Early Phase Product Development for Cyclone Dust Collectors

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Abstract

In this project a mechanical design process carried out which started from literature study to define the problem and then continued with searching for existing solutions and in next phase developing concepts based on what has been learnt from first two stages.

Pre-separators use cyclonic effect to separate solid particles from gas in a two phase media. There are two significant points defining the performance of a pre-separators; first the performance of the cyclone which is closely related to the geometrical parameters of the cyclone and second the process of removing collected dust which is the major factor of decreasing performance in existing products. This project aimed to define how an improvement can be made in both directions. First by understanding the mechanics of cyclones and determining effects of important parameters and then by developing concepts to empty the stored dust in the cyclone.

In the first phase a broad search carried out to identify the effects of different geometrical parameters of the cyclone and to develop the principles of design for new cyclones for pre-separators. Then to define the competition, similar products have investigated to identify 22 authentic products that has genial solutions.

In the second phase a conceptual design process carried out. Defining customer requirements and deriving technical specifications have led to develop a measure for future evaluation of detailed designs. Defining the system, sub-systems and functions made a better understanding of the problem. And finally in concept development stage all mentioned means have been used to develop sub-concepts to function for sub-systems. These sub-concepts stemmed from existing product’s solutions, similar industrial solutions or other miscellaneous industries. Moreover, these sub-concepts combined and evaluated in many steps. The outcome of this phase was design for prototypes of winning final concepts.
Acknowledgement

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The project was possible thanks to the help and supervision of Fredrik Borg from the department of Product Design Engineering at Semcon. I appreciate the trust that he put on me when he decided to work with me on this project, he has also been present any time I needed him and willing to answer all our questions. He taught me how to behave and carry out a job for a big company like Semcon, he was my mentor and introduced me to the products that I have worked on in this project, which was completely new and unknown for me. In addition, I would also like to thank Håkan Petersson from Halmstad University, who supervised me but yet gave me enough space for developing this thesis in my own way.

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<td>TRIZ</td>
<td>Theory of inventive problem solving</td>
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<td>FEC</td>
<td>Fractional efficiency curve</td>
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<td>CFD</td>
<td>Computational fluid dynamic</td>
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1 Introduction

1.1 Introduction to Semcon

Semcon is a product development company which is active in various countries and has more than 2000 employees worldwide. Semcon’s mission is “To turn technology into excellent user experiences” and as one of the strongest international partners in different industries they provide their customers with creative and innovative solutions and experiences. As one of five areas of focus in Semcon, “Industry” provides solutions for products and production. “Engineering development and industrial design are two areas where Semcon has extensive experience and wide-ranging specialist skills” and as such, innovative solutions would always be a spotlight in Semcon. [1]

Since Semcon has a strong profile and experience to support construction products manufacturers, there always is a search for improvements to be offered to these companies. As a possible field of implementation for these improvements is the Dust collection systems and industrial cleaning machines.

Since industrial dust collectors have a complex system, it is not reasonable to carry out a development for whole system and instead a specific problem was the focus of Semcon.

1.2 Introduction to pre-separators

Pre-separators are dust separation machines that would be connected to a dust extractor (vacuum) on one side and to a source of dust such as grinder or concrete cutter on the other side. Pre-separators collect larger particles of dust and thus increase the efficiency of the dust extractor and improves the durability of filters. [2] As it is shown in figure 1.1, pre-separators have three main connections:

1. Outlet to the dust collector – vacuum source
2. Inlet – suction of dusty air
3. Dust removal to plastic bag

While system is operating there is a vacuum inside the pre-separator. The plastic bag which is installed on the 3rd connection would be sucked and stuck to the connection. During the operation the large and medium size particles would be collected in the pre-separator’s tank and when the tank is full, the machine have to be turned off and the dust would fall down automatically due to its weight and absence of the vacuum.

1.3 Aim of the study

The aim of this project is to make a more in depth knowledge about pre-separators and search for related literatures. Moreover, investigation on existing solutions in
different industries and benchmarking competitors. Finally, developing concepts and solutions for new generation of dust collectors in order to remove the collected dust from the cyclonic chamber, without losing airflow and suction pressure to improve the performance.

1.3.1 Research questions
Main question in this project is to define “how the collected dust can be emptied without losing vacuum pressure in the inlet and thus improve the performance?”, but along with the main question there are secondary questions that also need to be answered:

- What are the existing solutions in same products and other industries that dealing with same sort of products or problems?
- What are the customer requirements for evaluation and more precisely what are technical specifications are the measures for comparing different products or prototypes? In addition, what is the relationship between determined specifications and customer requirements?
- What parameters are important and effective on the performance of a pre-separator and how they effect on efficiency?
- Increasing the productivity of the pre-separators is one of the main goals of this project. To what extent the productivity can improve?
- What constraints are limiting the design? Considerations such as human factors and standard dimensions make restrictions and constraints for applicable solutions.

1.3.2 Work structure
Based on a defined product development process the work have structured and listed major steps have taken to get the final results. To have a time frame for the project a Gantt chart have been made to clarify steps and activities. The Gantt chart can be found in appendix I.

- Literature study; to understand the mechanic principles and properties
- Benchmarking; both within the industry and outside to find existing solutions
- Customer requirement identification; to understand and direct goals of the project
- Concept development; to generate various concepts and then running an evaluation on them
- Detail design; design in a more detailed way for a selected concept
- Report and presentation; to prepare a comprehensive report about the process and results
1.4 Limitations
Limitations in this project can be defined in different directions. One aspect was time constraints; due to the complexity of the product and various sub-systems, a comprehensive development process needs a high level of resources which was not possible in the scope of thesis project. On the other side, defining customer requirement and technical specifications as well as evaluating concepts and taken steps needs a proper access to both end-users of the products and the manufacturer which was limited and in many stages some assumptions have been made stemming from industrial experience of the supervisor and the author. In literature study, the limitation was due to lack of experimental works, while simulations can be valid but in most cases in industry it is not a high reliable source. Moreover, while it was beneficial to prototype the final concepts in order to carry out a proper evaluation, but in the scope of this project, it was not possible.

1.5 Study environment
This thesis has conducted in Semcon office and few visits of Husqvarna’s research and development site in Jonsered carried out.

The major part of literature research, Benchmarking and development of concepts carried out in Semcon office and with support and supervision of “product design engineering” team. For short discussions and interviewing people from a manufacturer’s research and development department, few visits of test setups and facilities of Husqvarna for Dust and Slurry management department has been carried out.
2 Methods

2.1 Chosen methodology

As a guideline to the whole process of this project Ullmans book and suggested tools within the book have been used. A schematic of the comprehensive process has been shown in figure 2. The steps that have been taken starts from project definition to conceptual design and due to limitations proceeding to product development phase was beyond the scope.

![Figure 2.1 An overview of the mechanical design and product support process [3]](image)

To support this overall process literature study and benchmarking have been carried out during the process.

2.1.1 Literature research methodology

For literature research the search engine and data base of ScienceDirect have been used. Searching for keywords which are related to cyclones, their performance and efficiency and the related parameters such as diameter and heights led to numerous results. For instance many of the results have been achieved by searching “cyclone performance” in the titles, abstracts or keywords. After using filters for last 10 years published articles a total of 385 articles have found and in two more level the filtration carried out. First if the title was clearly of topic and second by reading the abstract. It should be considered that the full search process for articles was much wider and all other keywords searches and specific finding could not be recorded.
and therefore is not documented. Finally 30 articles have found closely related to the aims of this study which have been investigated more in next chapter.

2.1.2 Benchmarking
For benchmarking two directions have been taken. In one hand to search in other industrial applications of cyclonic separators and seek for nobility in their solutions and mechanisms that can support the conceptual design phase. On the other hand to search for all the competitors in the industry. In the latter one several products and manufacturers have found out and not surprisingly the number of copies were much more than the genial ones. Finally after comparing and determination of authentic products both within construction industry and other industries 22 genial products have been identified with their unique features. Details would be argued in next chapter.

