DOKUZ EYLÜL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

INTEGRATED DESIGN OF 3500X2500 MODEL SCRAP BALER

by
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İZMİR

INTEGRATED DESIGN OF
3500X2500 MODEL SCRAP BALER

A Thesis Submitted to the
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by
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M.Sc. THESIS EXAMINATION RESULT FORM

We have read the thesis entitled **"INTEGRATED DESIGN OF 3500X2500 MODEL SCRAP BALER"** completed by **ÇAĞATAY YELDAR YILDIRIM** under supervision of **PROF. DR. HİRA KARAGÜLLE** and we certify that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

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Çağatay Yeldar YILDIRIM

INTEGRATED DESIGN OF 3500X2500 MODEL SCRAP BALER

ABSTRACT

The Scrap Balers are used for the recycling of metal scraps. Metal scraps are compressed by the effect of hydraulic forces in the baling presses. In the production of these machines, process requirements should be determined, hydraulic and mechanical calculations should be made according to these requirements. In the scrap press subject to this study, chamber dimensions were determined as 3500 millimetre length 2500 millimetre width and outlet dimensions, the scrap outlet dimensions are in the form of a prism with an edge length of 600 millimetres. Our objective in this thesis is to propose a practical method for constructing the analysis model of the industrial baler.

In this study, structural calculations of the hydraulic cylinders of the balers are made. The hydraulic cylinder wall thicknesses and forces required for the process are calculated. After the determination of the hydraulic cylinders, the cycle time of the system is calculated. Hydraulic pumps and electric motors are selected. In addition, a procedure for automating the design of the metal scrap balers is provided. Balers of different sizes can be designed easily and quickly with this process. A solid model of a prototype baler is created in SolidWorks. The frame is considered in this work and modelled as assembly of parts in SolidWorks. Each section is modelled as multiple body modelling using a graphical user interface (GUI). The method uses the computer program developed in Visual Basic. The dimensions that are subject to change for each section are saved in an Excel file. The program reads the dimensions to be changed and automatically makes changes to the SolidWorks model using the commands of the application programming interface (API).

Within the scope of the study, models made with GUI are analysed with SolidWorks. This analysis is then evaluated and developed by applying the latest model improvements.

Keywords: Scrap Baler press, metal recycling, scrap baler, SolidWorks, Excel, finite elements, parametric design

3500x2500 MODEL HURDA PRESİNİN ENTEGRE TASARIMI

ÖZ

Hurda Balyalama makineleri, metal hurdaların geri dönüşümü için kullanılmaktadır. Balyalama preslerinde metal hurdalar hidrolik kuvvetlerin etkisi ile sıkıştırılmaktadır. Bu makinelerin üretiminde proses gereksinimleri saptanmalı ve bu gereksinimlere göre hidrolik ve mekanik olarak hesaplamalar yapılmalıdır. Bu araştırmaya konu olan hurda presinde, hazne boyutları 3500 milimetre uzunluk, 2500 milimetre genişlik ve hurda çıkış boyutları 600 milimetre kenar uzunluğu olan bir prizma şeklindedir. Bu tezin amacı, endüstriyel balya analiz modelini oluşturmak için pratik bir yöntem önermek, bu modeli kullanarak yapısal analiz yapmak ve deneysel çalışmalarla karşılaştırmaktadır.

Çalışma ile balyalama makinelerinin hidrolik silindirlerinin yapısal hesaplamaları yapılır. Hidrolik silindir et kalınlıkları ve gerçekleştirilecek işlem için gerekli kuvvetler hesaplanır. Hidrolik silindirlerin belirlenmesinden sonra, sistemin çevrim süresi hesaplanır. Hidrolik pompalar ve elektrik motorları seçilir. Ayrıca, metal hurda balya makinelerinin tasarımını otomatikleştirmek için bir prosedür geliştirilir. Farklı boyutlardaki balya makineleri bu işlemle kolay ve hızlı bir şekilde tasarlanabilir. SolidWorks'te prototip bir balya presi oluşturulmuştur. Bu çalışmada, parçaların montajıyla oluşturulmuştur gövde göz önünde bulundurulur. Bu parçalar, grafik kullanıcı arayüzü kullanılarak çoklu parça olarak tasarlanır. Yöntem, Visual Basic'te geliştirilen bilgisayar programını kullanır. Her bölüm için değişebilecek boyutlar bir Excel dosyasına kaydedilir. Program değiştirilecek boyutları okur ve uygulama programlama arayüzünün (API) komutlarını kullanarak SolidWorks modelinde otomatik olarak değişiklikler yapar.

Çalışma kapsamında GUI ile yapılan modeller SolidWorks ile analiz edilir. Analizler değerlendirilir. En son model iyileştirmeler uygulanarak geliştirilir.

Anahtar kelimeler: Hurda balyalama presi, metal geri dönüşümü, hurda presi, SolidWorks, Excel, sonlu elemanlar, parametrik dizayn

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CHAPTER ONE
INTRODUCTION

1.1 Introduction

Recycling is the process of converting the wastes, which can be evaluated from the wastes consumed by human beings, into a usable secondary raw material by a number of chemical and physical processes and including these secondary substances in the production process. Recycling of resources prevents environmental damage. It also contributes to the economies of countries.

Scrap presses are used for recycling metal materials. Metal materials are compacted in scrap press and made suitable for melting process. Steel production from scrap materials reduces emissions and uses less energy. It lowers costs and provides a sustainable solution for the environment and industry. The demand for scrap bailing machines with different technical specifications increases worldwide continuously.

Only a few countries and companies can produce hydraulic scrap baling press. German Lindemann company, Italian Vezzani company and American Harris Corporation are the typical manufacturers for heavy hydraulic scrap baling press. (Mingbo et al., 2016)

Nowadays, hydraulic scrap presses are generally used in places such as iron and steel plants, scrap yards, some government facilities and automobile industries. The reasons and benefits of the use of scrap presses in various fields are as follows:

- Reduction of energy costs due to reduced melting time
- Minimising melting losses. In particular, the fine material burns in the arc furnaces, causing large material losses. By increasing the density, these losses are prevented in baled material.
- Melting efficiency increases due to dense bales and high energy saving is provided.

- As the cover of the melting furnaces remains less open during loading, energy losses are reduced.
- By reducing the storage volumes of the scrap material, it becomes a big space is saved, cleaning and ordering becomes possible.
- Due to the high density of the baled material, a great advantage is achieved in all transport operations.
- The sales value of scrap is increased due to all these benefits.
- By means of a weighted dosing system, it is possible to measure and control the amount of scrap left.
- The life of the refractory cover of the melting furnaces increases due to the appropriate melting process. (Biber, 2005)

1.2 Classification of Scrap Baler

Hydraulic Scrap Baler Press are classified into three main groups because of their number of compression cylinder. They are subdivided according to working principles and chamber size or bale size. These are:

- Three compression scrap baler presses
- Two compression scrap baler presses
- Single compression scrap baler presses

1.2.1 Three Compression Scrap Baler Presses

The three compression scrap balers press compress the bulk metal scrap by applying force from three directions. They are divided into two types as continuous pressing and covered type. This study is concerned with the covered type three compression scrap baler. Covered type three compression scrap baler shown in Figure 1.1. The compression cylinders are numbered in figures. The system consists of a cover cylinder and two compression cylinders perpendicular to each other. The final compression force is higher than other types of presses, so the density of compressed metal scrap is better.

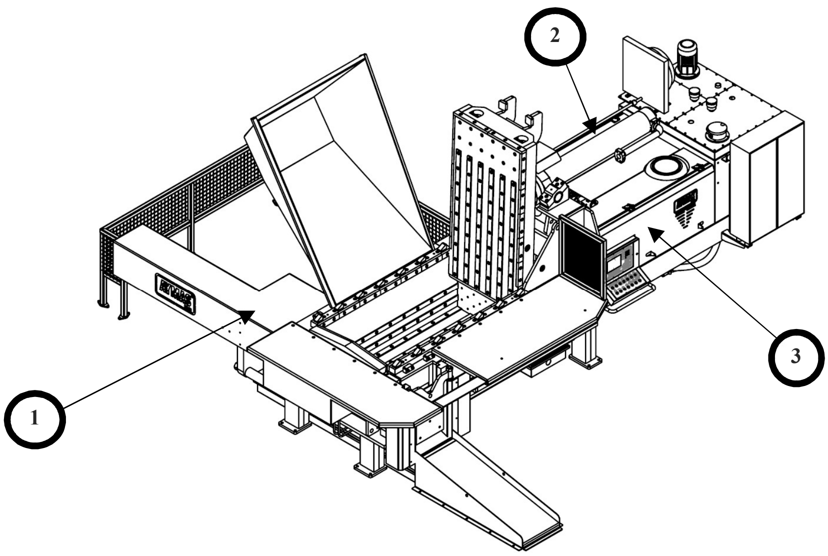


Figure 1.1 Covered type three compression scrap baler (Aymas, 2019)

The continuous type three compression scrap baler is shown in Figure 1.2. This type of machine can be used for fine scrap compression such as automotive waste. The continuous type three compression scrap baler has high production capability. Triaxial compression method (i.e. X, Y, Z direction) was used to achieve high density scrap block (2.2-3.2g/cm^3) which can effectively cut down the storage area, improve the transporting efficiency and reduce the heat loss of the smelting process. (Mingbo et al. 2016)

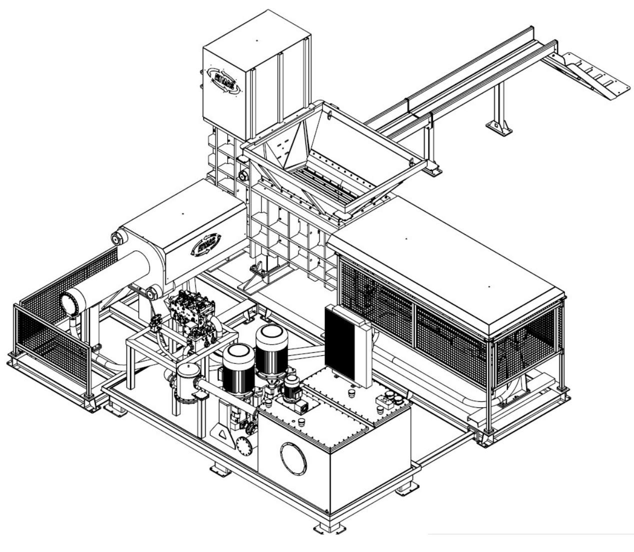


Figure 1.2 Continuous type three compression scrap baler (Aymas, 2019)

1.2.2 Two Compression Scrap Baler Presses

The two compression scrap balers press compress the bulk metal scrap by applying force from two directions and it is shown in Figure 1.3. The figure shows an example of a metal bale. System consists of a cover cylinder and main cylinder.

Figure 1.3 Covered type two compression scrap baler (Aymas, 2018)

The two compression continuous type scrap baler shown in Figure 1.4. This type of machine is used for thin sheet metal waste. It is used in the baling of waste produced in the automotive and electronics sectors. It consists of two compression cylinders perpendicular to each other and a large chamber. The machine can be used to compress various metals such as copper, aluminium, zinc and steel.

