ÇUKUROVA UNIVERSITY
INSTITUTE OF NATURAL AND APPLIED SCIENCES

MSc THESIS

Hulusi DELİBAŞ

SYSTEMATIC DESIGN OF CARTON SEPARATING MACHINE

DEPARTMENT OF MECHANICAL ENGINEERING

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We certify that the thesis titled above was reviewed and approved for the award of degree of the Master of Science by the board of jury on 10/02/2012

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ABSTRACT

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SYSTEMATIC DESIGN OF CARTON SEPARATING MACHINE

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Corrugated cardboards (carton boards) are used for making containers to protect goods. Containers are made by cutting and folding a flat sheet of corrugated cardboard to obtain a desired pattern for one-piece package with fold-down corner. Undesired portions of the flat sheet cardboard are separated from the desired one-piece pattern. This may be called as “the separation of the undesired pattern”. All of the steps are carried out using mass productions machines except “the separation of the undesired pattern” that is usually the last production step before shipping the patterns to customers. The last step is usually performed manually using an employee who uses tools such as pneumatic saw or an adze to separate the unwanted portion form the desired one-piece pattern. This manual process slows down the production and creates damages on the edges of the cardboard such as buckling of flute structures, tears, and etc. This thesis aims to design an automated machine for “the separation of the undesired pattern”. It uses systematic machine design methodology, which consists of conceptual design, embodiment design, and detail design stages. It also provides the steps of each phase including the results obtained.

Key Words: Machine design, Carton separation machine, Systematic design

ÖZ

YÜKSEK LİSANS TEZİ

KARTON AYIRMA MAKİNESİNİN SİSTEMATİK TASARIMI

Hulusi DELİBAŞ

ÇUKUROVA ÜNİVERSİTESİ
FEN BİLİMLERİ ENSTİTÜSÜ
MAKİNE MÜHENDİSLİĞİ ANABİLİM DALI

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: Prof. Dr. Melih BAYRAMOĞLU
: Yrd. Doç. Dr. Kerem ÜN

Oluklu kartonlar eşyaları korumak için mukavva kutu yapımında kullanılırlar. Mukavva kutular tek bir parça için istenilen modeli elde etmek için düz bir levha kartonun kesimi ve katlanmasıyla yapılırlar. Düz levha kartonun istenmeyen kısımları istenilen tek parça modelden ayrıştırılır. Bu “istenmeyen modelin ayrılması” olarak adlandırılır. Tüm adımlar “istenmeyen modelin ayrılması” hariç seri imalat makinelerinin kullanımıyla gerçekleştirilir. Bu genellikle modelleri müşterilere göndermeden önce ki son üretim basamağıdır. İstenmeyen kısmı ayırmak için son basamak genellikle pnömatik testere veya keser kullanan bir elemanın kullanımıyla istenilen tek parça modeli oluşturmak için elle yapılır. Bu manüel işlem üretimi yavaşlatır ve kartonun kenarında oluk yapısının burulması, yırtılması gibi zararlar oluşturur. Bu tez çalışmasında “istenmeyen modelin ayrılması için” otomatik bir makine tasarımı sistematik tasarım teknikleri kullanılarak yapılmaktadır. Sistematik tasarımda kavramsal tasarım, somut tasarım ve detay tasarım aşamaları makine tasarlamada kullanılmaktadır. Bu çalışma ayrıca elde edilen sonuçları içeren her aşamanın basamaklarını verir.

Anahtar Kelimeler: Makine tasarımı, Karton ayırma makinesi, Sistematik tasarım

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1. INTRODUCTION

Corrugated cardboard (carton boards) are used for making containers to protect goods. Containers are made by cutting and folding a flat sheet of corrugated cardboard to obtain a desired pattern for one-piece package with fold-down corner (Figure 1.1). Undesired portions of the flat sheet cardboard are separated from the desired one-piece pattern. This may be called as "the separation of the undesired pattern". All of the steps are carried out using mass productions machines except "the separation of the undesired pattern" that is usually the last production step before shipping the patterns to customers. The last step is usually performed manually using an employee who uses hand tools like a pneumatic saw or an adze to separate the unwanted portion from the desired one-piece pattern. This is a manual process in fully automated manufacturing environment and this slow down the production. As a result of this there is a demand that is coming from local carton board manufacturer for an automated carton board separation machine.

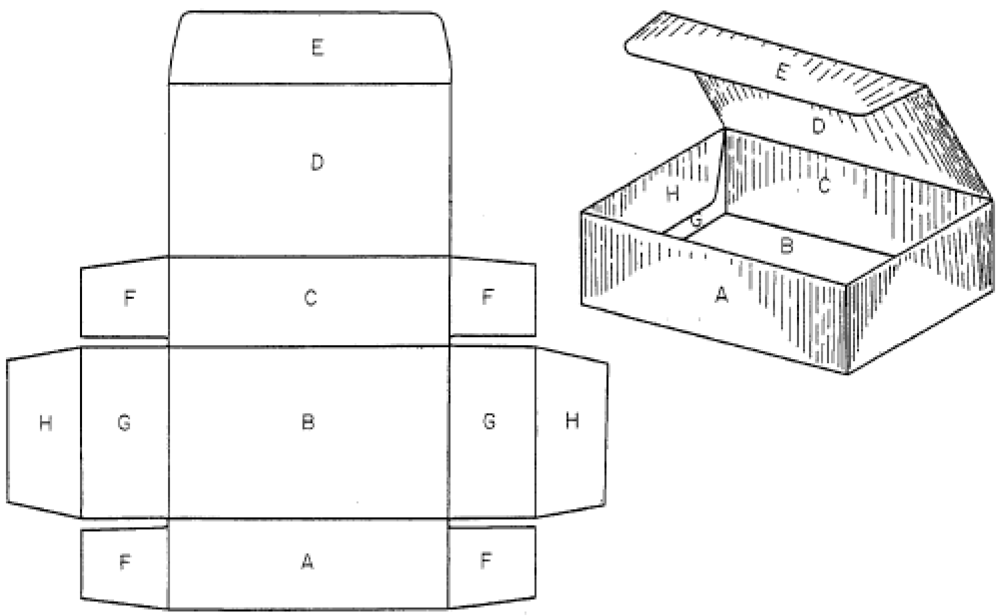


Figure 1.1. Desired Pattern (Thomas, 1966)

1.1. Die Cutting and Cardboard Patterning

Die cutting is one of the oldest methods of cutting. The die cutting process is done by using a tool, called a die, that has a series of machined knives (steel rules) that are pressed into the bulk product material creating the desired shape (www.augerlasercutting.com/diecutting.htm). A sample is shown as a die cutting product on Figure 1.1.

Die cutting affects almost every aspect of our daily lives. It is a key part of the manufacturing process of most of the products that we wear or use such as contoured plywood seats, lexan nameplates, dashboards of automobiles, folding cartons, gasket, labels, printed circuit boards and so on (www.larsonworldwide.com/process.html).

1.2. Die Cutting Machines

Numerous die cutting configurations exist to deliver optimal results for a variety of applications. Some of the most common types of die cutting tools include:

Clicker die cutting: Steel blades are welded with cold rolled steel braces for easy registering of the material. Clicker dies cut tough materials such as Kevlar or fiberglass and glove and shoe manufacturers often employ them.

Rotary die cutting: A cylindrical die cutting tool, rotary die blades can create corrugated boxes, but are also used to cut plastics, foam and rubber. The blades are formed around the outer surface of the cylinder, with blades ranging between .056 and .112 inches.

Steel rule die cutting: Sometimes called flatbed die cutting, this type of tool includes a flat construction with blade thicknesses ranging between .028 and .056 inches. Steel rule dies can make intricate designs that require a high level of accuracy.

Bolt die cutting: Gaskets and other applications that require internal cutouts or slits on thick materials use bolt die cutting. Wall thickness ranges from .084 and .112 inches.

Singulation die cutting: To create PC boards and other components that require fine trace lines, manufacturers use these tools because they have tight allowances (www.thomasnet.com/articles/custom-manufacturing fabricating/die-cutting-tools)

1.3. Die Cutting Process For Carton Boards

The process consists of four phases:

1) First of all carton boards are transferred to the cutting station
2) Carton boards are cut in desired shape by die cutter
3) Each carton board which is cut by die cutter is separated from unwanted portion by stripping board
4) Carton boards are stacked regularly

Process is shown in Figure 1.2.

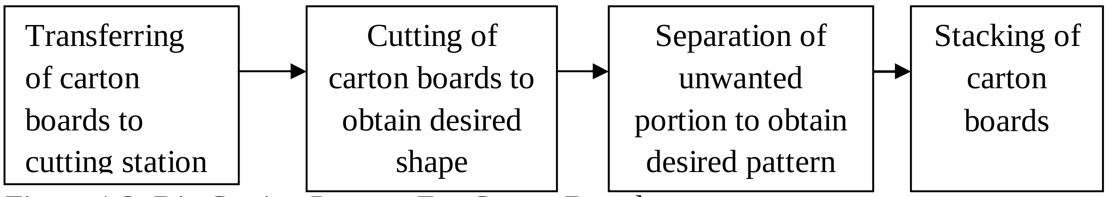


Figure 1.2. Die Cutting Process For Carton Boards

1.4. Structure of Die Cutter

There are mainly three types of material on a die cutter. A flatbed die cutter is shown in Figure 1.3. These are wooden board, steel rules and rubber.

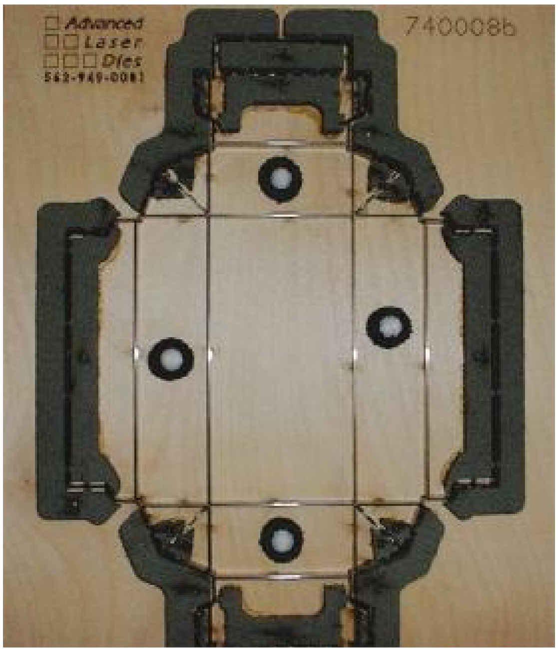


Figure 1.3. Male Flatbed Die Board Sample (www.advancedlaserdies.com)

Steel rules provide both accurate and clean tear lines on rapid and easy to remove panel sections, whilst maintaining box strength. Steel rules are chosen according to the flute type being used and direction of the perforating line. To obtain fold line, steel rules which have indented and protruding edges are used on the other hand to cut the carton board, steel rules which have straight line are used. Figure 1.4 illustrates steel rules. In addition thickness of the blades must be chosen carefully according to applied force onto the steel rules for long life cycle.

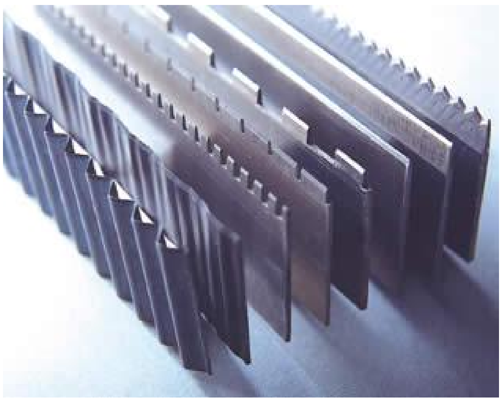


Figure 1.4. Steel Rules (www.accurategroup.com.au)

Rubbers are used to cover the blades. This helps to protect anyone handling the die board and stops the specialist machinery from getting damaged. Rubbers are shown in Figure 1.5.

Figure 1.5. Rubber (www.helenhudspith.com)

1.5. Structure of Stripping Board

Stripping boards are similar to die boards. It consists of wooden board, stripping pins and sponges. Upper and lower stripping boards are shown in Figure 1.6.

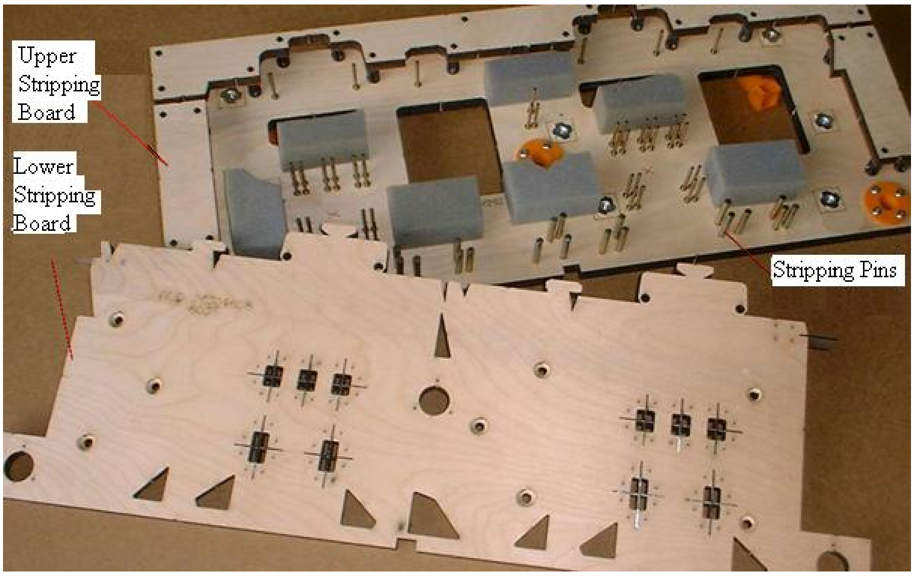


Figure 1.6. Stripping Boards (www.advancedlaserdies.com)

Scrap can be removed cleanly and quickly without damage to the product to obtain desired shape by stripping pins. Different types of stripping tools are available. Some of these are shown in Figure 1.7. Usually stripping pins which have sharp edge is used. Because they pull out the unwanted carton pieces directly and separates them.

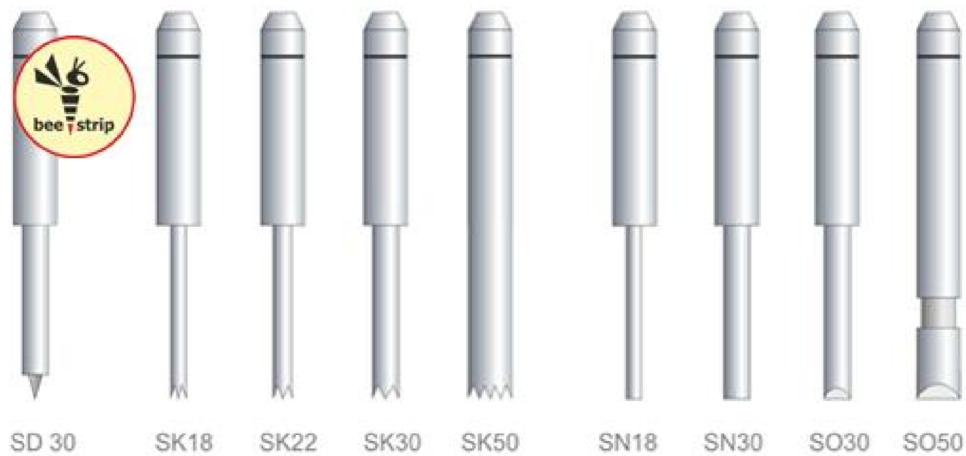


Figure 1.7. Stripping Pins (www.boxplan.de)

Sponges are used to prevent slipping of carton boards when the upper stripping board presses on the lower stripping board and stripping pins touches the carton board.

1.6. The State of The Art of Carton Board Separation Process in Local Manufacturers

Carton board manufacturers have been visited in our region. It has been seen that the Paper-Carton industry has been developed fast by private sector in last fifteen years. However this development has not been fully automated yet. The paper-carton industry requires high investment. Hence, carton board manufacturers are investing to old technology to avoid from high investment cost. Therefore this is causing to fall in quality and capacity. This is a main issue in separation process. This is mainly because the processing machine is not separating waste material exactly from main carton board to prevent tangling in transferring. The card board sample is shown in Figure 1.8.

Figure 1.8. Sample Which is Obtained After Carton Board Separation Process (Permission of a local manufacturer)

As a result of this second process is necessary to obtain finished product. But this process is being done primitively. Samples are stacked on a pallet on top of each other by an operator. Then pneumatic saw are being used to separate waste material from main carton board. But this process is not easy and slow down the manufacturing process. Furthermore separation of the middle side of the main carton board is very hard by a pneumatic saw. In fact it is impossible. Therefore an adze is being used to separate waste material on the middle section of the carton board. Pneumatic saw and an adze are shown in Figure 1.9 from left to right respectively. In addition to that manufacturing area becomes extremely dirty and untidy.

Figure 1.9. Pneumatic Saw and an Adze From Left to Right Respectively
(Permission of a local manufacturer)

This primitive process introduces damages to cardboards such as tears, crushes in product. As a result of this defected products increases causing losing of time and money. In addition this manual operation uses very valuable floor space in the production line. Therefore this process also results in dirty production floor that may affect companies’ reputation for customers (Figure 1.10).

Figure 1.10. View During Process (Permission of a local manufacturer)

Besides available machine is using different dies for each different product. This causes lose of money and floor space. Dies are shown in Figure 1.11.

Figure 1.11. Used Dies on Corrugated Paperboard Cutting Machine (Permission of a local manufacturer)

As a result of this a proper separation machine must be designed to prevent these problems in card board manufacturing process.

1.7. Local Demand For Card Board Separation Machine

A local manufacturer called Teknopak located in the region has been visited. The manufacturer is using fully automated card board manufacturing equipment. However, the company is using manual separation process. The manual separation is being carried out using manual tools. This step is performed manually using an employee who uses tools such as a pneumatic saw or an adze to separate the unwanted portion from the desired one piece pattern. This manual process results in creation of damages on the edges of the card board such as buckling of flute structures, tears etc. Therefore, they claimed a low-cost card board separation machine.

1.8. Systematic Design Process

Design is the interplay between what we want to achieve and how we want to achieve it. The precise description of “what we want to achieve” is a difficult task for designers. Many designers often begin working on design solutions before they have clearly defined goals. They also try to measure success by comparing their design with design goals that may not be established through customers’ needs. Therefore, they spend a great deal of time on improving and iterating the design. In order to generate an efficient design, the designer must begin the design process by stating the goals in terms of “what we want to achieve” in light of customer’s needs (Durmusoglu et al, 2008). Quality function deployment chart is good way to identify needs (product features, customer requirements).

Once the details of the design are clearly identified, the design team with inputs from test, manufacturing, and marketing teams generates multiple alternatives to achieve the goals and the requirements of the design (Khandani, 2005).

To obtain an optimal design concept between generated alternatives as a starting point for further development evaluation methods (pugh method, etc.) are used. A proper design concept evaluation can guarantee the fulfillment of customer needs and lead to realizing products that delight customers (Zhai et al, 2009).

During the embodiment phase, designer must determine the overall layout design (general arrangement and spatial compatibility), the preliminary form designs (component shapes and materials) and the production procedure, and provide solutions for any auxiliary functions (Pahl et al, 1988).

The detail design stage is the final step in the engineering design process before manufacturing and production is commenced. During this stage, commonly referred to as analysis and simulation, the designer selects the appropriate materials for each part and calculates accurately the dimensions and tolerances of the product (Haik et al, 2010).

2. PREVIOUS STUDIES

2.1. Mechanical Properties of Corrugated Carton Board

Corrugated board is widely used in the packaging industry. The main advantages are lightness, recyclability and low cost. This makes the material the best choice to produce containers devoted to the shipping of goods (Biancolini, 2004). Such a box is shown at different spatial scales in Figure 2.1.

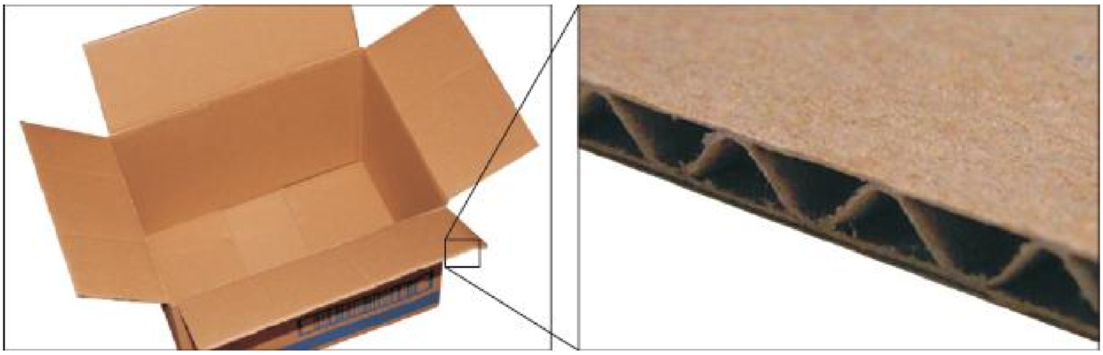
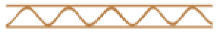
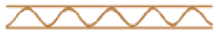
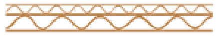
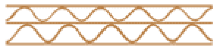
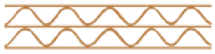


Figure 2.1. Corrugated Board Box at Different Scales (Thakkar, 2008).

Usage of corrugated carton board in an optimum manner requires the knowledge of its mechanical behavior (elastic, inelastic, failure, etc.). To determine its mechanical behavior, the corrugated cardboard can be considered as a structure.

The corrugated cardboard is an orthotropic sandwich with the surface plies (facing) providing bending stiffness, separated by a lightweight corrugated core (fluting) that provides shear stiffness (Aboura et al., 2004). Also air circulation which is inside of corrugating medium gives thermal resistance to corrugated board. So corrugating medium must be selected very carefully according to service conditions. Standard corrugating geometries, A, B, C, E flute, have traditionally been employed, although it is becoming increasingly popular to produce optimum geometries with respect to paper properties. Double or triple wall corrugated board are obtained by combining of flutes (Single and double-wall corrugated boards are classified as detailed in the Table 2.1).

Table 2.1. Types of Corrugated Boards (www.iapad.org/tips/cartonboard.htm)

Standards	Typical Caliper (mm) (i.e. Thickness)	Section
Single-face corrugated board		
E Flute	1.1 – 1.8	
B Flute	2.1 – 3.0	
C Flute	3.2 - 3.9	
A Flute	4.0 - 4.8	
Single-wall corrugated board		
B Flute	2.95	
C Flute	3.78	
Double-wall corrugated board		
EB flute	4.06	
BC flute	6.50	
CC flute	7.33	

A-flute, is stiff enough for vertical direction. It cannot be buckled easily. So it is used in stacking. In addition it has a good cushioning property. Because it can be crushed easily in horizontal direction. Pitch distance is high so high quality printing surface cannot be obtained. A-flute is used at internal surface in the double corrugated wall combinations. At the beginning in Turkey, A-flute was used commonly. Now C-flute is being used instead of A-flute because of its low cost.

B-flute has thinner wall thickness than A-flute. So it cannot carry vertical loads. Pitch distance is low. So it cannot be crushed easily and high quality printing surface can be obtained.

C-flute has appeared after A and B flutes. It have good properties of A and C flutes. Therefore it is used commonly on the world.

E-flute has high number of corrugations per meter. It can give best result on printing comparing to others. It is light. Therefore it is used successfully instead of carton package. Perfect packaging material obtained with combination of other flutes. It cannot be used as a carrying package by itself. E flute can be used as a consumer package with lamination of printed carton.

Single face corrugated board is combination of any flute with paperboard. This material is used for cushioning and decorative. It cannot be used in box making.

Double wall corrugated board is used in export boxes for carrying heavy items. If double wall corrugated board is not enough for carrying heavy items then triple wall corrugated board is used. Thickness of triple wall corrugated board can go up to 12 mm. Production rate of this board is low.

Two main directions characterize corrugated board. The first noted machine direction (MD) corresponds to the direction of manufacturing of the material. It coincides with the x-axis. The second noted cross direction (CD) corresponds to the transverse direction and coincides with the y-axis (Figure 2.2) (Aboura et al, 2004).

The cardboard has a high strength along the corrugated flutes, so this direction is usually put vertically in the cardboard box design to obtain the maximal stacking strength (N. Talbi et al, 2009). To facilitate dispensing of interior packages, boxes are sometimes stacked side-to-side or end-to-end or handled as unit loads by clamp trucks where MD strength becomes equally important (Urbanik, 1996).

In fact, all sections normal to y (called CD-sections) are identical and the material is continuous along y (beam-like structure along y), the core resists well the normal stress α_y (like the facings), so it gives great membrane and bending stiffness. On the other hand, the sections normal to x (called MD-sections) vary and the core material is not continuous along x, so it can resist little axial stress α_x, these gives very weak membrane and bending stiffness (Talbi et al, 2009).

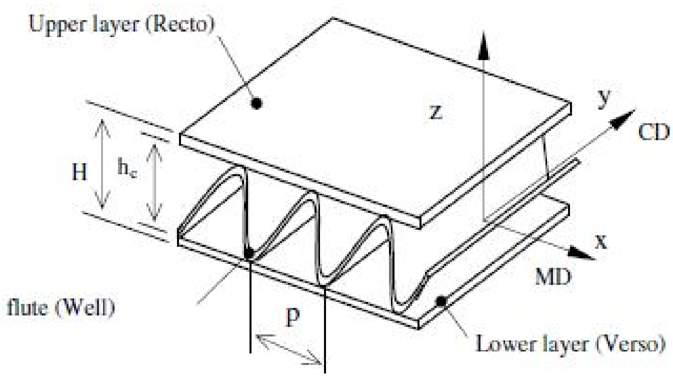


Figure 2.2. Cardboard Panel Geometry (Allaoui, 2009).

2.2. Corrugated Paperboard Die Cutting Machines

Die cutting is a manufacturing process used to generate large numbers of the same shape from a material such as carton, wood, plastic, metal or fabric. As mentioned in the previous sections there are different types of die cutting machines. Since flat bed die cutting and rotary die cutting machines are used in carton board industry, only both of them are explained.

2.2.1. Flat Bed Die Cutting Machine

Flat bed die cutting system (Figure 2.3) with cutting die tooling provides solution for cutting and trimming a wide array of component parts of products and materials.

Figure 2.3. Flat Bed Die Cutting Machine (www.bobst.com)

The process is simple. Process begins with carton feeding then continues with cutting and stripping respectively. Finally process finishes with stacking of carton boards. Process is shown in Figure 2.4.

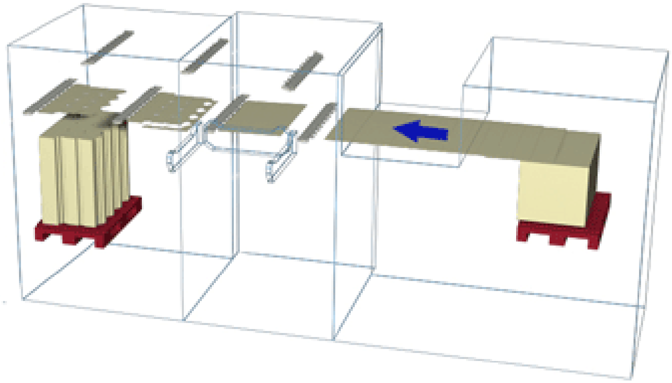


Figure 2.4. Cutting and Stripping Process (www.bobst.com)

Feed station: Corrugated boards are placed regularly on a pallet. Then the loader takes corrugated sheet pallets and supplies stacks to the die-cutter feeder. Feed station shown in Figure 2.5.

Figure 2.5. Feed Station (Anonymous)

Then the corrugated boards pass through aligning partition of the machine to give proper orientation to cartons before cutting process. Front and sides of carton board are precisely aligned. Aligning mechanism is shown in Figure 2.6.