2.1.3 Quality function deployment (QFD)
As a strong tool to define the relationship between customer requirements and technical specification, a QFD house have been developed. [4] While during this project QFD house have not been used to evaluate concepts or the products but developing this chart is a basis for further development of the concepts and product where the technical features can be measured and compared.

Two parts of the QFD house is critical; first customer requirements and second the specifications. Using video streaming websites, a numerous videos of the products in use have been investigated and a sort of observing method have been carried out to identify the customer requirements. On the other hand by using important and common specifications and measures from the articles, the technical specifications have developed. Then the developed matrix have been analyzed during a meeting with experts and it finalized to be used in future.

2.1.4 Importance matrix
In QFD house the importance of each customer requirement have to be defined. To proceed the evaluation a matrix have developed and requirements have been compared individually and then the scores of each requirement have summed up.

2.1.5 Pugh matrix
One of the strong tools to make decisions is using Pugh matrix. [4] In this project to evaluate the concepts and score them a Pugh matrix have been made and concepts together with two existing products have been compared.

2.1.6 Morphology chart
In the dust collector system the complexity can be solved by decomposing the whole system to different sub-systems which are carrying out sub-functions. After developing concepts for each sub-system, these sub-concepts have to be combined and a proper tool for this combination is morphology chart. [4] The complete morphology chart and further details would be argued later.
2.2 Alternative methods

Alternative methods were other options to approach to this project but they were not implemented in this project. However they have been considered and some inspirations have been made, but they were not the guideline to the process.

2.2.1 Generic product development

As a multidisciplinary point of view, Ulrich and Eppinger have modeled the product development process and a division have made between the tasks or steps of common departments; marketing, design, manufacturing and other function. [5] The schematic of the whole process is shown in figure 2.2.

![Diagram of the product development process](image-url)

**Figure 2.2** The product development process [5]
2.2.2 TRIZ
TRIZ “Teoriya Resheniya Izobretatelskikh Zadach” or theory of inventive problem solution is a Russian creativity method. Reasoning on inventions are always based on contradictions, it is defining 39 dimensions of a system or subsystem which can improve. Each dimension that needs improvement can worsen one or more other dimensions and here is the contradiction. Altshuller, the founder of TRIZ, introduced 40 principles that is base of all inventions and he structured a method to solve the inventive problems by identifying contradiction and using these 40 principles to solve the contradiction and so the problem. [6] Contradiction matrix is the main TRIZ tool in which 39 dimensions would represent in rows as improvement required features and same dimension in columns as worsening features and cross-section of each row and column would contain TRIZ principles that solve this certain contradiction. [7] To study TRIZ a contradiction matrix have developed which can be found in appendix II.

TRIZ is very strong and powerful method for inventive problem solving and concept generation, but due to time constraints it was not carried out in this project, however the contradiction concept was considered as an inspiration for solutions.

2.2.3 Biomimicry
Biologically inspired design is a system to develop solutions for engineering problem. [8] Or in another definition it is the intersection of biology and engineering and contain many different areas which engineering would enhance the solutions for biological problems and vice versa. Bioengineering, Biomechanics, biomedical engineering, biophysics, bionics and biomimicry are some of directions in this field and can be used interchangeably. [9]

With more precision, Biomimicry is studying natural processes to enhance the efficiency in man’s products and processes. It aims to lead to responsible and sustainable use of resources. [10]

In this study the close relation of dust removal problem as a generic problem and two important natural processes of digestion and excretion observed. However in concept generation phase these two natural mechanisms was inspiring, but biomimicry was not a followed direction or methodology to develop the concepts in this project.
3 Theory

3.1 Introduction

Cyclone dust separation is a method among four different methods to separate the solid particles from gas; electrostatic precipitators, fabric collectors or filters, wet scrubbers and inertial separators or cyclone separators. [11] Each of the four different type of dust collection method commonly is used for a certain range of particle size, Fig 3.1. [12]

<table>
<thead>
<tr>
<th>Separation method for different particle size (µm)</th>
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<tbody>
<tr>
<td>Electrostatic precipitators</td>
</tr>
<tr>
<td>Filters</td>
</tr>
<tr>
<td>Liquid scrubbers</td>
</tr>
<tr>
<td>Cyclone separator</td>
</tr>
<tr>
<td>Settling chambers</td>
</tr>
</tbody>
</table>

0.001 0.01 0.1 1 10 100 1000

Figure 3.1 Particle range for different separation methods [12]

Cyclone separators or simply Cyclones are seemed to be the most common systems being used to collect the dust and clean the air. [13] Cyclones are relatively simple and inexpensive to produce and are used in a variety of industries. Since this method of dust collection is more effective in larger particle size, cyclones mostly use as
pre-separators to enhance filter’s durability and performance. In figure 3.2 cyclone separators for construction sites have shown.

3.2 Mechanical principle
Cyclones use inertial principle to separate and extract the particulate matter from gases. [14] As it is shown in figure 3.3, under operation two vortex in the cyclone would be shape. The outer one is mostly made of entering dirty air and based on conversion of the inertia forces to centrifugal forces the particles would remain in the outer vortex and due to their weight gradually would drop and exit from the dust outlet. However the inner vortex is mostly made of gas and smaller or lighter particles which came from the outer vortex and would escape from the upper outlet. [15]

3.3 Performance
There are two major means that represent the performance of a cyclone; Pressure drop which is determined by Euler number and collection efficiency which is related with Stokes number. [16] While pressure drop and collection efficiency are both critical parameters to define the performance of a cyclone, these two parameter contradicts to some extent. [17] Studies have shown that cyclone with higher collection rate can have higher pressure drop which is not desired for the device. [15]

While the pressure drop is simply defined by the differences of pressure between inlet and outlet, collection efficiency is a rather more complicated factor.

Total collection efficiency in cyclone is determined as a fraction of weight of collected particles to the weight of total particles of the same size. [13] Since in real applications the particles are not in a certain size, the collection efficiency is defined by a curve called fractional efficiency curve (FEC). A typical fractional efficiency curve is shown in figure 3.4. Two important factor of FEC is cut-off size (d50) and the slope of the curve in that point. Cut-off size or d50 is the diameter of particles in which the cyclone has a 50% collection efficiency. [18]
Thus, for a cyclone there are following dependent parameters that can introduce the performance:

- Pressure Drop: which is the pressure difference between inlet and outlet
- Collection efficiency: which is a theoretical mean and is defined for a certain particle size
- Fractional efficiency Curve: which is a curve of collection efficiencies for different diameters
- Cut-off size or d50: which is diameter of the particles with 50% collection efficiency
- FEC slope in d50: which is the slope of the curve in cut-off point
- And Total collection efficiency which is define as the mass of the collected particles to the total introduced particles. In this efficiency the particle size would not be considered

As it is described in figure 3.5 there are many parameters and characteristics that effect the cyclone separators performance. Cyclone geometry, particle and gas properties and few other parameters.