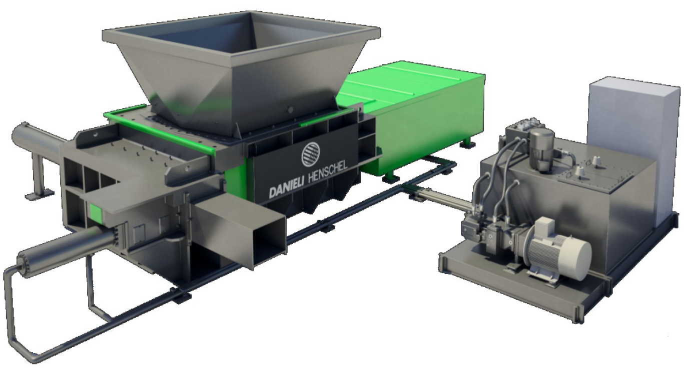


Figure 1.4 Continuous type two compression scrap baler (Danieli Henschel, 2019)

1.2.3 Single Compression Scrap Baler Presses

The single compression scrap balers press compresses the bulk metal scrap by applying force from one direction. Single compression scrap baler press is shown in Figure 1.5. This type of machine is used to compress thin metal sheets such as beverage cans. Therefore, the application areas are not very wide.

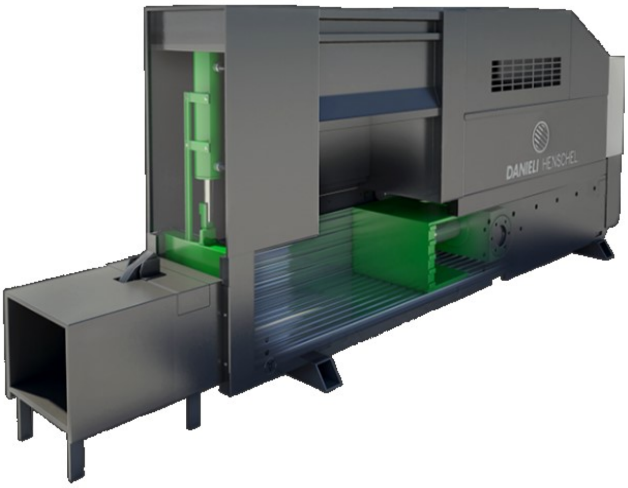


Figure 1.5 Single compression scrap baler press (Danieli Henschel, 2019)

1.3 Parts of Scrap Baler

Scrap Baling presses have three main sections: hydraulic, electrical-automation and mechanical. In this section, the main technical features of the main groups will be explained with figures.

1.3.1 Mechanical Parts of Scrap Baler

Baling presses have three main sections: hydraulic, electrical-automation and mechanical. In this section, the main technical features of the main groups will be explained with figures. These groups can be seen in Figure 1.6 except electrical-automation. Baler parts are numbered, and the numbers are shown in Table 1.1.

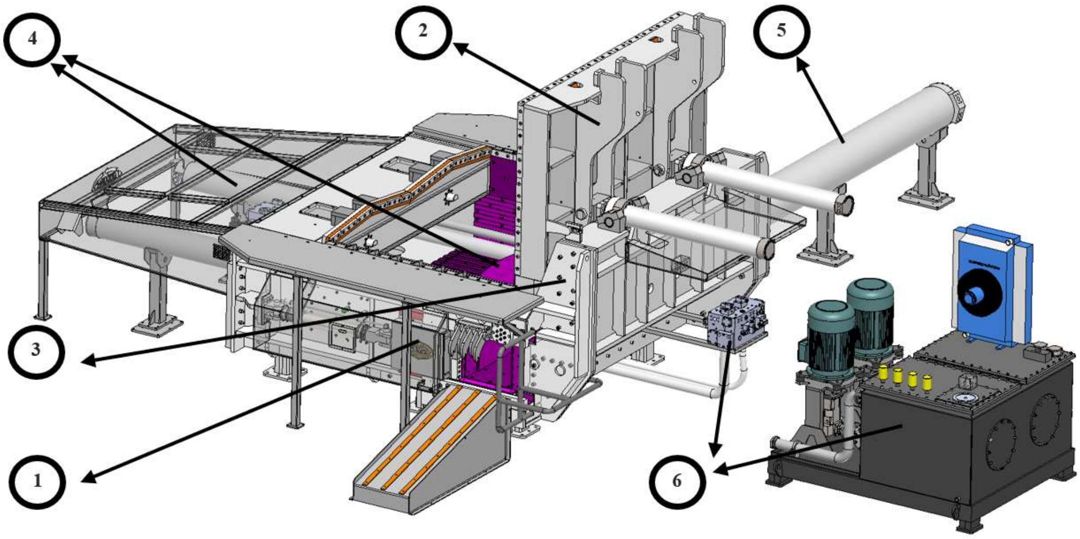


Figure 1.6 HP3W 60x60 3500x2500 scrap baler press (Aymas, 2018)

Table 1.1 Main parts of scrap baler press

1	Main Body
2	Top Cover
3	Outlet Cover Group
4	Pre-Compression Group
5	Main Compression Group
6	Hydraulic Group

1.3.1.1 Mechanical Section

The mechanical section can be summarised in first five groups in Table 1.1. In the following sections mechanical parts will be explained in detail.

1.3.1.1.1 Main Body. The main body of the press is usually made of structural steel. Compaction surfaces are made of HARDOX material. HARDOX plates are connected to the body with bolts. There are blades on the three sides of the chamber on the body. These blades and their counterparts on the top cover allows cutting of scrap hanging out of the chamber.

In the scrap baling press subject of the thesis, chamber dimensions are 3500x2500 millimetres. The height of the chamber is 600 millimetres when the cover is closed. The body is shown in Figure 1.6, side blades, front blades, HARDOX plates and chamber can be seen. The chamber dimensions and the outlet dimensions of the scrap bale are used for naming the machine. The name of the scrap baling press is HP 60x60 3500x2500.

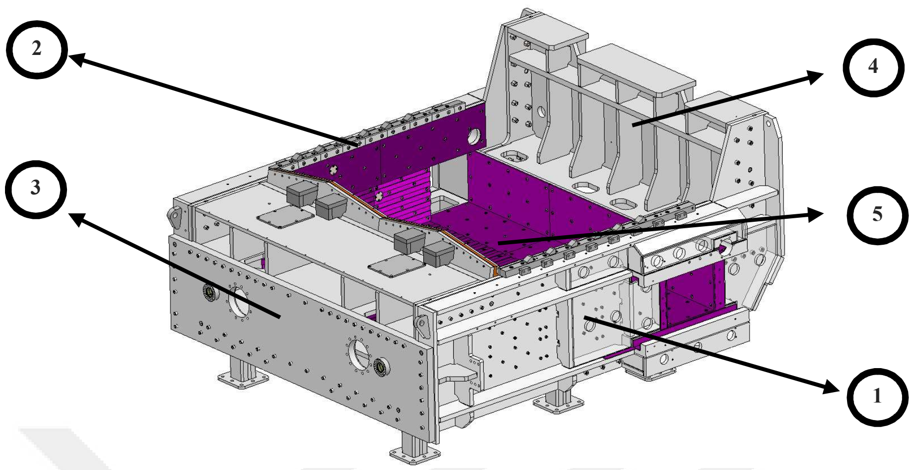


Figure 1.7 Main body of scrap baler press HP 60x60 3500x2500 (Aymas, 2018)

In the Figure 1.7 main body's parts are numbered. The main body's part names are listed in Table 1.2.

Table 1.2 Parts of main body

1	Right side Wall
2	Left side Wall
3	Frontside Wall
4	Backside Wall
5	Bottom Part

In the scrap baling press, all of the mechanical parts are assembled on the main body. All HARDOX on the main body are painted purple. Since these materials have high hardness, they show high resistance to abrasion. For this reason, the use of HARDOX materials with various properties in the chamber extends the service life of the machine.

1.3.1.1.2 Top Cover. The top cover allows the scrap loaded into the press to be introduced into the chamber and pre-compressed. The moving blades on the top cover are used for cutting scrap. The top cover is supported from the number 1 region to the body. The top cover is moved by the Cylinders. Cylinder characteristics shall be given in hydraulic calculations. The connections of the cylinders with the top cover are shown in the Figure 1.8. The cylinder connection supports are shown at number 2.

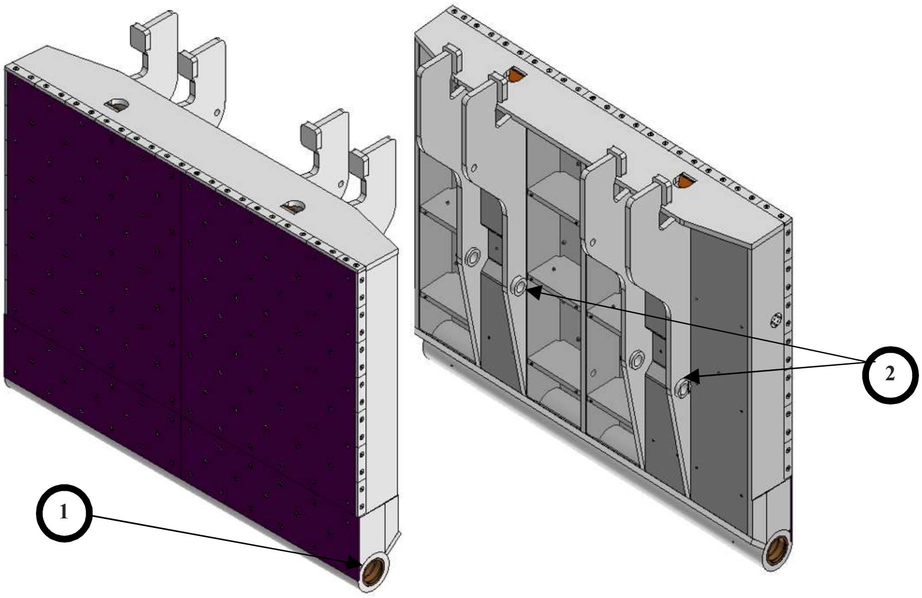


Figure 1.8 Top cover of the scrap baler press (Aymas, 2018)

When the bale of scrap is produced, the top cover closes first in the machine. When the top cover is closed, the height of the chamber is 600 millimetres. This measure is an edge length of the scrap bale.

1.3.1.1.3 Outlet Cover Group. The front cover is used to remove bales from the system. It also helps the compaction ram in baling the scrap. The front cover is shown in the Figure 1.9 and it is driven by a single hydraulic cylinder. The characteristics of this cylinder are given in the section on hydraulic calculations.

