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DEVELOPMENT OF OPTICAL SORTING MACHINE

Usama REHMAN

MASTER'S THESIS

SUPERVISOR

Prof. Dr. İsmail BÖĞREKCİ

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ACCEPTANCE AND APPROVAL

The thesis titled "DEVELOPMENT OF OPTICAL SORTING MACHINE", prepared by Usama REHMAN, a student of Department of Mechanical Engineering Program at T.C. Aydın Adnan Menderes University, Graduate School Of Natural And Applied Science, was accepted as a Master's Thesis by the jury below.

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	Title, Name Surname	Institution	Signature
Member:	Prof. Dr. İsmail BÖĞREKCİ	Aydın Adnan Menderes University	
Member:	Prof. Dr. Pınar DEMİRCİOĞLU	Aydın Adnan Menderes University	
Member:	Assoc. Dr. Arzum IŞITAN	Pamukkale University	

APPROVAL:

This thesis was approved by the jury above in accordance with the relevant articles of the Aydın Adnan Menderes University Graduate Education and Examination Regulations and was approved on the ……………. by from the Board of Directors of the Graduate School of Science in the ……………… numbered decision.

Prof. Dr. Gönül AYDIN

Institute Director

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Last but not least, I would like to give all my special thanks to my beloved parents. Without their support, I wouldn't be who I am and where I am right now.

Usama REHMAN

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LIST OF ABBREVIATIONS

CAD : Computer Aided Design

CFD : Computational Fluid Dynamics

HDPE : High Density Polyethylene

LASER : Light Amplification by the Stimulated Emission of Radiation

LED : Light Emitting Diode

MSW : Municipal Solid Waste

MRF : Material Recovery Facility

PET : Polyethylene Terephthalate

PP : Polypropylene

PS : Polystyrene

PVC : Polyvinyl Chloride

WEEE : Waste from Electrical and Electronic Equipment

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ÖZET

OPTİK AYIKLAMA MAKİNESİNİN GELİŞTİRİLMESİ

Rehman U, Aydın Adnan Menderes Üniversitesi, Fen Bilimleri Enstitüsü, Makine Mühendisliği, Yüksek Lisans Tezi, Aydın, 2022.

90'lı yılların sonundan itibaren optik ve fotonik teknolojisinde ve uygulamalarında bir yükseltme gözlemlenmektedir. Optik ayıklama, optik ve fotoniğin bir uygulamasıdır. Gıda, Madencilik ve Geri Dönüşüm endüstrisindeki gelişmelerle birlikte bu tür kompleks makinelere olan talep de arttı. Birçok büyük endüstri, nesnelerin manuel olarak ayıklamasından bu tür mekanizmalardan yardım almaya geçti.

Bu çalışmada, optik veya otomatik ayıklama makineler ve işleyişi üzerinde durulmuştur. Bir ayıklama makinesinin farklı bileşenleri, farklı endüstriler için açıklanmıştır. Ayrıntılı çalışma için odaklanılan endüstri, diğer endüstrilerle daha fazla benzerlik gösterdiği için Gıda endüstrisi olacaktır.

Bu çalışmanın ilerleyen bölümlerinde, Solidworks yazılımında tasarlanmış bir optik ayıklama makinenin özelleştirilmiş modeli de sunulmuştur. Bu CAD modeli, bu tür makinelerin pazardaki etkinliğini ve kullanılabilirliğini artırabilecek şekilde tasarlanmıştır. Tüm bileşenler ayrıntılı olarak inşa edilmiş ve açıklanmıştır.

Anahtar Kelimeler: CAD, Fotonik, Optik, Otomatik, Solidworks

ABSTRACT

DEVELOPMENT OF OPTICAL SORTING MACHINE

Rehman U, Aydın Adnan Menderes University, Graduate School of Natural and Applied Sciences, Mechanical Engineering, Master Thesis, Aydın, 2022

Since the late 90's, a boom in optics and photonics technology and its applications is observed. The optical sorter is an application of optics and photonics. Along with the development in Food, Mining and Waste/Recycle industry, the demand for such complex machines is also increased. Many big industries shifted from manual sorting of objects to take help from such mechanisms.

In this study, the focus is put onto the optical or automated sorters and their working. The different components of a sorter are explained for different industries. The focused industry for the detailed working is Food industry because it shows more resemblance with other industries.

Later in this study, a conceptualized model of an optical sorter is also presented which is designed in Solidworks software. This CAD model is designed in such a way that it can increase the efficiency and availability of such machines in the market. All the components are constructed and explained with details.

Key Words: Automated, CAD, Optics, Photonics, Solidworks.

1. INTRODUCTION

1.1. Thesis Structure

This thesis is divided into 6 Chapters. Chapter 1 ‘Introduction’ expresses the aims of the study and gives a background to the research together with a summary of the research methodology.

Chapter 2 ‘Literature Review’ reviews the literature on the subject of automated optical sorters, looking at the feeding and presentation, identification and classification, and separation components. The applications of sensor-based sorters (additionally alluded to as optical sorters in this thesis) and challenges to improve the separation efficiency are also discussed. Optical sorters are utilized in numerous areas. Focused industries are Food, Waste/Recycle and Mining.

Chapter 3 essentially clarifies the entire working of the optical sorter and characterizes the best combination for an optimal circumstance. The focused industry in this chapter is the food industry. Myriad kinds of ways used for feeding, presentation, identification, and separation are examined.

Chapter 4 ‘Conceptual Design’ focuses on designing a Computer Aided Design (CAD) conceptual model of an optical sorter based on the information obtained from Chapter 2 and Chapter 3. It is to be mentioned here that the electronics, optics, and photonics part is not explained and designed in this thesis.

Chapter 5 ‘Results and Discussions’ discusses and present the results of the chapter 4. The machine parts are assembled and discussed here.

Chapter 6 ‘Conclusions’ is based on opinion. It is the last chapter and all the work done and research conclusion is presented in this chapter.

1.2. Aim of Study

The aims of the study are supposed to be:

- Study the aspects of the optical sorters and how they are used in different industries.

• Explaining the working of the optical sorters. The role of such machines in food, mining, and waste/recycle industry.

• Suggest an optimal model of optical sorter for the food industry. Recommending different changings and diverse alterations which can be productive for the food industry.

• Depending on the suggestions and recommendation a CAD model prototype is to develop utilizing SOLIDWORKS program.

1.3. Background

Generally, the subject of optics has focused on the nature of visible light. Uses of optical standards might be followed back into artifact, with references to the utilization of lenses (or water filled vessels) for magnification and burning glasses and the cleaning of metal to get a reflective surface. According to a modern viewpoint, these are applications of geometrical optics, in spite of the fact that it was not until the contemplations of the Ancient Greeks that any sort of theoretical understandings of these phenomena was attempted. Figure 1.1 shows an ancient concept of burning material with glass.

Figure 1.1. Concept of burning wood with glass (Courtesy: The Royal Society)

Euclid’s Optics (circa 300 BC) is believed to be one of the earliest surviving theoretical texts regarding the topic of Optics. In this text, Euclid gave geometrical concept of light in which he explained light as a cone of beam through a vertex. However, the idea that light travels in straight lines remained an unexplained assumption. Hero of Alexandria, in his work Catoptrica, in around 40 AD explained geometrically that the path of a beam reflected from a plane to a perception point is the shortest possible path the light beam could have taken, dependent upon the constraint that the beam must contact the plane. The work of Hero can be described as the 'the principle of least distance' which looks similar to modern explanation. However, he couldn't appreciate that the light travels at different speeds in different media. In modern times, it is mostly described in terms of optical path length, which has dimensions of distance but remains directly proportional to time taken. Figure 1.2 shows ancient lens used for applications of optics.

Figure 1.2. Ancient lens (Courtesy: Ancient Wisdom)

The ending Greek civilisation gave a head start to the Islamic world in terms of philosophical enquiry. The world saw advancement in mathematics such as algebra, number bases and the development of algorithmic methods, it all attributed to Islamic thinkers. To name a few, Ibn Sahl (c. 940-1000), one of the early contributors to the field of optics, in his work 'On Burning Mirrors and Lenses' talks about the focusing of lights by curved mirrors and lenses. He is also the only one who gave detailed explanation of the concept, today in modern times, known as 'Snell's Law of refraction'. Figure 1.2 shows the depiction of snell's law of refraction. Alhazen (c. 965-c. 1040) in his book Kitab al-Manazir, translate to Book of Optics, talks about the experiments he performed on rectilinear propagation of light, reflection, and refraction. His major work in field of optics is to be detailed description of the working of human eye.

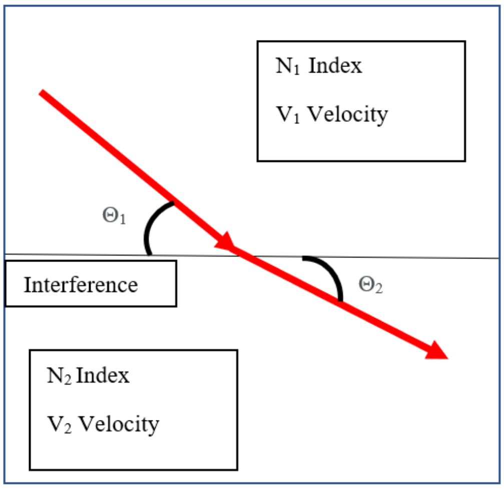

Figure 1.3. Depiction of Snell's Law

With the passage of time many advancements took place in the field of optics and new studies were conducted on Wave Optics, Electromagnetism, Quantum Mechanics etc.

1.3.1. Lenses and Mirrors

The main practical application of optics depends upon lenses and mirrors. All the theoretical understandings of the applications are based on geometrical optics. Telescopes and microscopes use a lot of lenses and mirrors to correct the deficiencies in vision. The concept of refraction and reflection also depends upon lenses and mirrors. The area of astronomy was also mainly introduced by refracting and reflecting telescopes. Nowadays microscopes have opened the realm of biological sciences.

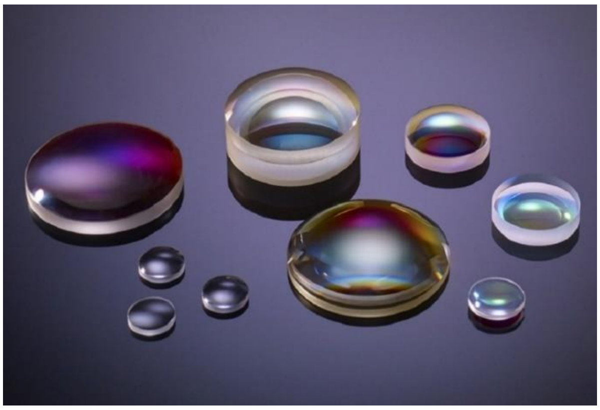

Figure 1.4. Lenses and Mirrors (Courtesy: Perkins precision)

1.3.2. Spectroscopy

Spectroscopy is basically study of absorption and emission of light and other radiation by matter. It involves breaking the light into its parts or constituent wavelengths same as a prism splits light. Many different techniques are available to perform this study which includes components like lenses, diffraction gratings, prisms, and cavities. Figure 1.5 shows the prism splitting the light.