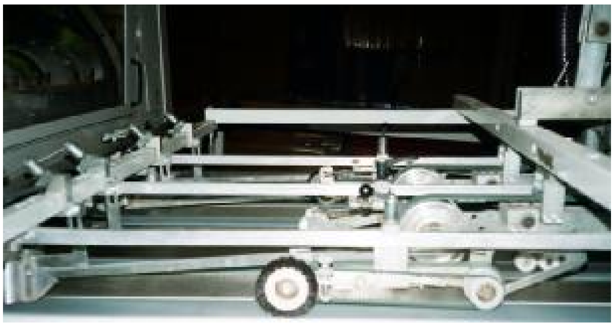


Figure 2.6. Aligning Mechanism (Permission of a local manufacturer)

Cutting station: Sharp shaped blades are used in die cutting. The blade is bent into the desired shape and mounted to a strong backing. The material being cut is placed on a flat surface with a supportive backing and the die is pressed on to the material to cut it. Selection of the correct grade and hardness is absolutely key to obtaining high quality cut parts and increased tool life. Good results depend on good press, good tooling and good cutting board. Boards which are used in cutting station are shown in Figure 2.7 and Figure 2.8.

Figure 2.7. Male Cutting Die Board (Permission of a local manufacturer)

Figure 2.8. Female Die Board (Permission of a local manufacturer)

If blades in the cutting board touches the yellow side in female board then folding edges are obtained on corrugated paperboard on the other hand if blades in the cutting board touches the female board, corrugated board is cut by blade.

Stripping station: In the stripping station, upper and lower stripping tools remove the waste between the blanks. Sponges are used to prevent shearing of corrugated board. Stripping station is shown in Figure 2.9.

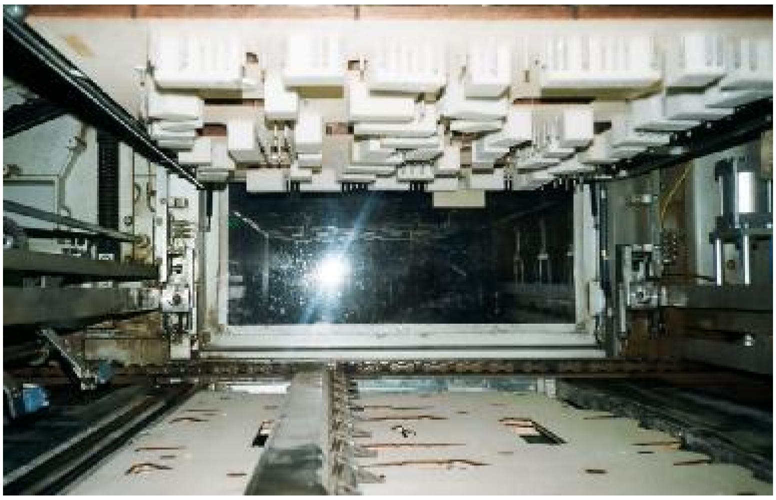


Figure 2.9. Stripping Station (Permission of a local manufacturer)

Stack station: Cut and stripped products are formed and loaded on pallet. Stack station is given in Figure 2.10.

Figure 2.10. Stack Station (Permission of a local manufacturer)

2.2.2. Rotary Die Cutting Machine

Rotary die cutting is another process used to cut paper, metal, rubber, plastic, vinyl and other material in a predetermined shape and size. Process is similar to flat die cutting process. Process begins with feeding of corrugated carton (Figure 2.11).

Figure 2.11. Feeding Station (http://bograma.ch)

Then process continues with aligning of carton boards (Figure 2.12).

Figure 2.12. Aligning Mechanism (http://bograma.ch)

Cutting process begins after aligning of corrugated carton board. Rotary cutter consists of a die cutter, which has three-dimensional cutter blades on the cylindrical outer surface, and an anvil roll, which has a smooth cylindrical outer surface, and raw material sheets are cut into the required product shape by passing those two rolls. Rotary cutter and cutting station are shown in Figures 2.13 and 2.14 respectively.

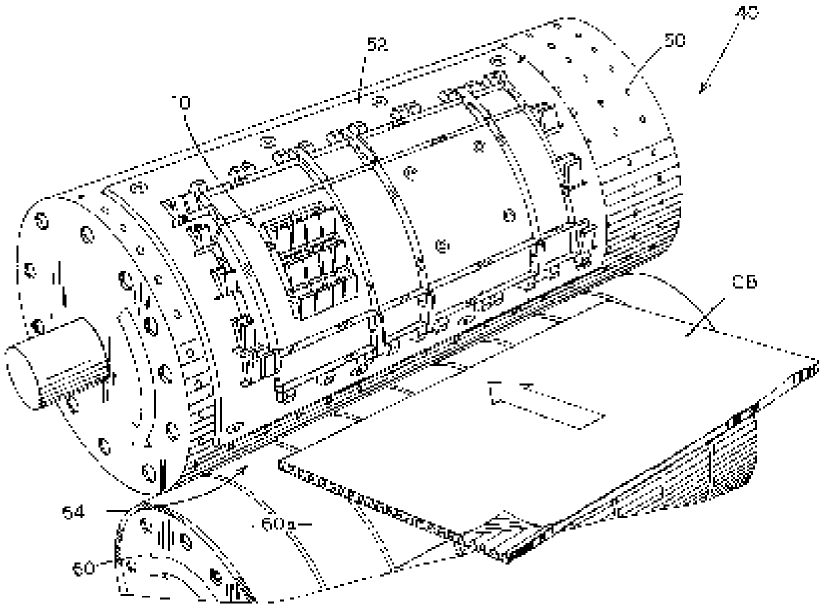


Figure 2.13. Cutting Mechanism (http://www.freepatentsonline.com)

Figure 2.14. Cutting Station (http://bograma.ch)

Afterwards waste material is separated from main carton board to obtain desired shape by an air blower (Figure 2.15).

Figure 2.15. Separation Station (http://bograma.ch)

Finally process finishes with stacking of carton boards (Figure 2.16).

Figure 2.16. Stacking Station (http://bograma.ch)

2.2.3. Determination of Mechanisms in Designed Machine

After process is investigated in available machine, the process which consists of lifting-lowering, transferring and separation of carton boards, is considered in designed automated corrugated carton board separation machine. Available mechanisms are given in Table 2.2 for each needed feature.

Table 2.2. Features and Mechanisms of Designed Separation Machine

Features	Mechanisms				
Lifting or lowering	Hydraulic	Pneumatic	Rack and pinion	Screw	Chain or rope
Transferring	Belt	Chains	Gears and shaft	Hydraulic	Pneumatic
Separation	Stripping pins	Vacuum	Air blower		

Screw mechanism is selected as a lifting-lowering mechanism since it lifts or lowers carton boards according to the thickness of a carton board. On the other hand the other mechanisms (hydraulic, pneumatic, chain and rope) are not sensitive to position control or causes to vibration (chain, rope, rack and pinion).

For transferring mechanism, pneumatic is considered since pneumatic systems have high speed; no vibration and mass of carton boards which will be transferred, are light.

Compatible solution for separation of carton boards is determined by combining of stripping pins and vacuum. While stripping pins separates scrap material from desired pattern, a vacuum gripper hold the separated carton boards and provides the transfer of carton boards easily to stacking station by pneumatic actuator without tangling.

2.3. Engineering Design Process

Systematic design process is going to be used in this work to solve the problem. Therefore the engineering design process is scrutinized.

Engineering design processes consists of three sub process. These are conceptual design, embodiment design and detail design. Figure 2.17 shows phases of the design process.

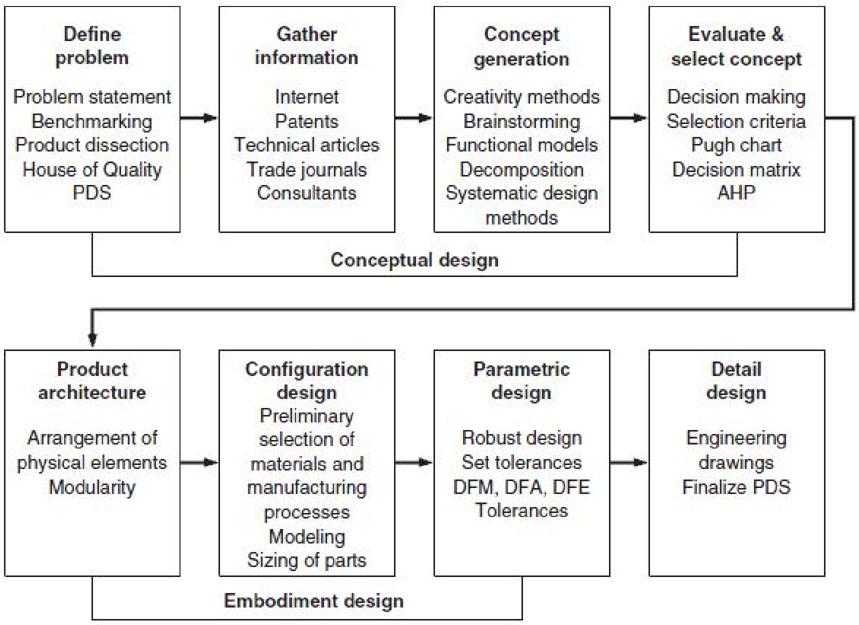


Figure 2.17. Engineering Design Process (Dieter, 2009)

2.3.1. Conceptual Design

2.3.1.1. Definition of Problem

Conceptual design can be described as a stage where design objectives are defined, functional requirements are specified, and concepts are generated, evaluated, and selected (Hambali, 2009).

Conceptual design sub process begins with problem definition. All of the steps in the engineering design process, problem definition is the most important. Understanding the problem at the beginning aids immeasurably in reaching an outstanding solution. So it is vital to understand and provide what it is that the customer wants.

The goal of problem definition is to create statement that describes what has to be accomplished to satisfy the needs of the customer. This involves analysis of competitive products, the establishment of target specifications, and the listing of constraints and tradeoffs. Quality function deployment (QFD) or House of quality (HOQ) is a valuable tool for linking customer needs with design requirements.

QFD was first developed and introduced in the late 1960s. A few years later, in1972, QFD was implemented in Japan at the Kobe Shipyards of Mitsubishi Heavy Industries. Using the QFD, Toyota was able to reduce the start-up pre-production costs by 60% from 1977to 1984 and to decrease the time required for its development by one-third (Cherif et al., 2010).

The three main goals in implementing QFD are as follows:

- Prioritize customer wants and needs (spoken, unspoken, and exciting)
- Translate these needs into technical characteristics and specifications.
- Build and deliver a quality product or service (Lo´pez et al., 2008).

Figure 2.18 shows sequences of a typical traditional four step QFD consist of product planning, product design, process planning and process control phases, which customer requirements (CRs) arranged as customer desires in rows and engineering characteristics (ECs) in columns of the first HOQ matrix. In each separate phase expert groups tries to sequentially find out the ways of conforming customer needs. As shown in the Figure at each stage, the ECs, may called "Hows" are carried to the next phase as CRs or "Whats".

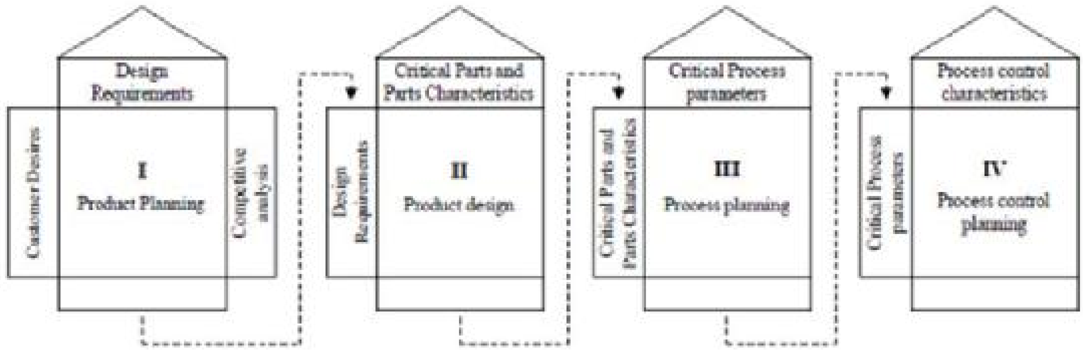


Figure 2.18. The Four Phases Traditional QFD (Raissi et al., 2011)

The extended house of quality is shown in Figure 2.19. And the following sub sections explain the sections of QFD.

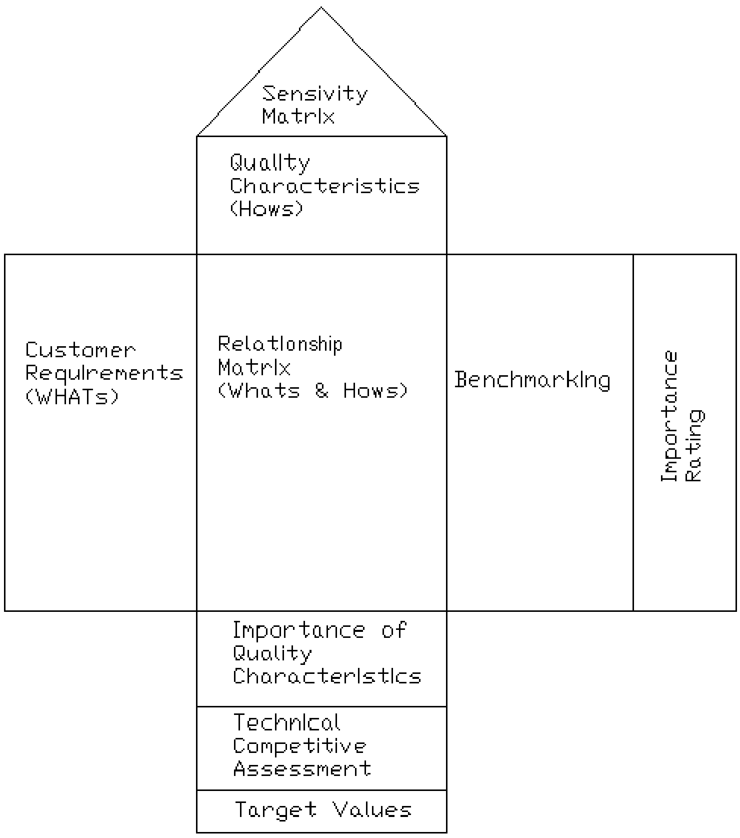


Figure 2.19. Quality Function Deployment or House of Quality

Customer requirements (Whats): Except standard functions of machine, Customer wants extra functions. So customers must be satisfied to sell the product. The best method to learn customers' needs is survey.
Quality Characteristics (Hows): Hows that enable satisfying the customer requirements are listed in columns. A way to arrive at the quality characteristics is to ask the question: "What can I control that allows me to meet my customer's needs?" These must not be specific design details or solutions but must be characteristics that can be measured and given target values like weight, force, velocity, etc (Dieter, 1999).

Relationship Matrix: Relationships within this matrix are usually defined using a four level procedure: strong, moderate, weak or none (Table 2.3).

Table 2.3. Standard Relationship Conventions (Prasad, 1998).

Matrix		Quantitative	Qualitative
WHATs versus HOWs	**Grade**	**Weight**	**Symbols**
	Strong relationship	9	Double or Solid Circle and/or •
	Moderate relationship	3	Circle (o)
	Weak relationship	1	Triangle (Δ)
	None	0	Blank
HOWs versus HOWs	**Grade**	**Weight**	**Symbols**
	Strong Positive relationship	9	Double or Solid Circle and/or •
	Medium Positive relationship	3	Solid Triangle (Δ)
	Positive relationship	1	+
	None	0	Blank
	Negative relationship	–1	–
	Medium Negative relationship	–3	Open Triangle (Δ)
	Strong Negative relationship	–9	Open Circle (o)

Sensivity Matrix: This relationship is described by means of a sensitivity matrix that forms the roof of the house of quality (Figure 2.19). The purpose of the roof is to identify the correlation between the characteristic items (HOWs). This is a very important feature of the house of quality because, at times, the possible solutions could be redundant and may not add much value to customer wants. If two HOWs help each other meet the target values, they are rated as positive or strong positive. If meeting one HOW target value makes it harder or impossible to meet another target value, those two HOWs are rated as negative or strongly negative (Table 2.3) (Prasad, 1998).

Benchmarking: Competitors who produce the similar products should be identified by the company under study. Knowing the company's strengths and constraints in all aspects of a product and in comparison with its main competitors is essential for a company if it wishes to improve its competitiveness in the relevant markets. This kind of information can be obtained by asking the customers to rate the relative performance of the company and its competitors on each WHAT and then to aggregate the customers' ratings. Useful ways of conducting this kind of comparison analysis are also via mailed surveys and individual interviews (Chan et al, 2005).

Importance rating: Importance of each customer requirement is shown in this region. If importance rating of a customer requirement is low, this customer requirement can be ignored. Importance rating can be found by following formulas:

- importance rating= relative importance × improvement ratio × sales point
- improvement ratio= $\frac{\text{Planned Product}}{\text{Product on market}}$
- Sales point= 1.5 (for strong) , 1.25 (for moderate), 1 (no sale). If sale point is high, this will cause your company a unique business position

Importance of Quality Characteristics: the main contribution of the House Of Quality is to determine which QC's are of critical importance to satisfying the CR's listed in room. Those QC's with the highest rating are given special consideration; for these are the ones that have the greatest effect upon customer satisfaction (Dieter, 2009).

Technical competitive assessment: This is technically evaluating the performance of the company's product and its main competitors' similar products on each HOW (Chan et al, 2005).

Target Values: Setting target values is the final step in the QFD. By knowing which are the most important QC's, understanding the technical competition, and having a feel for the technical difficulty, the team is in a good position to set the targets for each quality characteristic. Setting targets at the beginning of the design process provides a way for the design team to gauge the progress they are making toward satisfying the customer’s requirements as the design proceeds (Dieter, 1999).

2.3.1.2. Gathering Information

The need for information can be crucial at many steps in a design project. Information must be find quickly, and validate them as to their reliability (Dieter, 2009). The following questions are asked to obtain information:

- Ø What do I need to find out?
- Ø Who are the main suppliers of... ?
- Ø Is there a patent on... ?
- Ø What is the equation for... ?
- Ø Has there been any research on... ?
- Ø Where can I find it and how can I get it?

The gathering of information requires knowledge of a wide spectrum of information sources. These sources are:

- Ø The World Wide Web, and its access to digital databases
- Ø Business catalogs and other trade literature
- Ø Government technical reports and business data
- Ø Published technical literature, including trade magazines
- Ø Network of Professional friends, aided by e-mail
- Ø Network of Professional colleagues at work
- Ø Corporate consultants
- Ø University libraries

After finding information which are needed, the following questions are asked:

- Ø How credible and accurate is the information?
- Ø How should the information be interpreted form my specific need?
- Ø What decisions result from the information?
- Ø When do I have enough information?

2.3.1.3. Concept Generation

The goal of concept generation is to produce new ideas by looking at different ways to solve a problem. There are many activities and techniques that aid in the generation of ideas. Available concept generation techniques are given in Figure 2.20.

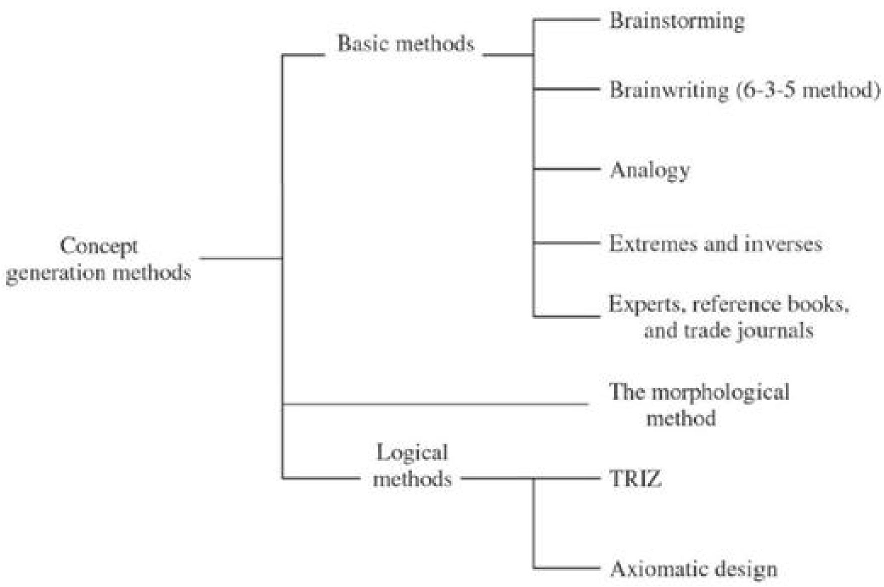


Figure 2.20. Concept Generation Techniques (Ullman, 1992)

Brainstorming: Brainstorming can be described as a method of generating a flood of new ideas. It was originally suggested by Osborn and provides conditions in which a group of open-minded people from as many different spheres of life as possible bring up any thoughts that occur to them and thus trigger off new ideas in the minds of the other participants (Pahl et al, 1988).

Brainwriting (6-3-5 method): Brainwriting is another concept where a group of people is asked to each individually come up with a number of ideas and write them on a sheet. The sheets are then exchanged, and individuals add to the list with improvements or ideas sparked from the ideas already on the sheet. This is then repeated a number of times until a sufficient number of ideas are generated (www.productdesignresources.com).

Analogy: Using analogies can be a powerful aid to generate concepts. The best way to think of analogies is to consider a needed function and then ask. What else provides this function? An object that provides similar function may trigger ideas for concepts. For example, idea for how the bike suspension may look and function can be drawn from motorcycles, cars, crickets, tree limbs, or anything else that provides some or all of the needed function (Ullman, 1992).

Morphological method: The morphological method consists of two steps. First step is developing concepts for each function. Then select one concept for each function and combine those into a single design. This method may generate too many ideas. The number of possible combinations is usually very high, and includes not only existing, conventional solutions also a wide range of variations and completely novel solutions (Cross, 2000). But the results may not make any sense.

TRIZ: TRIZ is the Russian acronym for the Theory of Inventive Problem Solving developed by Genrich Altshuller in Russia. Unlike brainstorming, it is a systematic approach to creativity. Altshuller originally wished to determine what made innovators different from the rest of us and studied thousands of patents (Fulbright, 2011). Altshuller recognized that the same fundamental problems or Contradiction in one area had been addressed by many inventions in other technological areas. He also found that the same fundamental solutions had been used over and over again. Based upon the 40,000 patents collected, Altshuller summarized 1201 standard engineering problems, named Contradictions and 40 fundamental solutions to these problems, named Inventive Principles. Figure 2.21 shows TRIZ approach.

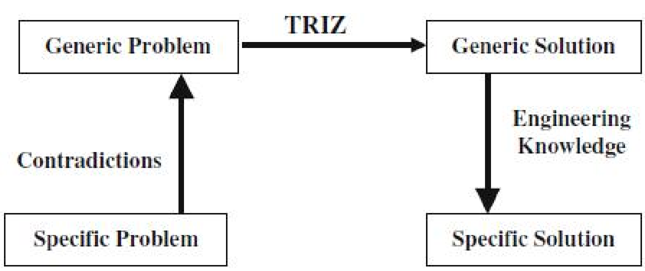


Figure 2.21. TRIZ Approach to Creativity (Shirwaiker et al., 2008)

To perform TRIZ first of all, find the major contradiction that is making the problem hard to solve and then use TRIZ's 40 inventive ideas for overcoming the contradiction.

Axiomatic design (AD): The AD approach provides a new search process using these iterations between "what (Functional requirements)" and "how (Design parameters, which are the key variables, are chosen to satisfy the specified FRs throughout the design process)" (Durmusoglu et al, 2008). The most important concept in axiomatic design is the existence of design axioms. The first design axiom is known as the independence axiom (IA), and the second axiom is known as the information axiom. They are defined as follows:

- Axiom 1 the independence axiom: Maintain the independence of functional requirements.
- Axiom 2 the information axiom: Minimize the information content.

The independence axiom states that the independence of functional requirements (FRs) must always be maintained, where FRs are defined as the minimum set of independent requirements that characterizes the design goals. The information axiom states that the design with the smallest information content among those satisfying the first axiom is the best design. An example for axiomatic design is given in Figures 2.22 and 2.23.

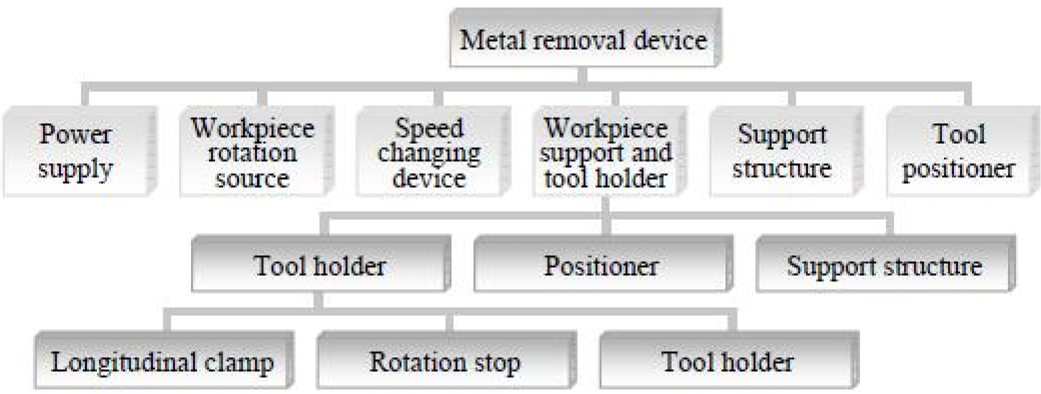


Figure 2.22. Functional Requirements (Park, 2007)

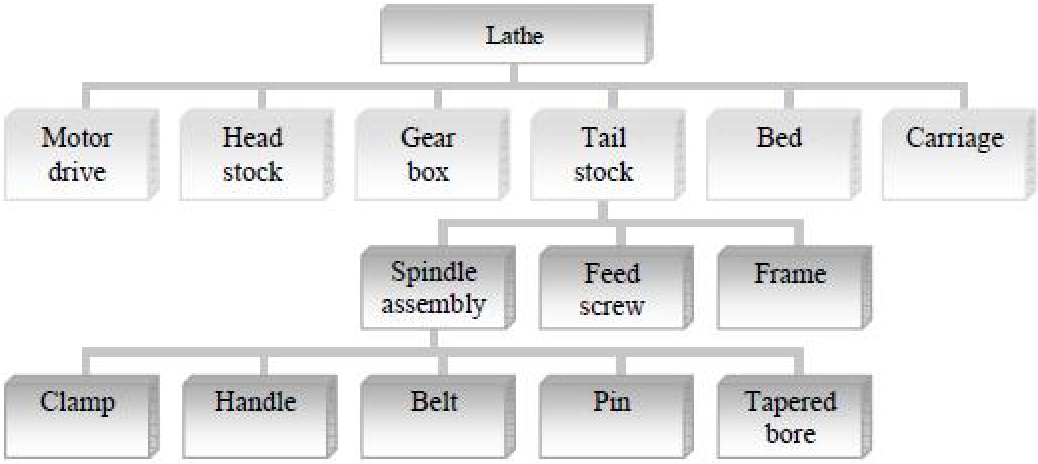


Figure 2.23. Design Parameters (Park, 2007).

2.3.1.4. Evaluate and Select Concept

QFD is evaluation of the concepts according to customer requirements. In similarly concept evaluation is evaluation of concepts according to engineering characteristics. These characteristics can be design for manufacturing (DFM), design for assembly (DFA) rules, QFD etc. Different concept evaluation methods can be found in literature. Methods are as follows:

- Evaluation based on feasibility judgment
- Go / No- Go Screening
- Pugh Chart (Basic decision matrix)
- Weighted decision matrix
- Analytic hierarchy process (AHP)

Among the above evaluation methods only weighted decision matrix method are explained. Other methods are available in the literature.