![Importance of parameters in cyclone performance](image)

*Figure 3.5 Important parameters in cyclone performance [19]*

### 3.4 Effect of geometry on performance

#### 3.4.1 Introduction

It has been studied that the geometry of the cyclone significantly affects the collection efficiency of cyclone separators. [20]

As it is shown in figure 3.6, a simple cyclone could be identified by 8 different parameters. [20]
3.4.2 Vortex finder (Dx and S)
In an experimental analysis the effects of the diameter and the length of vortex finder on performance have studied. [21] In another study using CFD simulations and by identifying the discrepancies in former literature the effect of two dimensions have investigated. [19] The results of two studies were:

- Increasing Dx would lead to less pressure drop
- Decreasing S would lead to less pressure drop
- And increasing (h-S)/D would lead to lower Euler and stoke numbers

3.4.3 Inlet (a and b)
E. Khairy in a study and simulation have used Reynolds stress model (RSM) for CFD analysis and has investigated the effects of inlet geometry on the performance of the cyclone. Major results are:

- Increasing a and b would lead to less pressure drop
- Increasing a and b would lead to higher d50
- Optimum ratio of b/a is 0.5-0.7

3.4.4 Diameter (D)
L.S Brar has studied the effects of changing D by using CFD simulation and enhancing RSM codes. [22] The results were:

- Increasing D would lead to less pressure drop
- Increasing D would slightly move the FEC to left
3.4.5 Barrel height (h) and Conic height (hc=h-t-h)
Brar and Khairy have studied the effects of changing height of the barrel part and conic part of the cyclone by using a CFD analysis developed on RSM model and following results were obtained: [23]

- Increasing h would lead to less pressure drop and decrease in d50 (changes are small when h/D is bigger than 1.8 [19])
- Increasing hc would lead to less pressure drop and decrease in d50 (Changes stop when hc/D is greater than 4 [19])
- Increasing hc would lift FEC and increases the slope

![Figure 3.8 Effect of changing barrel and conic height on performance [23]](image)

3.4.6 Scaling
In one simulation using CFD analysis based on RSM models Azadi et al. have investigated the effect of changing the size of the cyclone. [18] The following results have obtained:

- Decreasing the cyclone size (scaling down) would lead to less pressure drop and decreases the d50

In another study an experiment for 4 different cyclones with same fractional dimensions and different sizes have carried out by W. B. Faulkner et al. and results were as below: [24]

- Decreasing the cyclone size would lead to a higher slope of cut-point in FEC
3.4.7 Inlet angle

In another study Misiulia et al. have studied the effects of changing inlet angle by using Large Eddie Simulation (LES) code in CDF analysis. [25] The results was:

- Decreasing the input angle would move FEC to left and lead to higher performance

3.4.8 Dust bin and dip leg

E. Khairy in a CFD analysis have studied the effects of having dustbin or dip leg after the outlet of dust and the results of simulation have showed there is negligible changes in performance with and without dustbin and dip leg. [19]
3.4.9 Applications
Cyclones are used anywhere that there is particles that need to be separated from a gas stream. [19] They are used in various applications such as:

- In construction sites using with drills, grinders, cutters etc.
- Installations in ship loading and unloading
- In power stations
- Food industry
- Mining industry to increase productivity of drillers
- Upstream in oil and gas industry to enhance batch making
- Vacuum cleaning machines
- Equipment for dust sampling

Figure 3.11 Cyclones from left to right without dustbin and dip leg, with dustbin, with dip leg, with dustbin and dip leg [19]

Figure 3.12 Some of the cyclones applications in industry. From left to right: Atlas Copco Mining truck [33], Donaldson Separation Equipment [34], Wenproduct Wood dust collector [35], Villo pre-separator [36], Walinga grain loader [37]
3.4.10 Pros and Cons
Cyclones are a wide range use devices. Some of advantages and disadvantages of cyclones are: [11]

**Advantages:**
- Simple and inexpensive
- Rather compact and space saving
- Flexible to extreme temperature, pressure or chemical conditions
- No moving part
- Can be produces by a variety of materials
- Easy to coat for special use
- Flexibility with different incoming mixtures
- Operability for both solid and liquid particles
- Collected particles are not mixed with other materials and so they could be useful

**Disadvantages:**
- Low efficiency for fine/small particles
- High deviation from designed efficiency during operation (in Vacuumed devices)
- High pressure loss in some types
- Erosive wear is common due to particles abrasiveness
- High intensity to design and geometry
- Discontinuous working due to limited space for collecting dust (in Vacuumed devices)

3.5 Construction site pre-separators
While cyclones are being used in a variety of industries, for each application the design and geometry and sometimes the major engineering parts of them can vary. The cyclone that is the subject of this project is pre-separators used in construction sites and activating by another vacuum powered dust collector can be connected to floor grinders, power cutters, drillers and handheld dust generating tools. Figure below is a typical configuration of these machines.

*Figure 3.13 Pre-separator (center) in connection with Vacuum collector (right) and floor grinder (left) [26]*
3.5.1 Benchmarking
However all of these products use almost the same principles, but there are minor differences which can be investigated more. 22 authentic designs have identified which can be found in appendix III.

Figure 3.14 is showing some of the most renowned producer’s products.

Comparing to other dust collection cyclones the following features are common in the pre-separators which are used in construction applications:

- A continuous plastic bag (Longopac™) is being used for dust dumping
- The inlet is designed tangential and in the upper side of the tank.
- The outlet is designed in the upper face
- Due to the vacuum, plastic is sucked to the lower dust removal gate.
- During the operation dust is stored in the tank
- To remove the dust, machine has to be turned off so the vacuum would release and the dust would automatically fall down into the plastic bag

3.6 System and Function analysis
Despite rather simple geometry of the pre-separators they can be decompose to subsystems and several functions are carrying on by these subsystems.

3.6.1 System and Subsystems
The main system that would be investigated in this project is a pre-separator including dust dumping plastic bag, inlet and outlet. And subsystems are as following:

1. Gas outlet/Vortex finder
2. Dust feed
3. Separator
4. Dust storage/hopper
5. Valve
6. Dumping plastic

Figure 3.14 Construction site pre-separators from left to right DustControl [38], klindex [39], HTC [40], Husqvarna [32], Nilfisk [41]

Figure 3.15 Sub-systems in pre-separators [42]
3.6.2 Function and sub functions
The main function as stated in one of the manufacturer’s manual is “pre-separating dry, not combustible dust”. [2] Sub functions can be identified as:

- Separation dust from gas
- Collecting separated dust
- Storing dust
- Packing dust
- Transferring air (airflow) from inlet to outlet
- Transferring dust from tank to plastic bag (hopper)
- Preserving vacuum pressure
- Other sub functions such as protecting main vacuum machine (secondary sub functions)

3.7 Problem understanding
As practical knowledge of client, it has been observed that after a certain amount of dust storage, the collection efficiency of pre-separators would dramatically decrease. One of the main effective reasons for this performance drop could be the changes in main parameters of cyclone. While during the dust storage, geometry of cyclone (empty space) is very complex, but with simplifications in Academic researchers have shown that decreasing cyclone height would decrease the overall performance of the cyclone. [27]

Current solution for this problem is to turn of the machine when the pressure indicator on the vacuum cleaner indicates a high pressure drop which means the tank is almost full. In this stage dust needs to be removed and the machine have to be restarted. Two main problems with this solution is that the operator does not
know when to turn off the machine (when the machine is not working efficiently) and moreover this turning off the machine would distract the work and reduces the productivity.

Figure 3.16 can be imagined as a schematic demonstration of the dust collection during time. The manufacturers claim that at the start point the total efficiency is more than 90 percent and after 30 to 60 minute depending on the application, it can drop to 50 to 60 percent and then the operator needs to turn off the machine and empty the dust and package it and again restart the machine. The gaps between each cycle are the representative of mentioned pauses. It has to be noticed that all values are just to present the schematic and they are not measured or estimated values.

While the dust is stored in the tank, the vacuum would prevent the dust to transfer the dust to plastic bag. So as TRIZ principles argue, the contradiction is to increase the pressure behind the dust without losing vacuum.

3.7.1 Weight limitation
Since the design have to be based on the human behavior, weight of packed dust is critical for its transportability. As it is shown in figure 3.17, 25 kg can be considered as the maximum weight of the package for a worker to transfer; [28] but if the worker is assuming to use a wheelbarrow or similar tools, it can be rise up to an 80 to 150 kg package. [29]

![Figure 3.17 Weight limits recommendation to lift or lower](image)

Standard wheelbarrows vary in sizes and they can take normally a volume range of 85 L to 150 L and mass range of 80 kg to 150 kg. [29]

Volume of the package can be estimated by assuming density of collected dust is assumed to be equal to the average density of dry dirt (1041-1281 kg/m3) and
cement powder (1362-1522 kg/m3). [30] With simple calculation, assuming the density range of 1200-1400 kg/m3, the average volume for hand-lift package is 18.5 L and the average for wheelbarrow is 120 L.