Chemical analyses are also performed using the spectroscopy techniques. Different chemical substances can be identified by their absorption or emission spectra. Light is shone through the substances and different absorption and emission graphs are obtained, peaks obtained are unique for each chemical substance which results in its chemical signature and can be identified.

Somehow, astronomy also utilizes the modern spectroscopy concepts. Spectroscopic analyses of light are very useful in determining the temperature and other information of stars and chemical data of extra-terrestrial matter.

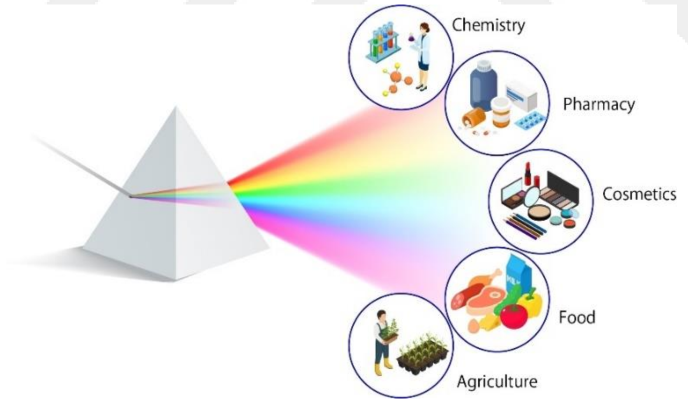

Figure 1.5. Prism splitting light (Courtesy: Yokogawa)

1.3.3. Photonics

Photonics can be termed as the benefits and applications of advance optics. It is the backbone of the instruments and machines like optical sorters and inspection devices. Photon is a quantum unit of light, and a field of science which involve study related to photons is Photonics. It is the science of using light to create or generate light energy through photon, extract and transmit information. This field has numerous benefits to the technology and has varied applications in electronic goods, internet, medical instruments, infrared cameras, remote sensing, laser cutting machines, inspection devices etc.

Optical detectors and photovoltaic cells are also linked to the Photonics. Such detectors and cells are used in almost all the industries. The basic mechanism is that of electron hole pair creation. Depending on the design it can either make semiconductor conductive or voltage that can be used to create power.

LEDs and LASERs have a great role to play in modern optical advancements. Different wavelength LED and lasers are used to excite the substances to obtain the required spectrum. The basic idea behind is the emission of the photons via electrons dropping down into lower energy states. The major difference is that the emission in LEDs is spontaneous whereas in laser it is stimulated emission.

2. LITERATURE REVIEW

At the beginning, books, articles, journals, scientific standards, library, and internet sources have been examined and reviewed. Previous studies including former researches on similar topics have been analyzed and considered. The literature review in this paper is later on categorized into three main industries which are Food, Waste/Recycling and Mining.

2.1. Configurations

The optical sorters or sensor-based sorting systems generally consists of four main components or stages (Arvidson, 2002; Salter and Wyatt, 1991; King, 1978) which are as follows:

i. Feeding
ii. Presentation
iii. Identification
iv. Separation

The Figure 2.1 of a flowchart shows the common order of the above-mentioned components of an optical sorter.

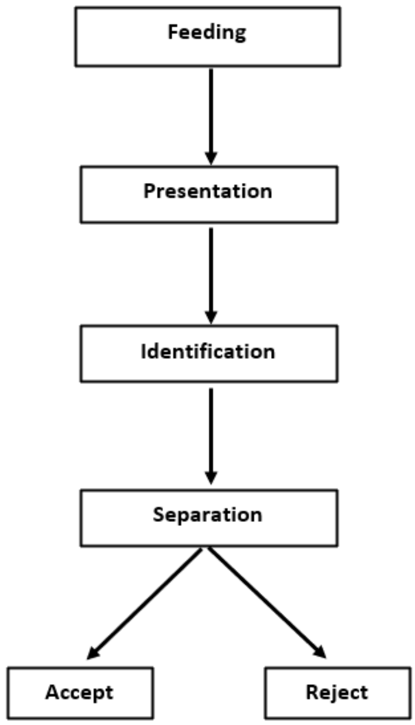

Figure 2.1. Flowchart of components of an optical sorter

2.1.1. Feeding and Presentation

Both feeding and presentation systems of a sensor-based sorter are very essential for the smooth operation and achieving high efficiency. The product to be sort start its journey from the feeding system and then travels into the chute before entering the presentation system. The design of the chute plays a vital role as it helps maintaining the acceleration and stabilization of the product onto the conveyor. The tumbling that may occur should be minimize or eliminated because the product should not bounce as it come off the chute (Stuart-Dick and Royal, 1992).

It was considered by Schapper (1977) that the feed material needs to present individually in order to get appropriate identification and deflection. The ratio of the feed material from large size to smallest size should be 3:1 or 2:1 (Arvidson, 2002) and this ratio is later linked to correct valve and pressure selection in order to achieve efficient separation.

The presentation system is designed according to the need of the user and the material to be sorted. The main concept behind the design of presentation system is to help the feed material to reach the identification area. There are different types of presentation systems such as free fall method which includes a chute, dropping from a conveyor belt, use of rotating discs etc. Some other deigns consist of very low throughput which results in high efficiency, it is suitable for material like small seeds, the material in such systems goes off the chute in separate or channeled conveyor belts which transport the feed material towards the identification (Blasco et al, 2009).

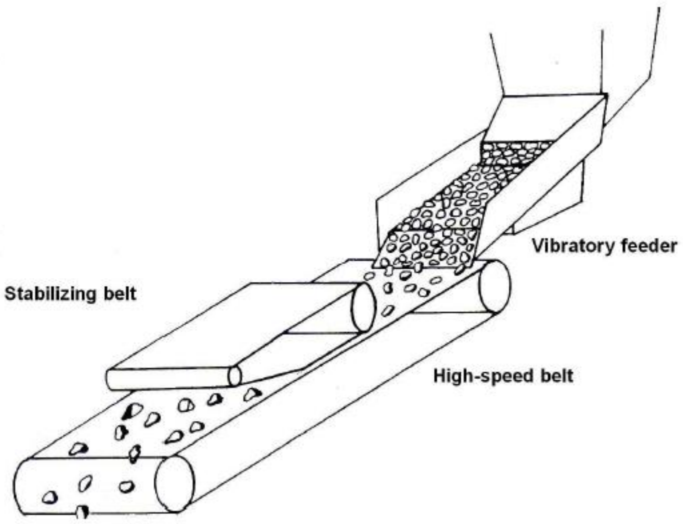

Figure 2.2. Feeding and Presentation (King, 1978)

In chute or free fall systems, the feed material falls from the conveyor or vibratory feeder, which scatter or spreads the material in such a way that it can be easily identified in identification zone, under the influence of the force of gravity. The benefit of such system is that the feed material while falling can be inspected triaxially or in other words from both front and back side. Coupling of optical sensors can be used in this arrangement. It is very beneficial for mining and food industry where the product to be sorted has to be inspected triaxially and also it takes less space to set up. Size fraction of the feeding material also plays a vital role in designing the system. For the free-fall 40 to 250mm size fraction is considered and 20 to 40mm for the conveyor belt (De Jong, T.P.R. and Harbeck, H., 2005). Figure 2.3 shows the simple free fall chute sorting system.

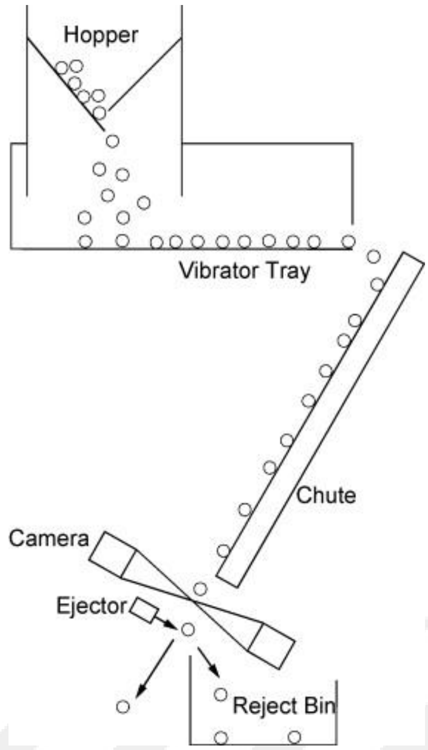

Figure 2.3. Basic free fall chute system

Apart from the free-fall chute design, the conveyor belt configuration allows the product to travel onto a conveyor belt. The product in most cases travel up to 2 to 5 meters. It is done to basically achieve the stability of the products and to minimize the overlapping of the products before it reaches the identification system. In such configurations of the sorter the stability of the product onto the conveyor belt is very challenging. Some sorter designs consisted of soft stabilization belt above the main conveyor belt to compress the products travelling so that overlapping can be stopped, and the product can be stabilized. Such designs had a major drawback, and is discarded in current sorters, as the compression formed mould and fungus around the product (King, 1978).

2.1.2. Identification

This system consists of two main parts, sensor array and illumination system. Sensors such as conductivity sensors, monochromatic, color or infrared cameras etc. are used according to the requirements and for the illumination part lighting sources such as fluorescent and halogen lamps, Light-emitting diodes (LED), lasers etc. are used. The placement of the sensors depends upon the arrangement and classification of the sorter. In the conveyor belt design, sensors could be placed underneath or on top of the belt. For the free fall chute design, the sensors are placed such that they able to see the trajectory of flight of the product.

The product to be sorted must have properties such as size, shape, color, brightness etc. that can be used for identification (Skoog et al, 1996). The improvement of the sorter depends upon the data obtained from the used sensors. Efficiency increased with the quality data, that is why newer sorters use multiple sensor systems (Kattentidt et al, 2003). There should be a good balance between the processing speed and the accuracy of the data obtained, it is essential for the efficiency of the identification process.

2.1.3. Separation

As soon as the product is identified, the next big step in the sorting process is to separate it. The reason behind the increased use of sorting system is the fast, accurate and efficient separation systems (Manouchehri, 2003). Different mechanism is available for the separation system to run such as water jet valves, suction valves, mechanical flaps, air valves. For the water-soluble products water jets are avoided.