The first step in weighted decision matrix is to identify the design criteria for comparison of concepts. Secondly determine the weighting factor for each of the design criteria. This is done by constructing a hierarchical objective tree (Figure 2.24)

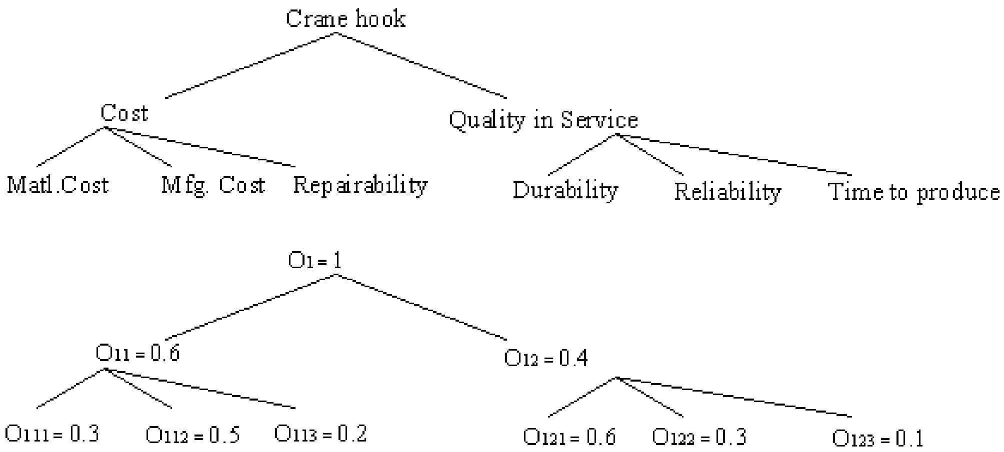


Figure 2.24. Objective Tree For The Design of a Crane Hook (Dieter, 2009).

The weights of the individual categories at each level of tree must add to 1. To get the weight of a factor for material cost, $Q_{111} = 0.3 \times 0.6 \times 1 = 0.18$

The rating for each concept at each design criterion is obtained by multiplying the score by the weighting factor (Scores are given relatively according to magnitude of each criterion for each concept). Thus for the criterion of material cost in welded plate design concept, the rating is 0.18 x 8 = 1.44. The overall rating for each concept is the sum of these ratings. Decision matrix is shown in Table 2.4

Table 2.4. Weighted Decision Matrix For a Steel Crane Hook (Dieter, 2009).

		Build-up Plates Welded			Build-up Plates Riveted			Cast Steel Hook		
Design criterion	Weight factor	Magnitude	Score	Rating	Magnitude	Score	Rating	Magnitude	Score	Rating
Material cost	0.18	60	8	1.44	60	8	1.44	50	9	1.62
Manuf. cost	0.3	2500	7	2.1	2200	9	2.7	3000	4	1.2
Repairability	0.12	Good	7	0.84	Excellent	9	1.08	Fair	5	0.6
Durability	0.24	High	8	1.92	High	8	1.92	Good	6	1.44
Reliability	0.12	Good	7	0.84	Excellent	9	1.08	Fair	5	0.6
Time to produce	0.04	40	7	0.28	25	9	0.36	60	5	0.2
				7.42			8.58			5.66

As seen from Table 2.4, concept 2 (Build-up Plates Riveted) must be chosen since it has maximum total rating value.

2.3.2. Embodiment Design

Embodiment design begins with product architecture. Purpose in product architecture is to arrange functions and components of design project to obtain required function. That is, product architecture shows relation and interference between components or functions. Also it is good road map for variation of available design in the future. According to development in technology, functions and components of available design project can be changed.

In configuration design, if it is necessary, shape of components (parts) is changed according to DFM, DFA rules. Sometimes using two standard parts instead of a complex part is not good because of high assembly cost. This step refines the parts of the design to obtain best configuration of parts.

After finding best form for each component, parts are sized in parametric design. According to loading type and service conditions finite element method or analytic methods are used to prevent failure of the product.

2.3.3. Detail Design

The last phase of the engineering design process is detail design. All details of the product must be given clearly to manufacturer. These details are including the following:

- All dimensions must have tolerance
- Materials and manufacturing detail must be in clear
- Each component is identified with a number or letter keyed to the bill of materials (BOM).
- Necessary detailed views, sections must be included.
- References can be made to other drawings and specific assembly instructions for additional information (Ullman, 1992).

3. METHOD

Die cutting machines, tools which are used in carton board industry and systematic design method have been studied in the previous chapter. In this section systematic design methodology will be applied to design an automatic corrugated card board separating and stripping machine. Figure 3.1 illustrates the methodology that is used in this study.

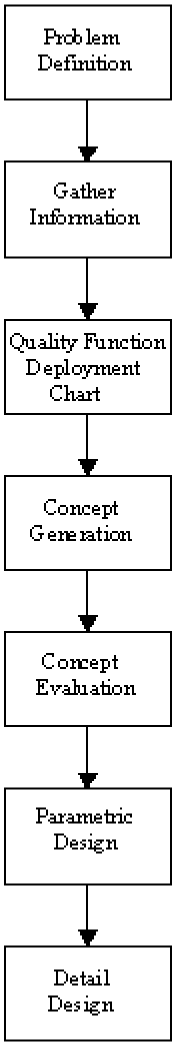


Figure 3.1. The Systematic Design Process Used in The Development of The Separating and Stripping Machine.

3.1. Problem Definition and Gathering Information

Goal of the study is to design an automated machine which separates scrap materials from the desired pattern. The problem is to separate unwanted scrap from the desired pattern without the manual operation.

When a machine is designed, firstly required information are gathered. For these reason available machines, tools and mechanisms which are used to obtain desired shape on carton boards are investigated. Manufacturing process of available machines is observed and evaluated.

3.2. Quality Function Deployment Chart of Designed Machine

Success of the product mostly depends on Quality Function Deployment (QFD). QFD must involve all requirements (customer requirements, basic functions which are included in machine). There are different methods to prepare QFD such as interviews, survey, complaints etc. But the most proper way is talking with customers. In this work, a cardboard manufacturer which is called as TEKNOPAK Ltd. Şti. Located in Hacı Sabancı Organize Sanayi Bölgesi, Toros Cad. No:3 Yakapınar / ADANA were visited number of times. At each visit technical personnel were listened to prepare QFD for the target machine. These attempts allowed to prepare the QFD given in Figure 3.2. As it seen from Figure, customer requirements (Whats) and quality characteristics (Hows) for the automated corrugated card board stripping and separation machine have been obtained.

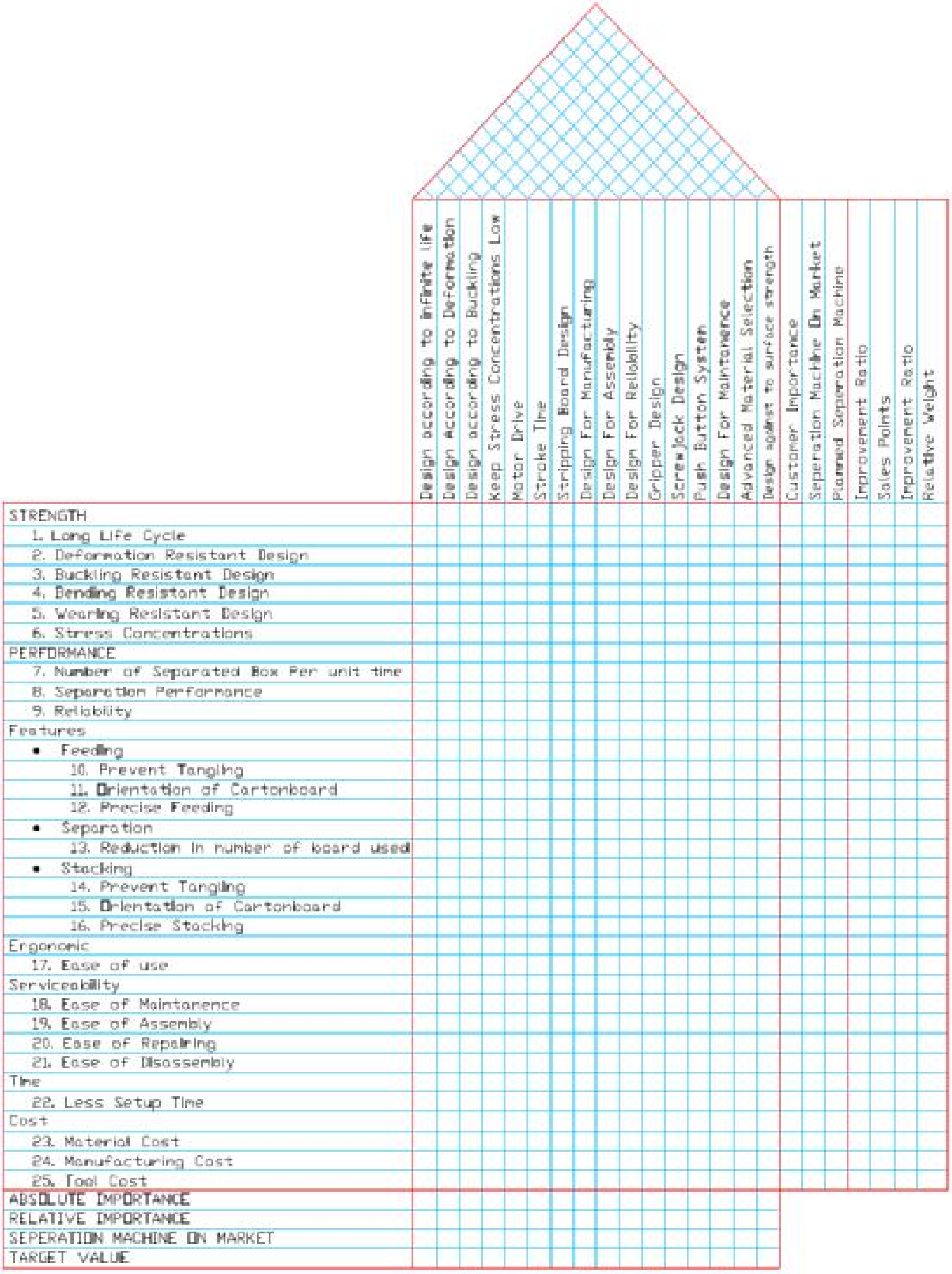


Figure 3.2. Quality Function Deployment Chart of Planned Machine

3.3. Concept Generation For Automated Corrugated Cardboard Stripping and Separation Machine

Concept generation is the hardest step in systematic design process. There are different types of problem solving techniques. There is no best concept generation technique. The selection is usually based on the problem.

However axiomatic design will be used in the design process. Because it decomposes the problem into smaller functions. This process helps the designer.

The design problem is divided to three main topics. These are:

1. Feeding of carton boards without tangling
2. separation of unwanted portion of carton boards
3. Stacking of carton boards without tangling.

Then the main topics are divided to components and so on.

Decompositioning process is carried out according to relationship between parts. That is, product architecture of concepts can be seen easily from functional requirements and design parameters for each generated concept.

Three concepts are generated by using axiomatic design method. Concept 1 is generated by using die separation technique. Concept 2 is generated by using vacuum separation technique and concept 3 is generated by merging the die and vacuum separation techniques. Therefore the last concept is a hybrid of concept 1 and 2.

When concept generation is made, QFD studies are considered at the conceptual design stage. If this cannot be made, the solution will not satisfy the demands of customers. Then the product will possibly fail in the market.

3.3.1. Concept 1: Using Die Separation Technique

As it is shown in Figure 3.3, process begins lifting of carton board by a power driven screw jack according to thickness of one carton board. Then rodless actuator takes carton board to separation station. Pneumatic actuator lowers stripping board which is driven on ball bushing supported rods at each corner. After unwanted portion of carton board is separated, pneumatic actuator is retracted and rodless actuator transports the carton board to stacking station. Finally screw jack lowers carton board according to thickness of one carton board on stacking station and process starts again. Also functional requirement and design parameters of concept 1 are shown respectively in Figure 3.4 and 3.5 by using axiomatic design method. Each function of designed machine is separated from each other to keep independence of each function (Axiom 1). Then each function is matched with a design parameter (Axiom 2).

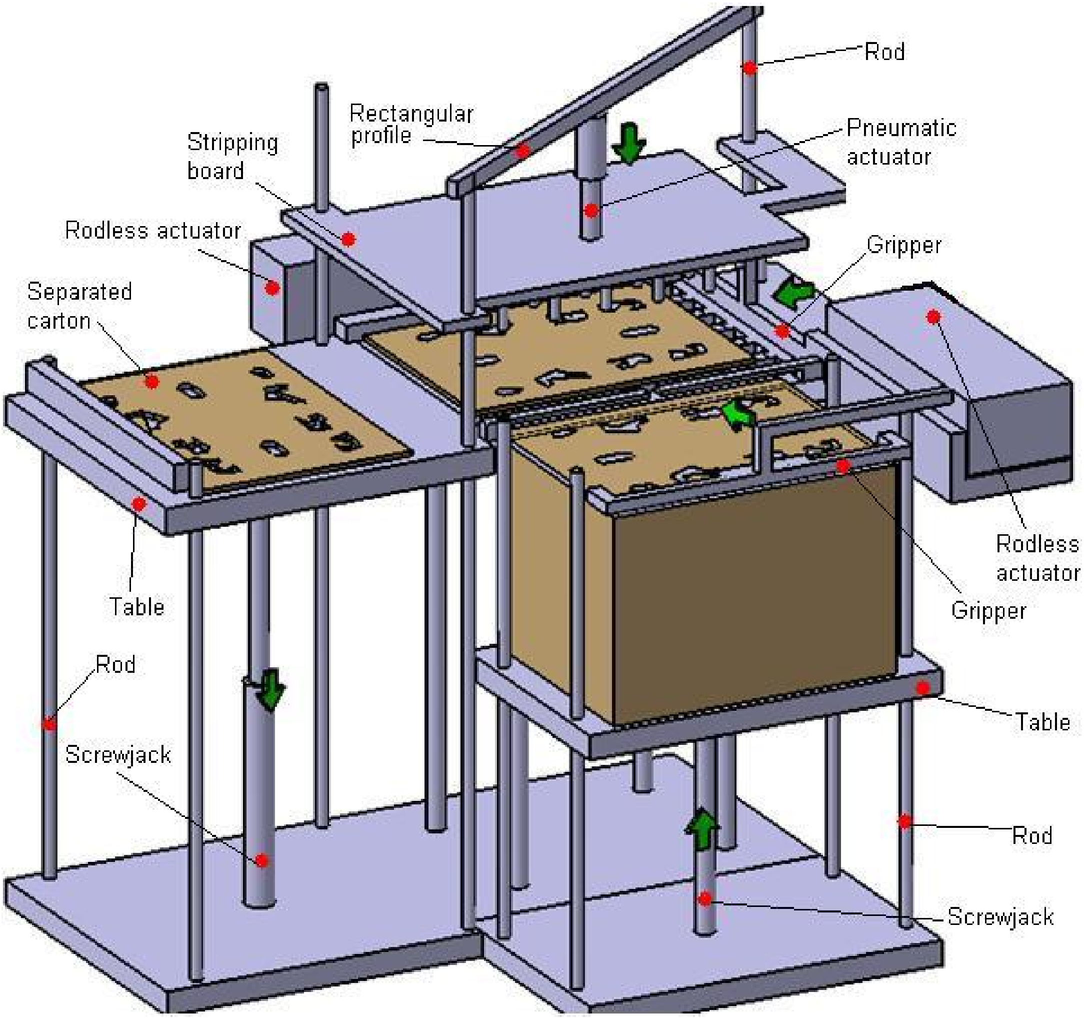


Figure 3.3. Concept 1: Carton Board Separation Machine Using Die Separation Technique

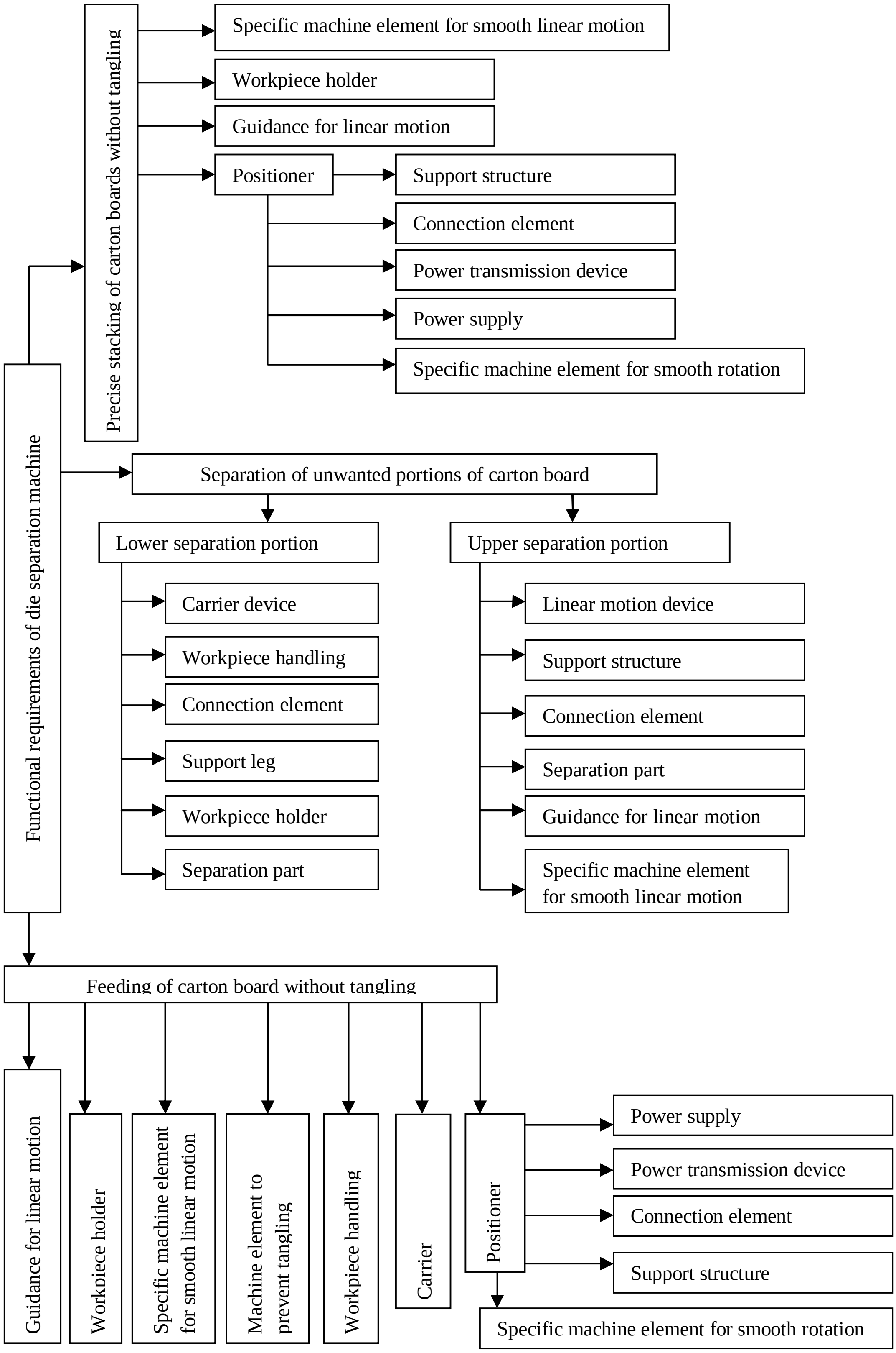


Figure 3.4. Functional Requirements of Die Separation Machine Based on Concept 1

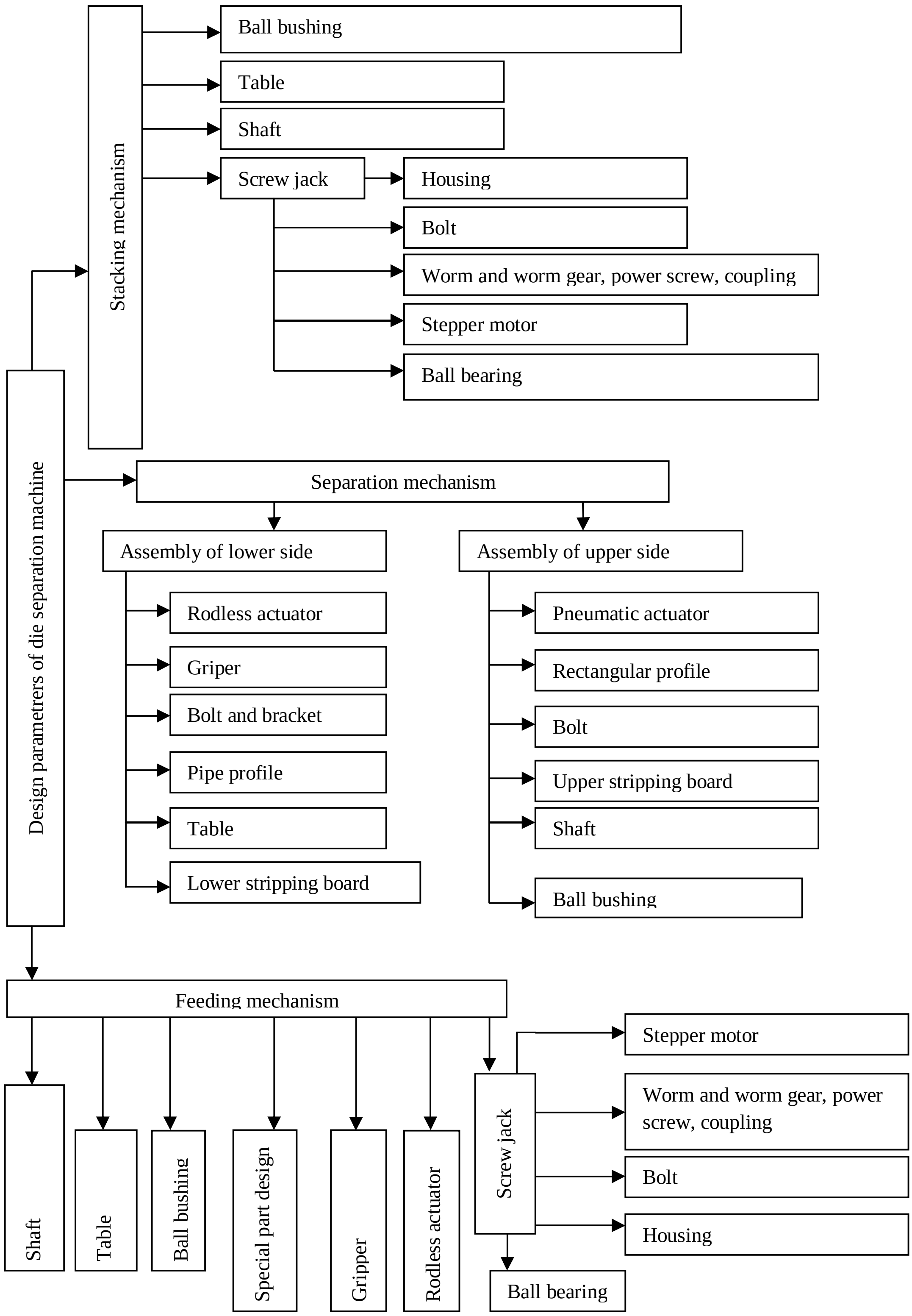


Figure 3.5. Design Parameters of Die Separation Machine Based on Concept 1

3.3.2. Concept 2: Using Vacuum Separation Technique

As seen from Figure 3.6, vacuum separation machine is similar to die separation machine. Their feeding and stacking processes are the same. In this concept there is vacuum gripper instead of stripping board and die in separation station. Unwanted portions of carton board are separated by vacuum. Then rodless actuator carries carton board to stacking station. Then the process is repeated similarly. Also functional requirement and design parameters of concept 2 are given respectively in Figure 3.7 and 3.8 by using axiomatic design method.

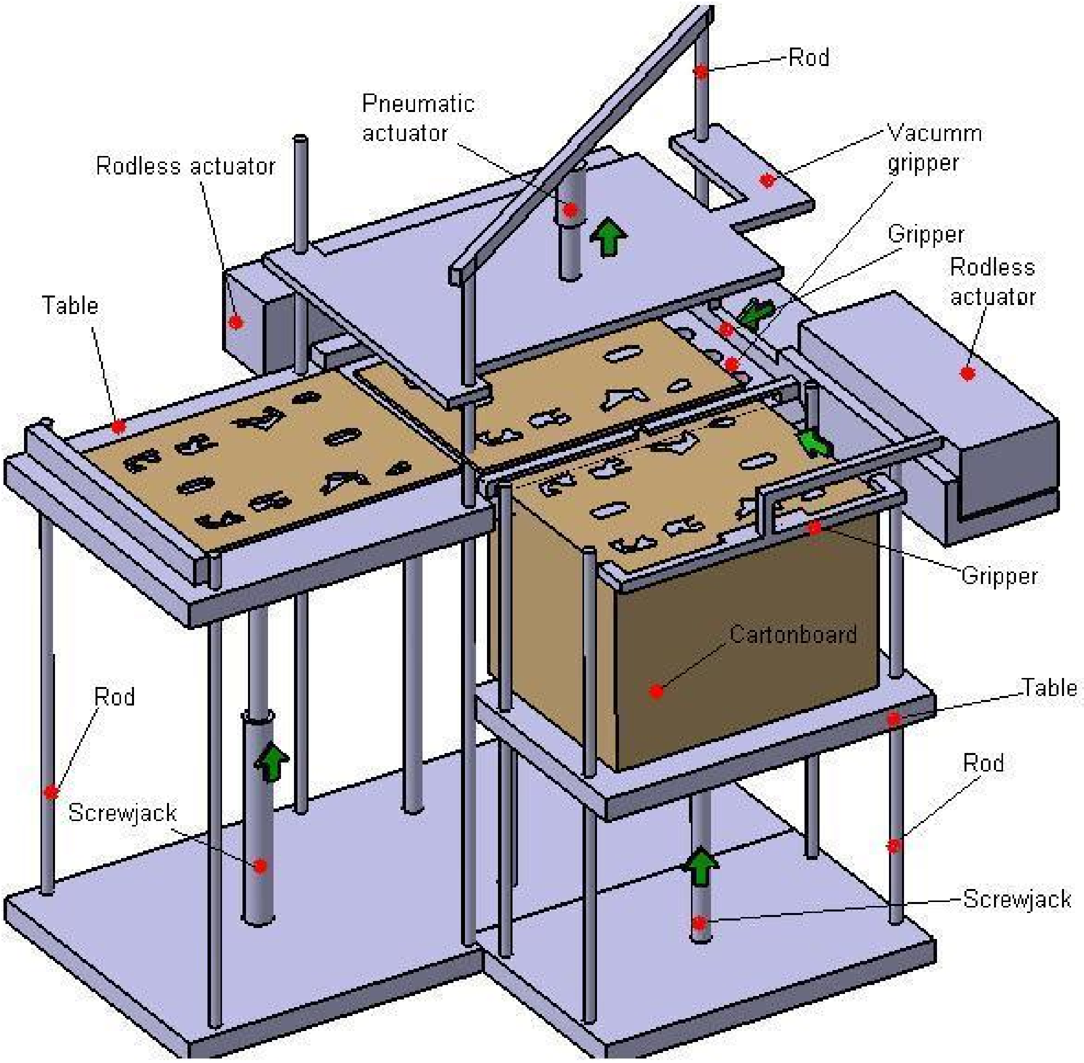


Figure 3.6. Concept 2: Carton Board Separation Machine Using Vacuum Separation Technique