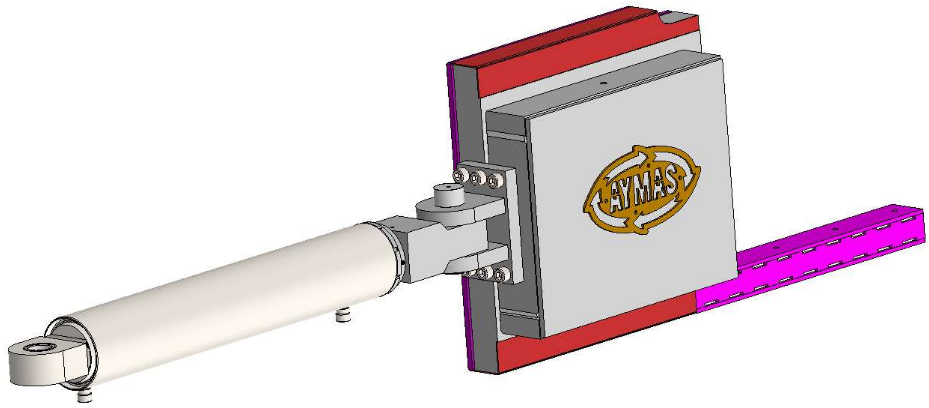


Figure 1.9 Outlet cover of the scrap baler press (Aymas, 2018)

1.3.1.1.4 Pre-compression Group. The pre-compression ram allows the scrap bale to be compressed to the second dimension. It is driven by two hydraulic cylinders. Hydraulic cylinder details will be given in the following sections. Due to the large width of the pre-compression ram, there are two guide pins. All of the parts of the pre-compression ram can be shown in the Figure 1.10.

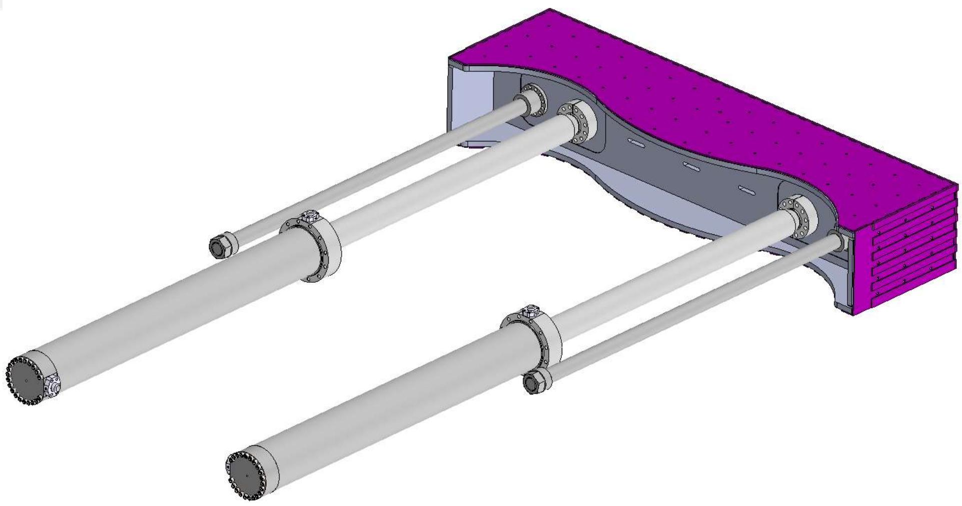


Figure 1.10 Pre-compression ram (Aymas, 2018)

By pre-compressing the scrap, the density of the bale is increased. Efficient compression is provided by the channels on the ram edges.

1.3.1.1.5 Main Compression Group. The main pressure ram is pushed by the most powerful cylinder of the press. It determines the length of the scrap bale, but it is not standard. The amount of scrap thrown into the reservoir affects the length. The main compression ram is shown in Figure 1.11.

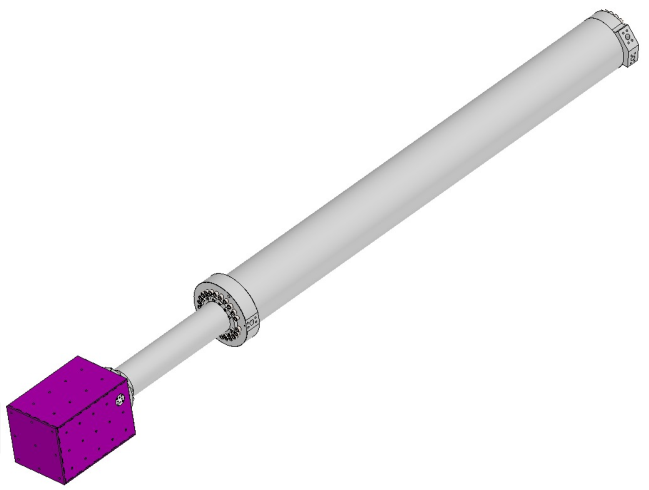


Figure 1.11 Main compression group (Aymas, 2018)

1.3.2 Hydraulic of Scrap Baler

Scrap baling press hydraulic group consists of hydraulic oil, oil tank, cooling, pumps, blocks and valves. In addition, steel pipes and hydraulic hoses are used for the transfer of hydraulic oil in the system. Some parts of the hydraulic group are shown in Figure 1.12. As the blocks and valves are in different positions on the machine, they are shown in Figure 1.13.

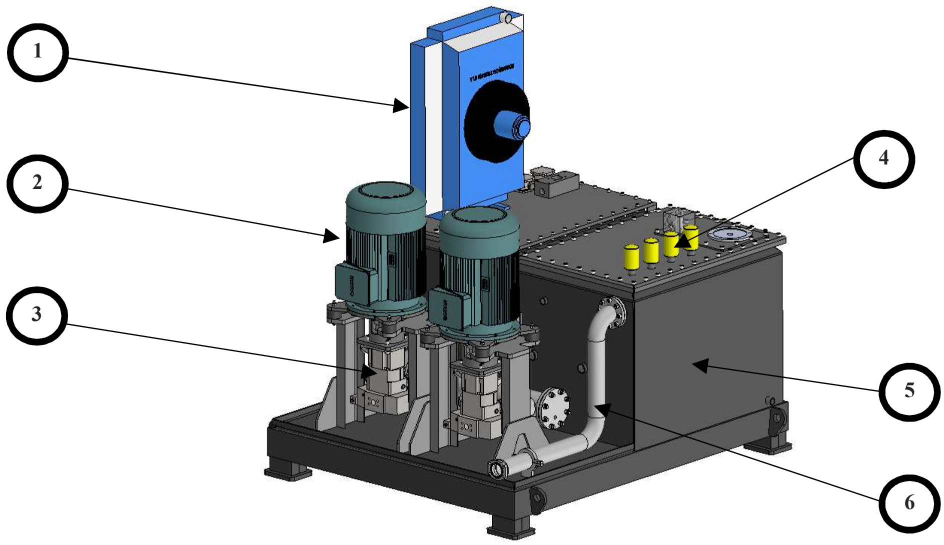


Figure 1.12 Hydraulic group of scrap baler (Aymas, 2018)

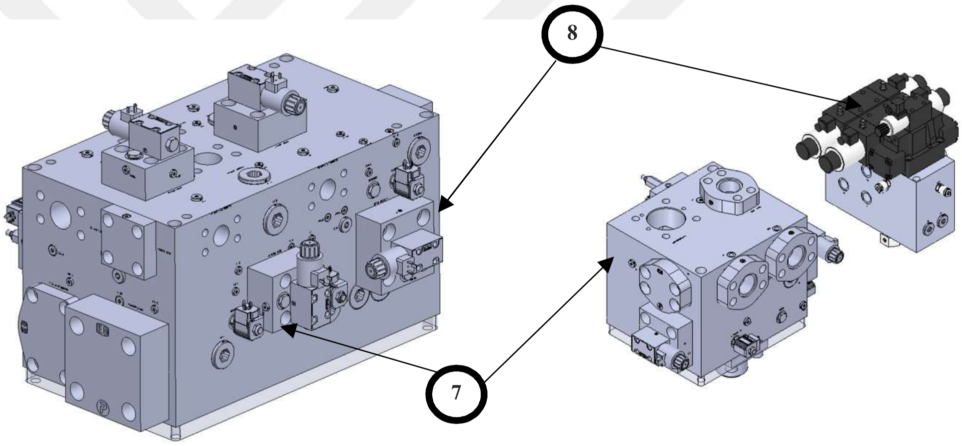


Figure 1.13 Backside and frontside blocks and valves (Aymas, 2018)

All hydraulic parts of the scrap baler press are numbered in Figure 1.12 and Figure 1.13. The parts names corresponding to the numbers are given in the Table 1.3.

Table 1.3 Hydraulic equipment of scrap baler press

1	Cooling Fan
2	Electric Motors
3	Hydraulic Pumps
4	Air Filters
5	Hydraulic Oil Tank
6	Hydraulic Pipe
7	Blocks
8	Valves

The most important task in this group is that the electric motor drives the pump through the coupling. The pumps are suitable for operation at high pressures. In baling presses, variable displacement piston pumps are used due to the need for very high pressure with a very high flow rate. Therefore, the selected valves must be highly conductive.

1.3.3 Electric-Automation of Scrap Baler

The electrical-automation panel is produced according to the electrical circuit project of the machine. Numerous sensors, pressure gauges used in the machine are processed and controlled by PLC. Figure 1.14 shows the remote control for automatic control in the compartment on the panel. Even if the machine is generally controlled automatically, there is a control section on the panel for manual control of the system when necessary.

Figure 1.14 Electric-automation board (Personal archive, 2019)

1.4 Literature Review

In literature research, firstly, studies on similar machines were examined. Then, documents similar to those planned to be made within the scope of the thesis were examined. For this reason, concentrated searches, scrap baling presses, finite element analysis (FEA), design automation, parametric design.

1.4.1 Scrap Baler

Mingbo et al. (2016) the study focused on the overall design of a scrap baling press that compresses scrap waste. In this study, the design and development of a heavy industrial press which can work with high compressive forces is given. A similar machine was compared with basic technical specifications.

Biber (2005) studied about module block applications in hydraulic driven scrap baling presses. The working principles of scrap baling presses are mentioned. Within the scope of the study, especially in hydraulic baling presses, the focus was on hydraulic equipment.

Prabaharan & Amarnath (2011) focuses on the optimisation of hydraulic presses and scrap balers. An optimisation study using ANSYS WORKBENCH software is included in the study content. In this study, a test study was performed using extensometer.

Bostan (2011) studied about examples of hydraulic systems developed for recycling machines. The work is mainly focused on shredders, also there have been research on scrap presses and metal recycling.

1.4.2 Design Automation and Parametric Design

Halkacı & Yiğit (2004) worked on parametric design using SolidWorks and Excel interfaces. They have worked on the design automation of fixed roller bearing. In the application, fixed roller bearing tables are entered in Excel. Dimensions were obtained with Excel VBA program. This data is transferred to the SolidWorks program to create a solid model.

Shah (2013) focuses on modelling with Excel and Autodesk Inventor. In this study, flanged coupling was chosen as geometry. Some dimensions of flanged coupling are entered in the table made in Excel. After then male and female coupling can be drawn using Autodesk Inventor.

Kadam & Nimbalkar (2015) studied about parametric modeling using Creo. Creo is a parametric modeling software. The Study is especially focused on box designs using the software. The aim of the study is to make automatic design based on input-output speeds and motor power of the gearbox.

Camba et al. (2016) examined three major modeling methodologies: horizontal modeling, explicit reference modeling and resilient modeling. In the study, SolidWorks was used for modeling. Industrial CAD models were selected for modeling at three different difficulty levels.

