new measurement devices. Scope: If the team did not find the problem a part of the scope gone fail.

Table 33 Example change management.

In the table above there a major change given and what needs to be done if they occur. The person that finds them or what to change in them, should fill in the next Excel sheet. The table exists of:

- The project name
- The date when to apply the change to get approved by
- The change request, the name of the person that wants to change something
- The change itself
- Assessed by who is going to help with the change
- Priority on a scale to 1-5
- The impact it has on the project
- The effort it takes to do it
- The cost of the change without the hourly rate
- Approved by the person in charge

Number	Project Name	Date	Change Request	Change	Assessed By	Priority	Impact	Effort	Cost (€)	Approved By
1	C.A.E.S.	17/02/2020	Matuesz	Fixing the broken part	Alejandro	5	High	medium	55	Cynthia
2	C.A.E.S.	24/02/2020	Roger	WBS	Dean	3	High	Medium	0	Roger
3	C.A.E.S.	2/03/2020	Matuesz	Better overall performance (changing gears)	Alejandro	2	High	high	0	Cynthia
4	C.A.E.S.	23/03/2020	Arne	Better overall performance (changing resistor)	Cynthia	2	Low	low	0	Cynthia
5	C.A.E.S.	22/04/2020	Arne	Making simulation software		3	medium	medium	0	Arne

Table 34 Request table for changes (change management)

17.2 Datasheet generator

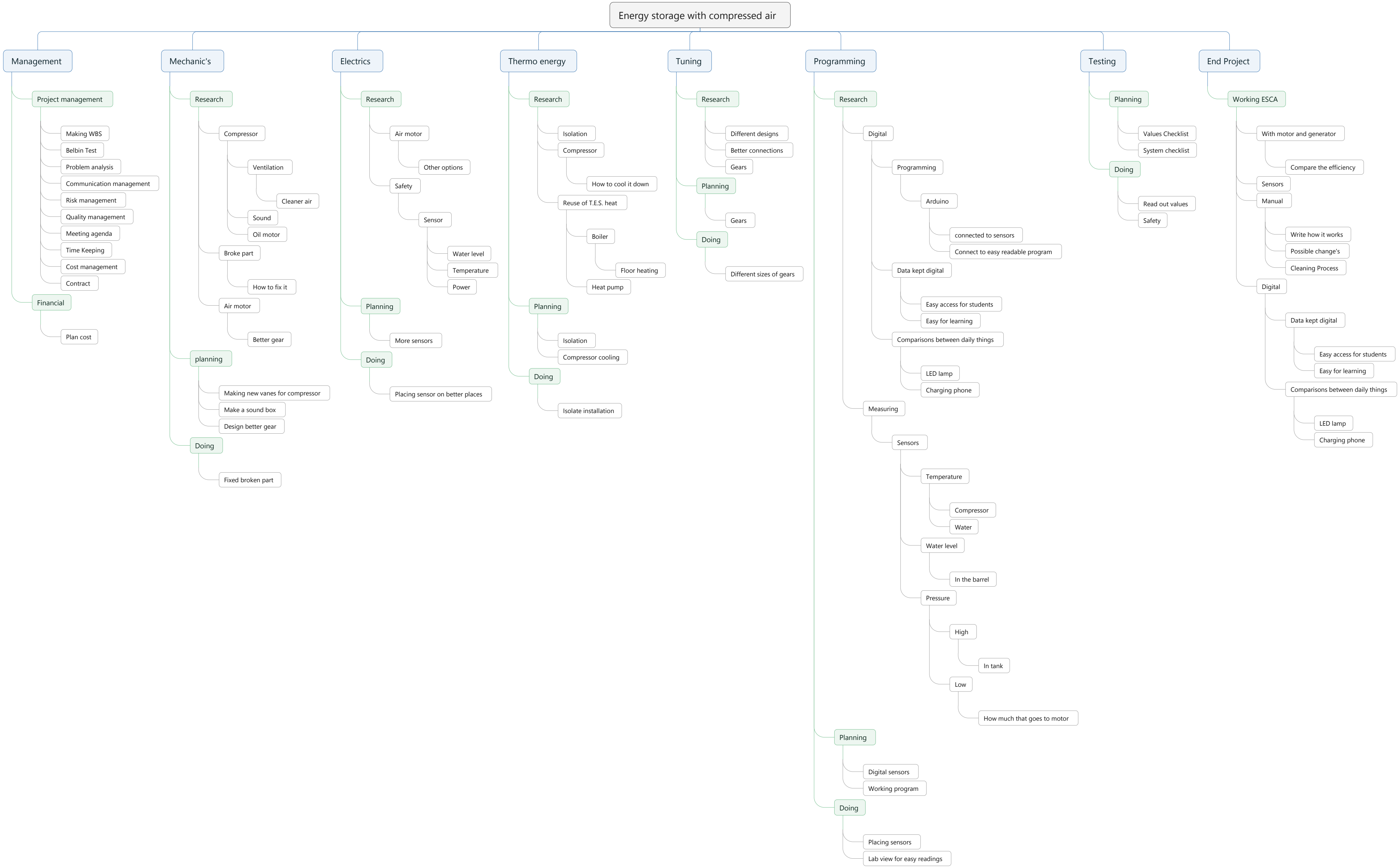
The current appendix give the requirement for the generators, it has to be said that the datasheet is similar to our current generator.

Specifications

Model No.	KA406XXX	**Motor flange size[mm]**	42
Rated output[kW]	0.06	**Rated armature voltage[V]**	70
Rated speed[min-1]	3000	**Maximum speed[min-1]**	5000
Continuous stall torque[N·m]	0.20	**Peak stall torque [N·m]**	1.2
Rotor inertia [×10-4kg·m2]	0.108	**Tachometer generator**	No
Output shaft	With key	**Connection**	Lead wire
Oil seal	No	**Protection rating**	IP43
Lead wire length[mm]	1000	**Ambient temperature**	0～40℃
Servo motor mass[kg]	0.5		

Table 35 Generator

17.3 WBS



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