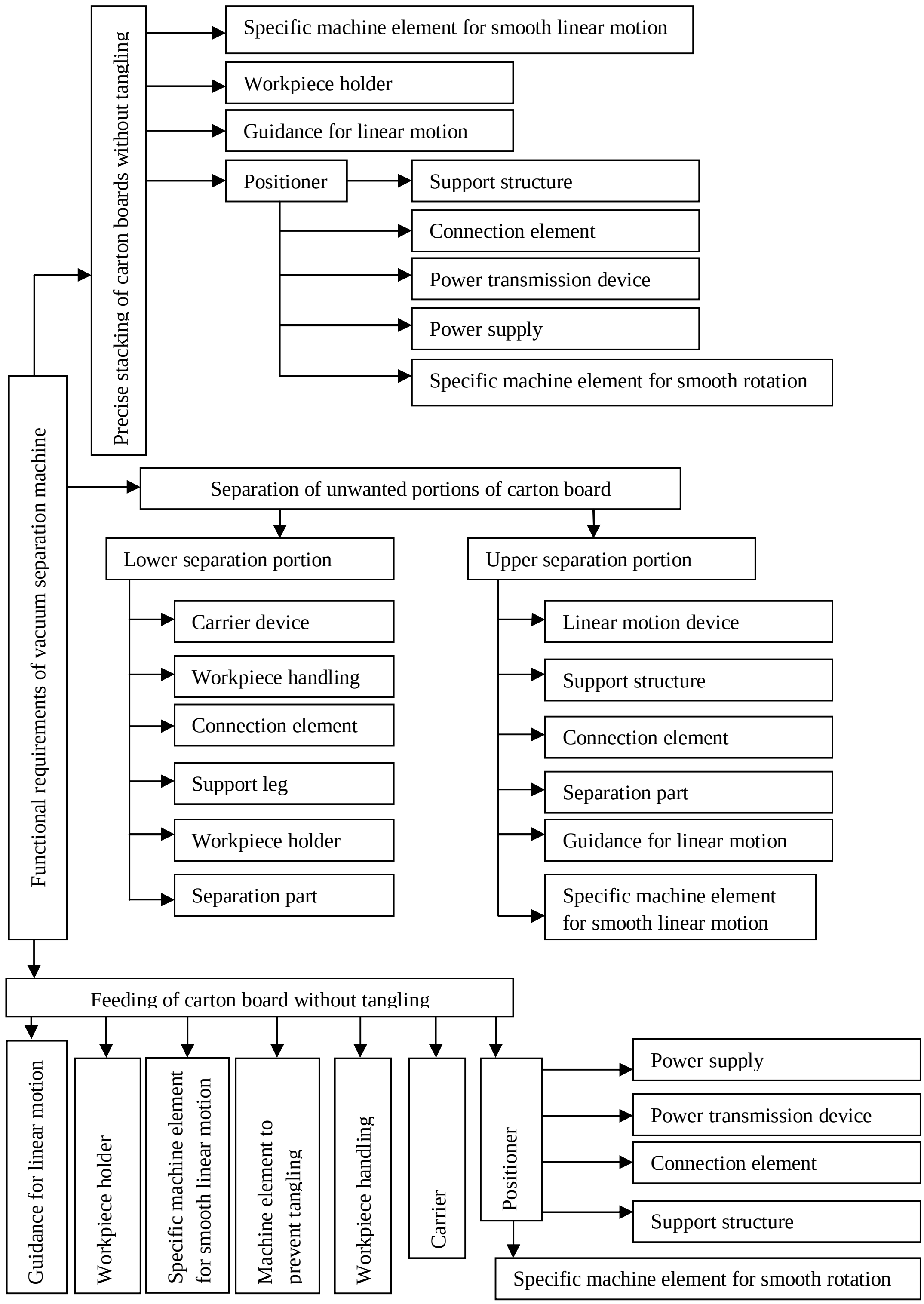


Figure 3.7. Functional Requirements of Vacuum Separation Machine Based on Concept 2

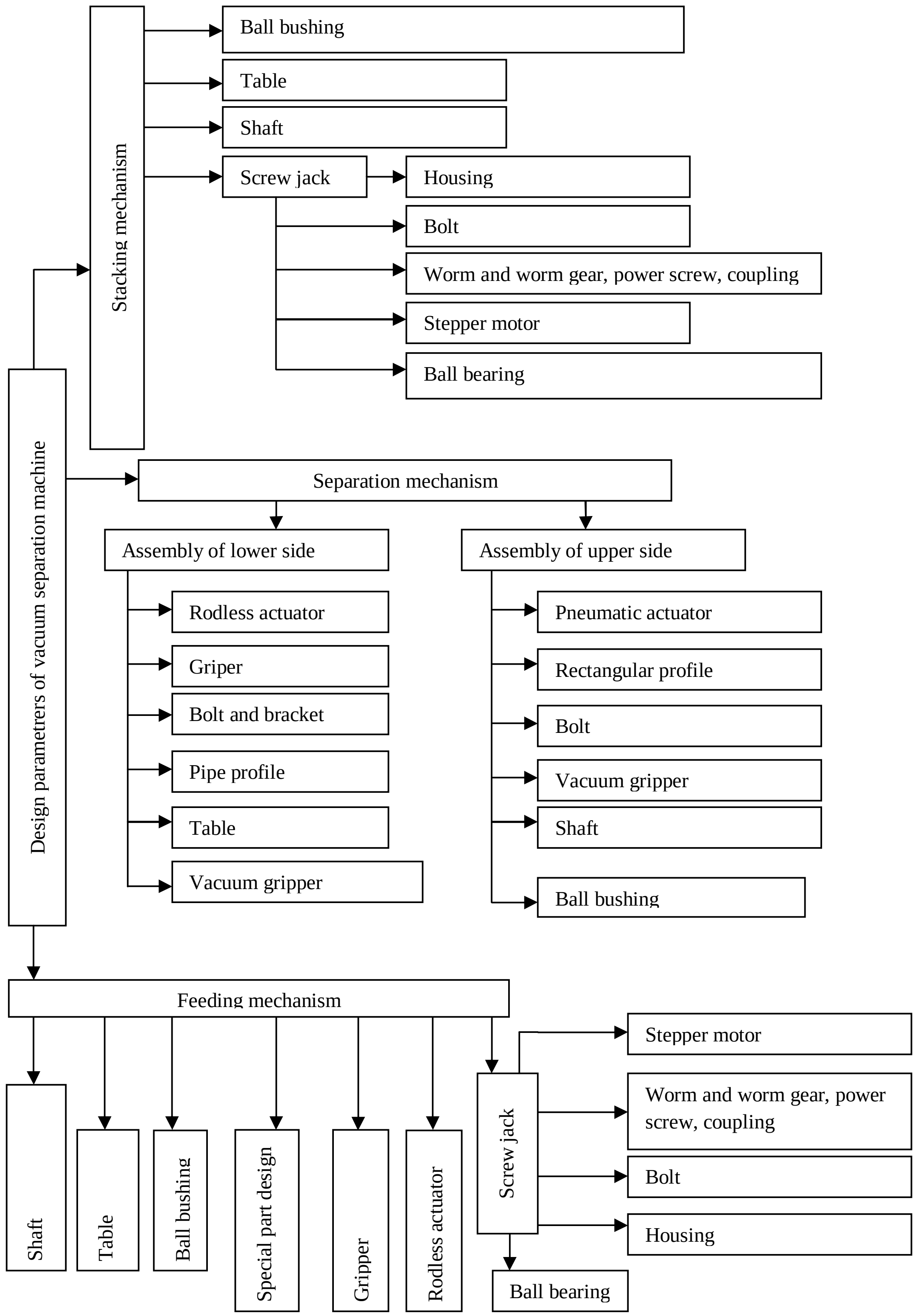


Figure 3.8. Design Parameters of Vacuum Separation Machine Based on Concept 2

3.3.3. Concept 3: Using Die and Vacuum Separation Technique

This concept draws inspiration from the other two concepts. So this concept combines die separation and vacuum separation machine. As pointed out in Figure 3.9, process begins with transfer of carton boards to separation station by a rodless pneumatic actuator. Then pneumatic actuator lowers the separation table (assembly of vacuum gripper and stripping board) to separate unwanted portions of the carton board. Then separated carton held by vacuum and the pneumatic actuator returns to retraction position. Finally carton carried to stacking station by a screw jack mechanism and process starts again. Also functional requirement and design parameters of concept 3 are given respectively in Figure 3.10 and 3.11 by using axiomatic design method.

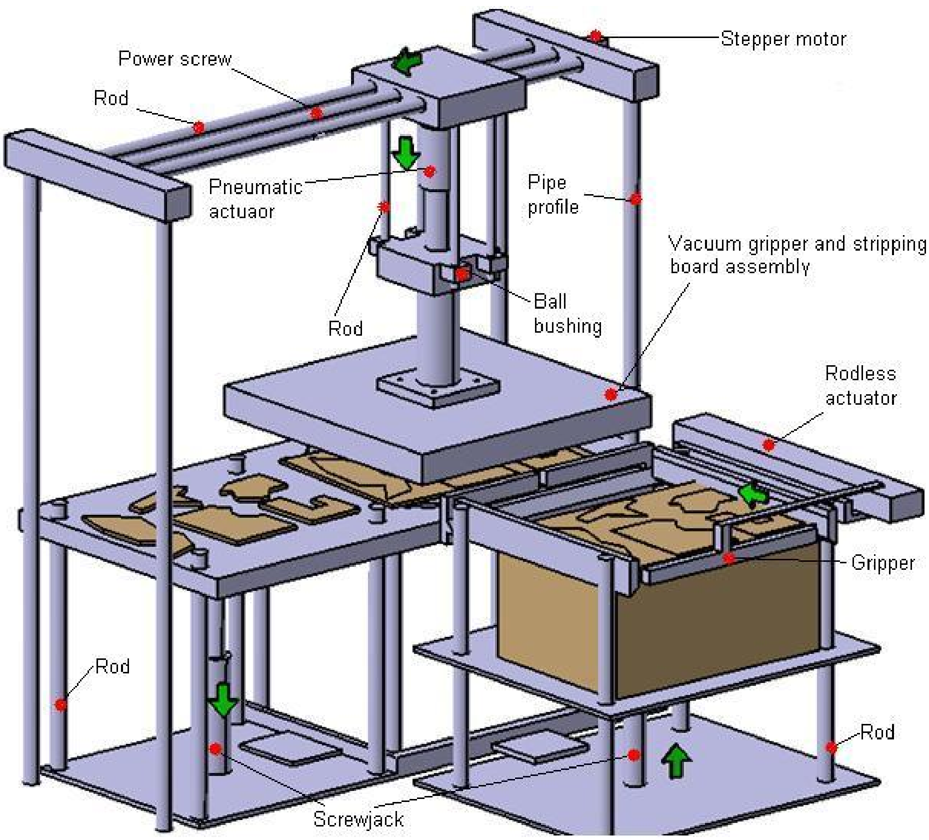


Figure 3.9. Concept 3: Carton Board Separation Machine Using Die and Vacuum Technique

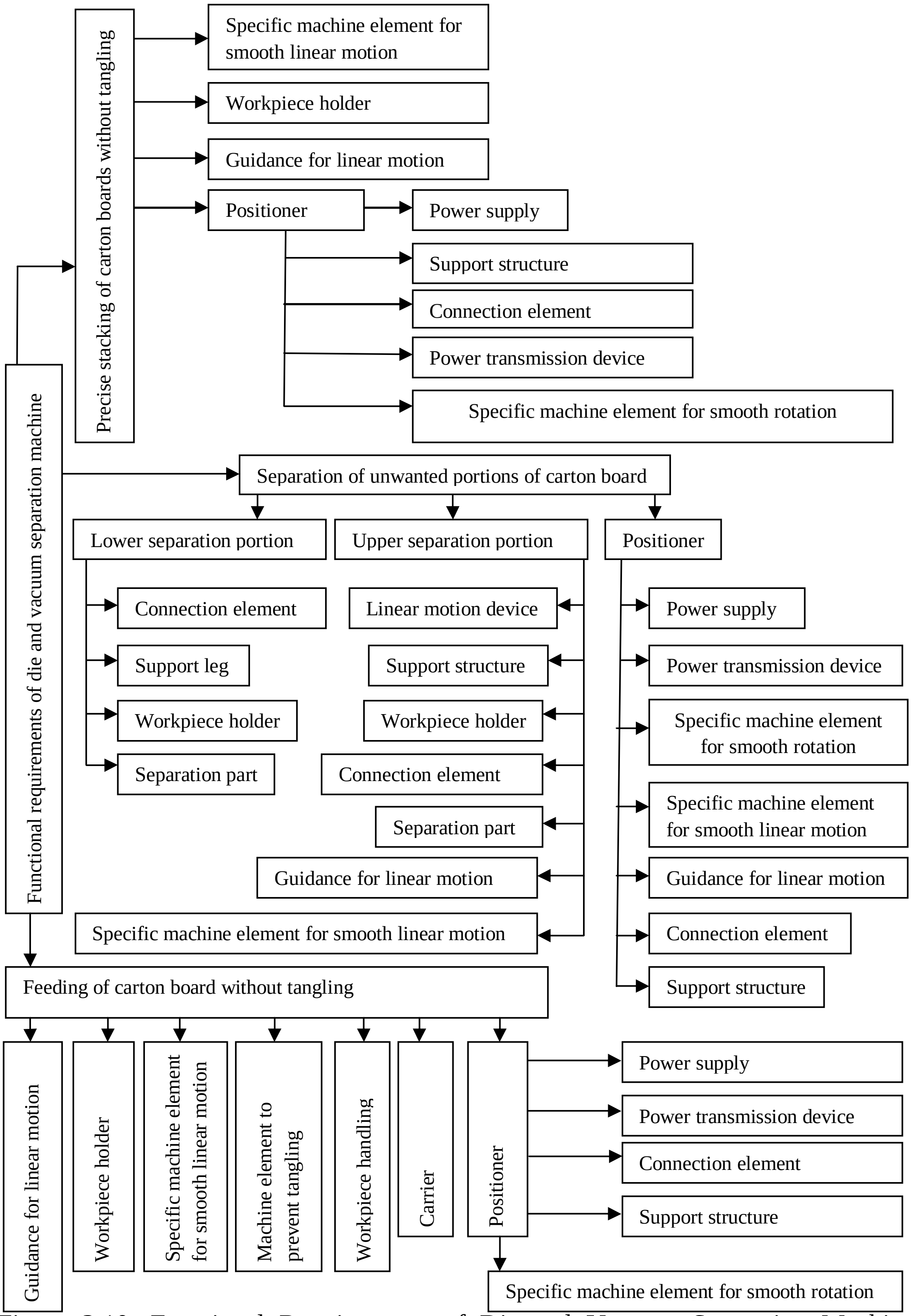


Figure 3.10. Functional Requirements of Die and Vacuum Separation Machine Based on Concept 3

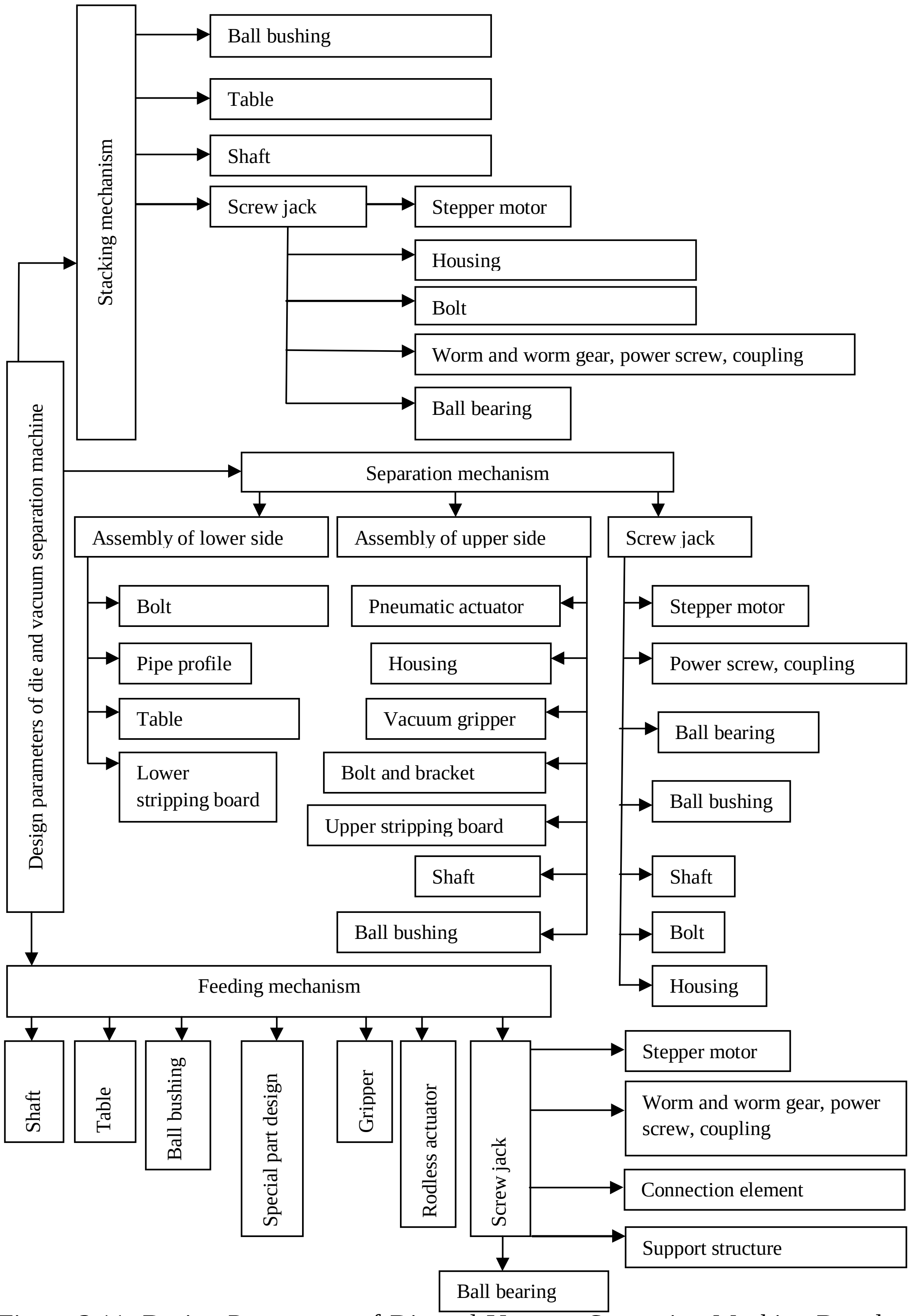


Figure 3.11. Design Parameters of Die and Vacuum Separation Machine Based on Concept 3

3.4. Concept Evaluation and Selection

Weighted decision matrix (Table 3.1) is going to be used for evaluation method in our design process. It is more quantitative than Pugh chart. Also it is not too complex like analytic hierarchy process. Value of weight factors was taken from quality function deployment chart. Concept 3 is chosen as a proper design among the generated concepts. Details are given in results and discussion section.

Table 3.1. Concept Selection Matrix

		Die separation machine		Vacuum separation machine		Die and Vacuum separation machine	
Design Criterion	Weight Factor	Score	Rating	Score	Rating	Score	Rating
1. Design against to infinite life							
2.Design according to deformation							
3.Design according to buckling							
4. Design against to surface strength							
5.Design for manufacturability							
6. Design for assembly							
7. Design for reliability							
8. Design for maintenance							
9.Flexibility							
10. Tangling of carton boards							
11.Orientation of carton boards							
12.Ease of use							
13.Production rate							
14.Less setup time							
15.Separation performance							
16.Cost							

3.5. Parametric Design of Concept 3

Parametric design of components of selected concept will be formed in this topic. In fact this is easiest step in the design process. The most important requirement in this step is to apply useful engineering theories for the design of each specific component to prevent failure of components.

Designed machine is divided to three sections these are feeding, separating and stacking section. Since feeding and stacking section has same parts both of them are presented in the same topic in contrast of separation station.

3.5.1. Design of Feeding and Stacking Station

3.5.1.1. Design of Carton Board Table For Deflection

Applied net force which occurs due to the mass of carton boards and pallet will cause deformation on the carton board table. This will adversely affect the feeding process. So amount of deformation must be minimized by designing table for deflection.

Singularity function method may be used among variant deflection methods. Loading condition of carton board table is shown in Figure 3.12.

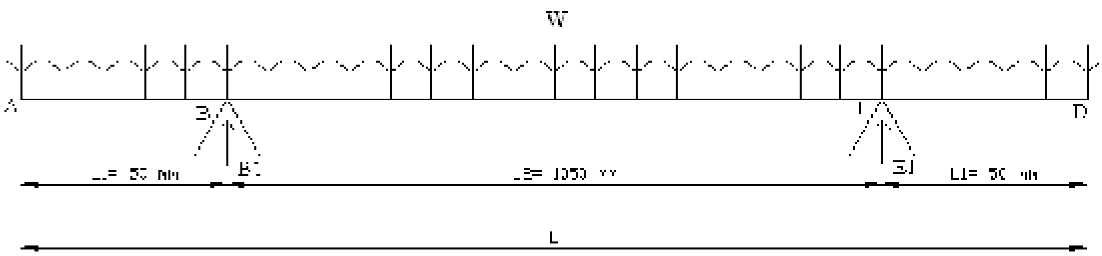


Figure 3.12. Carton Board Table Side View and Loading Condition.

W_{net} = [(mass of carton boards) + (mass of wooden pallet)].g

$W = \frac{Wnet}{L}$, assume that $L_3 = L_1 + L_2$, Where W: concentrated loading, W_{net} = net force, M: moment, B_1, E_1, F: reaction force and L, L1, L2, L3: length.

$$(\sum M)_A = 0 \Rightarrow (Wnet.\frac{L}{2}) = (B_1.L_1) + [E_1.(L_1+L_2)] \quad (3.1)$$

$$(\sum F)_y = 0 \Rightarrow Wnet = B_1 + E_1 \Rightarrow E_1 = Wnet - B_1 \quad (3.2)$$

$W(x) = W\langle x-0\rangle^0$

$V(x) = B_1\langle x-L_1\rangle^0 + E_1\langle x-L_3\rangle^0 - W\langle x-0\rangle^1$

$M(x) = B_1\langle x-L_1\rangle^1 + E_1\langle x-L_3\rangle^1 - \frac{W}{2}\langle x-0\rangle^2$

$EIy^{ll} = M(x) \Rightarrow EIy^{ll} = B_1\langle x-L_1\rangle^1 + E_1\langle x-L_3\rangle^1 - \frac{W}{2}\langle x-0\rangle^2$

$$EIy^{l} = \frac{B_1}{2}\langle x-L_1\rangle^2 + \frac{E_1}{2}\langle x-L_3\rangle^2 - \frac{W}{6}\langle x-0\rangle^3 + C_1$$

$$EIy = \frac{B_1}{6}\langle x-L_1\rangle^3 + \frac{E_1}{6}\langle x-L_3\rangle^3 - \frac{W}{24}\langle x-0\rangle^4 + C_1.x + C_2 \qquad (3.3)$$

Boundary conditions: $y(L_1)=0$ and $y(L_3)=0$

For $y(L_1)=0$ and from equation 3

$$C_2 = \frac{WL_1^4}{24} - C_1 L_1 \qquad (3.4)$$

For $y(L_3)=0$ and from equation 3

$$0 = \frac{B_1}{6}\langle L_2\rangle^3 - \frac{W}{24}\langle L_3\rangle^4 + C_1 L_3 + C_2 \qquad (3.5)$$

Use equation 4 in equation 5 => $0 = \frac{B_1 L_2^3}{6} - \frac{WL_3^4}{24} + C_1 L_3 + \frac{WL_1^4}{24} - C_1 L_1$

$C_1.(L_3-L_1) = \frac{WL_3^4}{24} - \frac{WL_1^4}{24} - \frac{B_1 L_2^3}{6}$ (note that $L_3 = L_1 + L_2$)

$C_1 L_2 = \frac{WL_3^4}{24} - \frac{WL_1^4}{24} - \frac{B_1 L_2^3}{6}$

$$C_1 = \frac{W}{24L_2}(L_3^4 - L_1^4) - \frac{B_1 L_2^2}{6} \qquad (3.6)$$

From equation 4 and 6

$$C_2 = \frac{WL_1}{24}\left[L_1^3 - \left(\frac{L_3^4 - L_1^4}{L_2}\right)\right] + \frac{B_1 L_2^2 L_1}{6} \qquad (3.7)$$

Maximum deflection will occur in the middle of table so y $(\frac{L}{2})$ must be equal minimum deflection.

3.5.1.2. Selection of Screw Jack

Two screw jacks will be used to obtain precision of motion. Selection procedure of screw jack is shown in Figure 3.13. For every step in the selection procedure following formulas are used

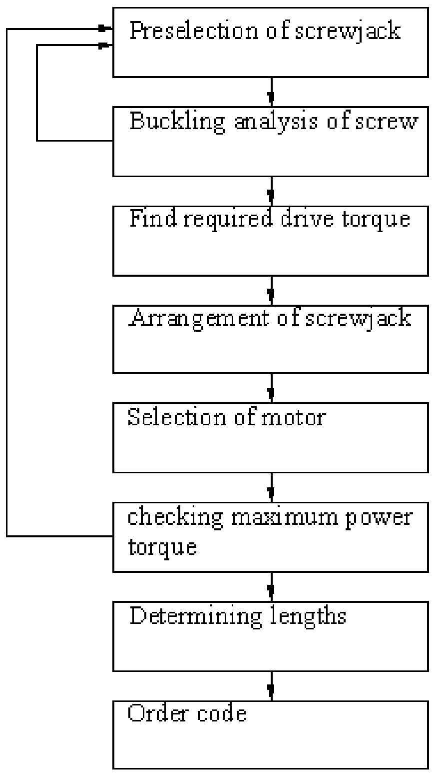


Figure 3.13. Selection Procedure of Screw Jack

Step 1: Pre-selection of Screw Jack :MSZ-5-SN is selected tentatively from zimm product catalog (www.zimm.com).

Step 2: Buckling Analysis of Screw**:**After pre-selection of screw jack, buckling will be considered by following formulas.

Euler formula must be used since zimm advised and since screw is thin bar subjected to compressive load.

$$P_{cr}=\frac{\pi^2 EI}{L_e^2} \qquad (3.8)$$

The screw may be considered as supported one end fixed, one end hinged. Then

$$L_e=\frac{L}{2} \qquad (3.9)$$

From equation 8 and 9 => $I=\frac{P_{cr}L^2}{4\pi^2 E}=\frac{\pi d_r^4}{64}$ so

$$d_r^4=\frac{64P_{cr}L^2}{4\pi^3 E} \qquad (3.10)$$

P_{cr}= nP (n: factor of safety, P_{cr}: critical buckling load, P: load)

$P=\frac{\text{(Total weight).g}}{\text{number of screwjack}}$

Total weight= (mass of carton board + mass of wooden pallet + mass of carton board table)

Where (E: modulus of elasticity, d_r: root diameter of screw)

Step 3: Finding Required Drive Torque

$$M_G\text{(Drive torque)}=\frac{F(kN).P(mm)}{2.\pi.i.n_{gearbox}.n_{spindle}}+M_L(Nm) \qquad (3.11)$$

P: pitch

i: gear ratio

M_L= idling torque

Values of M_L, $n_{gearbox}$, $n_{spindle}$ will be taken from table in the zimm product catalogue.

Step 4: Arrangement of Screw Jack :Arrangement of screw jacks is shown in Figure 3.14.

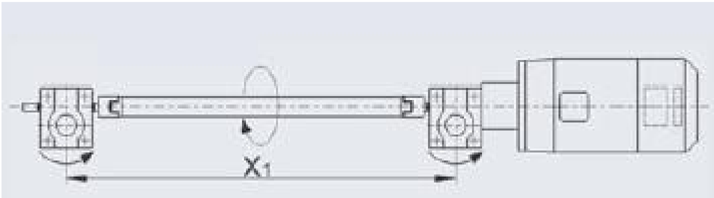


Figure 3.14. Screw Jack Layout

$$M_R = M_G.2,1 \quad (3.12)$$

M_R: Total drive torque for whole system

M_G: Required drive torque per screw jack.

Step 5: Selection of Motor

$$P_m(\text{power of motor}) = \frac{1,4.M_G.n(rpm)}{9550} \quad (3.13)$$

Step 6: Checking of Maximum Power Torque

Maximum drive torque table must be used from the zimm product catalog then compare with required drive torque.

Step 7: Determining Lengths

Spindle length = (Stroke) +(basic length)+(fixing flange)+(limit switch)+(protection against rotation) (3.14)

Protective tube length=(Stroke)+(basic length)+(limit switch)+(protection against rotation) +(cap) (3.15)

3.5.1.3. Selection of Ball Bushings, Shaft and End Supports

Position of screw jacks and ball bushings on carton board table are shown in Figure 3.15.