1.5 Organization of the Thesis

Chapter 1 is introductory chapter which includes scrap baler presses and classification, parts of the scrap baler, literature review on the scrap baler, finite element analysis (FEA) and design automation.

Chapter 2 presents structural and hydraulic calculations for scrap baling presses. For the structural calculations, the forces that can be applied by hydraulic cylinders and the thickness of the cylinder's tubes were calculated. In the hydraulic calculations section, the speeds of the hydraulic cylinders and the total cycle time are calculated.

Chapter 3 is related to the parametric design of the structure and finite element analysis. In this section, parameter values are determined, and an Excel file is created to change these parameters quickly. Changed parameters are applied to the SolidWorks model of the baler with Visual Basic API. Reconstructed models in SolidWorks. After modeling, Modal and Static analysis and improvements are made. A final model is created when the improvements are complete.

Chapter 4 is the conclude section where the results are summarised.

CHAPTER TWO
STRUCTURAL AND HYDRAULIC CALCULATIONS

2.1 Structural Calculations

Process characteristics should be determined well when making technical calculations in scrap baling presses. Compression density, capacity data and efficiency in scrap baling presses depend on technical calculations. The forces of the hydraulic cylinders used in the system affect the scrap density. The density of scrap affects the efficiency of the process. Besides, the hydraulic calculations will affect the speed and capacity of the press. Capacity is another criterion seen as efficiency in presses. For this reason, the hydraulic drive group of the system, force calculations and strength calculations of the critical parts should be made carefully. Structural calculations will be discussed under two headings. These are strength calculations and hydraulic calculations.

2.1.1 Strength Calculation

For strength calculations, the forces must first be determined. Forces depend on cylinder diameters and system pressure in the hydraulic systems. The variable displacement piston pumps selected for energy efficiency are generally operated at a pressure of 300 Bar. Cylinder diameters are determined according to the type of metal to be compressed.

2.1.1.1 Cylinders Forces Calculations

Metal scrap must be exposed to a pressure of around 50 Bar in order to become a bale. This pressure value may vary according to the metal and the compressed geometry. It is considered appropriate to apply 100 Bar force to the scrap surface in the subject press. The compression cylinder will be selected according to this criterion. In other cylinders, lower forces are sufficient. The basic data required for the calculations are shown in the table. The area of the bale surface is calculated for the selection of the main compression cylinder's diameter. The bale surface on which the main compression cylinder acts is 600 x 600 millimetres. The bale shown in the Figure 2.1.

Figure 2.1 Scrap bale (Personal archive, 2018)

w_{bale} = 600 mm

h_{bale} = 600 mm

L_{bale} = variable "Depending on the quantity of material"

P_{system} (Max) = 300 Bar or 30 MPa

$P_{bale} \geq 10$ MPa

$$A_{bale} = w_{bale}\, h_{bale} \tag{2.1}$$

$$P_{system}\, A_{main} = P_{bale}\, A_{bale} \tag{2.2}$$

$$A_{main} = \pi\, r_{main}^2 \tag{2.3}$$

$A_{bale} = 600\ x\ 600 = 360000\ mm^2$

$A_{main} = \frac{10\ x\ 360000}{30} = 120000\ mm^2$

If the diameter of the main compression cylinder is 200 millimetres:

$$F_{main} = n\ P_{system}\ A_{main} \tag{2.4}$$

$A_{main} = \pi\ x\ 200^2 = 125663.7\ mm^2$

$F_{main} = 1\ x\ 30\ x\ 125663.7 = 3769911\ N = 384\ Tonf$

$P_{bale} = \frac{3769911}{360000} = 10.48\ MPa$

When calculating cylinder forces, the forces in the return state must be calculated. The shaft area plays a role in the calculation of the return forces:

$r_{sha} = 145$ mm

$$F_{rmain} = P_{system}\ (A_{main} - A_{shaft}) \tag{2.5}$$

$F_{rmain} = 30\ x\ (125663.7 - \pi\ 145^2) = 1788298.88\ N = 182.3\ Tonf$

The maximum force calculations of other compression cylinders can be made using formulas 2.3 2.4 and 2.5.

Table 2.1 Cylinder specifications for forces calculation

	Quantity	Max Pressure (Bar)	Diameter (mm)	Shaft Diameter (mm)
Main Compression Cylinder	1	300	400	290
Cover Cylinder	2	300	200	140
Pre-compression Cylinder	2	300	250	180
Lock Cylinder	2	300	80	50
Outlet Cover Cylinder	1	80	160	100

$F_{cover} = 2\ x\ 30\ x\ \pi\ 100^2 = 1884955.6\ N = 192.1\ Tonf$

$F_{rcover} = 2\ x\ 30\ x\ (\pi\ 100^2 - \ \pi\ 70^2) = 961327.4N = 97.9\ Tonf$

$F_{prec} = 2\ x\ 30\ x\ \pi\ 125^2 = 2945243.1\ N = 300.2\ Tonf$

$F_{rprec} = 2\ x\ 30\ x\ (\pi\ 125^2 - \ \pi\ 90^2) = 1418429.1\ N = 144.6\ Tonf$

$F_{out} = 1\ x\ 8\ x\ \pi\ 80^2 = 160849.5\ N = 16.4\ Tonf$

$F_{rout} = 1\ x\ 8\ x\ (\pi\ 80^2 - \ \pi\ 50^2) = 98017.7\ N = 10\ Tonf$

Lock cylinders are used to support the system therefore their forces do not matter. Lock cylinders prevent opening of the top cover during operation. In the calculations, the pressure value of the pumps is taken as maximum. These pressure settings will be optimal during the operation of the press.

2.1.1.2 Cylinders Tube Thicknesses Calculations

It is necessary to calculate the wall thicknesses for the selection of the tubes of the power-calculated cylinders. The calculation of the thickness of the cylinder tubes formula is given as:

$$S_0 = \frac{D_{out}.P}{200.\sigma_y} \qquad (2.6)$$

where, S_0, D_{out} and σ_{ak} are thickness of tube, outer diameter of tube and yield strength of material. The data given in the Table 2.1 must be used for wall thickness calculations on all cylinders. (Ozcan, 2012)

Table 2.2 Cylinder specifications for thickness calculation

	Chosen Outer Diameter (mm)	Pressure	Yield Strength (35.5 daN/mm^2)	Calculated İnner Diameter (mm)	Chosen Thickness (mm)
Main Compression Cylinder	504	300	35.5	400	51
Cover Cylinder	245	300	35.5	200	22.5
Pre-compression Cylinder	320	300	35.5	250	35
Lock Cylinder	100	150	35.5	80	10
Outlet Cover Cylinder	190	150	35.5	160	20

$$s_{main} = \frac{504\ x\ 300}{200\ x\ 35.5} = 21.29\ mm$$

Chosen thickness of the main compression cylinder is 51 millimetres. This cylinder has a factor of safety 2.39.

$$s_{cover} = \frac{245\ x\ 300}{200\ x\ 35.5} = 10.35\ mm$$

Chosen thickness of the cover cylinder is 22.5 millimetres. This cylinder has a factor of safety 2.17.

$$s_{prec} = \frac{320\ x\ 300}{200\ x\ 35.5} = 13.52\ mm$$

Chosen thickness of the pre-compression cylinder is 35 millimetres. This cylinder has a factor of safety 2.58.

$$s_{lock} = \frac{100\ x\ 300}{200\ x\ 35.5} = 4.22\ mm$$

Chosen thickness of the lock cylinder is 10 millimetres. This cylinder has a factor of safety 2.37.

$$s_{out} = \frac{190 \ x \ 300}{200 \ x \ 35.5} = 8.03 \ mm$$

Chosen thickness of the outlet cover cylinder is 20 millimetres. This cylinder has a factor of safety 2.49.

2.2 Hydraulic Speed and Cycle Time Calculations

In baling presses, cycle times are extremely important. This is due to the fact that this time is used for capacity calculations. A successful press should be able to produce at high capacities. In the production phase, the target cycle time of the 3500x2500 scrap press is 80 seconds. The cycle completion rate per minute (n_c) is calculated as 0.75. The calculations made in this section are based on this cycle time.

When making time calculations in hydraulic system, it should be determined in advance that a regenerative circuit will be used. A regeneration circuit can double the extension speed of the same cylinder without using a larger pump (Trinkel, 2007).

In regenerative systems, hydraulic oil to be returned to the tank is reused. Re-use of the hydraulic oil after the return line is shown in the Figure 2.2.

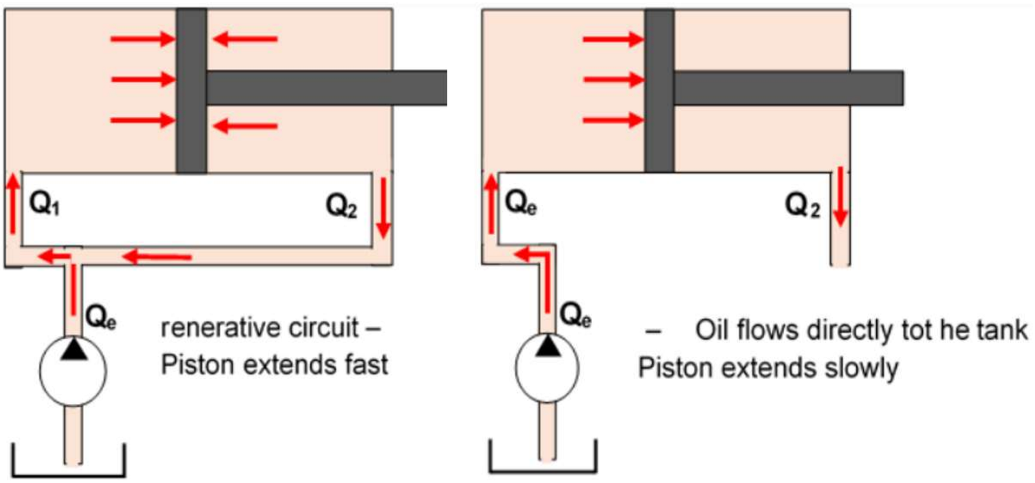


Figure 2.2 Regenerative and non-regenerative cycle

For the Q_1 flow we see in the diagram, the equation shown in 2.7 can be written:

$$Q_1 = Q_2 + Q_e \quad (2.7)$$

In addition to this information; The tube diameters (D_{in}), shaft diameters (D_{shaft}) and stroke lengths (L_s) of the cylinders to be used in the system must be known. D_{in}, D_{shaft}, L_s are shown in Table 2.3.