3.7.2 Dimension constraints
A typical pre-separator has a total dimension of 580x720x1590 mm [2] and excluding the carrier chassis and simplifying the dimensions, the total useful space is a 500x500x1500 mm box which contains the cyclone and the dumping area for plastic bag.

Other important dimension is the continuous plastic bag’s dimension. However there are three different diameters available (357, 465 and 570 mm) [31], but the 357 mm diameter is commonly being used for dust collectors which gives an approximate cross-section of 0.1 m². For example 30 cm distance between the lower part of the cyclone and the chassis gives a maximum 30 lit dumping area with these bags.
4 Results
Since the previous knowledge about this products where limited and mostly based on experiments, there are following goals and results for the project:

- Literature research and identification of cyclone mechanics and optimization
- Benchmarking of competitors and genial products within the industry
- Development of measures and evaluation basis of new concepts and products
- Conceptual design for sub systems then combining and evaluating them
- Presenting final winning concepts

While the first two have presented in previous chapter the other three would be presented here.

4.1 Requirements and Specifications
Current project is an original design and to have a proper evaluation of concepts the measures and technical specifications of the product have been developed. There are general parameters of a pre-separator which are known and represent its performance and in addition some other measures can define other qualities of the final concept. Regarding that a simple Quality Function Deployment (QFD) house have been developed to score final concepts which can be found in appendix V.

The importance of customer requirements have evaluated with a one by one comparison matrix which is presented in appendix V.

4.2 Conceptual design
In order to design concepts for this system an overall of subsystems have developed. In this way the concepts have generated for each subsystem individually. Before presenting the concepts, the configuration of subsystems and the overall system has to be considered. Subsystems based on the sub functions are as follows:

- **Separator:** This subsystem is responsible for cyclonic effect and separation between solid particles and the inlet gas
- **Actuator:** which is initiate the dust emptying process
- **Storage/Hopper:** however in most of the product designs and concept storage and hopper are integrated, the function of these two subsystems are different. Storage’s function is to store the collected dust and hopper’s function is to facilitate dust flow to plastic bag.
- **Valve(s):** which are controlling the matter flow between different spaces of the system.
- Three other subsystems are inlet, Outlet and plastic bag system which are subsystems and have important functions but since they are standard and hence not changeable, there wouldn’t be any concept generation for them
Above subsystems are the main subsystems of dust emptying concept, but due to weight limitation and human factors the dust bag packing system had to be considered as well. So the following subsystems have added to the final concept:

- **Sequencer (Spanner):** which is a subsystem to measure and determine division units
- **Divider:** that divides packages from each other

### 4.2.1 Sub concepts

In order to organize concepts and facilitate combination of sub systems, generated sub concepts have structured in a morphological table which is shown in table 4.1. Two of the competitor’s products from leading companies have selected to be used as evaluation measures. The details of each sub concept can be found in appendix VI.

**Table 4.1 Morphological table for sub-concepts**

<table>
<thead>
<tr>
<th>Concept 1</th>
<th>Concept 2</th>
<th>Concept 3</th>
<th>Concept 4</th>
<th>Concept 5</th>
<th>Concept 6</th>
<th>Concept 7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Storage integrated</td>
<td>Separate cyclone</td>
<td>Manual switch</td>
<td>Weight</td>
<td>Electric level meter</td>
<td>Pressure</td>
<td>Timer</td>
</tr>
<tr>
<td>Separator</td>
<td>Integrated</td>
<td>Manual switch</td>
<td>-</td>
<td>Airlock integrated</td>
<td>Separate storage hopper</td>
<td>Valve integrated</td>
</tr>
<tr>
<td>Storage hopper</td>
<td>Integrated</td>
<td>Manual switch</td>
<td>-</td>
<td>Butterfly</td>
<td>Flexible rubber</td>
<td>Screw</td>
</tr>
<tr>
<td>Valve</td>
<td>Large</td>
<td>Large</td>
<td>Large</td>
<td>Large</td>
<td>Large</td>
<td>Large</td>
</tr>
<tr>
<td>Bag</td>
<td>Large</td>
<td>Large</td>
<td>Large</td>
<td>Large</td>
<td>Large</td>
<td>Large</td>
</tr>
<tr>
<td>Sequencer (Spanner)</td>
<td>Large</td>
<td>Large</td>
<td>Large</td>
<td>Large</td>
<td>Large</td>
<td>Large</td>
</tr>
<tr>
<td>Divider</td>
<td>Large</td>
<td>Large</td>
<td>Large</td>
<td>Large</td>
<td>Large</td>
<td>Large</td>
</tr>
</tbody>
</table>

### 4.2.2 Overall concepts

However all mentioned sub concepts are valid to shape the final design, but since it can be numerous concepts can be generated by morphological matrix, a pre-evaluation stage carried out to rule out few sub concepts and narrow down choices. The reasoning behind these pre-evaluations can be found in appendix VII.
After first pre-evaluation overall concepts have developed in two groups representing two main sub-systems. First the dust emptying system which contains separator, actuator, storage, hopper and valves; and second the auto packaging system which contains sequencer and divider. The reason to make this grouping is that these two systems are rather independent and the overall concepts in each main sub-system can be analyzed independently.

In this stage again the concepts would be numerous and using Pugh matrix would be time consuming. To make fewer concepts for final scoring a second pre-evaluation step carried out for each main sub system. The reasoning behind second pre-evaluation can be found in appendix IX.
4.2.3 Final concepts

Finally 2 concepts have selected for dust emptying system and 3 concepts have selected for auto packaging system. Combining these concepts makes 6 concepts which have shown in figure 4.1.

Figure 4.1 Final concepts for Dust emptying (I and II) and Auto packaging (1-3)
4.2.4 Evaluation

Using a Pugh matrix all 6 final concepts have evaluated. To get a clearer evaluation two existing products have evaluated in the same matrix; First pre-separators C5500 model from Husqvarna brand and D60 model from HTC brand. These two products have been selected due to their rather high performance as well as having access to more information for these products.

Table 4.3 Pugh matrix

<table>
<thead>
<tr>
<th>Customer Requirement</th>
<th>Weight</th>
<th>C55</th>
<th>D60</th>
<th>I1</th>
<th>I1</th>
<th>I2</th>
<th>I3</th>
<th>I3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proper vacuum translation</td>
<td>10</td>
<td>0</td>
<td>0</td>
<td>-1</td>
<td>0</td>
<td>-1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Large dust capacity (nonstop working)</td>
<td>19</td>
<td>0</td>
<td>-1</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>0.5</td>
<td>1</td>
</tr>
<tr>
<td>Ease of use (operation)</td>
<td>12</td>
<td>0</td>
<td>0.5</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Ease of maintenance</td>
<td>3</td>
<td>0</td>
<td>-1</td>
<td>-1</td>
<td>-1</td>
<td>-0.5</td>
<td>-0.5</td>
<td>0</td>
</tr>
<tr>
<td>Ease of transfer (portability)</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Proper dust packaging</td>
<td>9</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>High producability</td>
<td>13</td>
<td>0</td>
<td>0</td>
<td>-2</td>
<td>-2</td>
<td>-1</td>
<td>-1</td>
<td>0</td>
</tr>
<tr>
<td>Low manufacturing cost</td>
<td>30</td>
<td>0</td>
<td>-1</td>
<td>-1</td>
<td>-0.5</td>
<td>-0.5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Using existing and standard parts</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>-2</td>
<td>-2</td>
<td>-1</td>
<td>-1</td>
<td>-0.5</td>
</tr>
</tbody>
</table>

Scores: 0 -16 10 17 1.5 -1 35 33

However the scores is offering that I3 is the best score in concepts but the difference between I3 and II3 is not considerable. As it can be noticed the Airlock system and Due-storage are not comparable in this stage and they need more development and prototype design can clarify the pros and cons for these two concepts. Moreover, for the auto-packaging system, since the production is a key factor in this development project, Hook concept is the promising concept and prototype design would be carried out.