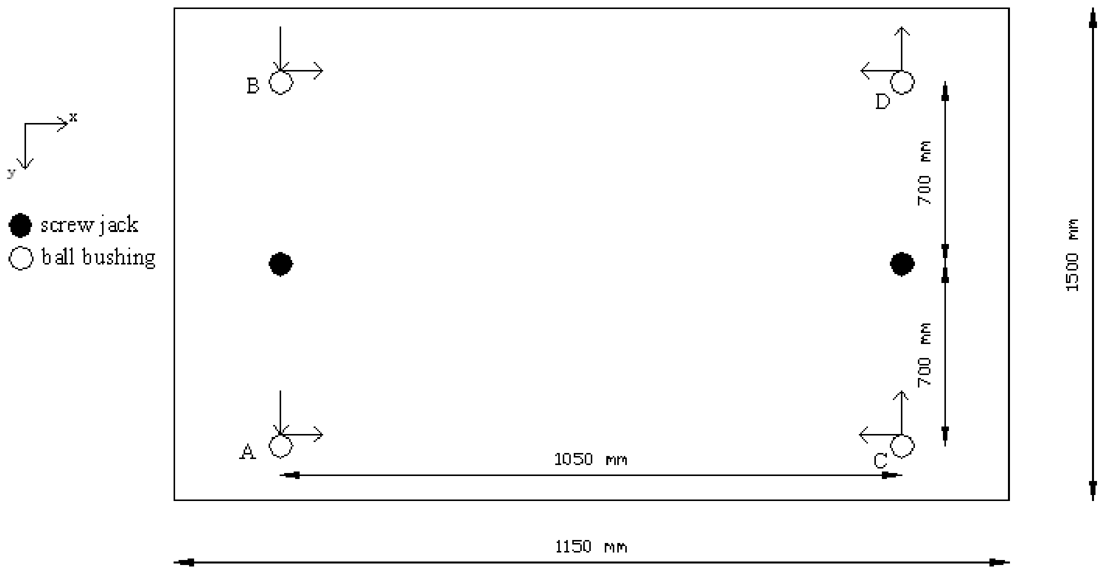


Figure 3.15. Top View of Carton Board Table

Product life of a ball bushing depends on the resultant load on the ball bushing, direction of resultant load, linear guide hardness and ball bushing orientation. So following formulas must be used to select a ball bushing.

W=[(mass of carton boards)+(mass of wooden pallet)+(mass of carton board table].g

$A_X=B_X=C_X=D_X=\frac{WL_2}{2L_0}$

$A_y=B_y=C_y=D_y=\frac{WL_3}{2L_0}$

$P=\sqrt{A_x^2 + A_y^2}$

L_2: distance between load action point to driving force (-x axis)

L_3: distance between load action point to driving force (-y axis)

L_0: distance between centers of ball bushings

$$Lm=2.s.f.L_h.60 \tag{3.14}$$

s: stroke

f: frequency in cycles per minute

L_h: required life in hour

$$W_R=\frac{P}{K_0.K_S.K_L} \text{ (}K_0\text{, }K_s\text{, }K_L\text{ will be taken from catalog)} \tag{3.15}$$

W_R= required dynamic load capacity

K_O = factor for direction of resultant load

K_S = shaft hardness factor (Equals 1.0 for 60 Case LinearRace)

K_L = load correction factor

$$\text{(Load most heavily loaded bearing)}= \left(\frac{\text{maximum applied load}}{K_0}\right) \tag{3.16}$$

3.5.1.4. Design of Carton Board Gripper Against to Deformation

Dimensions of gripper are shown in Figure 3.16.

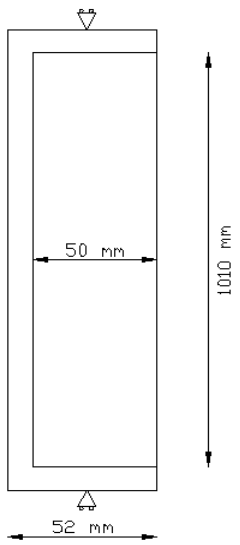


Figure 3.16. Top View of Gripper

Duty of gripper is transferring of carton boards which are cut by die cutter in desired shape from feeding station to separation station. Mechanical strength of cut carton boards is lower. So deflection of gripper will cause separation on carton boards before they are processed in the separation station. This may cause tangling on feeding station. To prevent this, gripper must be designed against to deflection. For this reason following formulas are be used.

$M_{gripper}$(mass of griper)=V(m^3).d($\frac{kg}{m^3}$)

$$W=\frac{M_{gripper}\cdot g}{L} \qquad (3.17)$$

Loading condition of gripper is shown in Figure 3.17.

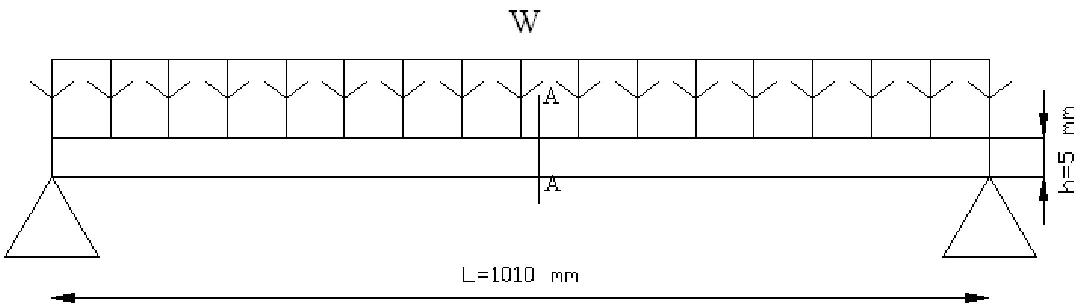


Figure 3.17. Load Condition of Gripper.

Equation 20 is obtained from deflection table according to loading condition. Deflection equation for this loading condition is available in literature (Beer et al, 2009).

$$y_{max}=\frac{5WL^4}{384EI} \qquad (3.20)$$

3.5.1.5. Selection of Rodless Actuator for Carton Board Gripper

Following formulas are used to select rodless actuator according to Manufacturer's (FESTO) advice (Direction of force and moment are shown in Figure 3.18).

$$\frac{F_y}{F_{ymax}} + \frac{F_z}{F_{zmax}} + \frac{M_x}{M_{xmax}} + \frac{M_y}{M_{ymax}} + \frac{M_z}{M_{zmax}} \leq 1 \tag{3.21}$$

F_{ymax}, F_{zmax}, M_{xmax}, M_{ymax}, M_{zmax} will be taken from Festo's catalog.

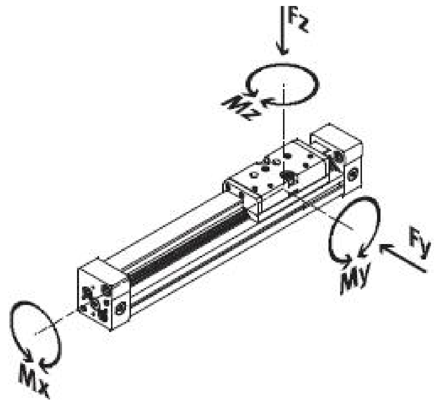


Figure 3.18. Direction of Forces and Moments on Rodless Actuator

Mass of the gripper will cause to reaction force and moment (F_z and M_x). To calculate the time of the process (transfer of a carton board from feeding station to separation station), traverse –time diagram which is shown in Figure 3.19 are used.

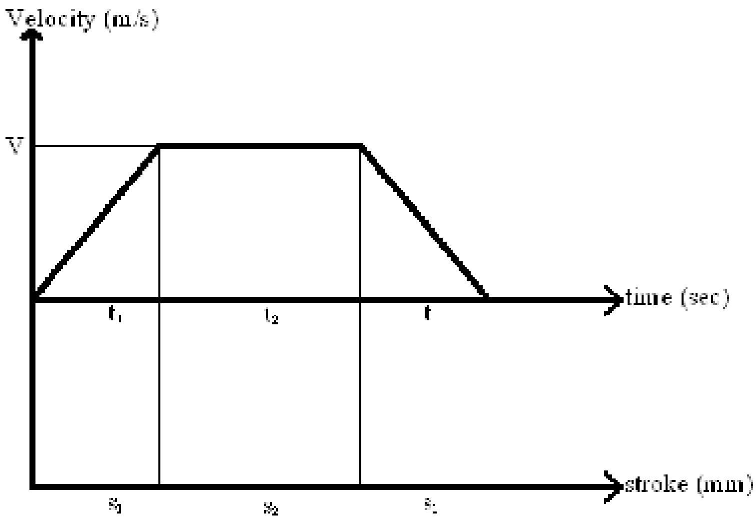


Figure 3.19. Traverse Time Diagram of a Actuator

Where s: stroke, t:time, V: velocity and a: acceleration

$$S_1 = \frac{1}{2}.a.{t_1}^2 \quad (3.22)$$

$$S_2 = V.t_2 \quad (3.23)$$

3.5.1.6. Selection of Liner Guide for Precise Motion of Gripper

Linear guide must be used to obtain precise motion when carton boards are transferred from feeding station to separation station. Following formulas must be used to select linear guide.

$$F = M_{gripper}.g \quad (3.24)$$

$$M_x = \left(\frac{F.L_{gripper}}{2}\right) \quad (3.25)$$

Where F: force and M_x: moment in x direction.

3.5.2. Design of Separation Station

3.5.2.1. Selection of Vacuum Gripper

Dimensions of chosen vacuum gripper are shown in Figure 3.20. It is obtained from a manufacturer which is called as joulin. Lifting capacity changes according to object which will be lifted.

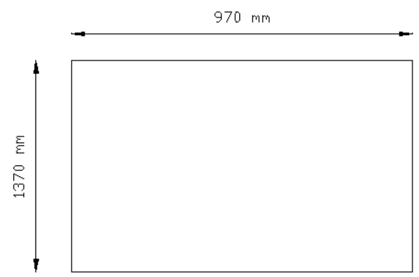


Figure 3.20. Dimensions of Vacuum Gripper

Thickness of vacuum gripper: 45 mm

Weight of vacuum gripper: 58,5 kg

3.5.2.2. Design of Stripping Board Against to Deformation

If stripping board is deflected more than allowable value, this will cause falling of separated carton boards from vacuum gripper. So this must be eliminated by selecting minimum amount of deflection. Top view of the stripping board and loading condition of stripping board are shown in Figures 3.21 and 3.22 respectively.

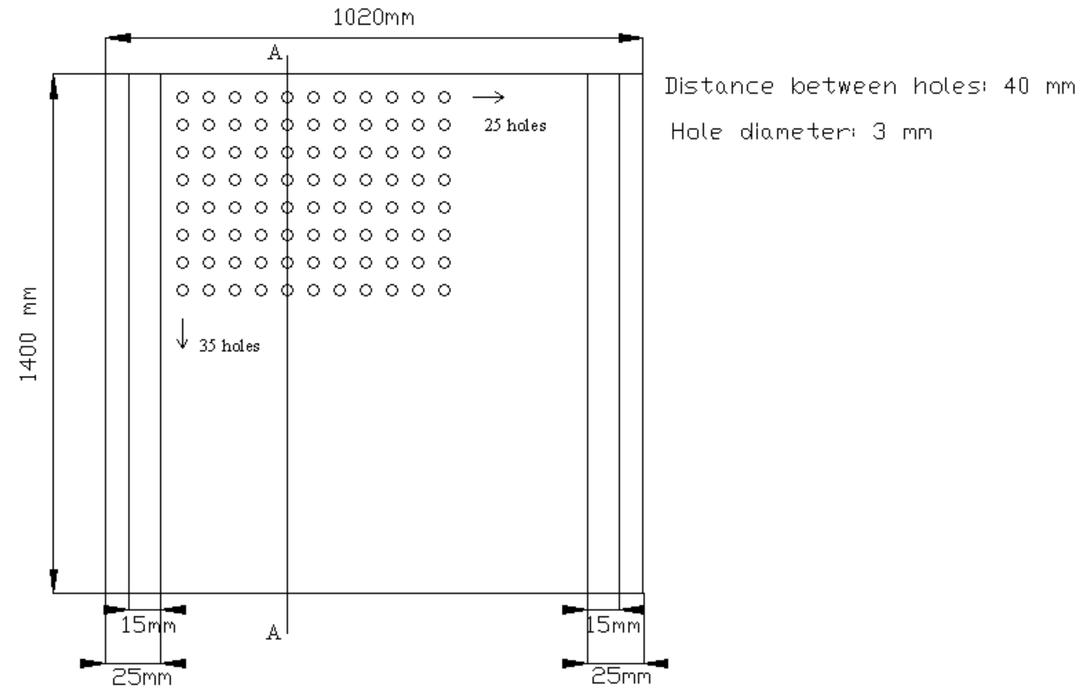


Figure 3.21. Overall Dimension of Stripping Board

$$W_{net} = m_{stripping\ board} \cdot g \tag{3.26}$$

$$W = \frac{W_{net}}{L} \tag{3.27}$$

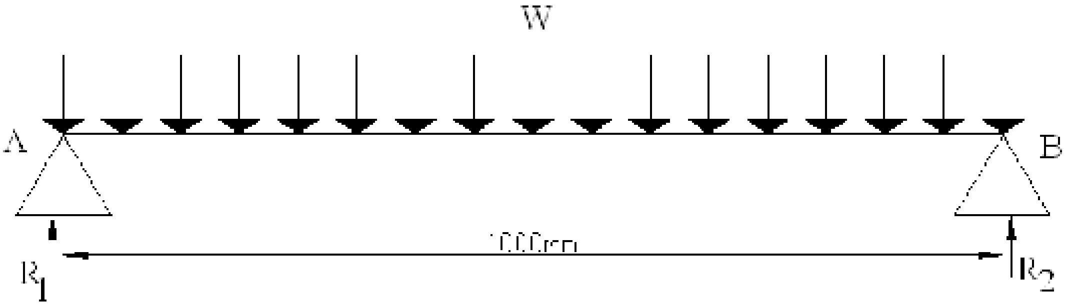


Figure 3.22. Loading Condition of Stripping Board

Equation 29 is obtained from deformation table according to loading condition (Figure 3.22). For this loading deflection equation is given by Beer et al in 2009.

$$y_{max} = \frac{5WL^4}{384EI} \tag{3.28}$$

A-A section of stripping board is shown on Figure 3.23.

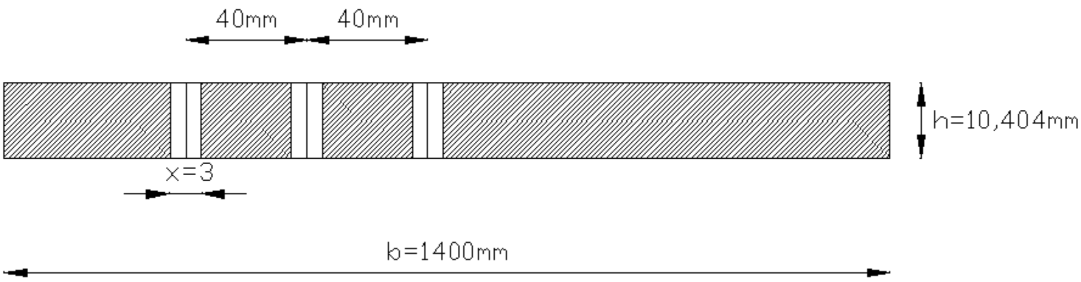


Figure 3.23. A-A Section of Stripping Board.

$$I = \left(\frac{1}{12}bh^3\right) - \left(\frac{1}{12}xh^3n\right) \tag{3.29}$$

Where n: number of holes and I: moment of inertia.

3.5.2.3. Selection of Rectangular Profile For Stripping Board

According to Figure 3.22 following equations 31 and 32 are obtained.

$$(\sum M)_A = 0 \Rightarrow (Wnet.\frac{L}{2}) = (R_2.L) \tag{3.30}$$

$$(\sum F)_y = 0 \Rightarrow Wnet = R_1 + R_2 \tag{3.31}$$

Then profile must be selected using maximum shear stress theory with following formulas which is given by Richard et al in 1986.

$$\sigma_x = \frac{Mc}{I} \tag{3.32}$$

$$\tau_{xy} = \frac{F}{A} \tag{3.33}$$

$$\sigma_{1,2} = \frac{\sigma_x + \sigma_y}{2} \pm \sqrt{(\frac{\sigma_x - \sigma_y}{2})^2 + \tau_{xy}^2} \tag{3.34}$$

$$\tau_{max} = \frac{\sigma_1 - \sigma_3}{2} \tag{3.35}$$

$$\tau_{max} \leq \frac{S_{sy}}{n} \tag{3.36}$$

3.5.2.3.(1). Selection of Screw to Joint Rectangular Profile to Stripping Board

$$P = \frac{m_{\text{stripping board}} \cdot g}{\text{number of screw}} \tag{3.37}$$

$$\sigma_x = \frac{P}{A} \tag{3.38}$$

$$\sigma_{1,2} = \frac{\sigma_x + \sigma_y}{2} \pm \sqrt{(\frac{\sigma_x - \sigma_y}{2})^2 + \tau_{xy}^2} \tag{3.39}$$

$$\sigma_{ea} = \sqrt{\sigma_1^2 + \sigma_2^2 - \sigma_1\sigma_2} \tag{3.40}$$

$$\sigma_{ea} = \frac{S_y}{n} \tag{3.41}$$

3.5.2.4. Selection of Actuator to Move Vacuum Gripper in Vertical Direction

Total force which consists of lifting force, friction force and acceleration force must be calculated for the selection of actuator. After finding total force actuator sizing nomogram must be used for the sizing of actuator. So following formulas must be used to select actuator.

$$F_L(\text{Lifting force}) = (m_{\text{stripping board}} + m_{\text{vacuum gripper}} + m_{\text{profiles}})g \tag{3.42}$$

$$F_M(\text{acceleration force}) = (m_{\text{stripping board}} + m_{\text{vacuum gripper}} + m_{\text{profiles}})a \tag{3.43}$$

$$F_T(\text{Total force}) = F_L + F_M \tag{3.44}$$

To find acceleration value in equation 44, traverse time diagram are formed (Figure 3.24).

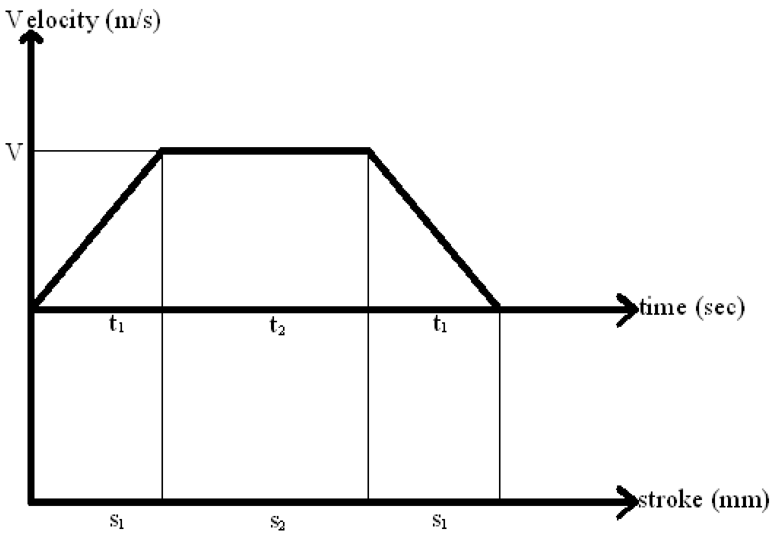


Figure 3.24. Traverse Time Diagram to Move Vacuum Gripper

Following formulas are used to find time and stroke variables in traverse-time diagram.

$$S_1 = \frac{1}{2}.a.t_1^{\ 2} \qquad (3.45)$$

$$S_2 = V.t_2 \qquad (3.46)$$

3.5.2.5. Selection of Ball Bushing and Shaft to Obtain Precise Motion in Vertical Direction

Factors which affect the performance of ball bushing are discussed in section 3.4.1.3. But here there is one difference. There is no reaction force in y direction since L_3=0. Following formulas are given to select ball bushing. Position of ball bushings according to actuator are shown in Figure 3.25.

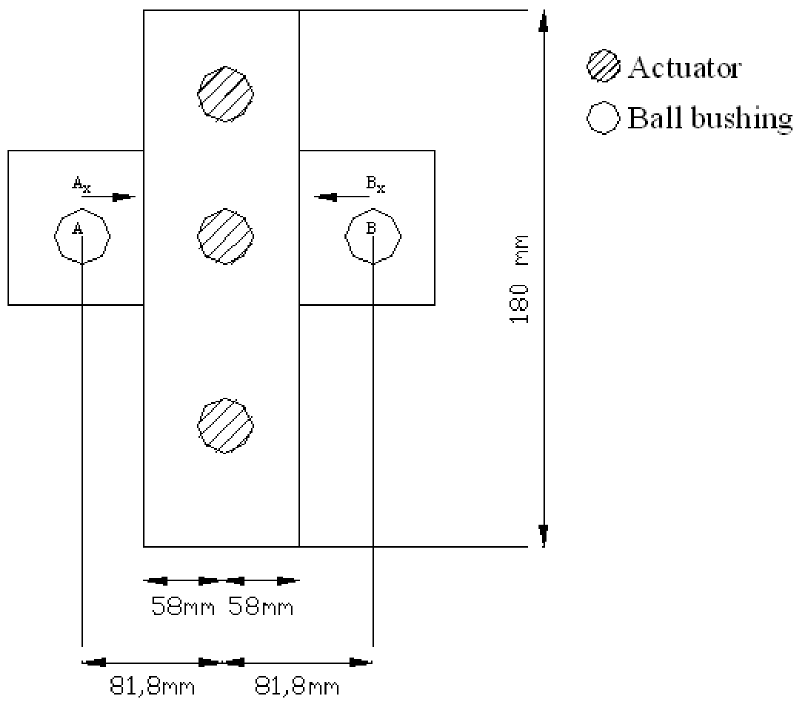


Figure 3.25. Position of Ball Bushings Relative to Actuator 2

$W=[(m_{stripping\ board})+(m_{vacuum\ gripper})+(m_{profiles})].g$

$A_X=B_X=\frac{WL_2}{2L_0}$

$A_y=B_y= 0$

$$P=\sqrt{A_x^{2} + A_y^{2}}$$

L_2: distance between load action point to driving force (-x axis)

L_3: distance between load action point to driving force (-y axis)

L_0: distance between centers of ball bushings

$$Lm=2.s.f.L_h.60 \tag{3.47}$$

s: stroke

f: frequency in cycles per minute

L_h: required life in hour

$$W_R=\frac{P}{K_0.K_s.K_L} \text{ (}K_0\text{, }K_s\text{, }K_L\text{ will be taken from catalog)} \tag{3.48}$$

W_R= required dynamic load capacity

$$\text{(Load most heavily loaded bearing)}=\left(\frac{\text{maximum applied load}}{K_0}\right) \tag{3.49}$$

3.5.2.6. Design of Interfaces to Join Parts

Interfacing members are need to join vacuum gripper to actuator (connection element 1) and to join actuator to rodless actuator (connection element 2). These two parts has same functions. Therefore they are designed in this section. Overall view of the part is given in Figure 3.26.

When a part which is not available in stock is designed, firstly it must be considered which material gives best performance. So firstly best material for connection element may be determined by using material selection method (Ashby, 1999).

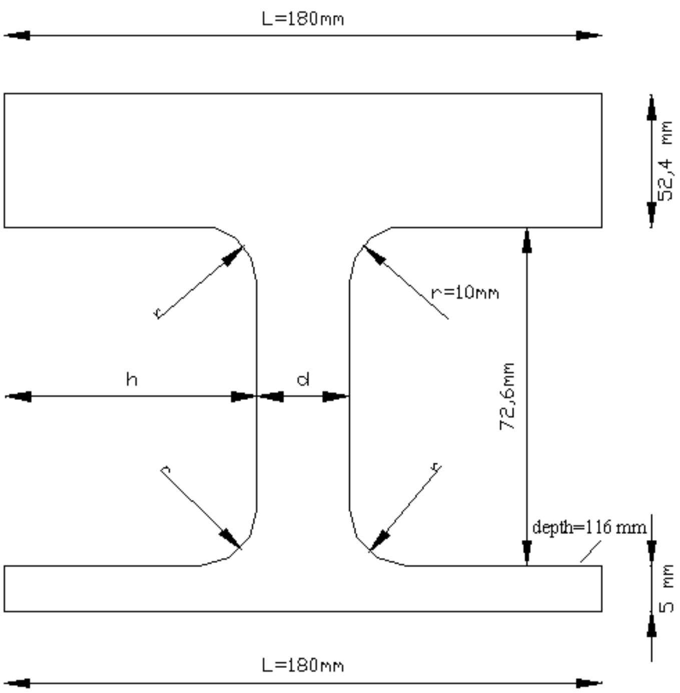


Figure 3.26. Dimension of Connection Element

There will be only axial stress on the connection element. So following formulas will be used to find performance index. Then performance index will be used to select best material for connection element.

$\sigma = \frac{P}{A}$, $\sigma \le \sigma_f$

$\frac{P}{A} \le \sigma_f$ => $A = \frac{p}{\sigma_f}$

Cost= $A.L.d.C_R$ => Cost= $\frac{p}{\sigma_f}.L.d.C_R$, performance index: $(\frac{\sigma_f}{dC_R})$

From strength and relative cost/unit volume chart values provided in Table 3.2 is obtained.

Table 3.2. Material and Performance Index Chart

Material	Performance index
Glass	
Al alloy	
Mg alloy	
Ti alloy	
Steel	

The thin part of the interface may also be subjected to buckling. Therefore the column subjected to buckling can be designed using following formulas:

$$F_{pressure} = P.A = P.\pi.\, r^2 \tag{3.50}$$

(P:operating pressure, r: radius of selected actuator and $F_{pressure}$: pressure force)

$$P_{cr} = \frac{\pi^2 EI}{L_e^2} = n\, F_{pressure} \tag{3.51}$$

(n: factor of safety, P_{cr}= critical bucklin load, L_e: equivelant buckling length, I: moment of inertia and E: modulus of elasticity).

Two end fixed $$L_e = \frac{L}{2} \tag{3.52}$$

$$I = \frac{\pi d^4}{64} \tag{3.53}$$

Lastly part must be designed for infinite life. Because exerted force is fluctuating between tensile and compression load. The part will be subjected fatigue failure. Also stress concentration effect existed on the part. So effect of stress concentration factor must be considered in design. For these reasons following formulas are used to prevent fatigue failure.

Applied force fluctuate between F_T and $F_{pressure}$

$$F_L(\text{Lifting force}) = (m_{stripping\ board}+m_{vacuum\ gripper}+m_{profiles})g \quad (3.54)$$

$$F_M(\text{acceleration force}) = (m_{stripping\ board}+m_{vacuum\ gripper}+m_{profiles})a \quad (3.55)$$

$$F_T = F_L+F_M \quad (3.56)$$

$F_{max}=F_{pressure}$, $F_{min}=F_T$

$$\sigma_{max} = \frac{4K_tF_{max}}{\pi(D-2h)^2} \quad (3.57)$$

$$\sigma_{min} = \frac{4K_tF_{min}}{\pi(D-2h)^2} \quad (3.58)$$

$$\sigma_{mean} = \frac{\sigma_{max}+\sigma_{min}}{2} \quad (3.59)$$

$$\sigma_{amp} = \frac{\sigma_{max}-\sigma_{min}}{2} \quad (3.60)$$

K_t (stres concentration factor) for square shoulder with filet in circular shaft

$$S_e = S'_e.k_a.k_b.k_c.k_d.k_e.k_f \quad (3.61)$$

$$S'_e = [0,566-9,68.10^{-5}.S_{uc}].S_{uc} \ \text{(for axial loading)} \quad (3.62)$$

$$Ke = \frac{1}{K_f} \quad (3.63)$$

$$K_f = 1+\left(\frac{K_t-1}{1+\sqrt{\frac{a}{r}}}\right) \quad (3.64)$$

$$\sqrt{a}= \frac{139}{S_{ut}} \quad (3.65)$$

$$S_m= \frac{S_e}{\frac{\sigma_{amp}}{\sigma_{mean}}+\frac{S_e}{S_{ut}}} \quad (3.66)$$

$$n= \frac{S_m}{\sigma_{mean}} \quad (3.67)$$

3.5.2.7. Selection of Rectangular Profile to Connect Connection Element with Selected Rectangular Profile of Stripping Board

As seen from Figure 3.27, reaction force F will cause bending stress and shear stress. So to prevent failure maximum shear stress theory may be used by following formulas.