The most widely used design is the compressed air jets (Arvidson, 2002). For heavier and coarser products, mechanical flaps are recommended. Suction valves are used to suck away the defected product for the stream of products (Pascoe, R.D., 2000).

In the compressed air valve system, the identified products travel in a trajectory and pass through the separation system to accept or reject according to their properties. The valve nozzles are placed with various configuration depending upon the design of the sorter. In the conveyor belt configuration, the nozzles are placed underneath the end of the belt or overlooking the belt. In free-fall chute configuration, the nozzles are placed rear or at front of the trajectory (Bayram and Oner, 2006). Figure 2.4 shows the air jets rejecting the product.

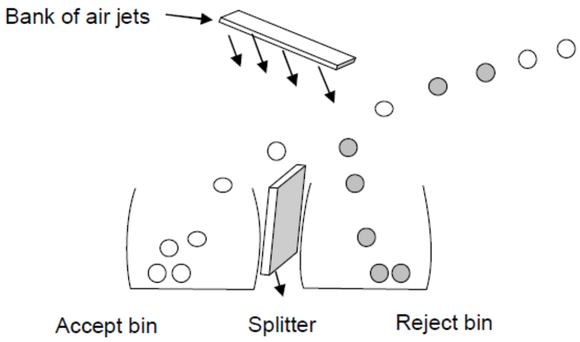

Figure 2.4. Diagram indicating air jets deflecting material

2.2. Utilization of Optical Sorters

Most of the surveys and review of the literature shows that the Mining, Food and Waste/Recycling are the industries where the use of optical or automated sorters are in large amounts. The potential benefits of such machines in Mining, Food and Waste/Recycle are discussed.

2.2.1. Mining

Sorting process is the part of human life since the stone age. Things were hand sorted by the man and slowly it shifted to automated sorting towards modern techniques. Hand sorting process has been explained by historians in numerous places. Even the high graded ores were treated and sorted using the different sorting practices. In the late 19th century in Germany up to 16 classes of products such as chalcopyrite were hand sorted (Taggart, 1945).

In the recent times, fully optical sorting machines have been developed which revolutionize the industries. It is said that in mining sector the development of sorting machines should be linked with the development of the laboratory analytical techniques along with the food processing and sorting methods (Salter and Wyatt, 1991). The sorting machines in food and mineral industry follow the same development path but for different reasons. The food industry realize earlier that such machines are the only viable and efficient alternative to expensive labor-intensive process. The mineral industry didn't take the sorting machines much seriously and got behind the food industry in terms of efficiency and development (Salter and Wyatt, 1991).

For the pre-concentration sulfide and uranium ores, sorters were installed and got good results (Gordon and Heuer, 2000). Salter and Wyatt (1991) explained in their study that automated sorters are capable of achieving the final product form out of diamonds and gemstones. Same process was also used to achieve the required results out of coal (De Jong et al, 2005). Later on, marble sorting also got shifted to optical sorters (Varela et al, 2006). It was thought that, aside from diamonds, sorting machines were used only for gold and uranium ores. The Table 2.1 shows the usage of sorters in many types of products since 1946 (Salter and Wyatt, 1991).

Table 2.1. Usage of sorters in many types of products (Salter and Wyatt, 1991)

Identification Technique	Minerals Sorted
Photometric	Gold, coal, limestone, metal sulphides etc.
Radiometric	Uranium and gold
Conductivity/Magnetism	Copper sulphides, scrap metals
UV fluorescence	Limestone, shale, scheelite
Microwave attenuation	Kimberlite
Gamma scatter	Base metal sulphides
X-ray luminescence	Diamonds

Some other benefits are as follows:

- The final and ultimate benefit from the sorting machines to any of the industry without any doubt is profit (Salter and Wyatt, 1991).

- Environmental benefits can be observed by the use sorting machines because such machines help in sorting coarser product, and it reduces the rate of leaching unwanted metals. Also, it minimizes the use of old ways of sorting ore from gangue (Arvidson, 2002).

- By processing the marginal grade products, higher recovery of ore can be obtained (Cutmore and Eberhardt, 2002).

- Optical sorters also help in reducing the general cost of the process, as it can sort in much coarser size and fractions (Manouchehri, 2006).

• Increased efficiency and production rate of minerals such as gold, gemstones etc. Also, it reduces the chances of theft by the workers (Arvidson, 1998).

Figure 2.5. Sorted product (left) Defected product (right)

2.2.2. Waste/Recycling

Waste is a big problem for both urban and rural communities. Organic material, recyclable material, electric and electronic waste (WEEE) along with the other waste is known as Municipal Solid Waste (MSW) or in other words Domestic waste. Generally, in early times wastes were directly disposed into the landfills (E. Gidarakos et al. 2006). Now, the waste can be recycled and reused after sorting or some other processes and is termed as Recyclable domestic waste. Typically, recyclable domestic waste can be extracted from MSW in a material recovery facility (MRF) (Bonello et al. 2017). In the MRF the unsorted waste, also known as commingled waste, contains materials that are categorized in three main categories, which are required material, non-required material and rejected material. The target materials are those which the facility can sort out easily and later on transfer it into furthermore different categories such as polyethylene terephthalate (PET), high density polyethylene (HDPE) etc. Manual sorting techniques are used in these facilities with humans hand sorting the materials on both side of the conveyor belt that transfer the material into different categories. In some facilities ferrous and non-ferrous materials are sorted out using semi-automatic techniques in which electromagnets are used. Figure below shows how plastic is hand sorted.

Figure 2.6. Hand sorted plastic (Courtesy: Ecoballa)

One of the main materials which the facilities like MRF tackle is plastics. It is part of everyday life and use in almost all the materials in variety of industries. The lifetime of plastic is very short and that is the reason that it accumulates in large amounts as waste. All over the world governments are trying hard to tackle with this problem. For the MSW it is a challenge to deal with such huge amount of waste all over the world (Zhuang et al. 2008). Generally, sorting process is performed on five major resins of plastics which are polyethylene terephthalate (PET), high density polyethylene (HDPE), polyvinyl chloride (PVC), polypropylene (PP) and polystyrene (PS). Sorting techniques of such resins usually based on chemical properties, optical, electrical, or physical property differences (Scheirs, 1998). For many years density-based separation methods such as float-sink tanks and hydro-cyclone have been used (Enick, 1996). Optical and spectroscopic based sorting is efficient. It can be used to separate plastic on the basis of color and type (Safavi et al. 2010).

Some common problems of the facilities like MRF are that they rely mostly on visual inspection of the waste passing on the conveyor. Most of the time there is not enough time for the manual sorter to take out the reject material. Also, the conveyor belt has to move at a slow speed which results in slow rate and low production. Health issues also arises in the operators and the manual sorters as the long shift of almost 8-12 hours causes fatigue and skin problems. Considering the problems, it is very natural for the industry owners to come up with some idea to minimize the defects and increase the production. For such reason an automated optical sorter is the best option, and it is cost effective compared to the manual sorting (M D. Jones, 1992).

In waste sorting machines different configuration are used. Both free fall chute and conveyor belt method are available along with arrangements of different types of sensors to identify the defects or the unwanted material (Bonello et al, 2017). In the rejection part mostly air jets are used to throw away the unwanted material. In the conveyor belt configuration, large components are removed from the waste using large, perforated sieves and inclined or horizontal shaking screens (McDougall, White, 2001).

Some of the applications of automated optical sorters in the waste and recycling industry, found in literature, are as follows:

- Sorting of metals and non-metals using conductivity-based sensors or electromagnets.
- X-ray sensors used to sort stainless steel from waste, scrap metal and dead car parts (Dalmijn and De Jong, 2004; Mesina et al, 2007).
- Separation of construction waste material where metal is removed by X-ray sorting machines (Zieger, 2005).
- Sorting of glass by their color properties (Zeieger, 2005).
- NIR and X-ray sensors used to sort plastic resins such as PVC, PET etc. (Killmann and Pretz, 2006; Pascoe, 2000).

Figure 2.7. Input material (Left), Accepted (Middle), Rejected (Right) (Courtesy: Ptonline)

2.2.3. Food

Food plays a vital role in everyday lives and food industry is backbone of many economies. With the passage of time, human perception about food quality has changed a lot. And in recent times, to fulfill those desires of maintaining the quality, optical sorters have been developed and introduced to the food industry. Along with the demand of quality, huge post-harvest losses and careless handling and processing of the food items, is responsible for the accurate, fast, and quality determining sorters (Narendra VG, Hareesh KS, 2010). Major areas of applications of optical sorters in food industry consist of evaluation of grains, vegetables, fruits, dry fruits, and processed foods. Modern sorters are also capable of determining the insect infestation and toxins in grains, fruits, and vegetables.

In general, sorting of edible items starts from the farmer level. They not only sort the items but also try their best to grade it so that more profits can be gain. Farmers related to agricultural and food products use traditional techniques such as visual inspection and handpicking to sort and grade the items. Such techniques are time consuming, tedious, slow, and non-consistent (Mahendran R. 2012). Sorting of products using human eye and hand are still practiced in rural areas where the cost of labour is very low. Good and bad food can easily be differentiated by its smell and color. However, the urban areas where the cost of labour increases, have been introduced with automated techniques (S.C. Bee and M.J. Honeywood, 2002). Also, human senses are not that strong to identify and sort out the defects, human senses can easily be fooled (Francis FJ. 1980). So, it became necessary to adopt the faster and better systems which can save time and provide more accuracy in sorting and grading of food products. Figure 2.8 shows the traditional hand sorting of fruits.

Figure 2.8. Traditional hand sorting (Courtesy: 123RF)

Food safety is a big concern in both developed and under-developed countries. Authorities, distributors, and factory owners have several reasons for inspecting the food items for both health of the people and integrity of the firms. Food safety deeply depends upon the identification of perilous bacterial and contagious contaminants. Commercially, the shipments including food items such as dried fruits, rice etc. have to inspect and verify according to the given standards by the authorities. Such measures are taken to avoid the cheaper variety of items that does not pass the quality standards. In only North America it is estimated that more than 30 percent of fruits and vegetables grown are discarded before they even reach the relevant markets or grocery stores because of defects and imperfections. Imperfect items remain unsold and ultimately ends in landfill sites. It should be in everyone's interest to reduce this waste in this era of skyrocketing food costs and global shortages (Matrox Imaging Case study). Also, there are contaminants that are capable of altering the physical and chemical characteristics of an edible items, such contaminants have to be identify before reaching to the markets (S.C. Bee and M.J. Honeywood, 2002).