4.3 Prototype

After evaluations three systems have to be prototyped; Due-storage, Air-lock and Hook. For each one a prototype setup have been designed. The design of prototypes carried out according to constraints and the aim was to make a simple and cheap prototype which can be tested for the expected function.

4.3.1 Due-storage

For this design three different sections have modeled. First the chassis which would be made of 2*2 square profile and the parts would be welded together. Second the fixtures which would be made of sheet metal using press cut and then drilling holes. Third the main section which would be made of following parts:

- Storage holders: which are specified by blued colors. These parts would be 3D printed with PLA material. The important point with these parts are the clearance of them with the storage itself and in order to be able to adjust these clearances for each part (upper and lower) a 4-point adjusting system
have designed that would be worked with tightening or loosening bolts and nuts.

- **Storage:** this part is consist of three different sub parts.
  1. **Casing:** this part would be 3D printed and would carry out the function. There are 4 holes in the surface of the casing that together with the Storage holder holes would act as blind valves. In each time section the upper hole of one side of the storage and the lower side of the other storage would be open and thus while one side is filling the other side is emptying. After a while the weight in filled part would initiate the rotation of the storage and would flip the storage.
  2. **Cover:** this part would be 3D printed and its function is just to cover the storage. It could be a one part storage but the cleaning inside for repetitive testing can be problematic.
  3. **Gasket:** this would be a gasket or sealing to seal the gap between cover and storage.

- **Bearings:** Two standard bearings would be mounted on two sides of the storage to facilitate the rotation. Inside the bearings metal pins would be mounted through the holes in chassis columns.

- **Springs:** Two springs would be mounted from one side to the storage and from other side to another hole in the chassis column. In the 3D model the second holes on columns have not been modelled because that should be taken place when everything is ready and the second hole is the adjustment feature for the spring. The function for the springs is that they would prevent the storage to locate in middle of the course; it would force the storage to move either full left or full right.

It shall be considered that the modeling of the prototype was to be given to the test facility to make and so some details that would be supplied from outside such as springs and bolts did not need to be modelled. An overall schematic of the prototype have shown in figure 4.2 and further details can be found in appendix X.
4.3.2 Air-lock

For this design three different sections have modeled. First the chassis which is the same chassis that would be used for the Due-storage to reduce the costs. Second the fixtures which would be made similar to fixtures in Due-storage. Third the main section which would be made of following parts:

- Body: That would be 3D printed and it is the main body of the valve and it consists of following parts:
  
  1. Casing: This part has a few features to enhance the functioning of the prototype. First the dust inlet (upper hole) is a multi-section hole that would start from a centric circle to facilitate the mounting of the cyclone and end with a side section that facilitate the rotation of the impeller due to the weight of the dust. Second the sections of inlet and outlet in the cylindrical area has an open angle of 60 degree and these two open sections are face each other; in this way, since the impeller have symmetric 6 blades, in each time section in the clearance course at least two blades would be present and the same count would be present in the other side and thus the pressure field in two side of the valve would be the same. In simple words, without initiation when the vacuum is connected the impeller would not rotate.
  
  2. Cover: Since the impeller have to be printed separately the casing have designed in two parts. The noticeable feature in cover is the bulge edge that would help to adjust concentricity of the bearing inside the cover.
  
  3. Gasket: To seal the gap between the casing and the cover the gasket should be mounted.

- Impeller: this part would be 3D printed and is specified by the blue color in the schematic. In order to get sure that the impeller can resist the vacuum pressure a simple analysis have carried out. The impeller has 6 blades distributed symmetrically and each blade has a 4mm thickness to have enough strength. In two side of the impeller two knobs have allocated for mounting the bearings.

- Bearings: Two bearing would be mounted in the casing and the cover to facilitate the rotation of the impeller, so the knobs of the impeller would be mounted inside two bearing.
An overall schematic of the setup have shown in figure 4.3 and to investigate more the details have brought in appendix X.

4.3.3 Hook
To Test the function of this concept a prototype would be made and mounted on the carriers of the existing products. The hooks would have following two parts and three sets can be mounted to test the function clearly.

- Hook-pipe: which would be made of pipe to reduce the costs and to not have any sharp edges that might tear up the plastic. Forming of the pipe has two directions; one to make the hook plan and two to make a 45 degree angled pressed end. The empty circular area inside the hook has a diameter of 3 inches to provide enough space and the 45 degree angle would facilitate the dust drop to the bottom.

- Pipe-connector: which is the connection between pipe and the carrier and is designed to make pipe foldable to test the wheel barrow with the same setup as well.

An overall schematic of the prototype have shown in figure 4.4 and further details can be found in appendix X.
4.4 Discussion
The results of the present project can be analyzed in two directions; development of the knowledge for future phases and concept development.

4.4.1 Development of the knowledge
Based on the lack of scientific background a literature study have been carried out in order to build up the principles of future designs for cyclonic chamber of the pre-separators. However the important parameters have identified and also for each parameter few experimental or simulation researches have been investigated, but the lack of proper experimental results can increase the uncertainty to the findings. Interestingly some of the findings have been implemented in existing products and it can show that the same directions in those manufacturer had been carried out.

In addition, the emptying process, which is similar to the hopper action in silos and grain storing industry, is a broad and complex area that in a separate investigation have to be studied. The results of such study can help to define the minimum dust outlet diameter of the cyclone and the dust emptying rate for different types of particle mixtures.

4.4.2 Concept development
This part of the project ended up with two sets of deliverables; first all the sub-concepts, overall concepts and final concepts which can be the base of next generation products and second the prototypes which need to be tested in order to validate the findings of the conceptual design phase.

The concepts have presented to one of the manufacturers and it would be a supporting document for their further product development but regarding to constraints and other considerations the prototyping could not be performed and hence the designs of the prototypes was the last steps of the project for the moment.

5 Conclusion
Present work is a pre-development project carried out to increase scientific knowledge about the cyclones as well as to run a conceptual design process to be continued in the manufacturer’s research and development department.

5.1 Conclusion
- Carry out a broad literature study to define important parameters which effects the performance of the cyclone separators.
- Define the effect of the geometrical parameters on the performance using close to 30 scientific article containing simulation or experimental results.
- Identifying customer requirements and the relative importance of them.
- Identifying technical specifications from scientific results in order to make a measure of comparison.
• Developing several concepts for each sub-system of the total product which are based on individual reasoning such as industry examples, calculations or scientific facts.
• Developing and evaluation overall concepts for dust emptying and auto packaging process.
• Developing and comparing final concepts with two existing products and scoring them respective to customer requirements.
• Developing prototypes for three winning overall concepts.

5.2 Recommendation to future activities
• A wider literature study can be recommended, since in this study only the ScienceDirect database have searched through
• Further development of sub-concepts can lead to a more detailed and thus more accurate evaluations
• Prototyping and testing the functions would give a clearer insight of the actual application of the concepts
• Further than prototyping a cost analysis for the detail product development can be carried out
• Since the ruling mechanics of the cyclone separators are complex, computational fluid dynamics (CFD) analysis can be carried out to study the processes and designs with low cost. It have to be considered that time constraints and high level complexity can make the experimental methods more reasonable.
• For auto packaging system further concept development can be carried out to have more accurate and detailed concepts.

6 Critical Review

6.1 Environment
Current products have been designed with an integrated feature of cyclone separator and storage tank. This design would need a bigger tank and thus more material would be needed to produce the product, hence with a smaller and lighter product the environmental harmful effects of the design can be decreased but still more detailed design and more accurate data have to be produced to define the exact influence of the new design.

On the other hand since this products are being used to collected unwanted dust, higher overall performance of this products can protect the environment especially when toxic or other harmful particles are being filtered.