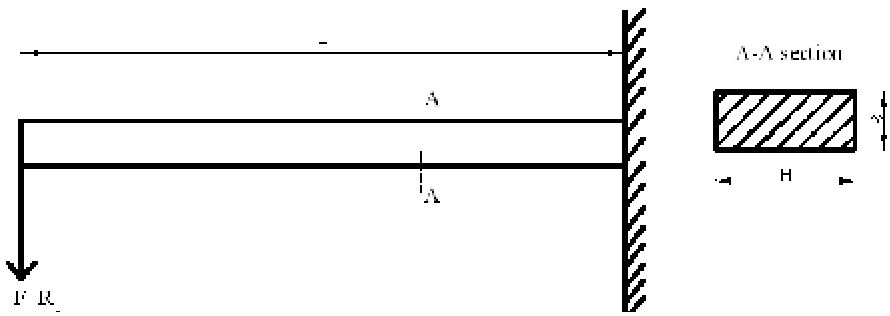


Figure 3.27. Load Condition of Rectangular Profile

$$\sigma_x = \frac{Mc}{I} \quad (3.68)$$

$$\tau_{xy}= \frac{F}{A} \quad (3.69)$$

$$\sigma_{1,2} = \frac{\sigma_x+\sigma_y}{2} \pm \sqrt{(\frac{\sigma_x-\sigma_y}{2})^2 + \tau_{xy}^2} \quad (3.70)$$

$$\tau_{max} = \frac{\sigma_1-\sigma_3}{2} \quad (3.71)$$

$$\tau_{max} \leq \frac{S_{sy}}{n} \quad (3.72)$$

3.5.2.8. Selection of Rodless Actuator For Transferring of Separated Carton Board From Separation Station to Stacking Station

Following formulas which are taken from festo catalogue are used to select rodless actuator (For direction of forces and moments according to position of rodless actuator are shown in Figure 3.18)

$$\frac{F_y}{F_{ymax}} + \frac{F_z}{F_{zmax}} + \frac{M_x}{M_{xmax}} + \frac{M_y}{M_{ymax}} + \frac{M_z}{M_{zmax}} \leq 1 \quad (3.73)$$

$$F_1=(m_{stripping\ board}+m_{vacuum\ gripper}+m_{profiles}+m_{connection\ element}+ m_{actuator}).g \quad (3.74)$$

$$F_2==(m_{stripping\ board}+m_{vacuum\ gripper}+m_{profiles}+m_{connection\ element}).a \quad (3.75)$$

$$F_z= F_1+F_2 \quad (3.76)$$

$$S_1=\frac{1}{2}.a.{t_1}^2 \quad (3.77)$$

$$S_2= V.t_2 \quad (3.78)$$

3.5.2.9. Design of Connection Element to Connect Actuator to Rodless Actuator

As mentioned before (in section 3.4.2.6) there is no need to explanation. Same logic is valid in this section too. Following formulas must be used against to fatique failure. Dimension of connection element is shown in Figure 3.28.

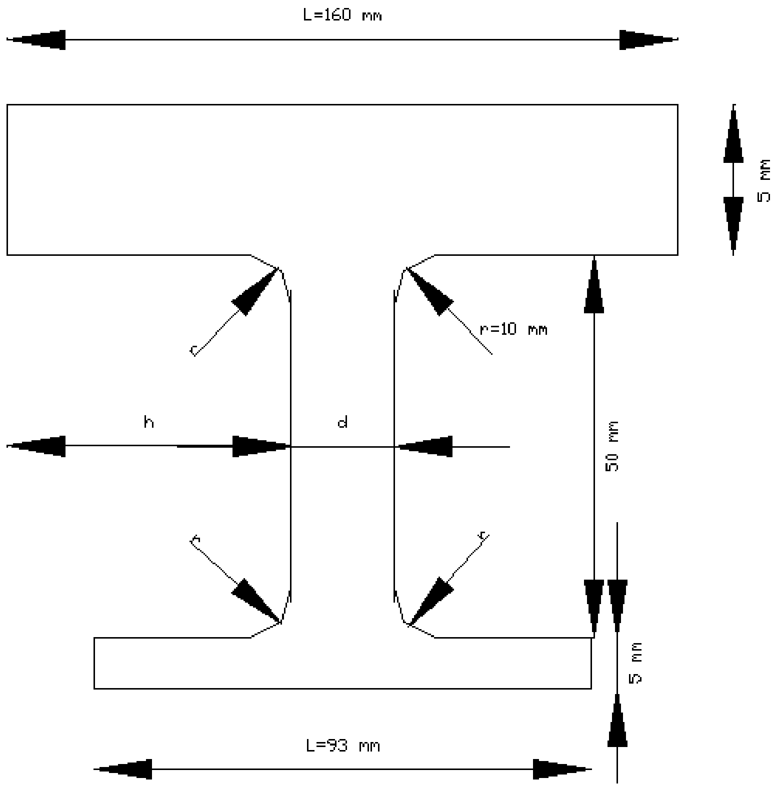


Figure 3.28. Dimensions of Connection Element 2

3.5.2.10. Design of Frame For Rodless Actuator

After finding dimensions of frame to prevent interferences between moving parts, force analysis are made for each profile. Then maximum stress is calculated for each profile and sizes of profiles are determined to stop failure. Used formulas for selection of each profile are given in order. Frame structure and dimensions are shown in Figure 3.29.

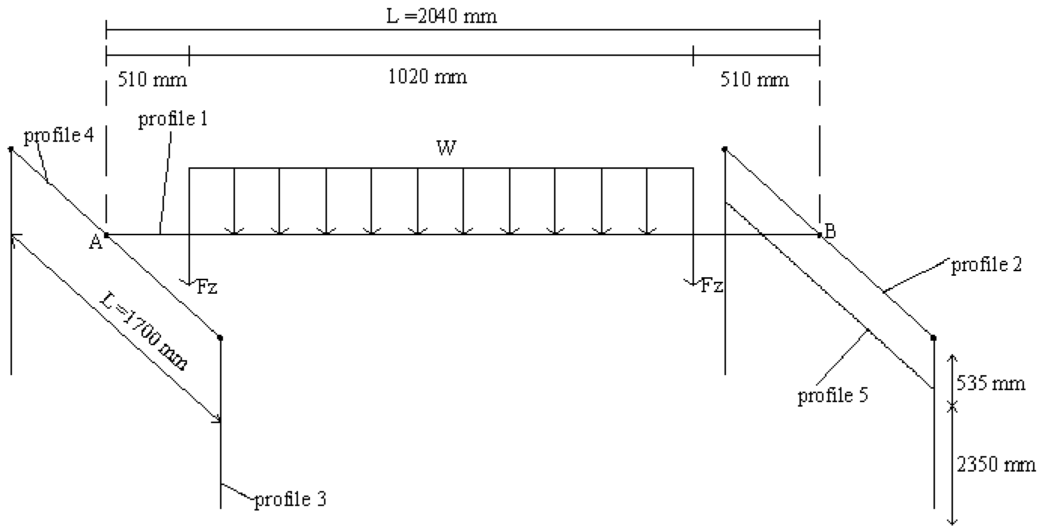


Figure 3.29. Structure of Frame

$$W_{net}=(m_{stripping\ board}+m_{vacuum\ gripper}+m_{profiles}+m_{connection\ element}+m_{actuator}+m_{rodless\ actuator}).g \quad (3.79)$$

$$W=\frac{W_{net}}{\text{stroke of rodless actuator}} \quad (3.80)$$

$$F_z=F_m \quad (3.81)$$

3.5.2.10.(1). Selection of Profile 1

As seen from Figure 3.30, reaction forces are calculated on connection points A and B using equilibrium equations. Then maximum shear stress theory are applied to determine profile size. Used equations are given follows:

$$(\sum M)_A = 0 \Rightarrow (W.\frac{L}{2}) + F_z.L_2+[F_z.(L_1+L_2)] = (R_2.L) \quad (3.82)$$

$$(\sum F)_y = 0 \Rightarrow Wnet+2F_z= R_1+ R_2 \quad (3.83)$$

$$\sigma_x = \frac{Mc}{I} \quad (3.84)$$

$$\tau_{xy}=\frac{F}{A} \tag{3.85}$$

$$\sigma_{1,2}=\frac{\sigma_x+\sigma_y}{2}\pm\sqrt{\left(\frac{\sigma_x-\sigma_y}{2}\right)^2+\tau_{xy}^2} \tag{3.86}$$

$$\tau_{max}=\frac{\sigma_1-\sigma_3}{2} \tag{3.87}$$

$$\tau_{max}\leq\frac{S_{sy}}{n} \tag{3.88}$$

$$I=\frac{1}{12}bh^3 \tag{3.89}$$

3.5.2.10.(2). Selection of Profile 2 and 4

Selection procedure of profiles 2 and 4 are similar to profile 1. After finding reaction forces, maximum shear stress theory are used to determine size of profiles 2 and 4.

3.5.2.10.(3). Selection of Profile 3

Exerted force on profile 3 will cause to buckling. SoEuler formulas which are given in the following equations are used to prevent failure.

$$P_{cr}=\frac{\pi^2 EI}{L_e^2}=n\,R_2 \text{ (n: factor of safety)} \tag{3.90}$$

One end fixed, one end free so L_e=2L (3.91)

$$I=\frac{1}{12}bh^3 \tag{3.92}$$

3.5.2.10.(4). Selection of Profile 5

Lower stripping board (Female stripping board) will be mounted to profile 5. When actuator is at extension position, there will be concentrated loading on profile 5 which is occurred by pressure force. So to prevent failure in profile 5 following equations are used.

$$F_{pressure}=P.A=P.\pi.\,r^2 \tag{3.93}$$

(P: operating pressure, r: radius of selected actuator)

$$W=\frac{F_{pressure}}{2L} \tag{3.94}$$

$$\sigma_x=\frac{Mc}{I} \tag{3.95}$$

$$\tau_{xy}=\frac{F}{A} \tag{3.96}$$

$$\sigma_{1,2}=\frac{\sigma_x+\sigma_y}{2}\pm\sqrt{(\frac{\sigma_x-\sigma_y}{2})^2+\tau_{xy}^2} \tag{3.97}$$

$$\tau_{max}=\frac{\sigma_1-\sigma_3}{2} \tag{3.98}$$

$$\tau_{max}\leq\frac{S_{sy}}{n} \tag{3.99}$$

3.5.3. Pneumatic Circuit of Corrugated Carton Board Stripping and Separation Machine

There are two design methods for drawing a pneumatic circuit. These are step counter design method and cascade design method. Both methods prevent formation of opposing signals like one way trip valve. Step counter design method is preferred since emergency module integration. When the emergency button is pushed, the normal sequence will stop after the current sequence step is completed. When the air supply is restored the interrupted sequence will continue to the end of cycle (traverse-time diagram of the circuit and pneumatic circuit are shown in Figures 3.30 and 3.31 respectively).

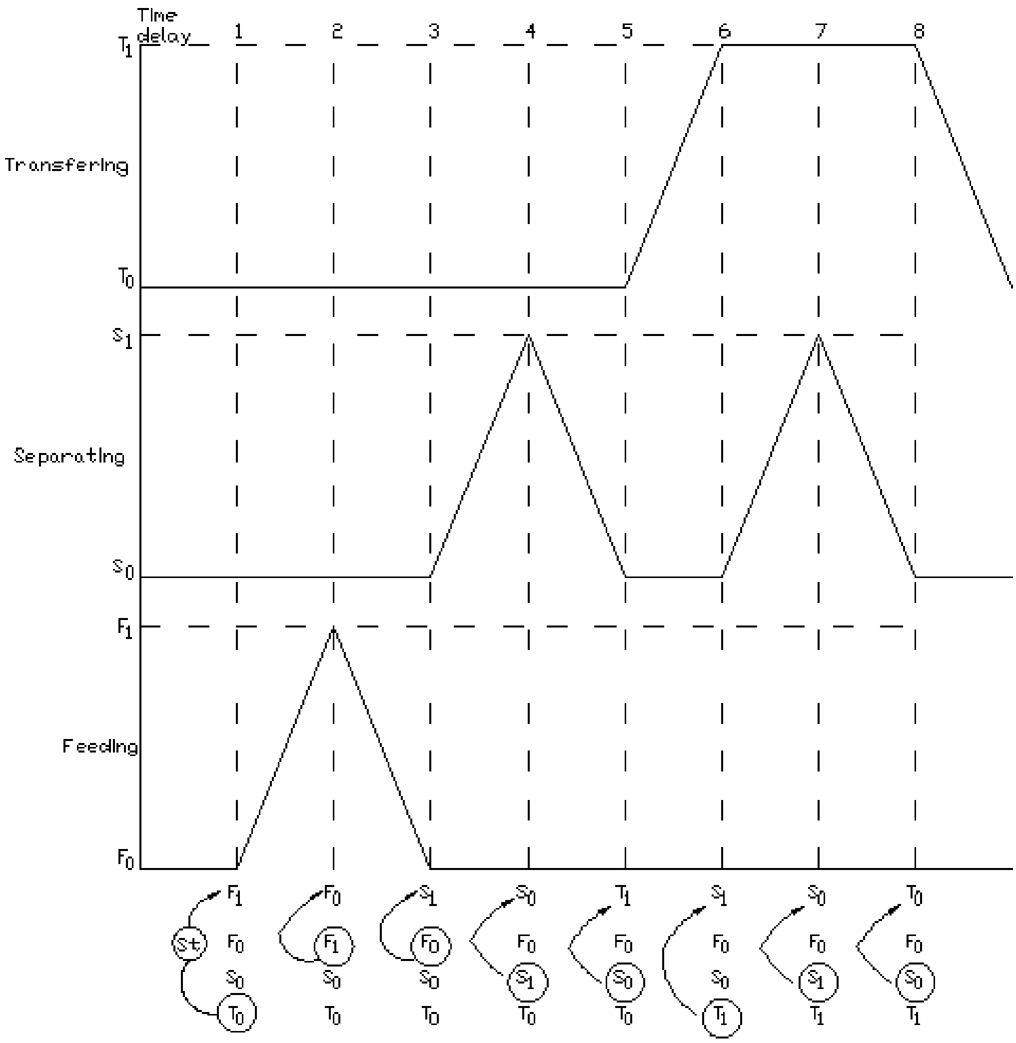


Figure 3.30. Traverse – Time Diagram

DCV inputs :

F1 = Step 1

F0 = Step 2

S1 = Step 3 + Step 6

S0 = Step 4 + Step 7

T1 = Step 5

T0 = Step 8

Step counter inputs:

Stepping module 1 = t_0 ● Start

Stepping module 2 = f_1

Stepping module 3 = f_0

Stepping module 4 = s_1

Stepping module 5 = s_0

Stepping module 6 = t_1

Stepping module 7 = s_1

Stepping module 8 = s_0

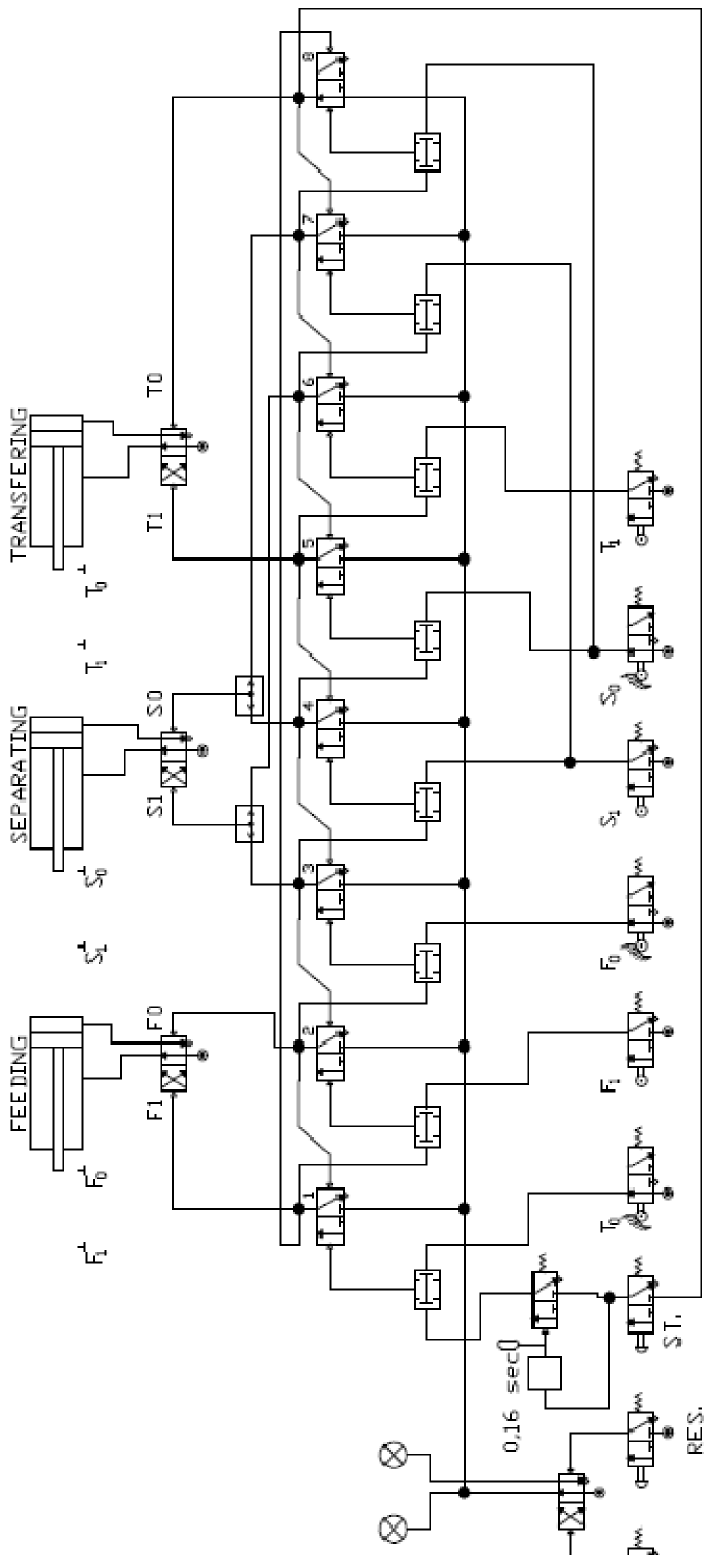


Figure 3.31. Pneumatic Circuit of Carton Board Separation Machine

3.6. Details of Designed Automated Corrugated Card Board Separation Machine

Technical drawings of components of designed machine and bill of material list are given in this section. Perspective and right view of the machine are given in Figure 3.32 and 3.33 respectively.

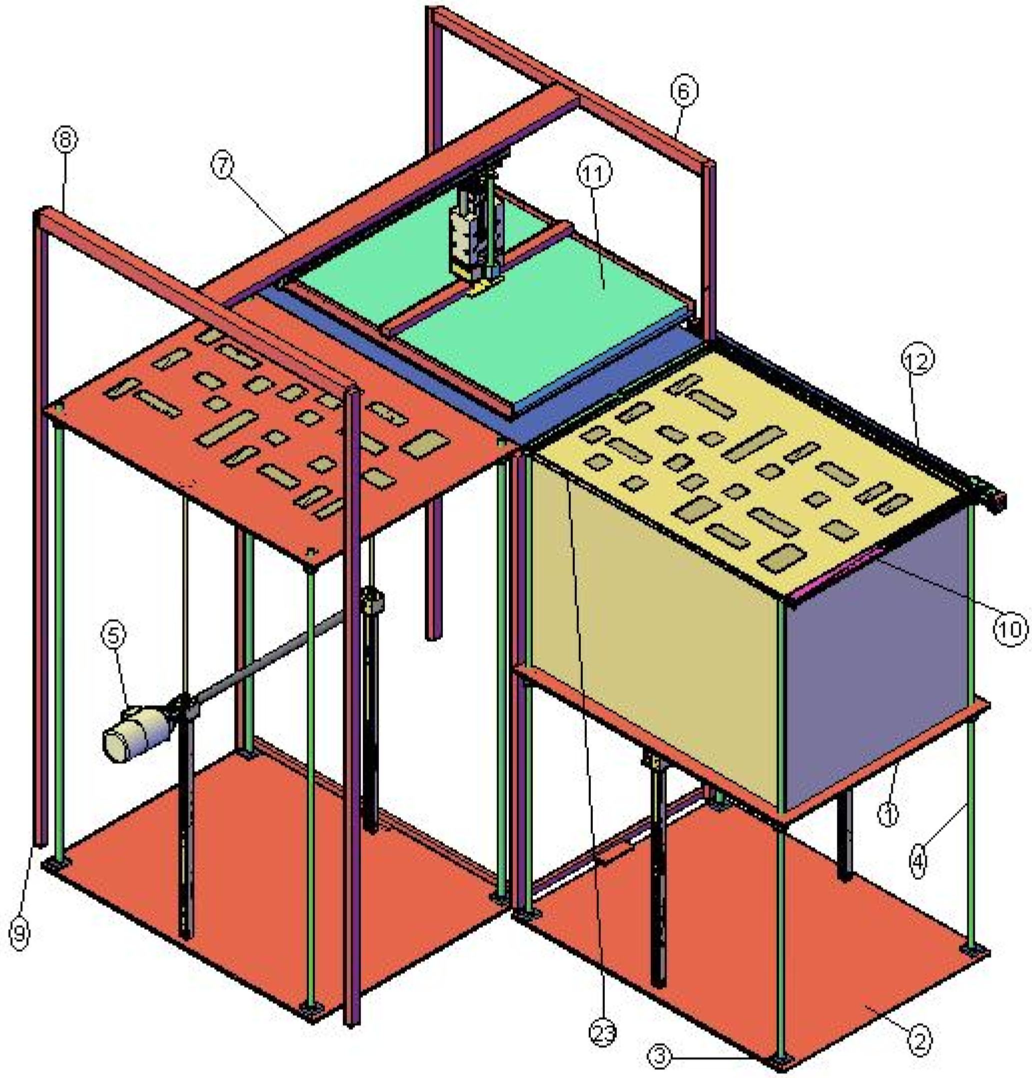


Figure 3.32. Three Dimensional View of The Designed Machine

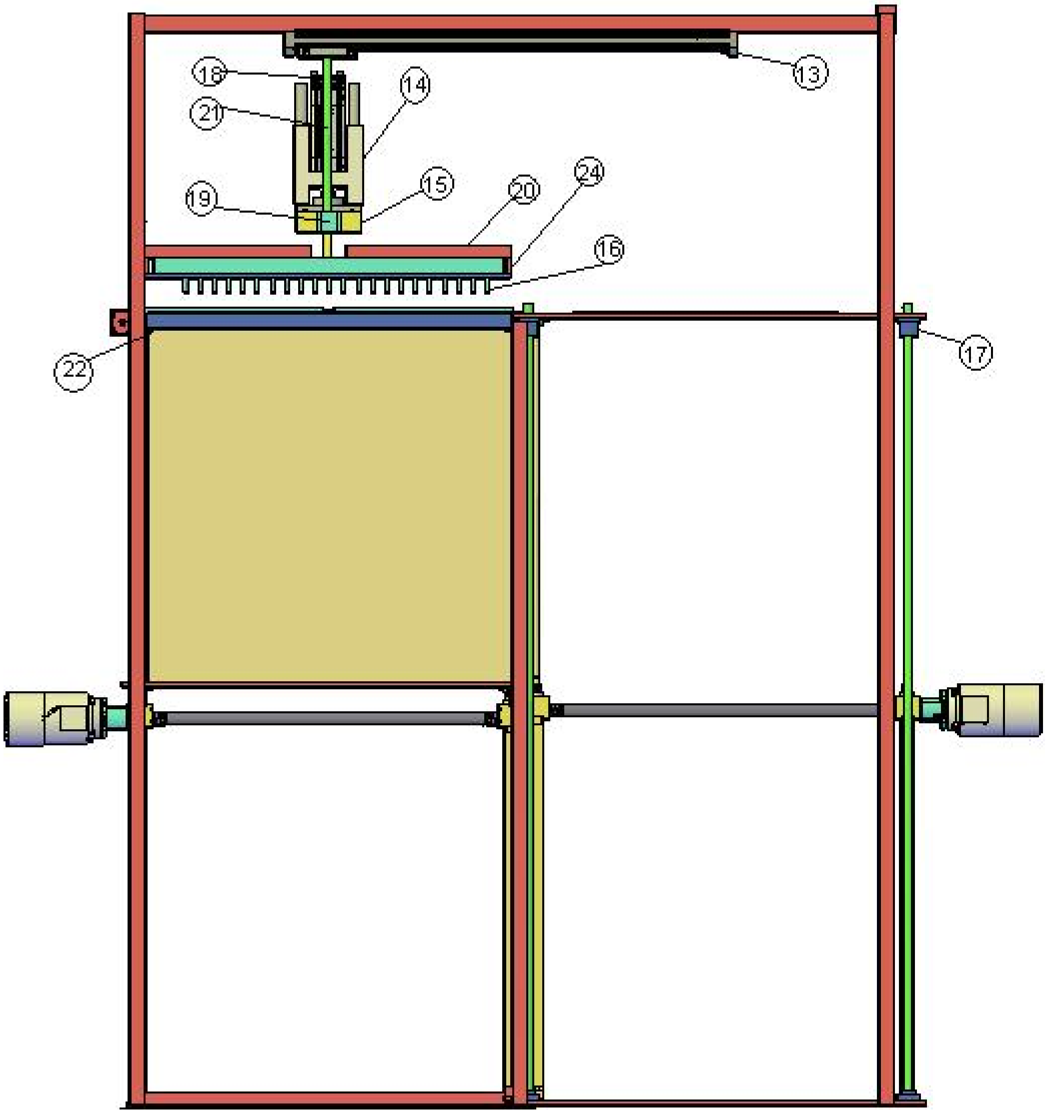


Figure 3.33. Right View of The Designed Machine

As seen from Figure 3.32 and 3.33, part numbering is done for each part. According to part number, detail drawing of designed parts which are not purchased, is given in millimeters. Therefore technical drawings of carton board table, bottom Table, stripping board Table, connection element 1, connection element 2 and carton board gripper are given between Figures 3.34 and 3.39 respectively. Also bill of material list of the machine is given in Table 3.3.