Table 2.3 Cylinders specification for cycle time calculations

	Quantity	Tube Diameters (mm)	Shaft Diameters (mm)	Stoke Lengths (mm)
Main Compression Cylinder	1	400	290	4331
Cover Cylinder	2	200	140	1475
Pre-compression Cylinder	2	250	180	2133.5
Lock Cylinder	2	80	50	98
Outlet Cover Cylinder	1	160	100	642

Depending on these variables, the compress area and the total cylinder volume can be calculated. The calculation of the volume of the cylinder's formula is given as Eq. 2.8:

$$V_{cylinder} = n\,.\,A_{cylinder}\,.\,L_{stroke} \quad (2.8)$$

The cycle volume of the cylinders must be known when performing the cycle calculation. In the turning stage, the volumes of the cylinder shafts must be subtracted from the tubes volumes. The formula for calculating the return volume is given Eq. 2.9:

$$V_{rcylinder} = n\,.\,(A_{cylinder} - A_{shaft})\,.\,L_{stroke} \quad (2.9)$$

Main compression cylinder volume calculation:

$V_{cylinder} = 1\ x\ 125660\ x\ 4331 = 544233460\ mm^3$= 544.23 L

$V_{rcylinder} = 1\ x\ (125660 - 59609.96)\ x\ 4331 = 258170747.6\ mm^3 = 258.17$ L

Pre-compression cylinders volume calculation:

$V_{cylinder} = 2\ x\ 49085.94\ x\ 2133.5 = 209449695.3\ mm^3 = 209.45$ L

$V_{rcylinder} = 2\ x\ (49085.94 - 23639.79)\ x\ 2133.5 = 100870973\ mm^3 = 100.87$ L

Cover cylinders volume calculation:

$V_{cylinder} = 2\ x\ 31415\ x\ 1475 = 92674250\ mm^3 = 92.67$ L

$V_{rcylinder} = 2\ x\ (31415 - 16021.65)\ x\ 1475 = 47263867.5\ mm^3 = 47.26$ L

Outlet cover cylinder volume calculation:

$V_{cylinder} = 1\ x\ 20105.6\ x\ 642 = 12907795\ mm^3 = 12.9$ L

$V_{rcylinder} = 1\ x\ (20105.6 - 12251.85) x\ 642 = 7865687.7\ mm^3 = 7.86$ L

Lock cylinders volume calculation:

$V_{cylinder} = 2\ x\ 5026.4\ x\ 98 = 985174.4\ mm^3 = 0.98$ L

$V_{rcylinder} = 2\ x\ (5026.4 - 3062.96) x\ 98 = 600340.65\ mm^3 = 0.6\ L$

The total volume of hydraulic cylinders in the system (V_{total}) is 1275.02 litres and the cycle completion rate per minute (n_c) is 0.75 1/minute. The required total pump flow rate (Q_{need}) is given in Eq. 2.10. Flow rate is given in litres per minute (LPM):

$$Q_{need} = V_{total} . n_c \qquad (2.10)$$

$Q_{need} = 1275.02 \text{ x } 0.75 = 956.27\ LPM$

The large stroke values of the hydraulic cylinders used in the system require the use of regenerative circuits. If a regenerative system is used, the total pump flow rate can be selected lower than the system needs. Two 270 cc displacement piston pumps were selected for the calculated total flow requirement. These displacement piston pumps are manufactured by companies such as Parker, Kawasaki and BOSCH-Rexroth. The Figure 2.3 shows a cross-section of variable displacement piston pumps as an example.

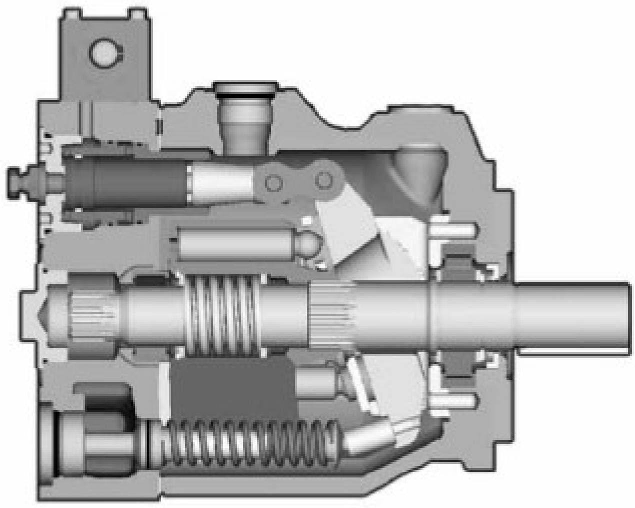


Figure 2.3 Piston pump (Parker, 2012)

The flow / pressure graphs of the pumps selected from the catalogues of these companies should be checked. Flow / pressure graphs will be used to calculate how the system will behave after regulation. The flow / pressure graph of a PV270 piston pump of Parker brand is shown in the Figure 2.4. The limit of regulation of the pump depends on the selected motor power. A motor producing 90 kW was selected for the system.

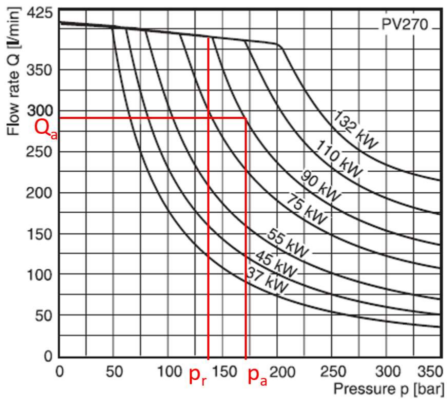


Figure 2.4 PV 270 flow rate / pressure graph (Parker, 2012)

According to the motor selection, the regulation pressure (p_r) of the system is determined as 124 bar. The mean post-regulation pressure (p_a) was 175 bar and the post-regulation mean flow (Q_a) was 293 LPM.

Total flow rate of the system is 540 cc. In addition, 1 cc equal to 1.45 LPM. Therefore, the total hydraulic oil flow rate (Q_e) of the system is 783 LPM. The area ratio (r_a) should be calculated for the cylinders where regenerative circuit will be used in the system. The area ratio can be calculated as shown in Eq. 2.11:

$$r_a = \frac{A_{piston}}{A_{rod}} \tag{2.11}$$

In line with this equation, the area ratios of the hydraulic cylinders using the regenerative system were calculated. These values are shown in Table 2.4. These values are multiplied by the Q_e value given in equation 2.7 and the regenerative flow rate is calculated.

Table 2.4 Area ratio table for regenerative calculations

	Area of piston (mm^2) A_{piston}	Area of piston rod (mm^2) A_{rod}	Area ratio of hydraulic cylinders r_a	Regenerative flow rate (LPM)
Main Compression Cylinder	125660	66050	1.90	1489.66
Cover Cylinders	62830	30786.7	2.04	1597.96
Pre-compression Cylinders	98171.87	50892.3	1.92	1510.42

All of the flow rates required equality for speed and time calculations were found. Calculations are continued by using the found values in equality 2.12 and 2.13. The value of t_f in Equation 2.12 indicates the time that the hydraulic cylinder completes its movement. The values of 60 and 1000 in the same equation are for making the result unit in seconds:

$$t = \frac{A_{piston} \ L_{stroke} \ 60}{Q \ 1000} \tag{2.12}$$

When the calculated value of t is replaced by equation 2.13, the speed of the cylinder is found:

$$V = \frac{L_{stroke}}{t} \tag{2.13}$$

All necessary preliminary information is provided for the calculation of cycle time. The calculations were made via Excel for each cylinder separately. The Table 2.5 shows the speed and time calculations for the main compression cylinder. When baling scrap, it is not known when the flow rate will be regulated. Therefore, only the regenerative forward and return times are considered when calculating the cycle time. In fact, when the pressure in the system exceeds 80 bar, the regenerative cycle is deactivated. For these reasons, the processing time calculated in the tables is only the forward with regenerative and return times.

Table 2.5 Hydraulic calculations of the main compression cylinder

Main Compression Cylinder				
	Flow rate (LPM)	Volume (L)	Time (s)	Velocity (cm/s)
Forward with regenerative	1489.66	544.23	**21.9**	197.58
Forward	783	544.23	41.7	103.90
Forward with regulation	586	544.23	55.7	77.72
Return	783	258.17	**19.8**	218.90
Total Time			**41.7**	

Table 2.6 shows the hydraulic cycles of the top cover cylinders.

Table 2.6 Hydraulic calculations of the cover cylinders

Cover Cylinders				
	Flow rate (LPM)	Volume (L)	Time	Velocity (cm/s)
Forward with regenerative	1598	92.67	**3.5**	423.90
Forward	783	92.67	7.1	207.70
Forward with regulation	586	92.67	9.5	155.45
Return	783	47.26	**3.6**	407.26
Total Time			**7.1**	

Table 2.7 shows the hydraulic cycles of the pre-compression cylinders.

Table 2.7 Hydraulic calculations of the pre-compression cylinders

Pre-Compression Cylinders				
	Flow rate (LPM)	Volume (L)	Time	Velocity (cm/s)
Forward with regenerative	1510.42	209.59	**8.3**	256.42
Forward	783	209.59	16	132.93
Forward with regulation	586	209.59	21.4	99.49
Return	783	100.87	**7.7**	276
Total Time			**16**	

Table 2.8 shows the hydraulic cycles of the outlet cover cylinders. The flow rate requirement of the outlet cover cylinder is low. Therefore, the cylinder working flow is determined as 185 LPM. There is also no regenerative circuit in short stroke cylinders.

Table 2.8 Hydraulic calculations of the outlet cover cylinder

Outlet Cover Cylinder				
	Flow rate (LPM)	Volume (L)	Time	Velocity (cm/s)
Forward	185	12.9	**4.2**	153.36
Return	185	7.86	**2.6**	251.66
Total Time			**6.8**	

Table 2.8 shows the hydraulic cycles of the lock cylinders. The flow rate of the lock cylinders is set to 80 LPM.

Table 2.9 Hydraulic calculations of the lock cylinders

Lock Cylinders				
	Flow rate (LPM)	Volume (L)	Time	Velocity (cm/s)
Forward	80	9.85	**0.7**	218.9
Return	80	6	**0.5**	217.65
Total Time			**1.2**	

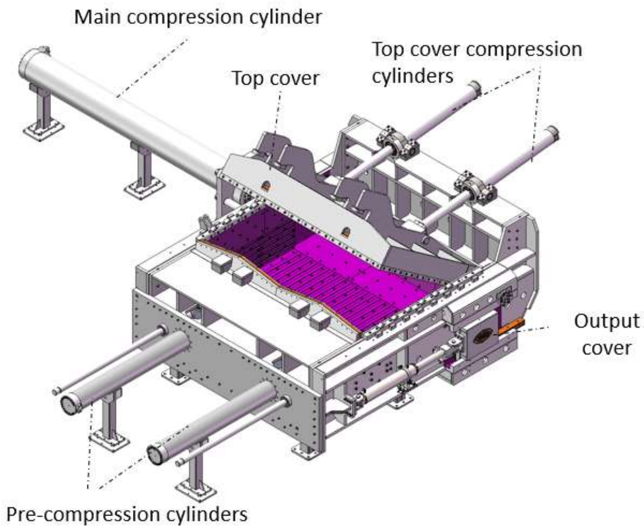
The total duration of the cycle is calculated as **72.8** seconds. However, decompression times should also be added to this circle time. Decompression is to tolerate oil compression to prevent system knocks.