6.2 Health, safety, society
The logic behind using a separator is closely related to the health and safety of the operators and other people contacting with dusty air. By new designs different directions can be improved in terms of health, safety and society such as below:
- Current collectors have a pulse back when they shut down (due to their big size of tank). With a better system this pulse back would be minimized.
- Performance of the separator is related to the total cleaning power of the machine and hence a higher performance in the machine can increase the air quality during operation.
- Pre-separators have designed to protect the filters and increase the total collection efficiency of the machine. Current products when get almost full would pass close to half of the dust to filters and would clog or even perforate the filters. So a better pre-separator can increase the efficiency of the fine particle’s filtration.
- With Auto packaging system the size and the weight of the dumping bags can be determined and so the machine itself would prevent the operator to make heavier bags which would be harmful when they are being lifted
- Another effect of using auto packaging system is to facilitate the packaging process for the operator which would decrease the risk of injuries or other harms during this process.

6.3 Economic
There are several aspects of the economic influence for the design. Following are examples of this positive effects:

- Due to a less material use in the new design the material costs and manufacturing costs can decrease
- Due to a lower cost (if achieved) a better competency can be achieved
- Due to increasing the performance, reliability and productivity an overall higher quality can be offered that would be led to increase in market share
- A better total collection efficiency would enable using a smaller and thus cheaper product for a higher standard or tougher application.
- Due to longer time in non-stop working increase in productivity can be achieved
- Due to a better handling and auto packaging solution the need for an extra operator would be minimized

6.4 Conducted work
In this project two process have been carried out which were first increasing the knowledge about the separators and second the conceptual design phase. However the results of this study can be used for future product development process, but it could more beneficial to focus on one process with more detailed information and thus narrower subject that could proceed to a more in detail, practical and close-to-production solutions.

Another direction that could be taken was to investigate different standards related to the project to increase the knowledge about good practices related to the project.
7 References


Appendix I – Gantt chart
Appendix II – Contradiction matrix

As an alternative method TRIZ have been studied and a contradiction matrix developed. While it can be used for a more detailed project but with time limitation it could not be used in this project.

<table>
<thead>
<tr>
<th>Improving Feature ↓</th>
<th>Weight of moving object</th>
<th>Weight of stationary object</th>
<th>Length of moving object</th>
<th>Length of stationary object</th>
<th>Area of moving object</th>
<th>Area of stationary object</th>
<th>Volume of moving object</th>
<th>Productivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>+</td>
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<td>35, 3, 24, 37</td>
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<td>+</td>
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</tr>
</tbody>
</table>

Productivity
Appendix III – Benchmarking
22 authentic competitors among numerous manufacturer have been recognized. While these 22 company has their own type of design, mostly the other products were copies and not genial. Following product are being used in various industries but the common feature is using them for grinding and cutting stone, concrete and other structural materials.
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Nilfisk[21]</td>
<td>ILMEG[22]</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Reference:

Appendix IV – Manufacturer interview

During the project there were some critical information that could not be derived from literature and web-based researches. While some of these data or information could be assumed or estimated but some other data a survey have designed and in a meeting with the manager of research and development department of a strong manufacturer of dust collectors. The outcome of the meeting in the form of questions and answers are as following:

1) **Dust collectors or specifically pre-separators are being used commonly in construction sites. What are the machines that normally get connected to pre-separators and what is the maximum rate of dust making by these machines?**

The typical machines that would be connected are floor grinders from small foldable to automatic self-driven ones, ground drills, power cutters and other miscellaneous machines. The dust production rate is strongly related to the type of machine, application, quality of material and operation but for the toughest application an average maximum of 2.5 kg/min can be estimated.

2) **Pre-separators have to be emptied when they are filled with dust and thus vacuum machine have to be turned off. How long is the span of non-stop working for pre-separators?**

Again the time can be different in different applications and for different products but a rule of thumb for our type of products is that every 30 minute operators would stop machine and pack the dust.

3) **In some standards we have noticed that a maximum of 25 kg weight have been recommended for packages to be carried by labors, but since wheel barrows can be widely used in construction sites, do you think a package of 100 kg or general packages heavier than one man’s strength is practical for dust packaging?**

However it is not completely impossible or improper, but the preferences is to keep the packages handle able for one man which is less than 25 to 30 kg.

4) **Pressure is one of the key factors in vacuum dust collectors and pressure drop is a negative effect of pre-separators. Do you have the information about the amount of vacuum pressures that commonly would be connected to the pre-separators and pressure drop during operation?**

The pressure of vacuum machines vary from machine to machine and can be found in the catalogues of products which normally has range between 20 to 40 kPa and this is a vacuum pressure of a blocked inlet. About the pressure drop for our products it starts with 1-2 kPa when the dust collector is empty and while it is
getting filled the pressure drop rises till approximately 15 kPa in which the operator needs to empty the dust and restart the machine.

5) What about the airflows? There can be some air leakage in pre-separators, have you investigated that?

The air leakage in cyclones are negligible and thus almost the same airflow in catalogues would be sucked into inlet of a pre-separator.

6) Do we have any standard dimension or size restriction for pre-separators?

For whole the product it is a half European pallet which is transportable by cars and thus excluding the carrier a design space of approximately 50 cm * 50 cm * 160 cm can be imagined.

7) In your products catalogue it has been mentioned that the tank has 100 liter capacity. Is it the point that operators would stop the machine normally?

No, it is the maximum amount of dust in the machine and normally operators stop the machine when it is filled by 50% to 60%. This amount of dust is being bagged to 2-3 packages to transport.

8) The performance and design can be very sensitive to the maximum size of the particles that can be made and sucked by machine. How large can the particles be?

In most application and almost 99% the maximum is particles with 3mm diameter, but absolute maximum can be assumed as particles with 10mm diameter.

9) As it can be considered there are some standard parts or common components that are a part of final products. Which main parts are standard?

Excluding common small standard parts such as bolts, nuts and fasteners, there are few parts that are now widely being used and are accepted by customers: longopac, longopac holder, textile strap, gasket and the connection of inlet and outlet.

10) As you mentioned pre-separators would be emptied every 30 minute, but does the main vacuum machine need to be cleaned as well? If yes how many time it is being cleaned?

Nowadays, the main machine is being cleaned 1-2 time in one working day and that’s mostly because of the amount of the dust escaping from pre-separators.

11) Can you give any common problems that can be occurred to the product? For example if there would be some times that the dust couldn’t come out of the tank or clog in the hinge valve?
There is not mentionable problems with product. And about the example normally it would not happened, only may be if operator leave the dust inside the tank for a long time.

12) Any other comments or suggestions can you give us?

An important thing to consider is that pre-separators would be used in construction sites and abusing the products is very probable, so it should be taken into account that if the operator didn’t operate machine as it should be according to instructions what can happened.

Moreover in the meeting the customer requirements and specifications have presented and discussed with experts.
Appendix V – Requirement and Specification

Customer requirements are the basis for measuring the quality of a product and to translate it to measurable technical specifications a QFD matrix have been developed:

<table>
<thead>
<tr>
<th>Customer Requirements</th>
<th>Y2K</th>
<th>Y2K+1</th>
<th>Y2K+2</th>
<th>Y2K+3</th>
<th>Y2K+4</th>
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<tr>
<td>Maintainability</td>
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<td></td>
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<tr>
<td>Durability</td>
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</tr>
</tbody>
</table>

- **QFD Matrix**

  - [Image of QFD matrix]

  - [Image of QFD matrix diagram]
Appendix VI – Sub-concepts

Sub-concepts are presented in morphological table by rough sketches in the report. Despite the simple drawings in table they are inspired from a wide range of products and industries. Following is the reasoning behind each sub concept.

- Among the products for pre-separation there were a common design which integrated the separator, storage and hopper. In these products the conic part of the cyclone has two functions, first the inertial function for settlement of particles and second the function of hopper which can be similarly observed in silos or funnels.

- However the articles argue that scaling down the cyclones theoretically would lead to more accurate cyclone due to a more vertical fractional efficiency curve FEC and less pressure drop, but the material flow of solid particle in the conic part can be interrupted by a narrow outlet. Since mechanical analysis of this material flow is very complex and out of the scope of this project, small geometry of an existing product which is working in reality have considered.
• This concept is a simple blind valve which is being used in various machines. It can be also a rotating handle for airlock which rotates airlock.