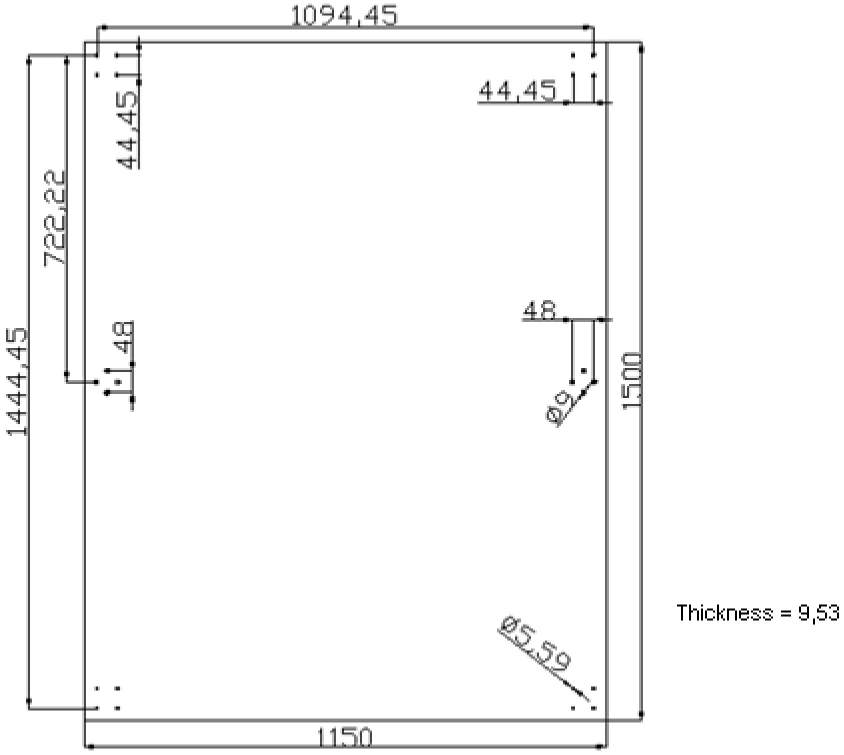


Figure 3.34. Carton Board Table

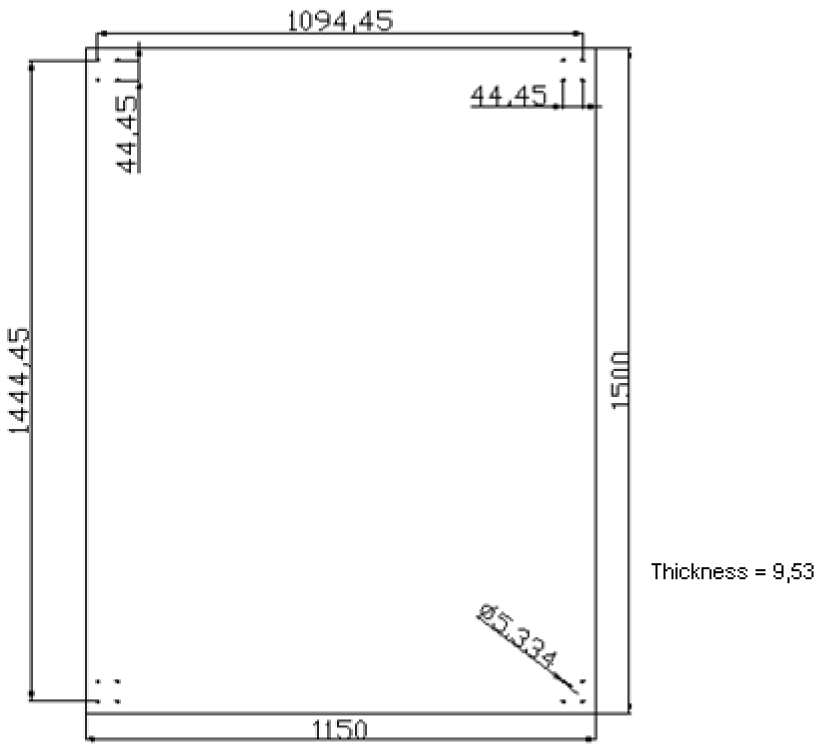


Figure 3.35. Bottom Table

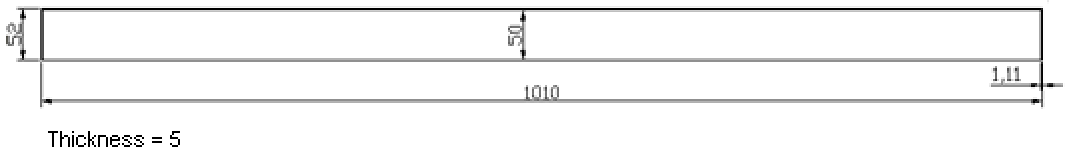


Figure 3.36. Carton Board Gripper

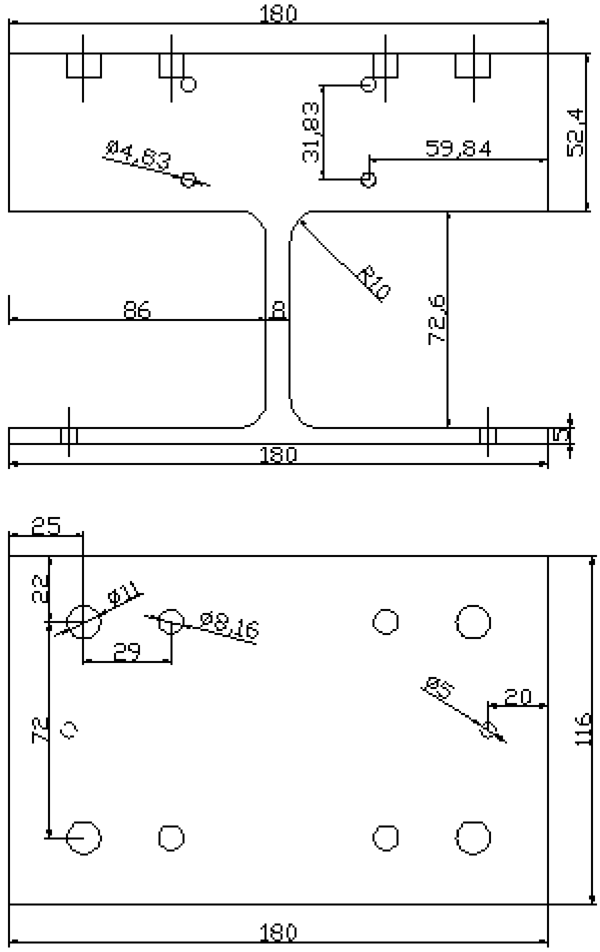


Figure 3.37. Connection Element 1

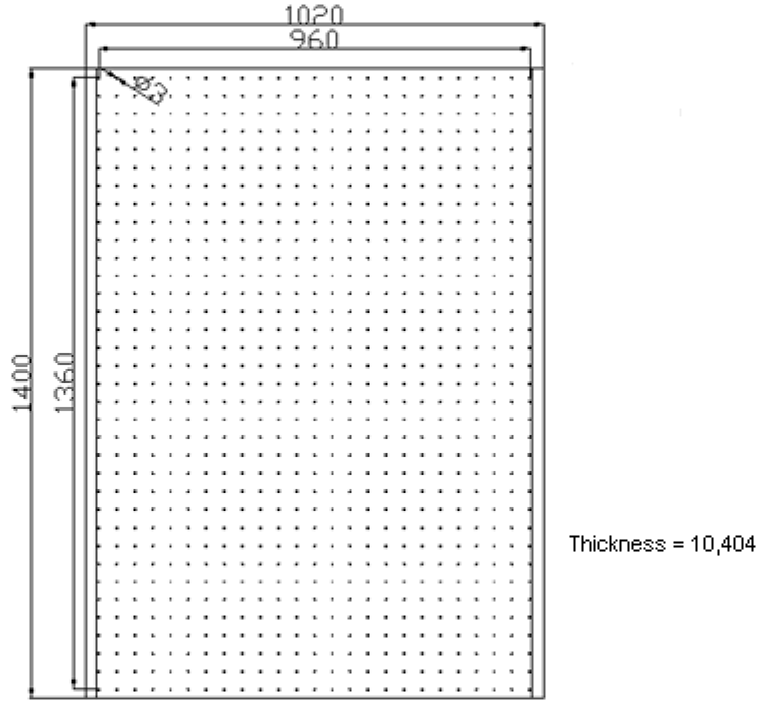


Figure 3.38. Stripping Board Table

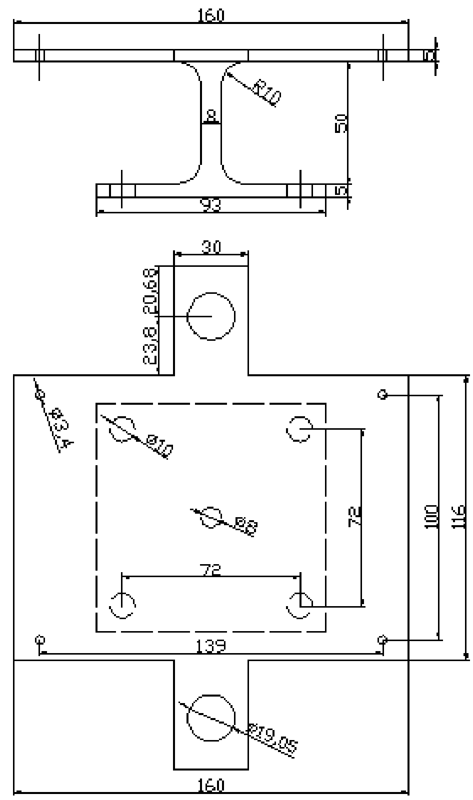


Figure 3.39. Connection Element 2

Table 3.3. Components of Designed Machine

Part name	Part no	Quantity	Order code or dimensions	Material	Provider
Carton board table	1	2	Figure 3.35	Stainless steel	www.custompartnet.com/sheet-metal-gauge
Bottom table	2	2	Figure 3.36	Stainless steel	www.custompartnet.com/sheet-metal-gauge
Shaft support block	3	8	FSB-12		www.thomsonlinear.com
Shaft	4	8	0,75-LPD-RL Length: 2230		www.thomsonlinear.com
Screw jack	5	2	MSZ-5-G-SN-Tr-1804-1-H228-BF-DIG-105-14-MSZ-5-MF-105-68-VWZ-30-LA960-11/11-KUZ-19-11/14-71-P4-0,37-B14C-B-SL-VS		www.zimm.at/en
Profile 2	6	1	FL5040 Length: 1500	Al 6063	
Profile 1	7	1	FL12040 Length: 2040	Al 6063	
Profile 4	8	1	FL5070 Length: 1700	Al 6063	
Profile 3	9	4	FL4030 Length: 3040	Al 6063	
Carton board gripper	10	1	Figure 3.37	Stainless steel	www.custompartnet.com/sheet-metal-gauge
Vacuum gripper	11	1	TC90/130C2		www.joulin.biz
Rodless actuator for gripper	12	1	DGC-25-1500-G-PPV-A		www.festo.com
Rodless actuator for transferring	13	1	DPGL-18-1020-PPV-A-B-HD18-D2 and HHP-18		www.festo.com

Table 3.3. (Continue)

Actuator	14	1	DNCB-80-100-PPV-A with DPNC80 and FENG-80-100-KF		www.festo.com
Connection element 1	15	1	Figure 3.38	1040	
Stripping board	16	1	Figure 3.39	Aluminum	www.custompartnet.com/sheet-metal-gauge
Ball bushing flanged	17	8	SSUFB-12		www.thomsonlinear.com
Connection element 2	18	1	Figure 3.40	1040	
Ball bushing pillow block	19	2	SSUPB-12		www.thomsonlinear.com
Profile 6	20	2	FL5030 Length: 460	Al 6063	
Shaft for ball bushing pillow block	21	2	0,75-LPD-CTL Length:530		www.thomsonlinear.com
Profile 5	22	2	L20x20x3 Length: 1500	BS4360 50D	
Linear rail guide	23	2	MRC12-1500 and MRC12C		www.pbclinear.com
Profile 7	24	2	FL5010 Length: 1400	Al 6063	

4. RESULTS AND DISCUSSION

Systematic design method was investigated and used to solve the problem in previous sections. In this section, results of quality function deployment chart which is presented in section 3.2 will be given. Then generated concepts in section 3.3 will be evaluated. Also components of automatic carton board stripping and separation machine will be sized, selected from catalogue by using equations which are given in section 3.5.

4.1. Results of Quality Function Deployment (QFD) Chart

Objective of QFD is to make sure that all of the customer's requirements are met.

In order to achieve this objective all needed information (customer requirements and features of machines) must be defined. Since these are explained in previous sections, outcomes of the QFD chart will be given in this section.

Table 4.1. QFD Chart of Automated Corrugated Cardboard Stripping and Separation Machine

	Design according to Infinite Life	Design According to Deformation	Design according to Buckling	Keep Stress Concentrations Low	Motor Drive	Stroke Time	Stripping Board Design	Design For Manufacturing	Design For Assembly	Design For Reliability	Gripper Design	Screwjack Design	Push Button System	Design For Maintenance	Advanced Material Selection	Design against to surface strength	Customer Importance	Separation Machine On Market	Planned Separation Machine	Improvement Ratio	Sales Points	Improvement Ratio	Relative Weight
STRENGTH																							
1. Long Life Cycle	9	9	9	9						9						9	5	5	5	1	1	5	0.02
2. Deformation Resistant Design		9	9													9	5	5	5	1	1	5	0.02
3. Buckling Resistant Design			9														5	5	5	1	1	5	0.02
4. Bending Resistant Design	9	9															5	5	5	1	1	5	0.02
5. Wearing Resistant Design																9	5	5	5	1	1	5	0.02
6. Stress Concentrations				9													5	5	5	1	1	5	0.02
PERFORMANCE																							
7. Number of Separated Box Per unit time					9	9											5	5	2	0.4	1	2	0
8. Separation Performance							9										5	3	5	1.7	1.5	12.8	0.05
9. Reliability	9									9							5	5	5	1	1	5	0.02
Features																							
• Feeding																							
10. Prevent Tangling											9						5	5	5	1	1	5	0.02
11. Orientation of Cartonboard											9	9					5	5	5	1	1	5	0.02
12. Precise Feeding											9	9					5	5	5	1	1	5	0.02
• Separation																							
13. Reduction in number of board used							9										5	2	5	2,5	1,5	18,8	0,07
• Stacking																							
14. Prevent Tangling							9				9						5	5	5	1	1	5	0.02
15. Orientation of Cartonboard											9						5	5	5	1	1	5	0.02
16. Precise Stacking											9	9					5	5	5	1	1	5	0.02
Ergonomic																							
17. Ease of use													9				5	3	5	1,7	1,25	10,6	0.04
Serviceability																							
18. Ease of Maintenance														9			5	2	5	2,5	1,5	18,8	0,07
19. Ease of Assembly									9								5	2	5	2,5	1,5	18,8	0,07
20. Ease of Repairing									9								5	2	5	2,5	1,5	18,8	0,07
21. Ease of Disassembly														9			5	2	5	2,5	1,5	18,8	0,07
Time																							
22. Less Setup Time							9										5	4	5	1,3	1,25	8,1	0,03
Cost																							
23. Material Cost															9		5	1	5	5	1,5	37,5	0,14
24. Manufacturing Cost								9									5	4	5	1,3	1,25	8,1	0,03
25. Tool Cost							9										5	1	5	5	1,5	37,5	0,14
ABSOLUTE IMPORTANCE (x100)	54	54	54	36	0	0	279	27	126	36	108	54	36	126	126	54	1170					270.6	
RELATIVE IMPORTANCE (%)	5	5	5	3	0	0	24	2	11	3	11	5	3	11	11	5							
SEPARATION MACHINE ON MARKET	mm																						
TARGET VALUE	mm	1 sec	1,0																				

As pointed out in Table 4.1 combination of customer requirements and engineering characteristics is considered. Each customer requirement is matched with least one engineering characteristic. Level of interrelationship is weighted on one point scale (high) and level of interrelationship is entered into the matrix cell (high=9).

Customer importance is determined from appointments and entered into the cell as 5 which is the highest value. Designed product is rated on a 1-5 scale with existing product relative to the customer requirements. Sales points which will facilitate selling the new product in to the market are rated with a 1.5 given to the highest sales points and 1 to lower rated features in QFD chart. For the automatic corrugated carton board stripping and separation machine high sales points are given to the separation quality, reduction in number of used die boards, tool cost, material cost, ease of maintenance, ease of assembly, ease of repairing and disassembly.

Stripping board design is noted as the most important engineering characteristic by 24 percent of relative importance.

4.2. Evaluation of Generated Concepts

Automated corrugated carton board stripping and separation machine is designed to obtain desired patterns without any problem such as tears, damages on flute structure of corrugated carton boards.

Three concepts have been generated: Concept 1: Using die separation technique, Concept 2: Using Vacuum Separation technique and Concept 3: Using die and vacuum technique.

To select best quality product, which must meet both customer and engineering requirements design criteria, are identified. QFD is used as a source to identify criteria.

Weight factor for each design criterion is determined by looking at QFD chart (Table 4.1).

Score for each concept at each design criterion is assigned based on engineering judgment between 1-10 scales. Then rating is calculated by multiplying the weight factor with score for each design criterion and concept. Finally total ratings are found by summing ratings (results of decision matrix is shown in Table 4.2).

Decision matrix shows that Concept 3: Using die and vacuum technique is highest probability of succeed on the market. So concept 3 is chosen as a proper concept.

Table 4.2. Results of Decision Matrix

		Concept 1: Die separation machine		Concept 2: Vacuum separation machine		Concept 3: Die and Vacuum separation machine	
Design Criterion	Weight Factor	Score	Rating	Score	Rating	Score	Rating
1.Design against to infinite life	0,05	7	0,35	7	0,35	7	0,35
2.Design according to deformation	0,05	7	0,35	7	0,35	7	0,35
3.Design according to buckling	0,05	7	0,35	7	0,35	7	0,35
4. Design against to surface strength	0,05	7	0,35	7	0,35	7	0,35
5.Design for manufacturing	0,02	4	0,08	5	0,1	7	0,14
6. Design for assembly	0,11	3	0,33	7	0,77	5	0,55
7. Design for reliability	0,03	6	0,18	6	0,18	6	0,18
8. Design for maintenance	0,11	5	0,55	5	0,55	4	0,44
9.Flexibility	0,24	3	0,72	3	0,72	9	2,16
10. Tangling of carton boards	0,34	5	1,7	5	1,7	7	2,38
11.Orientation of carton boards	0,15	6	0,9	6	0,9	6	0,9
12.Ease of use	0,03	7	0,21	7	0,21	7	0,21
13.Production rate	0,3	3	0,9	3	0,9	3	0,9
14.Less setup time	0,24	3	0,72	9	2,16	5	1,2
15.Separation quality	0,24	3	0,72	3	0,72	9	2,16
16.Cost	0,37	9	3,33	8	2,96	7	2,59
			11.74		13,22		15,21

4.3. Results of Parametric Design

Parts of concept 3 will be sized and selected from manufacturer's catalog in this section by using given formulas in section 3.5 for each component.

4.3.1. Design of Feeding and Stacking Station

Components of feeding and stacking station will be sized and selected from the manufacturer's catalog in this section.

4.3.1.1. Design of Carton Board Table For Deflection

Table 4.3 is obtained by using of given formulas and following inputs:

- Dimensions of carton board: 1400x1000x4 mm
- Mass of a carton board: 0,502 kg
- Total number of carton boards: 250
- Total mass of carton boards: 125,5 kg
- Mass of wooden pallet: 25 kg
- Wnet = 1476,405 N
- W = 1283,830 N/m
- L_1=0,05m, L_2=1,05m, L_3=1,1m
- y(0,575) = 1 mm, E=207 GPa

Table 4.3. Thickness of Carton Board Table

Equation number	Symbol	Results
3.1 and 3.2	B_1 and E_1	738,207 N
3.6	C_1	-61,054
3.7	C_2	3,0522
3.3	h	9,193 mm. From sheet metal thickness catalog 9,525 mm is chosen
	Mass of the table	124,485 kg

4.3.1.2. Selection of Screw Jack

Using steps in Figure 3.13, components of screw jack will be chosen from manufacturer's catalog (www.zimm.com).

Step 2: Design Against to Buckling**:**Spindle diameter and pitch of selected model (MSZ-5-SN) is 18x4 mm. For the following inputs:

n=3, E= 210 GPa, L(stroke)= 1000mm

By using equation 3.10, d_r is found as 9,988 mm. Root diameter of preselected screw jack is 14 mm. So this is safety

Step 3: Finding Required Drive Torque:For the following inputs:

- F= 1,35kN
- P= 4mm
- i= 4
- M_L= 0,1 Nm
- $n_{gear\ box}$= 0,84
- $n_{spindle}$= 0,399

By using equation 3.11, M_G=0,741Nm.

Step 4: Arrangement of Screw Jack :For M_G=0,741Nm and using equation 3.12, M_R=1,56Nm.

Step 5: Selection of Motor:For the following inputs: n=1500 rpm, M_G= 1,56 Nm

By using equation 3.13, P_m=0,343 kW.

Step 6: Checking of Maximum Power Torque:From maximum drive torque table (www.zimm.com), maximum drive torque for MSZ-5-SN with 1500 rpm; M_R=6,4 Nm. Calculated required drive torque is smaller than maximum drive torque. So there is no problem

Step 7: Determining Lengths:Spindle length= (1000) + (139) + (70-22) + (41) = 1228 mm (equation 3.14).

Protective tube length= (1000) + (48) + (69) + (5) = 1122 mm (equation 3.15).

Buckling of screw is calculated according to 1000mm stroke. But spindle length is 1228 mm. So buckling must be recalculated again.

By using equation 3.10, d_r=11,068 mm. Root diameter of preselected screw jack is 14 mm. So screw jack can be purchased by order code (MSZ-5-G-SN-Tr-1804-1-H228-fixed flange-brake motor-coupling-rotary pulse encoder-motor flange-lubrication strip-protection against rotation-protective tube-protective cap-connecting shaft VWZ-30-LA-960).

4.3.1.3. Selection of Ball Bushings, Shaft and End Supports

For the following inputs which are given in Table 4.4, results are given in Table 4.5.

Table 4.4. Inputs For the Selection of Ball Bushings

Design parameters	Results
W	2,7 kN
L_2	525 mm
L_3	700 mm
L_0	1050 mm
s	4 mm
f	20
L_h	2 year
K_L (From travel life chart for inch product)	0,67
K_S (From shaft hardness chart)	0,97
K_0 (From polar graph for super smart ball bushing flanged)	0,71
A_x=B_x=C_x=D_x	675 N
A_y = B_y = C_y = D_y	900 N
P	1125 N

Table 4.5. Results For the Selection of Ball Bushing

Equation number	Symbols	Results
3.16	Lm	$6{,}622.10^6$ inch
3.17	W_R	2438,078 N
3.18	Load most heavily loaded bearing	1584,51 N

Considering required travel life and load on most heavily loaded bearing chart SS6UTFB-8 is chosen from the manufacturer's catalog (www.thomsonlinear.com). Dynamic load capacity of selected model is 2357,56 N. This value is lower than required dynamic load capacity. So SSUFB-12 is chosen. Shaft (0,75LPD-RL) and end support (FSB-12) is chosen according to selected ball bushing model.

4.3.1.4. Design of Gripper Against to Deformation

Results are given in Table 4.6 for the following inputs:

- Thickness=1,11 mm (From standard steel thickness chart)
- Material: stainless steel; E=207 GPa, d=7850 kg/m^3.
- V =8,697.10^{-5} m^3.
- $M_{gripper}$(mass of griper) = 0,683 kg.

Table 4.6. Results of Gripper Against to Deflection

Equation number	Symbols	Results
3.19	W	6,697 N/m
3.20	y_{max}	0,303 mm

$y_{max} \leq 1$ mm so this is acceptable.

4.3.1.5. Selection of Rodless Actuator

Results are shown in Figure 4.1 for the following inputs:

- F_z =6,697 N, M_x = 3,382 Nm.

Piston diameter is chosen as 25 mm according to F_z, M_x values and using equation 3.21.

From permissible piston velocity and effective load diagram: V= 1,5 m/s. Time, stroke and velocity values are shown in Figure 4.1.

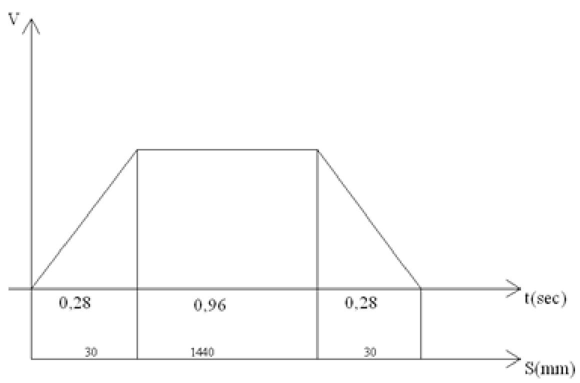


Figure 4.1. Stroke, Time and Velocity Diagram

Order code for rodless actuator is DGC-25-1500-G-PPV-A

4.3.1.6. Selection of Linear Guide For Precise Motion of Gripper

Outcomes for the selection of linear guide are shown in Table 4.7.

Table 4.7. Obtained Results For Linear Guide

Equation number	Symbols	Results
3.24	F	6,697 N
3.25	M_x	3,382 Nm

(MRC12-1500) and carriage (MRC12C) are chosen according to calculated M_x and F values.

4.3.2. Design of Separation Station

Components of separation station will be sized and selected from the manufacturer’s catalog in this section.

4.3.2.1. Selection of Vacuum Gripper

Manufacturer of vacuum gripper designs their product according to customer needs such as weight of lifted object and volume of lifted object. TC90/130C2 is chosen according to dimensions of a carton board.

4.3.2.2. Design of Stripping Board Against to Deformation

Obtained results are shown in Table 4.8 for the following inputs:

- Material Aluminum; density= 2700 kg/m^3, E=80 GPa
- Area= 1,403 m^2
- t=10,404 (from aluminum sheet metal chart catalog)
- $m_{stripping\ board}$ =39,42 kg

- n(number of holes)=35

Table 4.8. Results For Stripping Board Against to Deflection

Equation number	Symbols	Results
3.26	Wnet	386,71N
3.27	W	386,71 N/m
3.29	I	$1,215.10^{-7}$ m^4
3.28	y_{max}	0,52 mm

$y_{max} \leq 1$ mm. So this is acceptable.

4.3.2.3. Selection of Rectangular Profile For Stripping Board

Calculated reaction forces are given in Table 4.9 for the following inputs:

- Material: AL 6063; Sy=48 MPA, Sut=90 MPa, E=80 GPa, Density=2700 kg/m^3
- Wnet=386,71 N
- L=1000 mm
- Ssy=0.5.48=24 MPa
- n=2

Table 4.9. Results of Calculated Reaction Forces

Equation number	Symbols	Results
3.30	R_2	193,355 N
3.31	R_1	193,355 N

Shear (V) and moment (M) diagram is shown in Figure 4.2 according to calculated reaction force

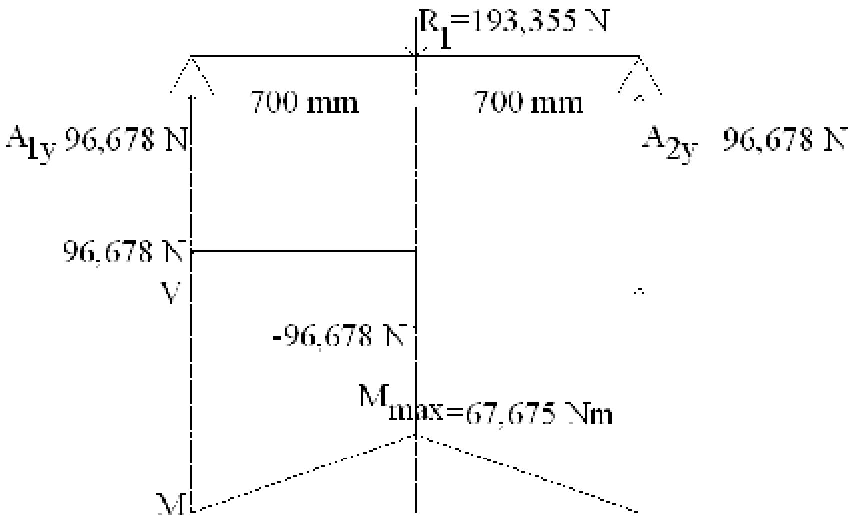


Figure 4.2. V and M Diagram For Rectangular Profile For Stripping Board

According to selected rectangular profile FL5010 which has $1{,}041.10^{-7}$ m^4 (moment of inertia), ooutcomes are given in Table 4.10.

Table 4.10. Calculated Stresses For the Rectangular Profile of Stripping Board

Equation number	Symbols	Results
3.32	σ_x	16,252 MPa
3.33	τ_{xy}	0,19 MPa
3.34	σ_1 & σ_2	16,254 & $-2{,}22.10^{-3}$ MPa
3.35	τ_{max}	8,128 MPa

This is safe since 8,128 MPa ≤ 12 Mpa.

4.3.2.3.(1). Selection of Screw to Joint Rectangular Profile to Stripping Board

For the following inputs, results are shown in Table 4.11.

- $m_{stripping\ board}$=39,42 kg
- number of screw=4
- property class 5.8: Sy=395 MPa and n(factor of safety)=4

Table 4.11. Results for Screw to Joint Rectangular Profile to Stripping Board

Equation number	Symbols	Results
3.37	P	96,68 N
3.38, 3.39, 3.40, 3.41	d	1,12 mm

d=1,12 mm so M5x0,8 is chosen.