The persistent problems that occur in sorting for food industry are dependent upon color, shape, and size of the items (Aleixos et al. 2002). One of the main parameters that is identified by the optical sorters is size. Size is identified using optical and machine vision techniques by measuring projected area (Tao Y et al. 1990), perimeter (Sarkar N, Wolfe RR, 1985), or diameter (Brodie JR et al. 1994). For the determination of surface area of the products, size measurement is really important. The measuring of the size leads to another important quality feature and that is shape. Shape can be considered as the important visual factor regarding quality parameters. Myriad kinds of fruits and vegetables can be identified by just knowing their shape. Shape is considered as one of the features that can be easily identify by human but create difficulties in comprehending by machines. Agricultural products grow naturally in their habitat, and environment around them can cause irregularities in shape which influences the identification process (Mahendran R. 2012). Another factor effecting the quality that has been widely discussed and studied is the color of the product (Singh N et al. 1993, Hahn F, 2002). The reflected light that receives from the surface of the product is detected in different wavelengths. These wavelengths are then used to determine the color of the product. Each biological component varies widely as a function of wavelength, these spectral variations become a unique key point in identifying and distinguishing factor for the optical and vision systems (Mahendran R. 2012). In optical sorting systems, color identification process is also used in grading, as it tells freshness, ripeness, and defects of the product (S. Jha et al. 2016).

In food sorting machines different configurations of the system can be used. For the feeding system vibratory hoppers or flat conveyors are used. For the presentation part mostly free fall chute method is used. As it can be used for various sizes and different kinds of food items. Conveyor belt systems are also viable in many areas. Both systems help in arranging the product into a uniform layer. It helps in presenting the products to the identification or optical system with constant velocity (S.C. Bee and M.J. Honeywood, 2002). The setting of the belts and vibratory conveyor can be altered to obtain the adequate results which is why many different kinds of products can be sort using the same machine by changing some simple parameters. In the identification or inspection area of the process, reflectivity of the food product is sensed by different types of sensors. The optical components are arranged in a box, called optical box, to avoid any contact with the fast flow or free fall of the product stream. The product which is under the sorting process should not come in direct contact with the optical box. Multiple boxes may exist in some machines as to view or sense the product from more than one direction (Anon, 1987). Using of multiple optical boxes or in other words sensors plays an important role. In early days machines used to inspect from only one side, which means they were only able to detect the contaminants facing the sensors (S.C. Bee and M.J. Honeywood, 2002).

After the identification process, ejection takes place. The ejection unit has to be precisely arranged as it depends on factors such as the size of the product. The system should be capable of removing the defected products from the stream. The ejection systems in food industry generally takes place when the product is in free fall motion, the defected products are deflected away, and good ones are allowed to continue their flow. The deflection process is usually done by small and fast air guns which shoots compressed air through nozzles and aim directly at the defected products. For the large food products such as potatoes, corn, apple etc. mechanical flaps or piston powered mechanisms are used to deflect due to the large size of the products.

Figure 2.9. Accepted Apple (left) Rejected Apple (right) (Courtesy: Tomra)

3. MATERIAL AND METHOD

In this chapter a thorough study has performed on the components of an optical sorter so that a conceptualized design can be created. The beginning of any design is based on generating some conceptual ideas. And for coming up with a final concept, detail research has to be performed so that the desired results can be achieved while designing the final idea on any CAD software.

Data is evaluated through different sources to come up with basic understanding of the system. Information gathered through literature review is taken under consideration for conceptualizing the feed, presentation, identification, and rejection system. The conceptual design is to be based on optical sorting system for the food industry. The specific design information is also formulated by visiting and gathering the information from local dried fruit plants.

3.1. Feed

The feed system is a common process in almost all the sorting machines. The products to be sorted have to start their journey from the feed system. In that case, feed system must be carefully selected and designed. The stability of the product is very important for the identification part of the machine, for that feeding has to be working in such a way that the product must be stabilize before reaching the identification zone. The selection of feed system depends upon many factors such as cost, type of product, mobility, efficiency, maintenance etc. The basic functions that a feeding system must provide in a sorting machine are as follows:

i. It should ensure that the required number of objects per unit time should pass through the identification area.

ii. The speed of the product travelling must be controlled. In other words, constant velocity must be acquired. As it is very important that the travelling of the object from identification point to the ejection point must be constant so that the ejectors can perform their duty accurately and accordingly.

iii. It should be capable of providing controlled alignment or trajectory of the products through the identification and then the ejection points.

Generally, for the food industry, above-mentioned tasks are achieved by the vibratory feeders. To completely achieve the task, vibratory feeder is further employed with few components to work properly. The commonly employed systems are:

- Free-fall chute
- Conveyor belt (flat)
- Conveyor belt (Inclined)
- C-shaped belt
- Rotating rollers
- Grooved belt

For the food industry, the optimum systems used are Free-fall chute and Flat conveyor belt system. The other mentioned systems fall into the sub-category of conveyor belt system.

3.1.1. Vibratory Feed – Conveyor Belt

In this system, belt is used as a conveying medium. It is one of many types of conveyor systems. It mostly consists of two or more pulleys with a loop belt that rotates about it. The pulleys, one or both, are electrically powered which helps move the belt carrying the product forward. The selection of the belt material or the conveyor itself must be done carefully depending upon the industry in which it should be used. For food industries, food graded, or agricultural suited material must be used for the belt. Figure 3.1 shows a typical belt conveyer. The belt conveyors are usually of higher cost in the long run. There are some food applications where the use of belt conveyor becomes the best option.

Figure 3.1. Typical food grade belt conveyor (Courtesy: Dynamicconveyor)

The applications included are:

- Elevation is required in some of the agricultural product plants. Belt conveyors are considered to be ideal for achieving the elevation.

- It can use to store and handle large volumes of material on it.

- Packaged product can easily be conveyed using the belt conveyor. For packaged product applications belt conveyor is considered to be effective.

Traditionally, many food processing companies used belt conveyor to transport the bulk material and packaged product. Low capital cost makes these types of conveyors seems affordable but when ongoing maintenance expenses are taken into account such conveyor becomes an expensive option. High maintenance and sanitation cost makes the total cost of the ownership of a belt rise quickly. The operational roadway of a conveyor belt system can be explained in steps:

i. Vibratory feeder is used to evenly spread the products so that they cannot mix or overlap. The feeder presents the product to the conveyor belt with the speed close to that of the conveyor belt.

ii. The product falls onto the conveyor belt. The conveyor accelerates the particles to the desired speed before letting them pass through the sensors.

iii. The products enter the identification area. The sensors perform the identification process and record the required data and position of the product.

iv. The received data is processed, ejectors are allowed to activate, and the products are separated or sorted accordingly.

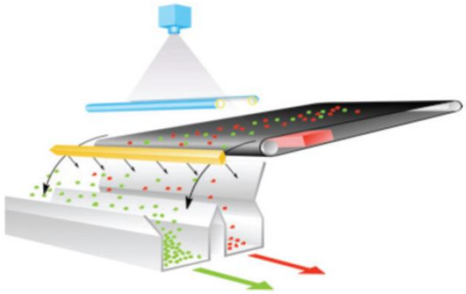

Figure 3.2. Typical Conveyor belt sorting system (Harbeck, Kroog, 2008)

To reliably identify the defects on products the inspection must be done from both sides. In the belt conveyor system, the sensors are able to see from only one side and that is from the top of the stream of the products. Observing the products from both sides can also be done in this system by placing the sensor below the stream of the product as soon as it leaves the belt. The problem with this configuration is that the bottom sensor gets covered by the product too soon. It creates problem for the sensor to detect properly.

3.1.2. Vibratory Feed – Free Fall Chute

Free fall chute system is a compact and easy to use system. It also consists of less moving parts which leads to less maintenance. The overall cost analysis compared to belt system is low. In other words, this system is a combination of vibratory feeder and a slide. Vibratory feeder act as a main component here, it conveys and stabilize the products before letting it fall freely through the chute. This system is much cleaner than the belt as there is no lamination and wearing of the belt problems. Free fall chute system is one of the most common system used in sorting machines. The chutes are made of food-safe material and are used to separate the product from one another. The chutes act as small channel or grooves which helps material to fall in a straight line and at the same time make the speed of the product constant so that the sensors can easily identify them.

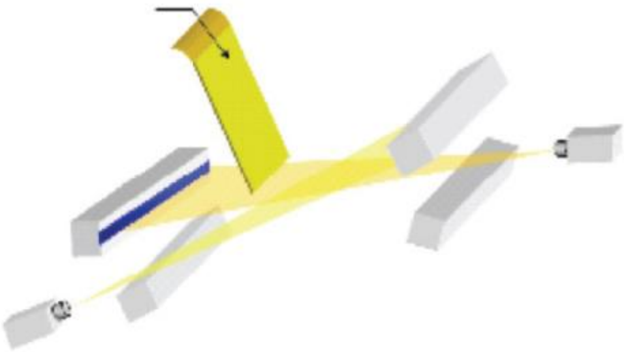

Figure 3.3. Typical Free fall chute system (Harbeck, Kroog, 2008)

Some of the advantages of the free fall chute system are:

- Such systems are compact. Chutes have smaller footprint as they don't require much space.

- Chutes can be customized according to the needs. Same machine can be used to sort different product by applying slight changes to the chute.

- Precision can be gain from chute system. The free fall chute system can sort small items as the channeling helps to provide and hold single file of the products which leads towards the better precision.

- Sensors can easily examine the product from multiple viewing points.

However, there are disadvantages of the free fall chute method. One of them is the relatively low throughput of product as compared to the conveyor belt system. Throughput can be increase by adding more channels to a machine.

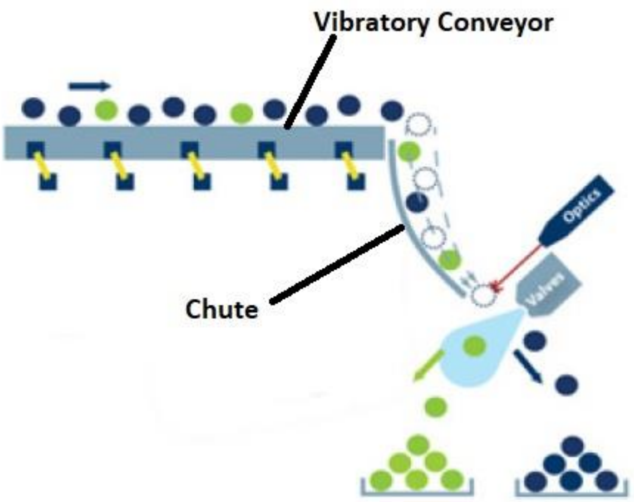

Figure 3.4. Vibratory Conveyor-Free fall chute system (Courtesy: Key Technology)

The operational roadmap of the working of free fall chute system can be explained in steps as below:

i. The material is fed to the vibratory conveyor. It helps in controlling the flow and separates into single particles.

ii. From vibratory feeder, materials go on to the chute and falls by gravity and distribute evenly to increase distance between each other.

iii. In identification area, sensors inspect them and required data is send to the control unit.

iv. After analyzing, ejectors are turned on to throw away the rejected material.