• Actuating based on weight came up from a simple calculation of the energy and force which is not being used now and the idea is to use this force and energy to actuate the auto emptying or auto packing system. The course of action for this weight assumed as the height of one bag and longopac with diameter of 357 mm diameter have taken as packing system.

\[ F = m \cdot g = 25 \, kg \times 9.8 \, m/s^2 = 245 \, N \]

\[ h = \frac{v}{A} = \frac{m}{\rho \cdot \pi r^2} = \frac{25 \, kg}{1.25 \, kg/m^3 \cdot \pi \cdot (0.357 \, m)^2} = 0.2 \, m \]

\[ E_p = m \cdot g \cdot h = 245 \, N \times 0.2 \, m = 49J \]

• Level transmitter or level indicators are widely being used in various industries. However some LTs can be very expensive due to their accuracy or other features, other simpler types could be low price or even a customized one can be designed based on same mechanisms.
Based on the huge difference between starting pressure drop (2 kPa) and the pressure drop at restart point (15 kPa) again a calculation can show that there is a considerable force to actuate automation system. In this case the vacuum inlet or outlet with diameter of 76 mm can be use as bypass system and so the force can be calculated based on section area.

\[ F = P \cdot A = P \cdot \pi r^2 = 13 \text{kPa} \cdot \pi \cdot (0.076 \text{m})^2 = 59 \text{N} \]

One of other actuator concepts came from a routine tool. Garden watering valve which can be set to specific time span.

It is a good practice to use dust bin, storage or other compartments to lead separated particles to. This idea again inspired from one of the high quality products in the industry.
- The concept of integrating storage with dumping plastic bag was stemming from eliminating any excessive parts. Of course it is a conditional concept since the valve between separator and plastic bag have to supply enough pressure drop so we can obtain atmospheric pressure in plastic bag and somewhere close to 0.7 bar absolute pressure in the separator. Some investigations in airlock valve catalogues shows that it can be possible.

- This concept came from the common sizes of rotary airlock valves which are standard products in food industry and conveying systems. The idea is to use a standard airlock valve which can have a diameter of 6 inch to bigger than 30 inch and since this valves are quite large they can contain considerable amount of dust to be considered as storage as well.

<table>
<thead>
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<th>8V</th>
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</tr>
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<td></td>
</tr>
<tr>
<td>11X10</td>
<td>0.44</td>
<td>0.61</td>
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<tr>
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<td>20X20</td>
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</tr>
<tr>
<td>25X25</td>
<td>20</td>
<td>20</td>
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</tr>
</tbody>
</table>

- This concept is rather genial and it is stem from separating two functions which are mostly have been integrated, the storage and hopper. With this concept two pressure fields of vacuum and atmospheric have been disconnected and while dust is transferring from separator to right part of the valve, the left part is emptying in the plastic bag. So in this case right part of the valve is vacuumed and left part is pressurized. After filling right part the differences between weights would initiate a rotation and the positions would be vice versa and so on.
• This concept is based on Darcy law which is calculating the porous media flow and the pressure drop in its length. Theoretically it is possible to have a column of dust and have a pressure drop which would lead to a pressure difference of 0.3 bar that we need to connect separation unit and plastic bag without any valve. Further calculation have carried out which is not in the scope of this report but it is so uncertain to use such a complex idea.

Figur 0.8 https://byjus.com/physics/darcys-law/

• This concept is based on the current solution for preserving vacuum in pre-separators.

Figur 0.9 https://www.youtube.com/watch?v=SqWK0N10sJw

• Concept of using airlock mechanism for dust transportation from vacuum tank to atmospheric pressurized plastic bag is stemming from grain conveying systems which are using the same principles in larger scale to transport solid particles.

Figur 0.10 www.vortexglobal.com
• This concept is based on simple butterfly check valves.

Figur 0.11 www.dezurik.com

• This concept is borrowed from mining industry where drilling trucks use some sort of same two stage separation for dust collection from the hole while drilling. In that system a flexible rubber have been used to block the air inlet from dust exit. The uncertainty of the actual system of these valves prevented us to develop more the concept.

Figur 0.12 www.nilmeg.com

• This concept is inspired from plastic injection machines and screw pumps which are being used to pump solid particles.

Figur 0.13 catalog.conveyorspneumatic.com
• This concept is a typical control valve which is a widely used part in industry.

• The concept is based on the trigger mechanism that would initiate the divider mechanism. The spring behind the flat base is the idea of approximate linear relation of force and compression in springs. So with calibration of triggers it would initiate dividing system with certain weight span.

• This concept is similar to the last one from some aspects. It uses the spring and calibration idea. Using a special topology in flaps of rotating part it can narrow down the longopac and make a neck to facilitate dividing system.

• This concept is coming from automation industry which is working based on timed systems or similar processes. The concept is using an electrical accurate system to initiate divider.
• This system is using the airlock system as inspiration. The concept is to use rotating energy of the airlock which is caused by the force of dust weight. The idea is to connect a gear that would press a spring and would store the energy and every few turn counts a trigger would release the spring which would provide the energy for dividing.

• This is an idea that instead of dividing dust in the package just facilitate the operator to divide it himself. Since the dust would fell down to the minimum potential level it would fill the lower bag and when it filled the next one would get filled and so on. However this concept does not actually divide the packages but it is very simple to use and helps operator to carry out the dividing task much more simply.

• The idea comes from traditional sausage making which uses intestines of the animal and after each step of filling, the casing (intestine) would twist and the next filling continues.

Figur 0.15 www.thespruceeats.com
• Again from sausage industry, this concept is based on the mechanism called “sausage linker knotter” which uses ropes to make the sausage blocks.

Figur 0.16 https://www.youtube.com/watch?v=lUOE2De6e0

• This concept is related to sausage clippers which uses metal clips to divide block.

Figur 0.17 https://www.youtube.com/watch?v=Arqm9s-cxro

• One simple mechanisms for connecting tree branches is tape tie machine. The concept is using similar concept for dividing packages.

Figur 0.18 https://www.youtube.com/watch?v=ILownjfaVno
Another mechanism for making ties is wire twister machines.

This mechanism is based on the same idea of twisting but from sides.

This concept is inspired from heat seal mechanism for packaging which generally need electricity and so is very limited.

This concept is using blades and reciprocating action would divide and cut packages.
Appendix VII – Pre-evaluation I

Since the concepts that can be derived from morphological table is numerous and it is not possible to analyze all of them, a decision has been made to rule out few concepts which are last priorities and most probably would end up with losing concepts.

Reasoning for each eliminated concept would be explained after the schematic figure of this pre-evaluation. It has to be noticed that since two main rather independent system can be imagined (dust emptying system and auto packaging), this two overall concept would be developed almost independently.

<table>
<thead>
<tr>
<th>inlet</th>
<th>CSS</th>
<th>DGO</th>
<th>Concept 1</th>
<th>Concept 2</th>
<th>Concept 3</th>
<th>Concept 4</th>
<th>Concept 5</th>
<th>Concept 6</th>
<th>Concept 7</th>
</tr>
</thead>
<tbody>
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<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>sepa</td>
<td></td>
<td></td>
<td>Storage integrated</td>
<td>Separate cyclone</td>
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<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>actua</td>
<td></td>
<td></td>
<td>Manual switch</td>
<td>Weight</td>
<td>electric level meter</td>
<td>Pressure</td>
<td>Timer</td>
<td></td>
<td></td>
</tr>
<tr>
<td>stro</td>
<td></td>
<td></td>
<td>Separation area</td>
<td>Separate hopper</td>
<td>Plastic bag integrated</td>
<td>Airlock integrated</td>
<td>Separate store/hopper</td>
<td>Valve integrated</td>
<td></td>
</tr>
<tr>
<td>vall</td>
<td></td>
<td></td>
<td>Hinge</td>
<td>Manual switch/ball</td>
<td>Airlock</td>
<td>butterfly</td>
<td>Flexible rubber</td>
<td>Screw</td>
<td>Central valve</td>
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<tr>
<td>bag</td>
<td></td>
<td></td>
<td>Spring trigger</td>
<td>Turn and weight</td>
<td>Timed</td>
<td>Turns count</td>
<td>Hanger</td>
<td>Hanger with sensor</td>
<td></td>
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<tr>
<td>sequi</td>
<td></td>
<td></td>
<td>Plane trigger</td>
<td>Sausage link knotter</td>
<td>Metal clips</td>
<td>Tape clipper</td>
<td>Wire twist tie</td>
<td>Side twist tie</td>
<td>heat seal</td>
</tr>
</tbody>
</table>

Reasoning for pre-evaluation:

- **Separator:**
  - Storage integrated: It takes too much space and restrict the space for other systems and specially auto packaging system.