CHAPTER THREE
PARAMETRIC DESIGN AND FINITE ELEMENT ANALYSIS OF BALER

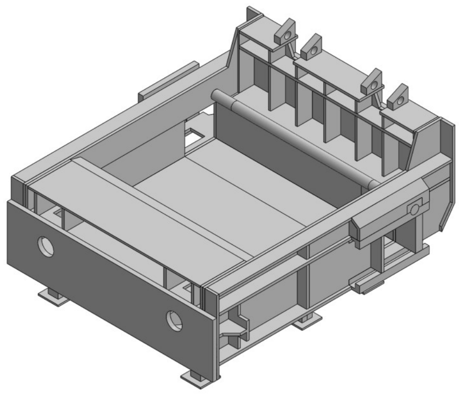
3.1 Design Automation Procedure

This chapter of the thesis procedure to automate the design of metal scrap balers is presented. Balers with different sizes can easily and quickly be designed by the procedure. The solid model of a prototype baler is created in SolidWorks. The frame is considered in this work and it is modelled in SolidWorks as the assembly of parts. Each part is modelled as multibody part modeling by using the graphical user interface (GUI). The details such as holes and welding grooves are not considered in the analysis model. The initial prototype model is designed depending on the experience. After the initial analysis, iterative work is necessary to obtain the final design by making changes in the design. A method is presented for quick and easy iteration work. The method uses the computer program developed in Visual Basic in this study. The dimensions subject to change for each part is recorded into an Excel file. The program reads the dimensions (that are) changed and automatically makes the changes in SolidWorks model by using the commands of the application programming interface (API). The procedure is applied to design two models of balers with different technical specifications.

The production model of the first prototype system is shown in Figure 3.1 (a). The analysis model of the frame is shown in Figure 3.1 (b).



(a)



(b)

Figure 3.1 (a) Production model and (b) analysis model of frame of baling press

The scrap chamber dimensions of HP3 60x60 3500x2500 are 350 cm x 60 cm x 250 cm. The analysis model is created by experience initially. The dimensions of the output bale is 60 cm x 60 cm x L_b where L_b is the length of the bale. A similar system (HP3 50x50 2500x2000) considered has the scrap chamber dimensions of 250 cm x 50 cm x 250 cm, which produces bales with the dimensions of 50 cm x 50 cm x L_b.

There are three steps in the process of scrap bailing:

Step 1: Cover compression cylinders press the top lid and sizes the scrap to the chamber dimensions (350 cm x 60 cm x 250 cm).

Step 2: Pre-compression cylinders press the scrap to the dimensions of 350 cm x 60 cm x 60 cm.

Step 3: The main compression cylinder applies 300 bar and the scrap bale with a size of L_b x 60 cm x 60 cm is produced.

The cracking pressures are 300 bar for Step 1 and 2. The rigidity of the scrap determines the pressures in these steps. The pressure is fixed as 300 bar for Step 3, and the rigidity of the scrap determines L_b in this step.

3.2 Flow Chart of Design Procedure

The flow chart of the procedure introduced in this work to is shown in Fig. 3.2.

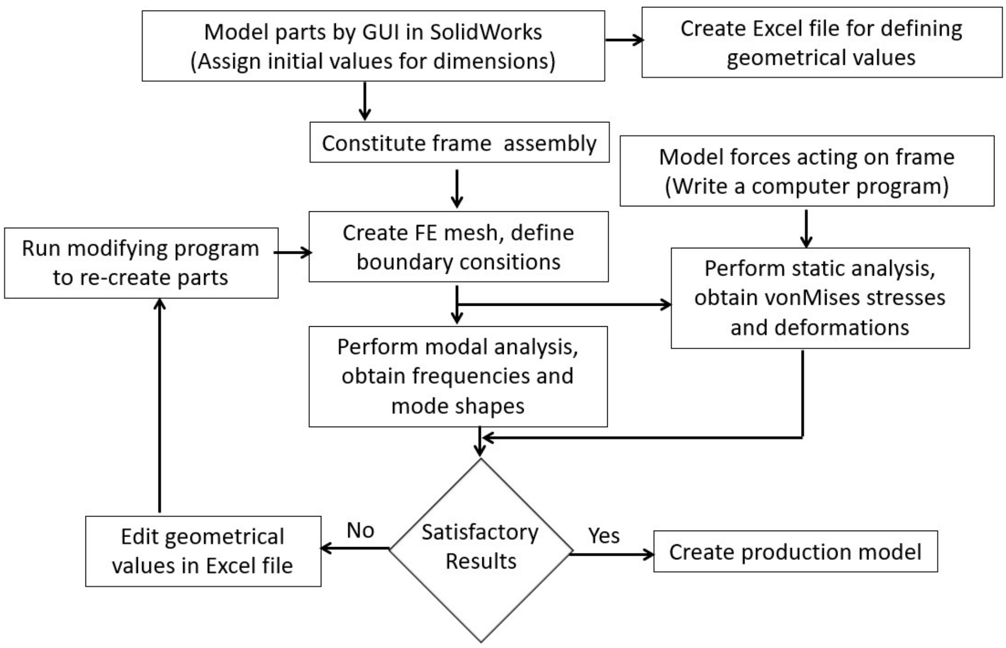


Figure 3.2 Flow chart of analysis procedure

First, the parts (bottom, left, right, front, back and shaft) are modelled in SolidWorks by using graphical user interface (GUI). The details such as holes and welding grooves are not considered in the analysis model. Sketches are drawn, boss and cut-extrude operations are applied for modeling the parts. The model of analysis is shown in Figure 3.3 with an exploded view.

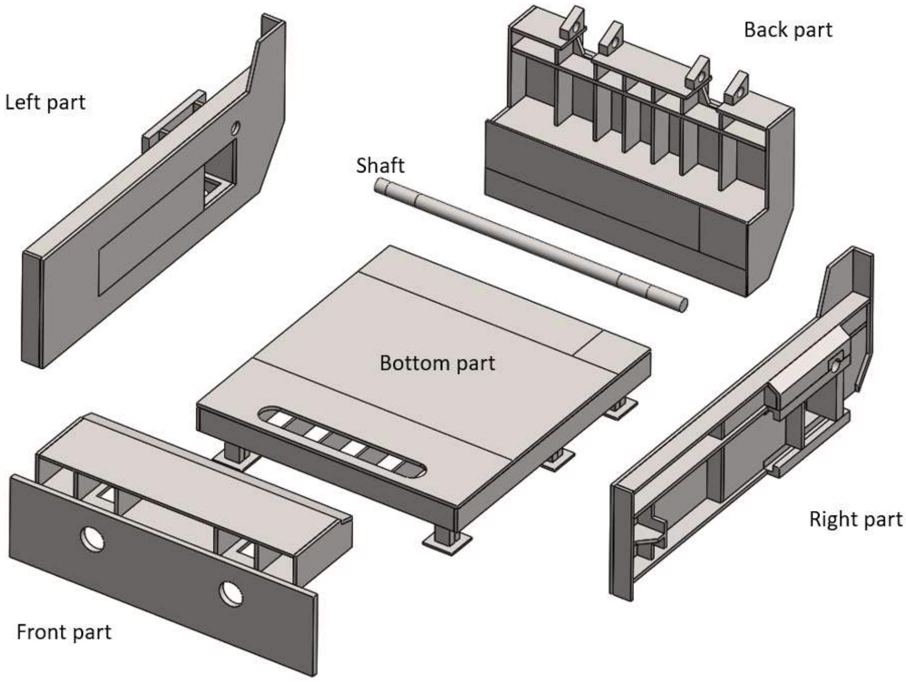


Figure 3.3 HP 60x60 3500x2500 exploded analysis model

Each sketch has dimensions. The dimensions can be classified as independent dimensions and related dimensions. Related dimensions can be defined by using GUI. Equations can also be used to define dependent variables. Extrusions are not merged to obtain multi-body models of the parts. The frame assembly is constituted by defining mates by using GUI. The initial dimensions are given by experience. An Excel file is created where the geometrical values under consideration for the parametric design of the frame are defined.

The iterative process starts with the finite element analysis of the frame. The modal analysis and static analysis are performed. The rigidity of the frame is evaluated by the results of the modal analysis. The strength and deformation of the frame are evaluated by the results of the static analysis. If the results are not satisfactory, the geometrical values are re-defined in the Excel file. A computer program developed in this work in Visual Basic reads the changed geometrical values from the Excel file and automatically modifies the SolidWorks model by using the SolidWorks Application Programming Interface (API). The finite element analysis, evaluation of the results, editing the Excel file, modifying the SolidWorks model loop continues until the satisfactory results are obtained. The production model is created from the final analysis model.

3.3 Application of Procedure

3.3.1 Modeling

Excel file contains 7 sheets titled as “param”, “bottomp”, “backp”, “frontp”, “leftp”, “rightp”, and “shaftp”. Here, Sheet- “backp”, for example, indicates that there is a SolidWorks file titled as “backp.SLDPRT” where the back part has been modelled by GUI as explained in Section IA. Sheet-“param” includes the list of the part file names and the common dimensions which are used by several parts. Sheet-“backp”, for example, includes the information about the model of the back part. Example data is given below:

Table 3.1 Example data for model of back part

	A	B	C	D	E	F
.	.	.	…	…	…	…
3	a		extrude	30.00	Sketch1	Boss-Extrude-1
4		A	D1	3540.00		
.	.	.	…	…	…	…
17		0	extrude		Sketch11	Boss-Extrude-11
18	s		D1	30.00		
19		A	D2	862.50		
20	a		D3	3000.00		

Here, for example, “Sketch11” has a dimension “D2” with a value of 862.5. It has been extruded named as “Boss-Extrude- 11”. The extrusion value is normally given in Cell-D17 (Row 17, Column D), which is empty for this example because the extrusion value is related to other dimensions defined in SolidWorks. The extrusion value for “Boss-Extrude-1” is 30. The values given in Column-D is used to modify the model if the text in Column-A or Column B is “a”. The text “s” stands for that the modification is not requested. The text “0” stands for that the modification is not applicable. The values of Column-D can be changed if the text in Column-A is not empty. The values of Column-D are dependent if the text in Column-B is not empty, and the values are assigned by Excel formulas. The formula for Cell-D4, for example, is “=param!F1”, and the value is assigned from Cell-F1 of Sheet- “param” as 3540.

Visual Basic program (Modifying program), uses Microsoft Office Excel Library and SolidWorks library by adding the references to the Visual Basic project. The libraries can be used by the following commands:

```
dim swapp as object, veri as object
swapp = GetObject(, "sldworks.application")
Set veri = CreateObject("excel.application")
```

All the modifications are performed automatically in SolidWorks by using “for… next” loops in the modifying program by reading the data from the Excel file. The value at Cell-D19 in Sheet-“backp”, for example, is used to change the dimension D2 in Sketch11 in the SolidWorks file by the following commands:

```
veri.worksheets("backp").Select
…
cc = dnumc + "@" + sketchc + "@" + fl
bs = part.Extension.SelectByID2(cc, "DIMENSION", 0, 0, 0, False, 0, Nothing, 0)
Set myDimension = part.Parameter(cc)
myDimension.SystemValue = dv / 100
```

where the text in Cell-F3 (D2), the text in Cell-E17 (Sketch11), the text “backp” and the value in Cell-D19 (862.5) are assigned to the variables dnumc, sketchc, fl and dv in the “for…next loop” in the program, respectively.