3.1.3. Selection Matrix

The selection table is made by evaluating the above mentioned two separate designs. The table below act as a screening matrix to help select which design would be better for the food industry. The selected design would be considered for the conceptual designing. A point is awarded for each criteria, to both the systems, if the condition is in their favor.

Table 3.1. Selection matrix for the design

	SYSTEM	
SELECTION CRITERIA	**Conveyor Belt**	**Free fall Chute**
Size	0	1
Ease of use/setup	1	1
Safety	1	1
Durability	0	1
Sensor-Multiview	0	1
Sorted container	1	1
Large material handling	1	0
High throughput	1	0
Maintenance	0	1
Portability	0	1
TOTAL	**5**	**8**

As it can be seen from the above table that free fall chute system is the clear winner. For the conceptual design building, free fall chute system is selected.

3.2. Ejection

Ejection system is basically used to deflect the unwanted objects from the stream of the products. In the identification process, unwanted materials or defects are pointed out and signals are sent to turn on or off the ejectors with specified positions to deflect the material in the air. Many developments have taken place in the field of ejection. The selection of ejection system solely depends upon the type of product, size, shape, and overall design of the machine. Following is the list of ejection systems that have been used in the industry.

- Water jets.
- Suction nozzles.
- Mechanical flaps.
- Pneumatic valves.

Water jets is relatively old for ejection system. Such types of ejectors are not useful for the food industry. Along with the complexity it also leads towards the wasting of the water.

Also, such systems cannot be used for the water-soluble products. Water jets were mostly used in the mining industry.

On the other hand, suction nozzle system is proved to be very costly. The pressure drop create problems for the product to get sucked in completely. Also, such system destroys the product in food industry. It is viable in industries where the size of the product is relatively small.

Mechanical flaps are still in use in many industries. It consists of a lever shaped flap that mostly moves with the help of piston. Mechanical flap system is relatively slow system as compared to pneumatic valve system. It is mostly used for the large products such as potatoes, tomatoes, corn etc. Figure below shows mechanical flap used to sort the potatoes.

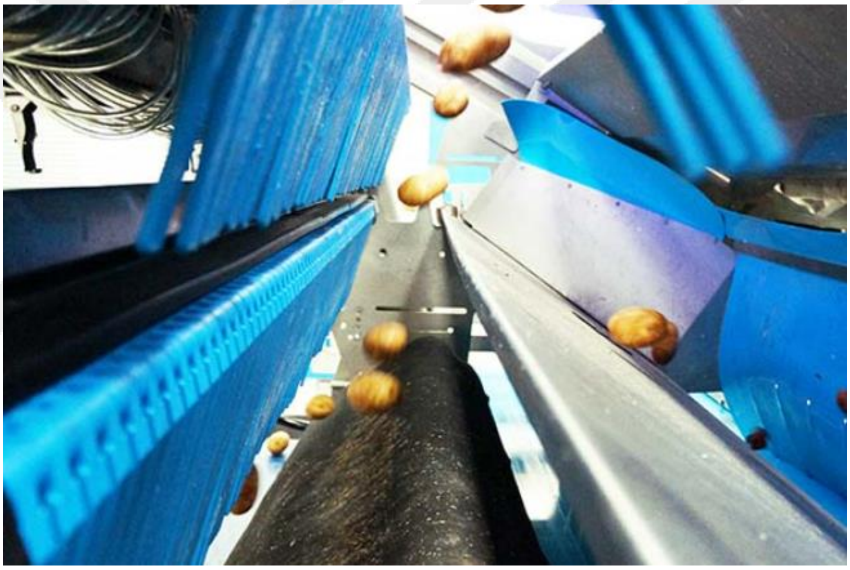

Figure 3.5. Mechanical Flaps (Courtesy: Tomra)

Pneumatic valves system is actually known as compressed air ejector. It became the industry standard decades ago. It remains very effective in almost all the industries. The response time of such valves are exceptional, that is the reason that almost all industries prefer such system. Pneumatic valve system has rapid action, reliability, and long lifetime. The pressure of the compressed air can be selected depending upon the size of the object. Such systems do not take much space, so multi smart ejection systems can be designed. In many industries two way or three-way ejection system are used which consist of pneumatic valves in layers. The best option from the above-mentioned systems is the pneumatic valve or compressed air ejector system. For the conceptual design pneumatic valve system is selected.

4. CONCEPTUAL DESIGN

The information collected from the literature review and methodology section helped in creating the conceptual design. The machine is drawn in parts and then later on assembled. The specific design specification is formed based on research done through literature and discussion done with the plant owners. A thorough material selection exercise is also carried out to select the most suitable and appropriate material, as the machine is designed for the food industry, food graded material is specifically used. Solidworks program is used for all the CAD designs.

4.1. Vibratory Feeder

For the vibratory feeder design, two basic ideas are taken under consideration which are steel spring and composite leaf spring. Steel spring design is very common and is being used in industry for quite a lot of time. The maintenance and assembling such systems are really a mess. Steel springs are more effective according to the properties. In food industries less thickness steel springs are used which leads to breakage. Also, for different amplitudes steel springs are not recommended.

Figure 4.1. Spring vibratory conveyor (Courtesy: Indiamart)

Composite leaf springs are used in food industries so that thickness is increased easily, and breakage is reduced. They can also withstand different amplitude, which leads to the benefit of using same feeder for different products.

Figure 4.2. Composite fiber glass leaf spring (Courtesy: MW systems)

So, leaf spring design is used for the vibratory feeder. In the industry, material used for the leaf spring is fiberglass EPGC203 and for the rest of the frame AISI304 is used. Figure 4.3 shows the CAD design of the frame of the vibratory feeder.

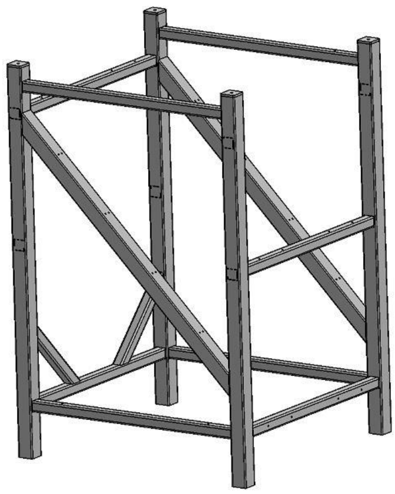

Figure 4.3. Vibratory feeder frame

Figure 4.4 shows the CAD design for the upper part of the vibratory conveyor. Leaf springs are assembled.

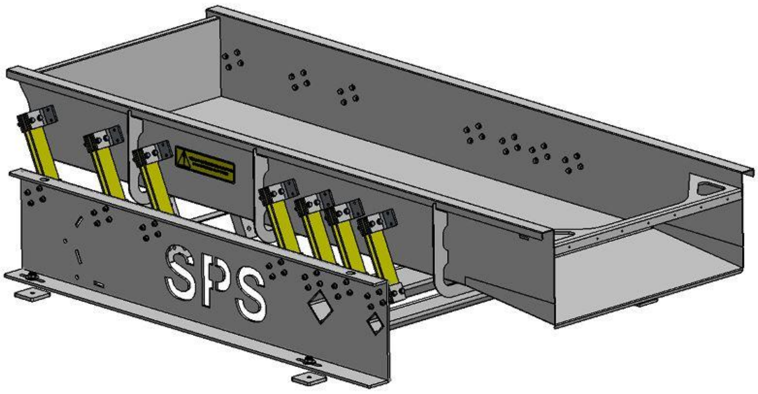

Figure 4.4. Leaf spring assembled vibratory conveyor frame

4.2. Chute

The chute act as a slide for the products to move towards the identification zone. The chute design is done so that it can be fixed to the main body. The material used for the chute is AISI304. Figure 4.5 shows the chute design.

4.3. Identification Box

For identification, optical components are required. The optical components are put inside the optical boxes to protect the optics from outer environment. The material used for the optical box is AISI304 and aluminum. Figure 4.6 shows the CAD design of the optical boxes.

Figure 4.5. Chute design

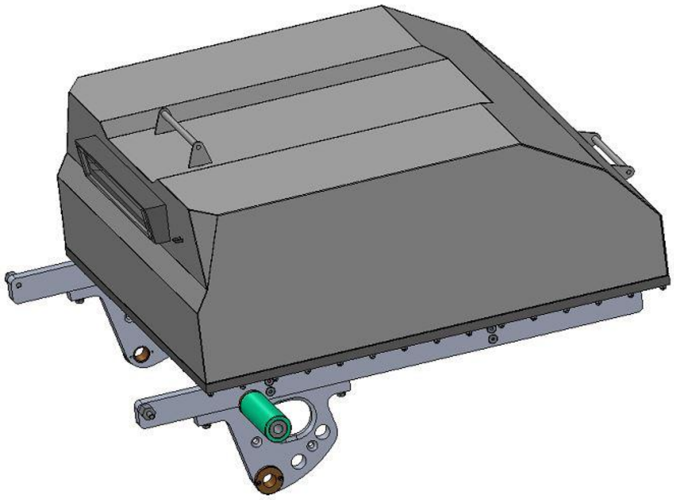

Figure 4.6. Optical box design

4.4.Ejection

As pneumatic valves system is selected for the ejection unit, a manifold is designed which can house the pneumatic valves into it along with the nozzles. It is designed so that it can attach to the main body and assembled just below the inspection zone. The material used is AISI304. Figure below shows the CAD design for the ejection manifold.

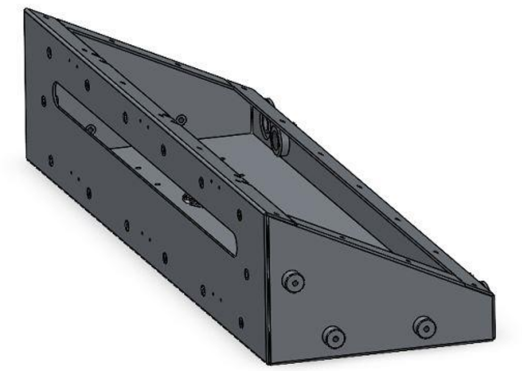

Figure 4.7. Ejection unit manifold

4.5.Main Frame

The main frame of the machine is designed as compact as possible. It should be able to assemble the other components. The material used is AISI304. Figure 4.8 shows main frame design.