4.3.2.4. Selection of Actuator to Move Vacuum Gripper in Vertical Direction

Calculated forces are given in Table 4.12 for the following inputs:

- $m_{vacuum\ gripper}$=58,5 kg
- $m_{profiles}$=3,78 kg
- $m_{stripping\ board}$=39,42 kg

Figure 4.3 shows stroke and time values for the actuator of vacuum gripper

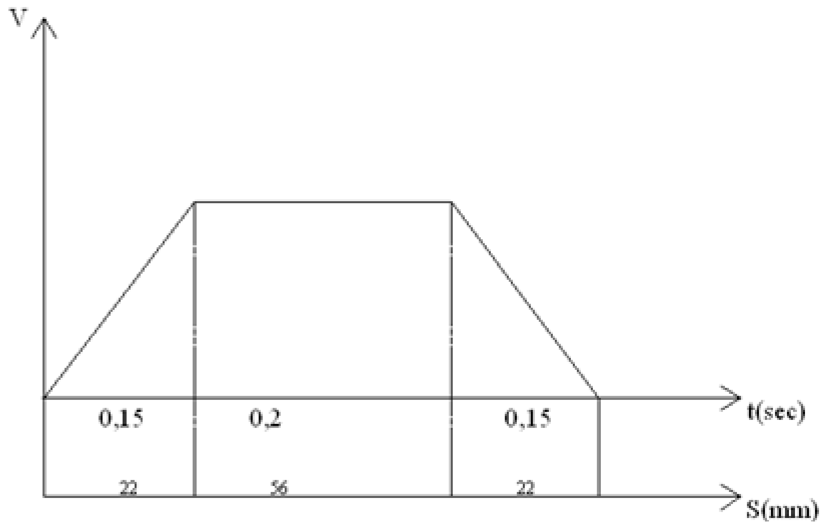


Figure 4.3. Stroke, Time and Velocity Diagram For Actuator of Vacuum Gripper

Table 4.12. Calculated Forces For Actuator of Vacuum Gripper

Equation number	Symbols	Results
3.42	F_L	997,68 N
3.43	F_M	199,332 N
3.44	F_T	1197,012 N

According to F_T=1197,012 N for 6 bar from nomogram using curve B, diameter is found as 80 mm. So from festo product catalog DNCB-80-100-PPV-a is chosen with DPNC-80 (for end cap) and FENG-80-100-KF (guide unit for smooth linear motion)

Weigth of the selected actuator =16,665 kg.

4.3.2.5. Selection of Ball Bushing and Shaft to Obtain Precise Motion in Vertical Direction

For the following inputs which are given in Table 4.13, results are given in Table 4.14.

Table 4.13. Inputs For The Selection of Ball Bushings

Design parameters	Results
W	997,68 N
L_2	81,8 mm
L_3	0 mm
L_0	163,6 mm
s (reciprocating stroke)	200 mm
f	40
L_h	2 year
K_L (From travel life chart for inch product)	0,15
K_S (From shaft hardness chart)	1
K_0 (From polar graph for super smart ball bushing flanged)	0,86
A_x=B_x	498,84 N
A_y = B_y	0 N
P	498,84 N

Table 4.14. Results For The Selection of Ball Bushing

Equation number	Symbols	Results
3.47	Lm	662,205.10^6 inch
3.48	W_R	3866,98 N
3.49	Load most heavily loaded bearing	580,047 N

Considering required travel life and load on most heavily loaded bearing chart SSUPB-12 is chosen from the manufacturer’s catalog (www.thomsonlinear.com). Dynamic load capacity of selected model is 5026,4886 N. So this model is acceptable since we need 3866,98 N. Shaft (0,75LPD-CTL) is chosen according to selected ball bushing.(note CTL=20,91 inch)

4.3.2.6. Design of Connection Element to Connect Vacuum Gripper with Actuator

Performances of the materials are shown in Table 4.15 for the design of connection element

Table 4.15. Performance Index of Alternative Materials

Material	Performance index
Glass	200 - 80
Al alloy	27,7
Mg alloy	12
Ti alloy	5
Steel	55,5

The best material which has the highest performance index is glass relative to Table 4.15. But The glass is very brittle. Also machinability of the glass is hard. So steel is selected as a material for connection element. Between the available steel, 1040 steel is selected because of finding easily in stocks.

Properties of 1040 steel forged; S_y= 365 MPa, Sut=634 Mpa, E= 207 GPa, density=7850 kg/m^3.

After finding best material for connection element, firstly the connection element will be designed against to buckling.

Calculated minimum diameter which is required to prevent buckling is shown in Table 4.16 for the following inputs:

- r (radius of selected actuator):40 mm
- P:6 bar, n(factor of safety)= 3

Table 4.16. Diameter Which is Needed to Prevent Buckling in Connection Element

Equation number	Symbols	Results
3.50	$F_{pressure}$	3,02 kN
3.53	d	3,31 mm

Lastly part (connection element) will be designed against to fatique failure since applied force fluctuates between F_T and $F_{pressure}$ which are shown in Table 4.16 and 4.17.

Table 4.17. Calculated Force Values on Connection Element

Equation number	Symbols	Results
3.54	F_L	997,68 N
3.55	F_M	199,332 N
3.56	F_T	1197,012 N

Using equation 3.62 for the following inputs:

- $k_b=k_c=k_d=k_f=1$
- $k_a=0,42$ (as forged)

$S_e'=319,934$ MPa. Obtained results are shown in Table 4.18.

Table 4.18. Results For the Connection Element 1

Equation number	Symbols	Results for first iteration (d=3,31mm, Kt=1,065)	Results for second iteration (d=15 mm, Kt=1,263)	Results for third iteration (d=8mm, Kt=1,161)
3.63	k_e	0,943	0,8	0,87
3.61	S_e	126,713 MPa	107,497 MPa	116,903 MPa
3.57	σ_{max}	-373,775 MPa	-21,584 MPa	-69,754 MPa
3.58	σ_{min}	148,15 MPa	8,56 MPa	27,65 MPa
3.59	σ_{mean}	-112,813 MPa	-6,512 MPa	-21,052 MPa
3.60	σ_{amp}	-260,963 MPa	-15,072 MPa	-48,702 MPa
3.66	S_m	50,421 MPa	43,274 MPa	46,8023 MPa
3.67	n	0,446	6,645	2,2

Diameter of connection element 1 is found as 8 mm according to Table 4.18

$m_{\text{connection element}}$ (Weight of connection element) = 9,44 kg.

4.3.2.7. Selection of Rectangular Profile to Connect Connection Element with Selected Rectangular Profile of Stripping Board

Material properties of rectangular profile (Al 6063): S_y=48 MPa, Sut=90 MPa, E=80 GPa, Density=2700 kg/m^3

As seen from Figure 4.4, there will be bending stress and normal shear stress. Results are given in Table 4.19.

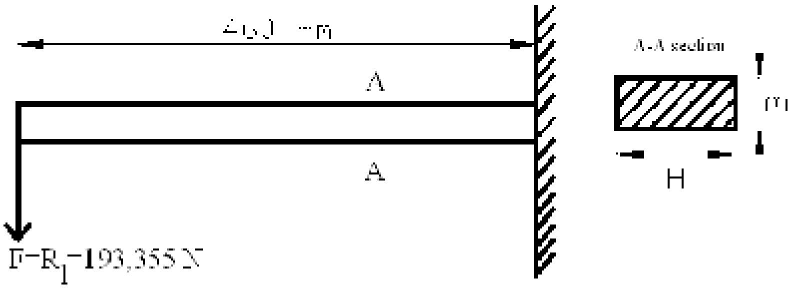


Figure 4.4. Loading Condition of Rectangular Profile

Table 4.19. Calculated Stresses For Rectangular Profile to Connect Connection Element with Selected Rectangular Profile of Stripping Board

Equation number	Symbols	Iteration 1	Iteration 2
		Product code=FL5040 Area: 2.10^{-3} m^2 I=$2,666.10^{-7}$ m^4	Product code=FL5030 Area: $1,5.10^{-3}$ m^2 I=$1,125.10^{-7}$ m^4
3.68	σ_x	6,672 MPa	11,86 MPa
3.69	τ_{xy}	0,1 MPa	0,13 MPa
3.70	σ_1 and σ_2	6,673 Mpa and -0,001 MPa	11,861 MPa and -0,001 MPa
3.71	τ_{max}	3,3365 MPa	5,9305 MPa
3.72	n	3,56	2,02

FL5030 is chosen according to Table 4.18

Weight of selected profiles=7,452 kg.

4.3.2.8. Selection of Rodless Actuator For Transferring of Separated Carton Board From Separation Station to Stacking Station

Calculated forces are given in Table 4.20 for the following inputs:

- $m_{vacuum\ gripper}$=58,5 kg
- $m_{profiles}$= 11,232 kg
- $m_{stripping\ board}$=39,42 kg
- $m_{connection\ element}$ = 9,44 kg
- $m_{actuator}$ = 16,665 kg

Figure 4.5 shows stroke and time values for the actuator of vacuum gripper

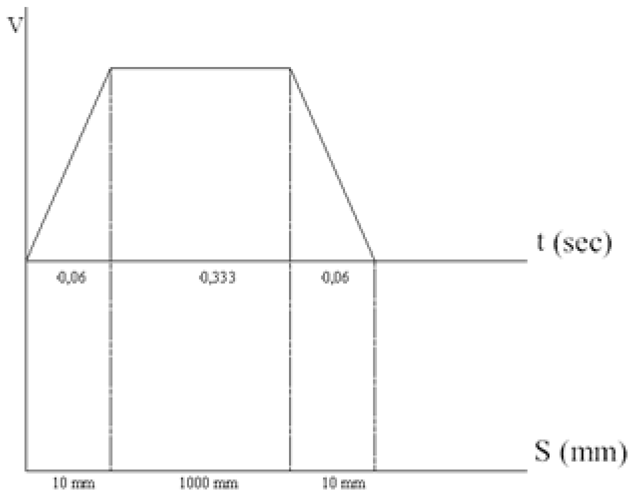


Figure 4.5. Stroke, Time and Velocity Diagram

Table 4.20. Calculated Net Forces on Rodless Actuator

Equation number	Symbols	Results
3.74	F_1	1315,688 N
3.75	F_2	230,206 N
3.76	F_z	1545,894 N

There is no force and moment in other direction because of central mounting. So HD-18 which supports 1820 N in z direction is chosen from catalog using equation 3.73. V=3 m/s for HD-18

Order code: DGPL-18-1020-PPV-A-B-HD18-D2, Part no: 161993, Type:HHP-18 for mounting

$m_{rodless\ actuator}$=13,308 kg

4.3.2.9. Design of Connection Element to Connect Actuator to Rodless Actuator

As mentioned in section 4.3.2.6, no need to further explanation. Same logic is valid in this section too. Therefore calculated forces and stresses are given in Table 4.21 and 4.22 respectively.

Table 4.21. Calculated Force Values on Connection Element

Equation number	Symbols	Results
3.54	F_L	1326,871 N
3.55	F_M	232,44 N
3.56	F_T	1559,311 N

Using equation 3.62 for the following inputs:

- k_b=k_c=k_d=k_f=1
- k_a=0,42 (as forged)

S_e'=319,934 MPa.

Table 4.22. Results For The Connection Element 1

Equation number	Symbols	Results for first iteration (d=8mm, Kt=1,16)
3.63	k_e	0,87
3.61	S_e	116,903 MPa
3.57	σ_{max}	-69,693 MPa
3.58	σ_{min}	35,985 MPa
3.59	σ_{mean}	-16,854 MPa
3.60	σ_{amp}	-52,839MPa
3.66	S_m	35,217 MPa
3.67	n	2,09

Diameter of connection element 2 is found as 8 mm according to Table 4.22

4.3.2.10. Design of Frame For Rodless Actuator

Material for all frame profiles (except profile 5) is Al 6063, S_y=48 MPa, S_{ut}=90 MPa, E=80 GPa.

Applied forces on frame structure are given in Table 4.23.

Table 4.23. Calculated Forces Acting Upon Frame Structure

Equation number	Symbols	Results
3.79	W_{net}	1457,423 N
3.80	W	1428,846 N/m
3.81	F_z	232,44 N

4.3.2.10.(1). Selection of Profile 1

Calculated reaction forces on connection points, maximum moment and shear forces are shown in Figure 4.6 for profile 1.

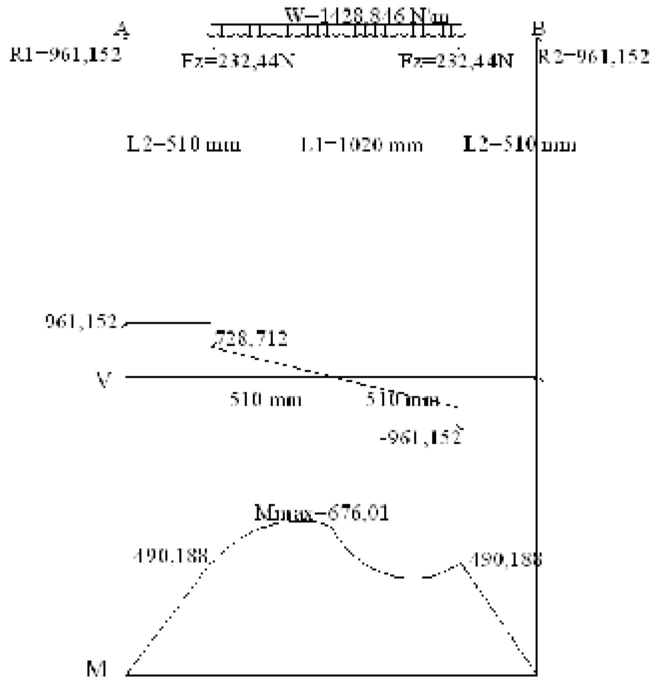


Figure 4.6. Shear Force and Bending Moment Diagram For Profile 1

According to calculated M_{max} (maximum moment in Figure 4.5) and using given equations in sections 3.5, profile 1 is selected. Obtained results (factor of safety values) are given in Table 4.24 for different size profiles.

Table 4.24. Selection of Profile 1

Equation number	Symbols	Results for FL9010	Results for FL9040	Results for FL10015	Results for FL12040
3.84, 3.85, 3.86, 3.87, 3.88	n	0,12	1,71	0,266	2,272

FL12040 is chosen relative to Table 4.24.

4.3.2.10.(2). Selection of Profile 2

Calculated reaction forces on connection points, maximum moment and shear forces are shown in Figure 4.7 for profile 2.

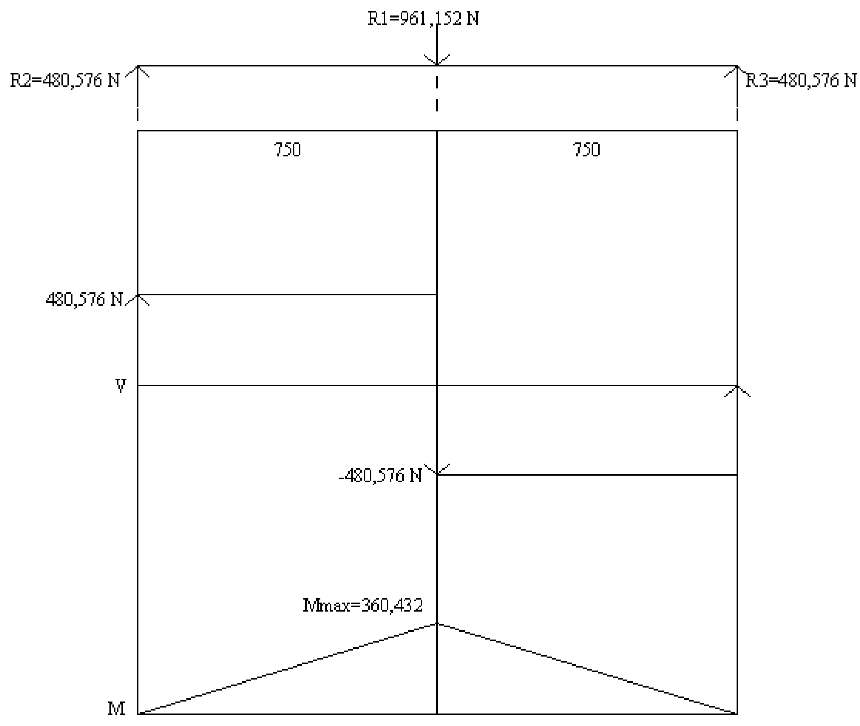


Figure 4.7. Shear Force and Bending Moment Diagram For Profile 2

According to calculated M_{max} (maximum moment in Figure 4.7) and using given equations in sections 3.5, profile 2 is selected. Obtained results are given in Table 4.25 for different size profiles.

Table 4.25. Selection of Profile 2

Equation number	Symbols	For FL5030 A= $1,5.10^{-3}$ m^2 I= $3,125.10^{-7}$ m^4	For FL5040 A= 2.10^{-3} m^2 I= $4,166.10^{-7}$ m^4
3.84	σ_x	28,834 MPa	21,63 MPa
3.85	τ_{xy}	0,32 MPa	0,24 MPa
3.86	σ_1 and σ_2	28,568 MPa and -0,273MPa	21,635 MPa and 0
3.87	τ_{max}	14,421 MPa	10,817 MPa
3.88	n	1,664	2,22

so product FL5040 is chosen according to Table 4.25.

4.3.2.10.(3). Selection of Profile 3

As seen from Figure 4.8, there will be buckling on profile 3. To prevent buckling I (moment of inertia) must be higher than $6,08.10^{-8}$ m^4 for n = 3(equation 3.90). Obtained results are shown in Table 4.26

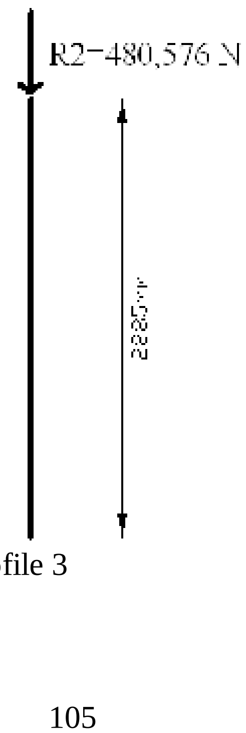


Figure 4.8. Loading Condition of Profile 3

Table 4.26. Selection of Profile 3

Equation number	Symbols	Results for FL4030	Results for FL4025
3.92	I	9.10^{-8} m^4	$5{,}208.10^{-8}$ m^4

so product FL4030 is chosen according to Table 4.26 for profile 3.

4.3.2.10.(4). Selection of Profile 4

Calculated reaction forces on connection points, maximum moment and shear forces are shown in Figure 4.9 for profile 2.

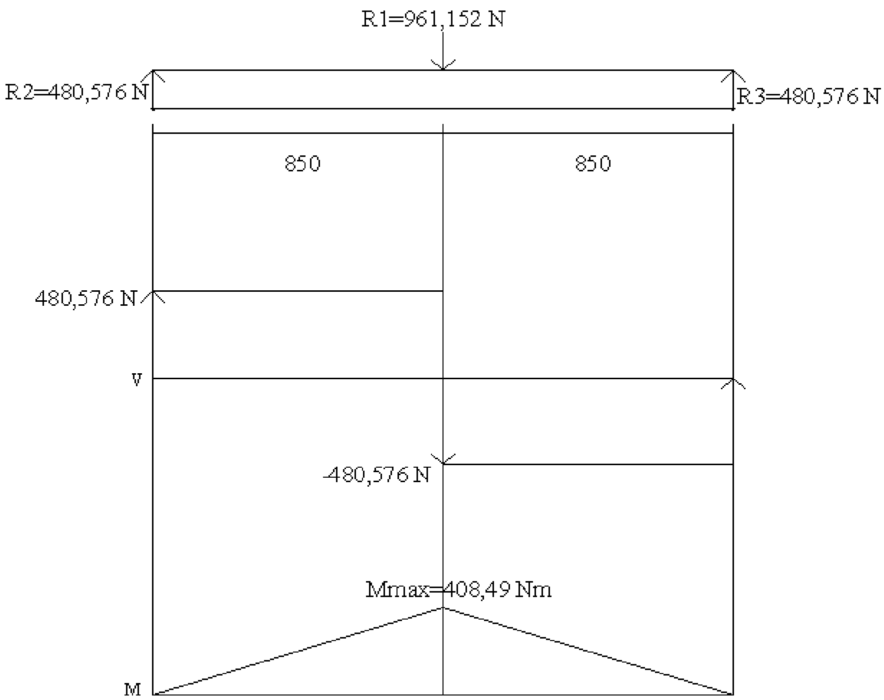


Figure 4.9. Shear Force and Bending Moment Diagram For Profile 4

According to calculated M_{max} (maximum moment in Figure 4.9) and using given equations in sections 3.5, profile 4 is selected. Obtained results are given in Table 4.27 for different size profiles.

Table 4.27. Selection of Profile 4

Equation number	Symbols	For FL5040 A= 2.10^{-3} m^2 I= 4,166.10^{-7} m^4	For FL5070 A= 3,5.10^{-3} m^2 I= 1,43.10^{-6} m^4
3.84	σ_x	24,513 MPa	10 MPa
3.85	τ_{xy}	0,24 MPa	0,14 MPa
3.86	σ_1 and σ_2	24,517 MPa and 0	10 MPa and 0
3.87	τ_{max}	12,26 MPa	5 MPa
3.88	n	1,96	4,8

so product FL5070 is chosen according to Table 4.27.

4.3.2.10.(5). Selection of Profile 5

For $F_{pressure}$=3020 N, W=1006,666 N/m, calculated reaction forces on connection points, maximum moment and shear forces are shown in Figure 4.10

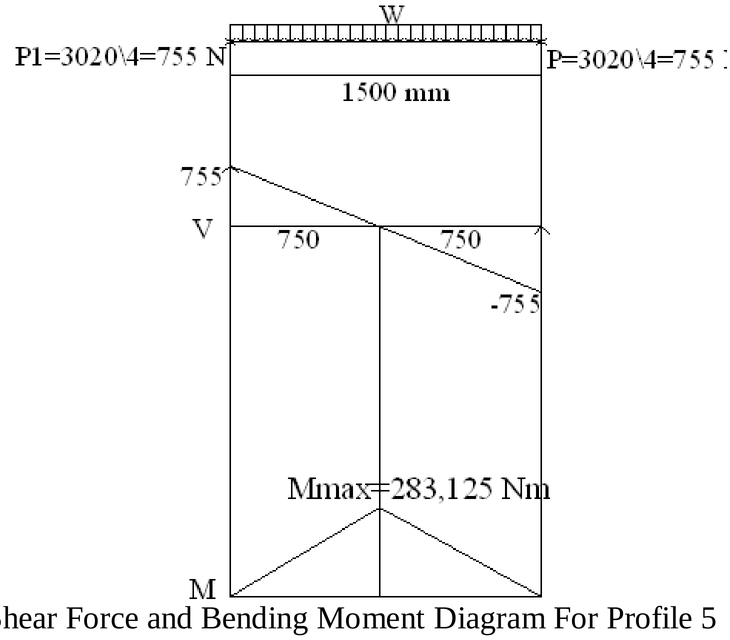


Figure 4.10. Shear Force and Bending Moment Diagram For Profile 5

Material (BS4360 50D) which is used for profile 5; S_{ut}=680 MPa, S_y=355 MPa

According to calculated M_{max} (maximum moment in Figure 4.10) and using given equations in sections 3.5, profile 5 is selected. Obtained results (factor of safety values) are given in Table 4.28.

Table 4.28. Selection of Profile 5

Equation number	Symbols	For product L20x20x3
3.95, 3.96, 3.97, 3.98, 3.99	n	8,16

Since L20x20x3 is the smallest product in the catalog, there is no need to iteration. So L20x20x3 is chosen for profile 5.

5. CONCLUSION

Die cutting is a manufacturing process which is used to obtain desired shape on low strength materials such as rubber, paper, sheet metal, printable circuit boards, corrugated card boards and so on.

Most well known die cutting machines which are used in packaging industry are flat bed die cutting and rotary die cutting systems. Both of them have special solutions to obtain desired patterns.

Production rate of rotary die cutting machines are higher than flat bed die cutting machines. But rotary die cutting machines are not useful for corrugated card boards in contrast to flat bed die cutting machines.

The die cutting process consists of four steps to obtain card boards in desired shapes. These steps are feeding, cutting, separation and stacking of carton boards.

Goal of the study is finding solution to problems which occur in carton board separation step such as tearing of carton boards, internal damages which causes decreasing strength of carton boards using systematic design method which is developed by Dieter and Schmidt. Systematic design method is given in Figure 2.17.

As a first step in the systematic design process, to identify problem clearly, interviews were made and employees were listened in the local factory which is located in Adana. Available machines for carton board separation process and structure of carton board were investigated. Available machines for carton board separation process and structure of carton board were presented in section 2.2, 2.1 respectively. Afterward quality function deployment (QFD) chart was formed to describe problem. QFD chart is given in Figure 3.2.

Three concepts were generated to meet the requirements in QFD chart by using axiomatic design method. Generated concepts and working principle of each concept were presented in section 3.3.

Adequate concept was chosen among the generated concepts. Then components of the selected concept were designed according to failure theories and deflection analysis. Some components were chosen from product catalogues. Therefore manufacturing cost is decreased.

Designs for X (Design for assembly, Design for manufacturing) rules were applied to designed parts. Standard parts were used as possible. Also parts were designed so that they can be assembled to each other in vertical direction.

Systematic design method is an iterative process. If problem arises on the designed product during the design phase, the product must be modified to overcome problem. For this reason selected concept was modified number of times. Pneumatic rodless actuator was preferred for transferring of carton boards from separation station to stacking station instead of using screw mechanism since pneumatic systems has higher velocity. In addition two screw jacks were used to obtain precise motion at feeding and stacking station instead of using one screw jack.

Finally systematic design process was completed with technical drawings of parts and bill of materials of designed parts. Designed automated corrugated card board separation machine is given in Figure 5.1. (for the other details such as sectional view of parts and bill of materials are given in section 3.6).

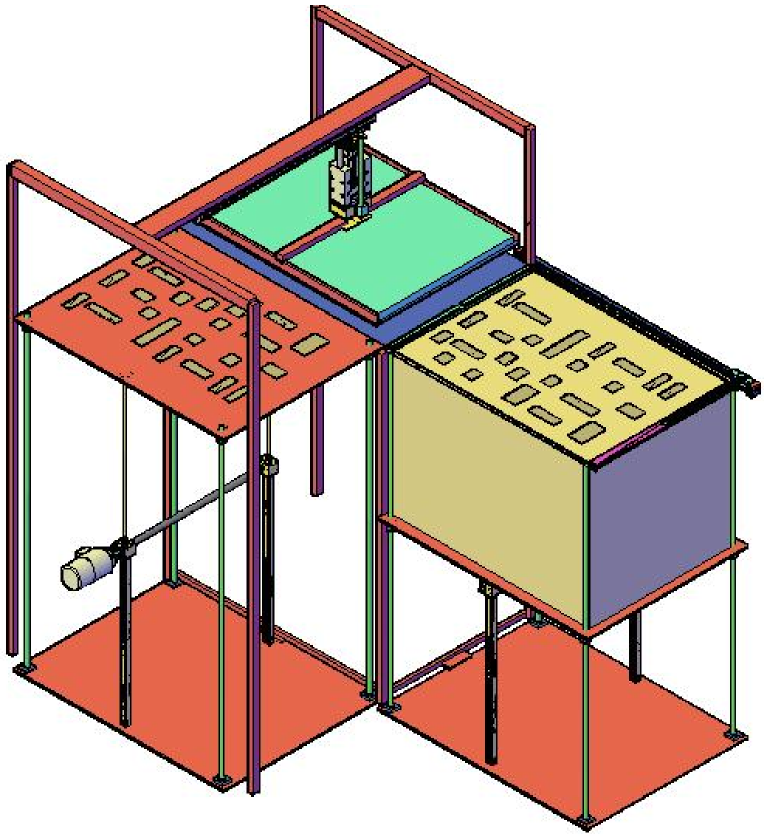


Figure 5.1. Designed Machine

Automated corrugated card board separation machine is designed to eliminate lack of available machine. Performance of the automated corrugated card board separation machine can be increased by separating more than one corrugated card board in one cycle using new approaches for the future studies.

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BIOGRAPHY

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