- **Actuator:**
  - Pressure: uncertainty in the pressures and the high variability of pressure drop makes it very complex to design a stable and steady system.
- Electric level meter and Timer: Since these two are electric and electrical systems is not desired it has been decided to have one electrical overall concept and so all electrical sub-concepts grouped to an electrical concept.

- Storage/Hopper:
  - Separator integrated: A major problem with integration of storage and separator is to lose efficiency significantly during the tank filling.
  - Valve integrated: Based on hopper technology for silos it can be observed that it is not possible or so complex to make a very narrow outlet of dust due to clogging problems.

- Valve:
  - Screw: Despite in the valve section the elimination took place less due to its function in few sub-systems, this type of valve is rather expensive to make and complex.
  - Control valve: this sub concept have allocated in electric concept.

- Sequencer (spanner):
  - Timed: this sub concept have allocated in electric concept.

- Divider:
  - Plane twister: it upgraded to another concept. Rotating a filled bag with more 20 kg weight needs much more energy rather than rotating the longopac itself. So the concept changed to rotating longopac.
  - Metal clipper and wire twist tie: these two concepts use metal parts to make a tie or clip and while the longopac is made of plastic these two dividers raise the risk of plastic rapture and so eliminated for this stage.
  - Side twister: this concept have put aside due to the complexity of bag’s geometry as well as high required energy for rotating a heavy bag.
  - Heat seal: this sub concept have allocated in electric concept.
Appendix VIII – Overall Concepts

Two main sub systems have developed from sub concepts. 6 concept for dust emptying system and 6 concept for auto packaging have developed. In some concepts the sub – concepts have modified.

<table>
<thead>
<tr>
<th>CSS</th>
<th>DMO</th>
<th>Concept 1</th>
<th>Concept 2</th>
<th>Concept 3</th>
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<th>Concept 5</th>
<th>Concept 6</th>
<th>Concept 7</th>
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</tr>
<tr>
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<td>3</td>
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<td>Hinge</td>
<td>Valve</td>
<td>Hinge</td>
<td>Valve</td>
<td>Hinge</td>
<td>Valve</td>
</tr>
</tbody>
</table>

- **Dust Emptying Concepts:**
  1. **Electric:**

This concept is based on using electric components.
2. **Manual:**
This concept is based on a bypass system just to eliminate the need to turn off the machine in dust emptying process.

3. **Airlock:**
This concept is automatically and gradually empty the dust to bag and with airlock system required pressure drop would be provided.

4. **Airlock-storage:**
This concept is automatically and gradually empty the dust to bag and with airlock system and added storage required pressure drop would be provided.
5. **Airlock-valve/storage:**

This concept is automatically and gradually empty the dust to bag and with airlock system and added storage required pressure drop would be provided. The idea in this concept was to use standard rotary airlocks which are rather large and can function as storage as well.

---

6. **Due-storage:**

This concept is empty the dust is two step. Fist from separator to valve (vacuum) and then from valve to plastic (atmospheric pressure).
• Auto Packaging Concepts:
  1. Full-Auto:

This concept is based on using tapes instead of zip ties which are being used currently to make packages and sealing them. In each process of 25 kg packaging 2 tape clips would be tie the longopac and a scissor would cut in between. The spring in between would mechanically weight the bag and facilitate the proper filling of the bag and two side springs would be compressed during the filling process and when the 25 kg trigger is being initiated, side spring’s energy would be used to perform clipping and cutting action.

2. Spinner:

This concept is using the spring to measure the weight due to almost linear relation of weight to compression of the spring. When the leaning plate moves down due to increasing weight it would continue till the grooves and on grooves the plate would spin and make a division on longopac.
3. **Longo-twister:**

This concept is using the concept of twisting longopac holder instead of filled bag and it can be initiated by the rotation of airlock blades. For example when 30 turns of rotation occurs a spring would be release and longopac would spin and makes the division.

4. **Whirligig:**

This concept is using the weight as initiator as well. The concept is to use a topology in plates which would make a neck when they are getting close to each other and a tape is clipping there to facilitate operators package making action.
5. **Trigger-knotter:**

This concept is using triggers in supporting columns to initiate a rotation on linker knot mechanism or a tape clipper.

![Diagram of Trigger-knotter concept]

6. **Hook:**

This mechanism is not actually divide the packages but due to a longopac necking in the hooks it will facilitate the operation for operator and it’s designed to sequence the division by length of the longopac. The standard longopac has a section area of 0.1 m² and 25 cm height can make an approximately 25 liter package.

![Diagram of Hook concept]

7. **Electric:**

This concept is based on using electric sensors or timers for sequencing system and using heat seal or other electrical system for dividing. Since the electrical concept was strongly rejected the sketches for auto packaging have not drawn.

![Diagram of Electric concept]
Appendix IX – Pre-evaluation II

1. **Electric:**

While electrical concept has a high level of certainty but the first problem with it is that the pre-separators are separate products and they don’t use electricity or other electronics. Moreover this concept would increase the costs and so is not desirable.

2. **Manual:**

This concept is now being used by one of the manufacturers. However it is a working system but since it does not change the performance status, we decided to put this option aside and after development of other concepts we can compare.

3. **Airlock:**

This item has been selected.

4. **Airlock-storage:**

Storage part was added to the airlock concept because it was uncertain if the pressure drop would be enough and if the turbulent flow in separator would affect the operation of the valve. So this option has been put aside and it would be further investigated only if the airlock system is not working as expected.

5. **Airlock-valve/storage:**

This concept was based on using the standard airlock valves in the market, but since the whole product would be redesigned there is no advantage of using a bigger airlock system.

6. **Due-storage:**

This item has been selected.

7. **Full-Auto:**

This item has been selected.

8. **Spinner:**

The grooves are complex design which would make a narrow space for abusing the product which can happened occasionally. Furthermore, rotating the full bag need a lot of energy and since there are more reasonable ideas, it is not desirable.

9. **Longo-twister:**

This item has been selected.
10. Whirligig:
Complexity and uncertainty of this concept is too much and it is not desirable to develop it more since there are much convincing concepts.

11. Trigger-knotter:
This concept needs other features in product however no special value can be added implementing it. Moreover, complexity and uncertainty would move it to the second priority.

12. Hook:
This item has been selected.

13. Electric:
Same as first item.
Appendix X – Prototypes

For making a setup to test the prototypes few parts have to be purchased and other parts can be 3D printed with PLA material or a transparent material if it is needed. Supporting parts that have to be purchased are a wood workshop plastic cyclone, bearings, springs, bolts and nuts, square profile steel and buckles for fixture.

Figure 0.1 wood workshop's plastic cyclone [https://toolsdirectsales.com]

Figure 0.2 springs [www.biltema.se]

Figure 0.3 Bearings [www.biltema.se]
Due-Storage Prototype:
Air-lock prototype:
Hook prototype:
As a mechanical engineer I am deeply interested in Product Development, Design and project-based engineering. Since my truly passion is to influence my surrounding in a positive way, I have a target during upcoming years to become a productive leader in mentioned fields.