4.6. Bottom Conveyor

A bottom conveyor is also designed to carry away the defected material. The defected material after the rejection falls into the bottom conveyor which conveys it out. The design is same as that of the vibratory feed conveyor but smaller and shorter in size. The material used is AISI304 and fiberglass EPGC203. Figure 4.9 and figure 4.10 shows frame and main body of bottom conveyor respectively. Composite leaf spring are assembled on the main body of bottom conveyor.

Figure 4.8. Main frame of the optical sorter

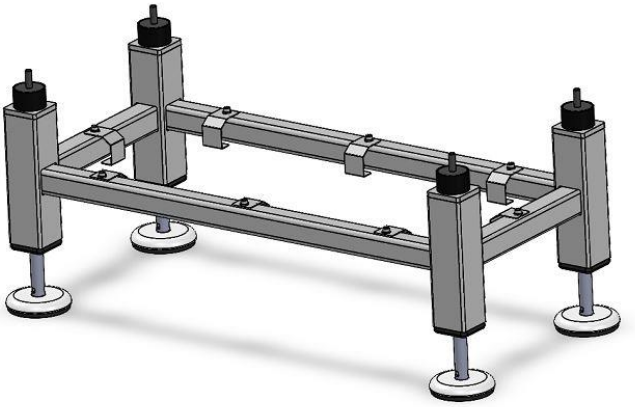

Figure 4.9. Bottom conveyor frame

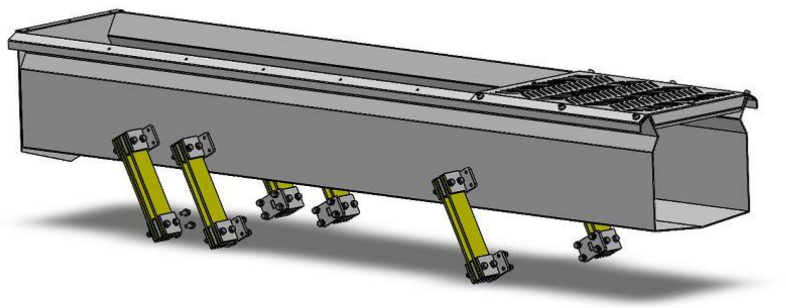

Figure 4. 10. Bottom conveyor main body

5.RESULTS AND DISCUSSIONS

The assemblies are performed, and final results are evaluated. The machine consists of three main parts Vibratory conveyor, Main body, and bottom conveyor. The results are as follows.

Figure 5.1 shows the complete body of the vibratory conveyor.

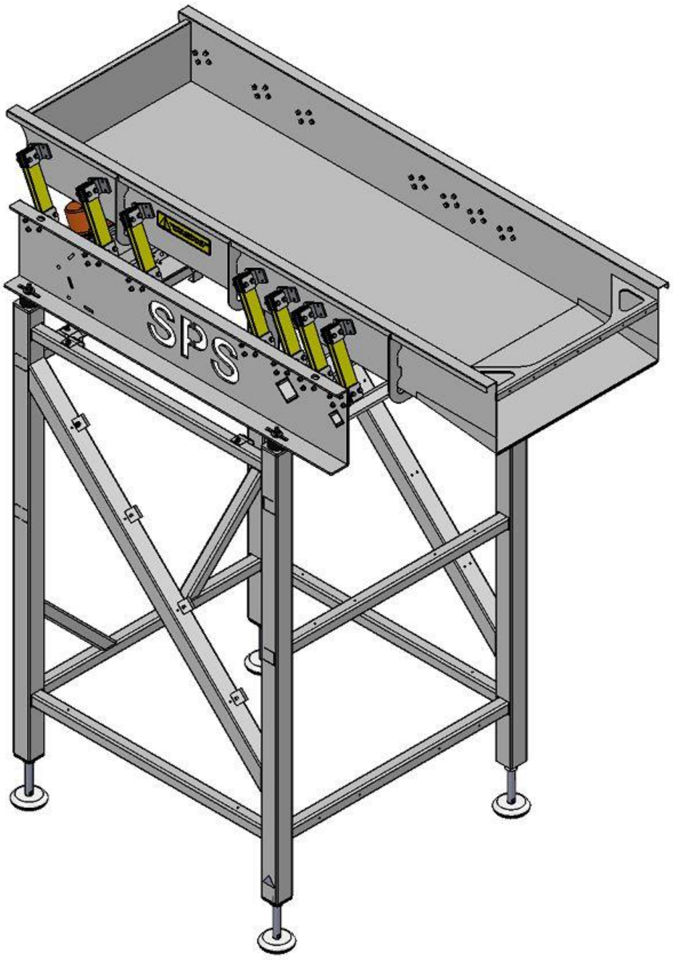

Figure 5.1. Vibratory Conveyor View 1

Figure 5.2. Vibratory Conveyor View 2

Figure 5.3 and Figure 5.4 shows the assembled CAD design for the main body of the optical sorter. Free fall chute is also attached along with optical boxes and some other necessary components.

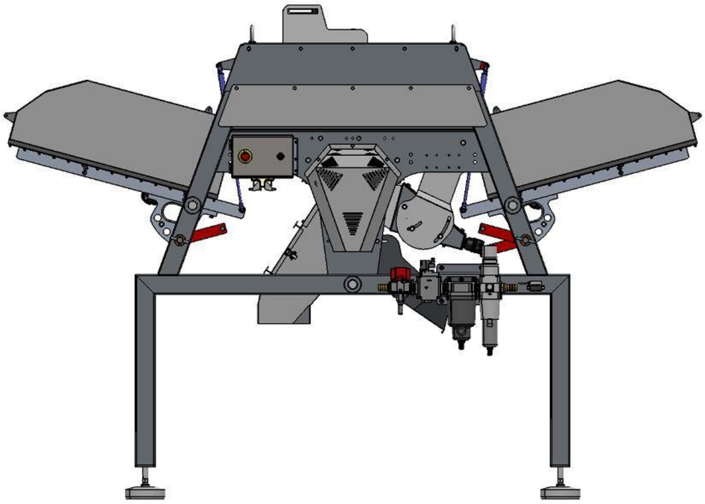

Figure 5.3. Main body of optical sorter View 1

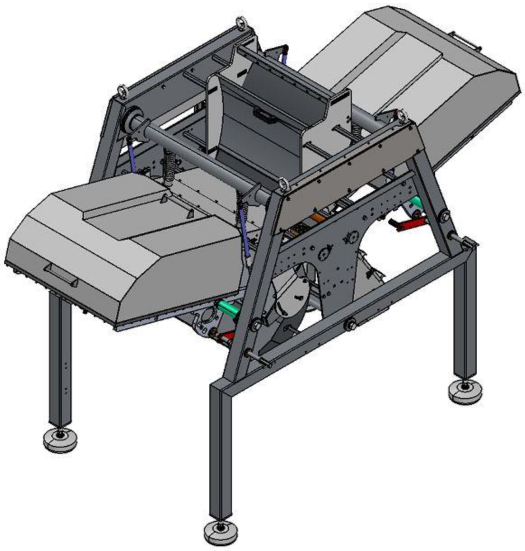

Figure 5.4. Main body of optical sorter View 2

Below are the figures for the bottom conveyor.

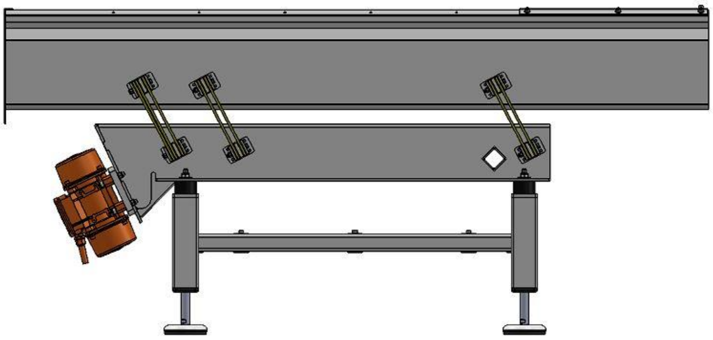

Figure 5.5. Bottom Conveyor View 1

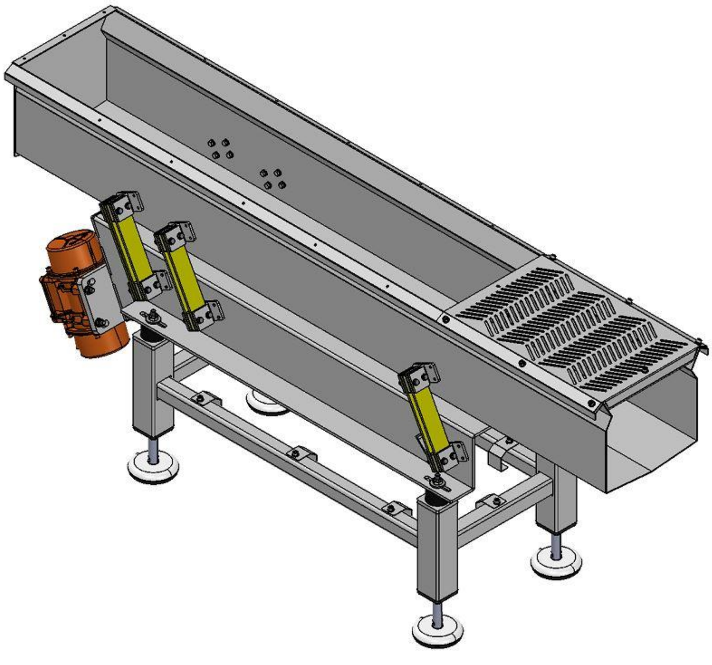

Figure 5.6. Bottom Conveyor View 2

For the main assembly, all three main parts altogether are shown below.

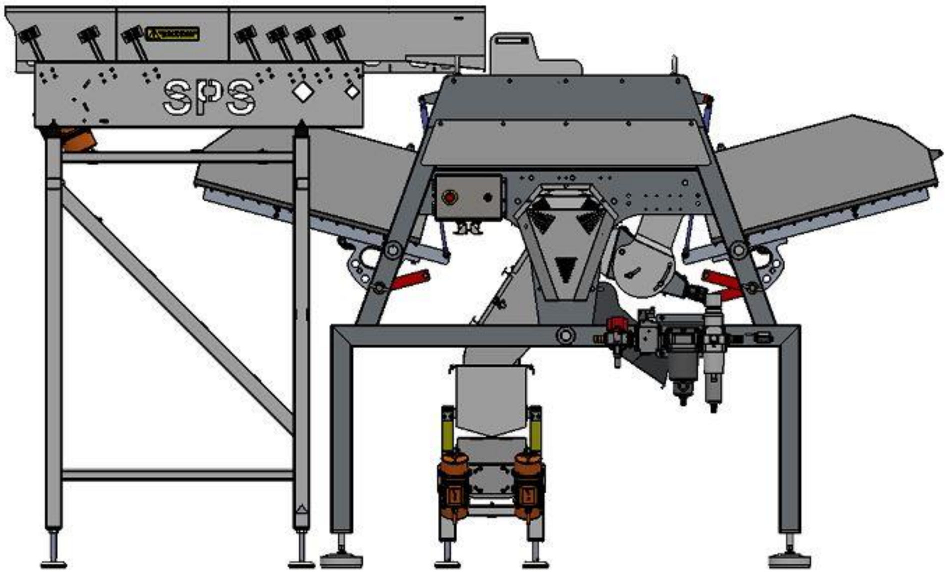

Figure 5.7. Main Assembly of optical sorter View 1

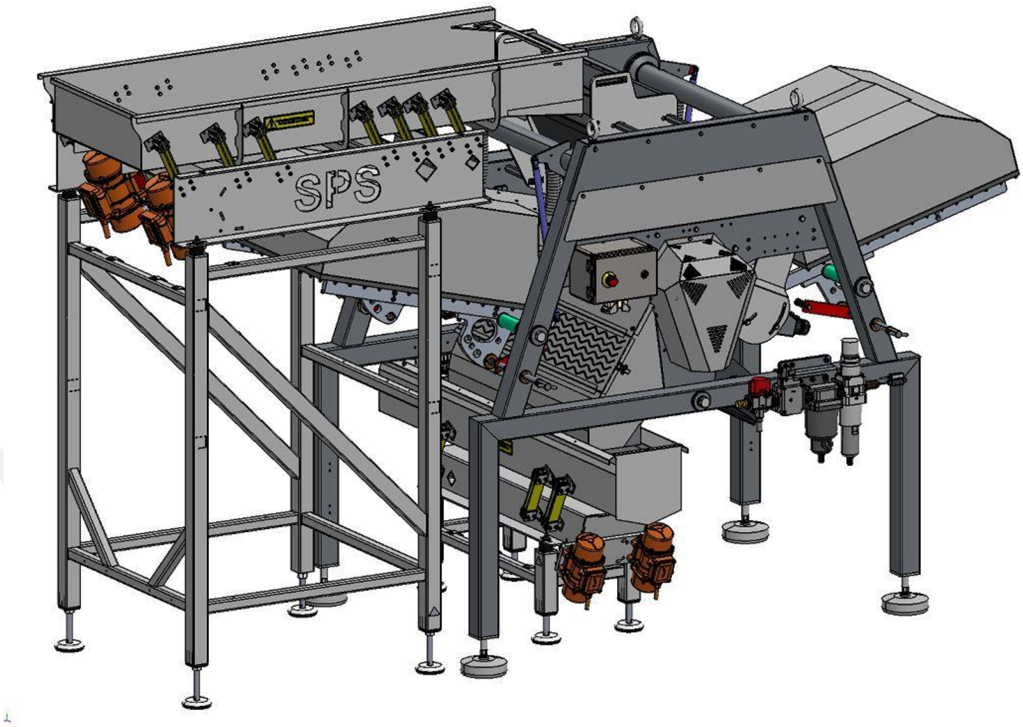

Figure 5.8. Main Assembly of optical sorter View 2

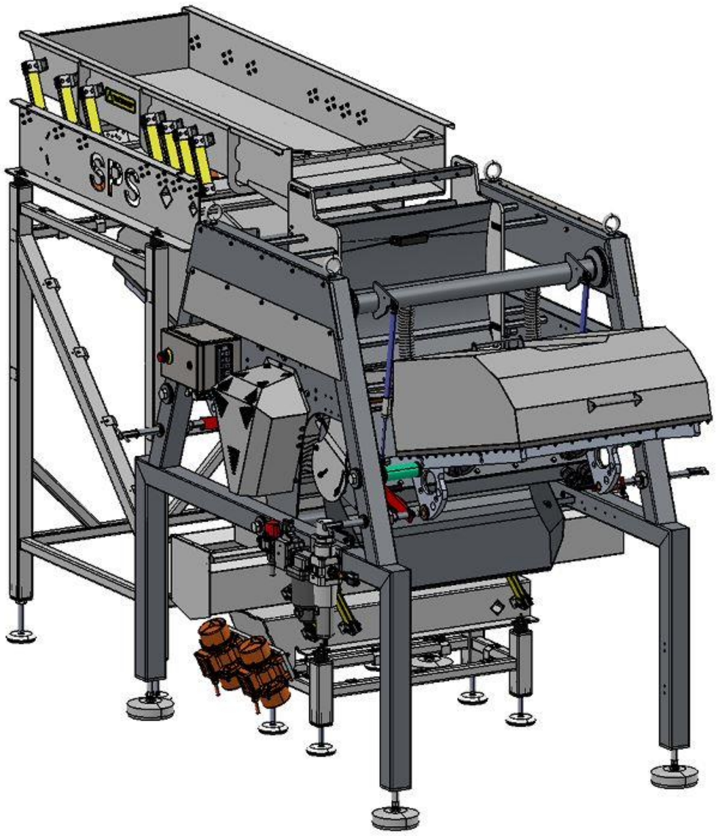

Figure 5.9. Main Assembly of optical sorter View 3

Structural analysis is also performed for the conveyor parts. As there are no specific or external forces acting onto the main body, so main body is discarded. ANSYS software has been used for the static structural analysis of the assemblies. As it is a conceptual design, structural steel material is selected from the ANSYS library. For the leaf springs, composite Epoxy E-glass is selected.

Mesh for the Vibratory conveyor is as below.

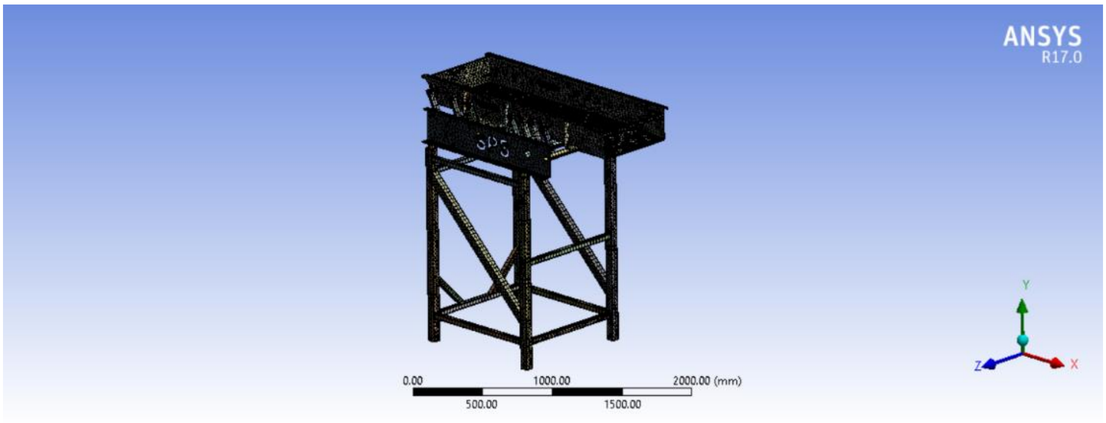

Figure 5.10. Mesh for Vibratory conveyor

Figure below shows boundary conditions such as fixed constraint which is applied to the feet. The load applied is 5000N to the surface where the products are supposed to fall.

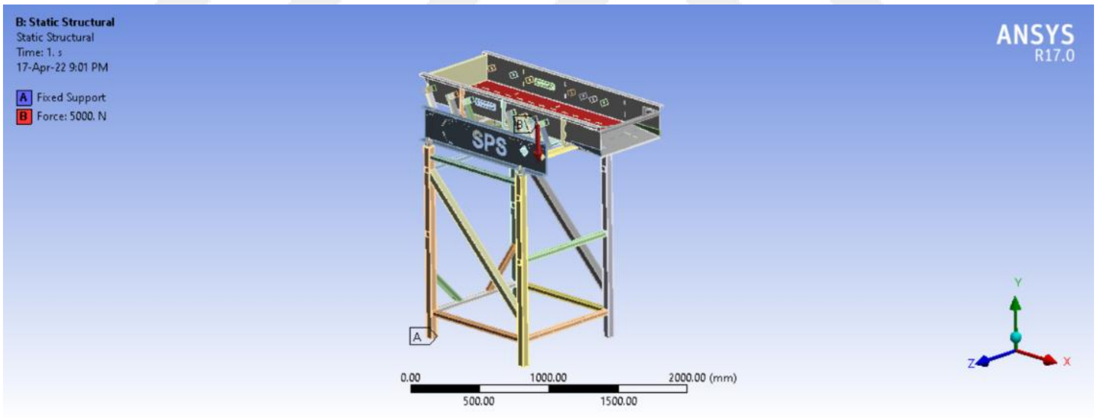

Figure 5.11. Boundary condition of Vibratory conveyor

Figure below shows the Total deformation.

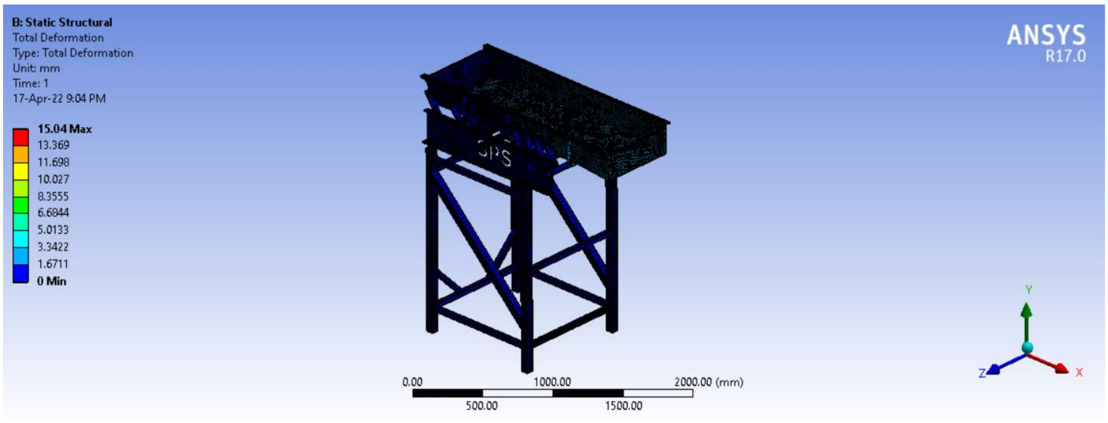

Figure 5.12. Total deformation Vibratory conveyor

Figure below shows Von mises stress.

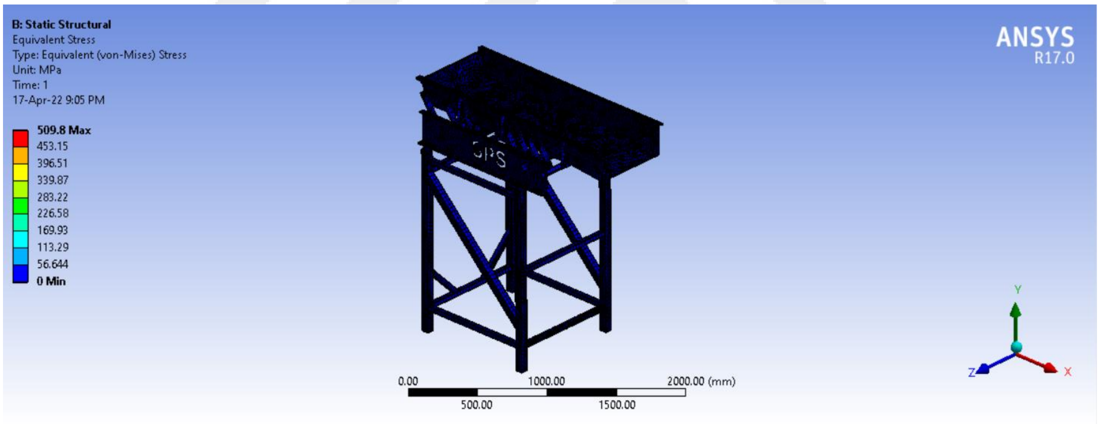

Figure 5.13. Von mises stress Vibratory conveyor

For the bottom conveyor, mesh, boundary condition, total deformation and von mises stress figures are as below respectively. The material selected is structural steel and composite Epoxy E-glass. Boundary conditions such as fixed constraint is applied on the feet and load is applied where the products are supposed to fall. Applied load is 500N.

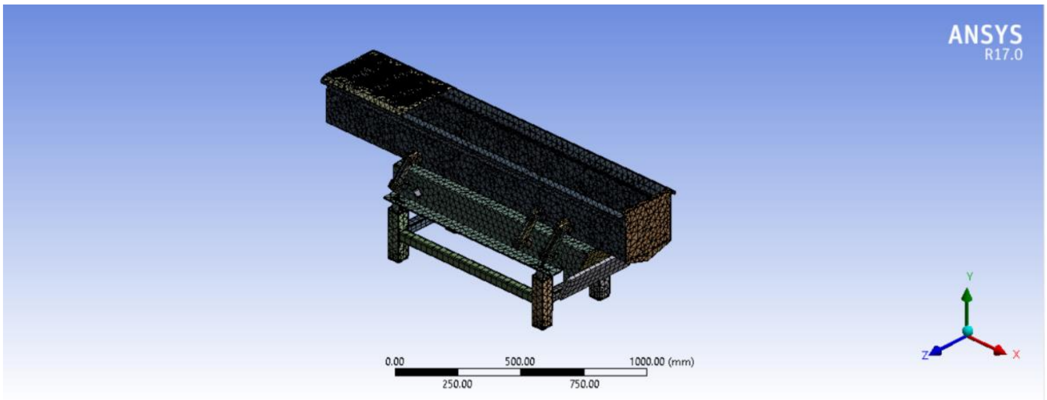

Figure 5.14. Mesh Bottom conveyor

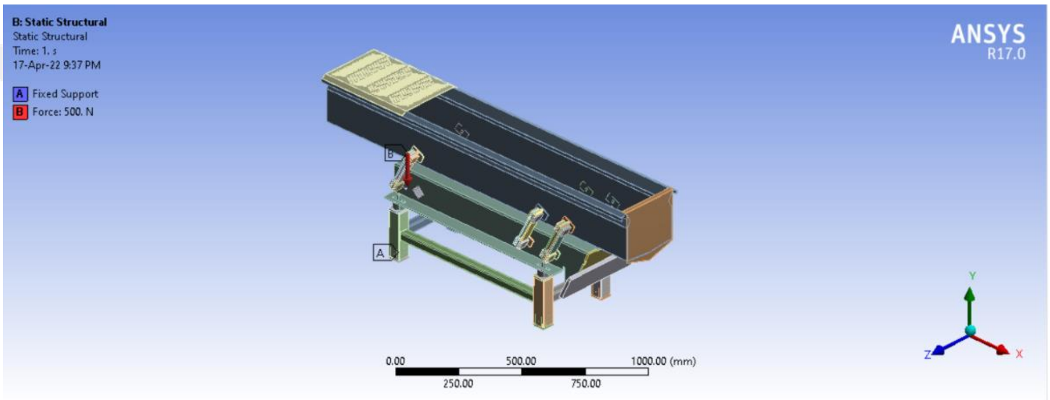

Figure 5.15. Boundary condition bottom conveyor

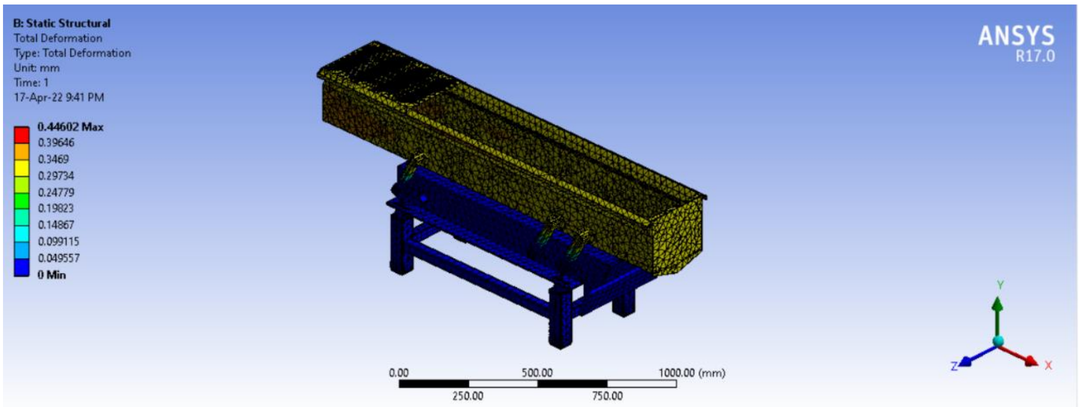

Figure 5.16. Bottom conveyor total deformation

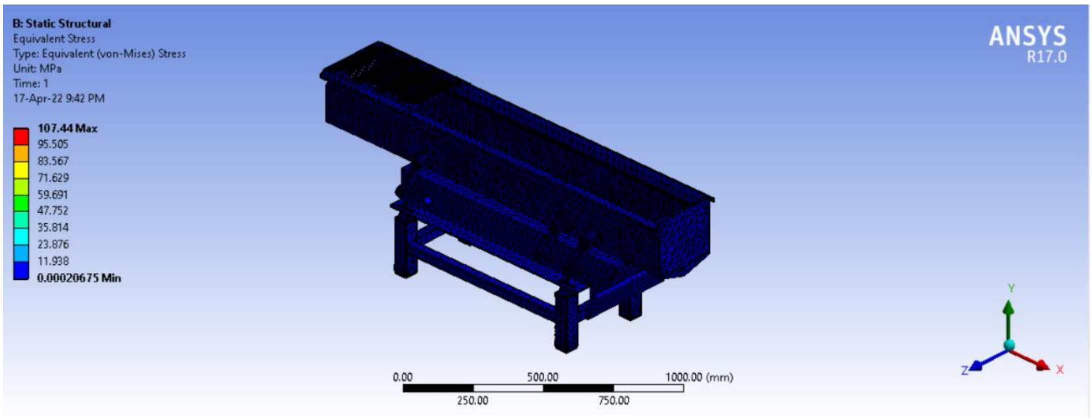

Figure 5.17. Von mises stress bottom conveyor

6. CONCLUSION

After the prolong studies, it is to be conclude that this field has immense potential in the upcoming future. Along with the advancement in technology, optical sorters also hold a big role in economic gains. Such machines are capable of implementing food safety, which can eventually raise the health standards. Different diseases that raise due to hand sorting the waste/recycle material can be stopped by using the sorting machines.

Sensor based sorting is still not widely recognized and used as a beneficiary process in applications other than Food, Mining and Waste/Recycle. All these industries have a great impact on the technology advancement of optical sorters. Identification and Separation component of an optical sorter holds immense opportunity for advancement and development.

Free fall chute and conveyor belt systems are the most common systems used in food industry. Conveyor belt system works great when large amount of throughput is required. The free fall chute system is used for the conceptual design. It can be used for myriad kinds of food applications.

Developments can be made in the optics side of the sorter. The design conceptualized in the above chapters holds significant role in efficiency. The core information couldn’t be shared because of reasons such as pending patents. For the future works, optical part can be designed with the details of lenses, mirrors, filters etc. Ray tracing simulations can be performed for the complete system along with CFD analysis of the pneumatic air valve ejection system.

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T.C.

AYDIN ADNAN MENDERES UNIVERSITY

GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

SCIENTIFIC ETHICAL STATEMENT

I hereby declare that I composed all the information in my master's thesis entitled Development of Optical Sorting Machine within the framework of ethical behavior and academic rules, and that due references were provided and for all kinds of statements and information that do not belong to me in this study in accordance with the guide for writing the thesis. I declare that I accept all kinds of legal consequences when the opposite of what I have stated is revealed.

Usama REHMAN
22/04/2022

CURRICULUM VITAE

Last name, First name: Rehman Usama

Nationality: Pakistan

Place of birth and date:

Telephone:

Email:

Foreign language: English (Advanced), Turkish (Intermediate), Hindi (Intermediate), Punjabi (Intermediate)

Education

Bachelor's:	Aydın Adnan Menderes University-2018
Master's:	Aydın Adnan Menderes University-Continue

Work Experience

2018-Present	HAUS Centrifuge Technologies	R&D Engineer