The value at Cell-D3 in Sheet-“backp”, for example, is used to change the extrusion value for Boss-Extrude-1 in the SolidWorks file by the following commands:

```
Set swFeat = part.FeatureByName(bossc)
Set swExtrudeFeatData = swFeat.GetDefinition
swExtrudeFeatData.SetDepth True, dv / 1000
swFeat.ModifyDefinition swExtrudeFeatData, part, Nothing
```

where the text in Cell-F3 (Boss-Extrude-1) and the value in Cell-D3 (30) are assigned to the variables bossc and dv in the “for…next loop” in the program, respectively. “ksw” button has been added in the window to see the changes made. With the ksw button "0" selected, the changes are shown in the window before they are applied to the SolidWorks model. Figure 3.4 shows the window.

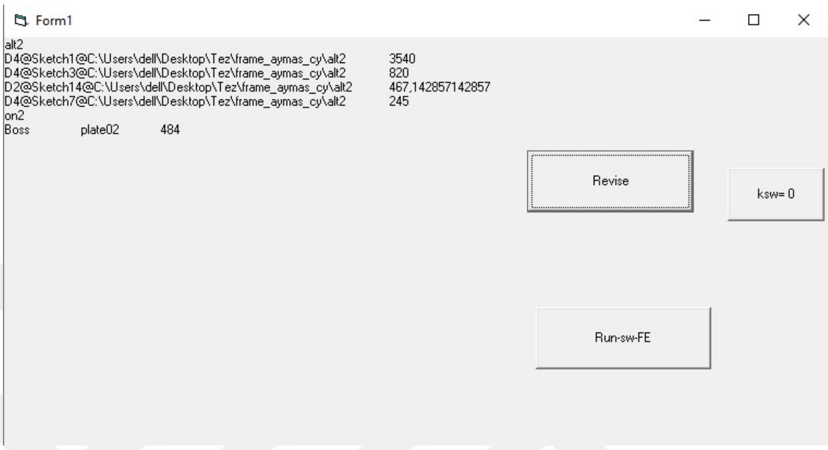


Figure 3.4 Window of Visual Basic program

The user changes the values in the Excel file and runs the modifying program to make changes in the SolidWorks models automatically. So, the iteration shown in Figure 3.2 can easily and quickly be achieved to obtain the final design.

The SolidWorks model for the frame for HP 50x50 2500x2000 as shown in Fig. 3.5 is obtained by making the relevant changes in the Excel file.

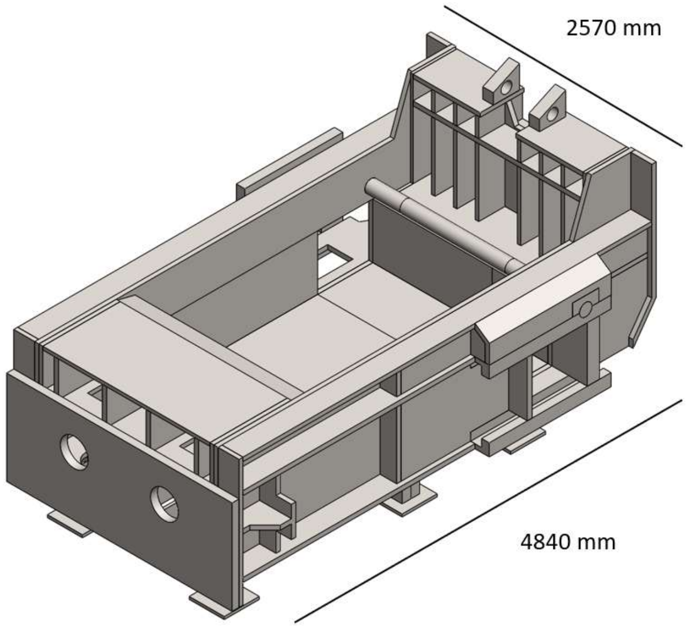


Figure 3.5 Analysis model of frame of HP3 50x50 2500x2000

3.3.2 Analysis

Modal analysis and static strength analysis are performed in SolidWorks Simulation by the finite element (FE) method. The results are given for HP-350 below. The faces contacting to the ground are fixed. The curvature-based mesh was used. The default mesh size given by the program is 293.5 mm. The mesh size was chosen as 100 mm for finer meshing.

3.3.2.1 Forces

Static analysis requires finding the forces acting on the frame using the principles of mechanics. The free body diagram of the top cover shown in Fig. 3.6 is considered to find the forces.

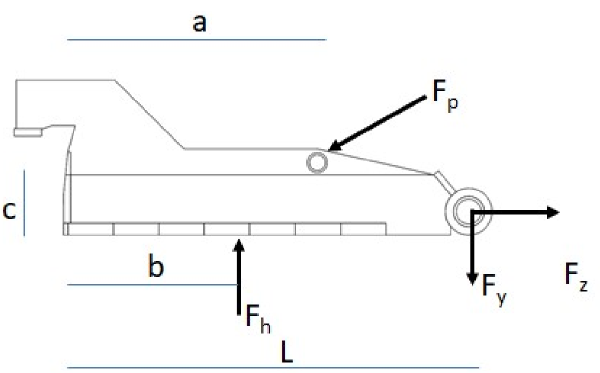


Figure 3.6 Free body diagram of top cover

The opposite of the forces F_p, F_y, F_z and F_h act on the frame. The force, $-F_p$, acts at the bushings at A_1 and A_2 (See Fig. 3.7).

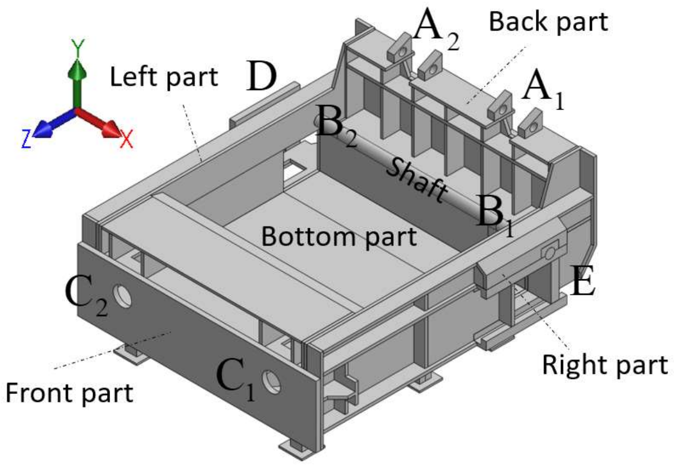


Figure 3.7 Analysis model of frame of HP3 60x60 3500x2500

The forces, $-F_y$ and $-F_z$, act at the bushings B_1 and B_2. The force, $-F_h$, is the distributed force in the y direction and it acts on the face of the bottom part contacting the scrap. It is assumed that there are forces at the faces contacting the scrap in the z and y directions also (F_{hz} and F_{hy}). The forces are calculated for the three steps as explained below:

Step 1: The pressure in the top cylinders is taken as the maximum cracking pressure (300 bar). Then F_p is calculated. Applying the static equilibrium to the free body diagram in Fig. 3.6, F_h, F_z, and F_y are calculated. F_{hz} and F_{hy} are calculated by

$F_{hz}=F_{hy}=\nu F_h$, where ν is a constant like Poisson's ratio. The constant, ν, was taken by trial as 0.15. The pressure in the front cylinders is calculated from F_{hz}. The forces at C_1 and C_2 are calculated from the pressure in the pre-compression cylinders. The pressure in the main compression cylinder is calculated from F_{hx}. The force at D is calculated from the pressure in the main compression cylinder.

Step 2: The pressure in the pre-compression cylinders is taken as the maximum cracking pressure (300 bar). Then F_{hz} is calculated. F_h and F_{hx} are calculated by $F_h=F_{hx}=\nu F_{hz}$. Applying the static equilibrium to the free body diagram in Fig. 3.6, F_p, F_z, and F_y are calculated. The pressure in the top cover cylinders is calculated from F_p. The pressure in the main compression cylinder is calculated from F_{hx}. The force at D is calculated from the pressure in the main compression cylinder. The forces at C_1 and C_2 are calculated from the pressure in the pre-compression cylinders.

Step 3: The pressure in the main compression cylinder is known as 300 bar. Then F_{hx} is calculated. F_h and F_{hz} are calculated by $F_h=F_{hz}=\nu F_{hx}$. Applying the static equilibrium to the free body diagram in Fig. 3.6, F_p, F_z, and F_y are calculated. The pressure in the top cover cylinders is calculated from F_p. The pressure in the pre-compression cylinders is calculated from F_{hz}. The force at D is calculated from the pressure in the main compression cylinder. The forces at C_1 and C_2 are calculated from the pressure in the pre-compression cylinders.

Calculated forces are given in Table 3.2:

Table 3.2 Calculated forces acting on the frame for HP3 60x60 3500x2500

	Step-1	Step-2	Step-3
FAz (kN)	-1758	-80	-236
FAy (kN)	678	30	91
FBz (kN)	1758	80	236
FBy (kN)	206	308	514
FCz (kN)	36	2950	708
FDx (kN)	-6.1	-76	-3770
FEx (kN)	6.1	76	3770
p_h (MPa)	0.11 (y)	1.4 (z)	10.5 (x)

Calculated maximum pressure values in the cylinders are given in Table 3.3:

Table 3.3 Calculated maximum pressure (bar) for HP3 60x60x 3500x2500

	Step-1	Step-2	Step-3
Top compression cylinders	300	70	112
Front compress. cylinders	4	300	144
Side compression cylinder	0.5	6	300

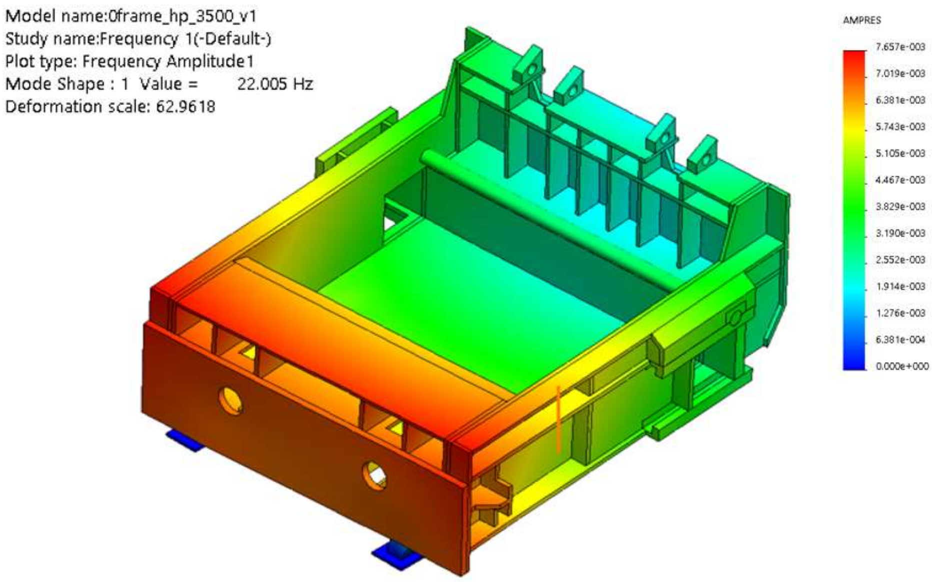
3.3.2.2 Modal analysis

The modal analysis results are given in Table 3.4:

Table 3.4 Natural frequencies (Hz) for HP3 60x60 3500x2500

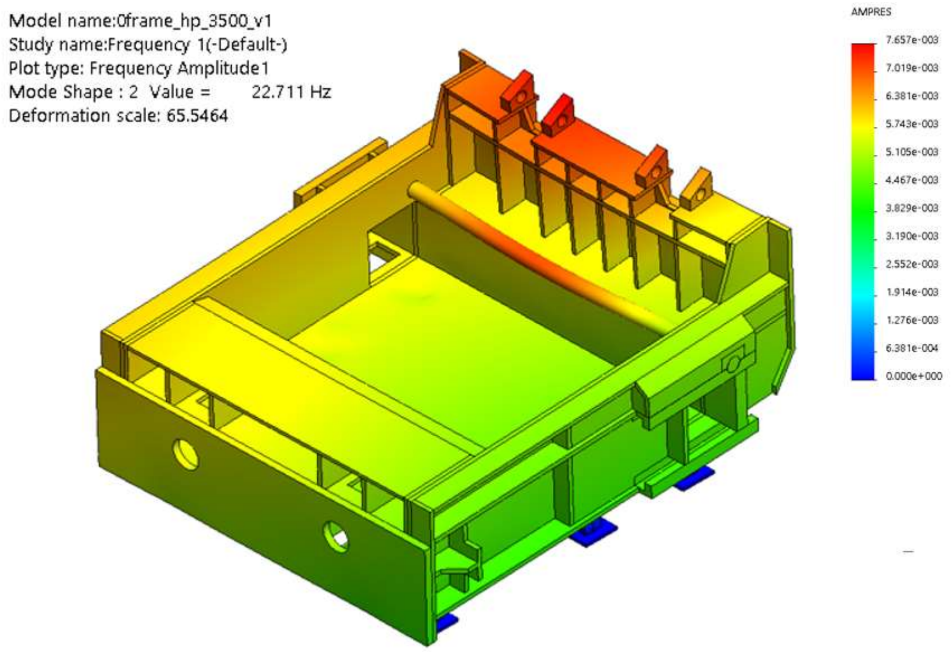
	f_1	f_2	f_3
Initial design	22.0	22.7	27.1

The images of the natural frequency analyses made for the first design are given in the Figure. Mode shape I is shown in Figure 3.8 (a), mode shape II is in (b) and mode shape III is in (c).

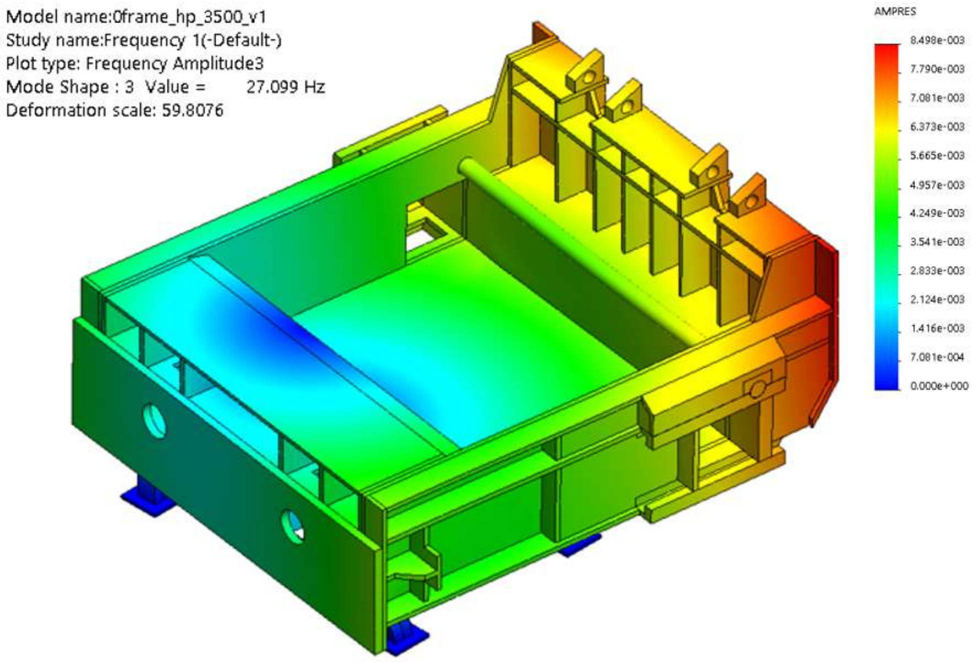


(a)

Figure 3.8 (a) Mode shape I (b) mode shape II (c) mode shape III of initial model



(b)



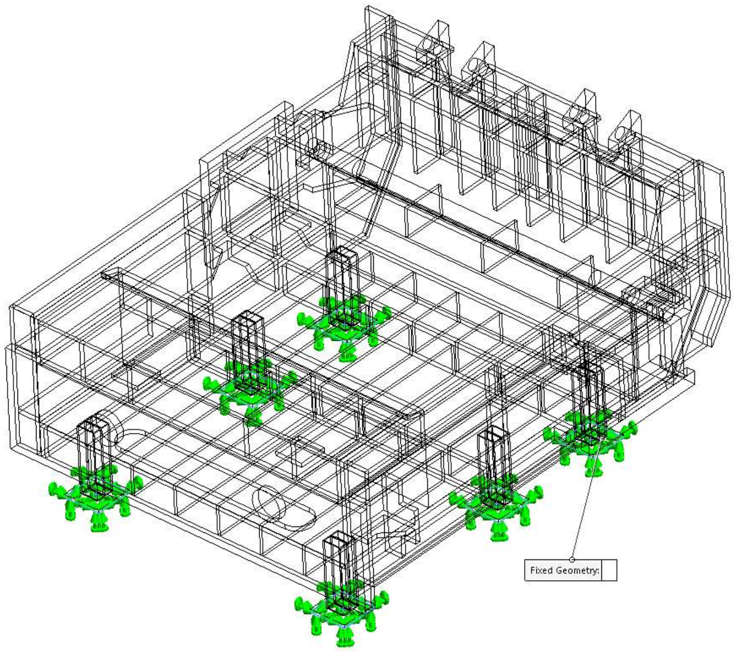
(c)

Figure 3.8 continues

The mode shape for f_1 is mainly torsional vibration of the structure about y axis. The mode shape for f_2 is mainly flexural vibration of the structure about x axis. The mode shape for f_3 is mainly flexural vibration of the structure about z axis. Mode-2 is dominant for Step-1 and 2. Mode-3 is dominant for Step-3. It is noted that the machine under study does not have high speeds, and resonance evaluation is not done. Natural frequencies are considered for the evaluation of the rigidity of the machine. Higher natural frequencies indicate more rigid structures.

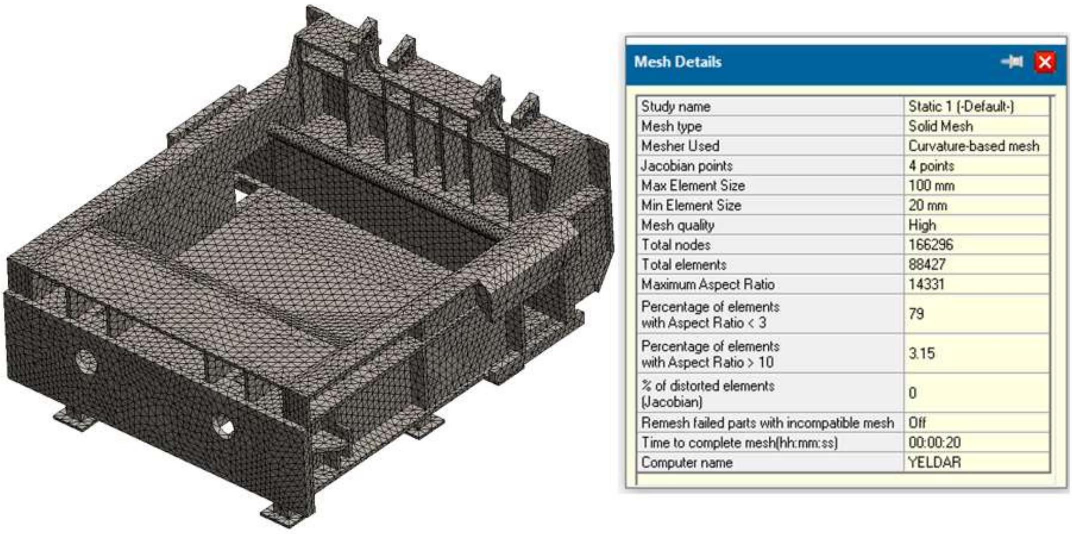
3.3.2.3 Static strength analysis

The forces for each step are defined in SolidWorks Simulation and the FE analysis is performed for the frame. The materials used in scrap press are defined. Shaft material is 1040 steel. The rest of the body is made of St-52 material. VonMises stresses and deflections are evaluated. In order to perform static strength analysis, fixed supports are determined first. fixed supports are shown in figure 3.9 (a). secondly, the model should be meshed by selecting an appropriate size. The meshed version of the initial model of the scrap press is shown in figure 3.9 (b).



(a)

Figure 3.9 (a) Fixed supports (b) mesh details of HP3 60x60 3500x2500



Mesh Details

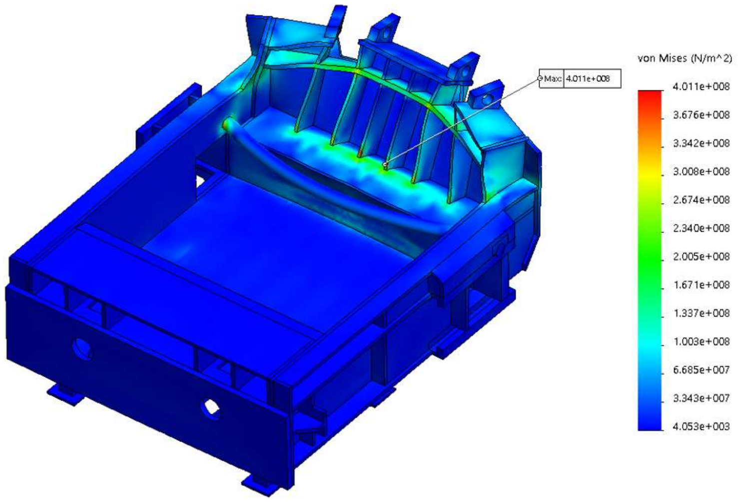
Study name	Static 1 (-Default-)
Mesh type	Solid Mesh
Mesher Used	Curvature-based mesh
Jacobian points	4 points
Max Element Size	100 mm
Min Element Size	20 mm
Mesh quality	High
Total nodes	166296
Total elements	88427
Maximum Aspect Ratio	14331
Percentage of elements with Aspect Ratio < 3	79
Percentage of elements with Aspect Ratio > 10	3.15
% of distorted elements (Jacobian)	0
Remesh failed parts with incompatible mesh	Off
Time to complete mesh(hh:mm:ss)	00:00:20
Computer name	YELDAR

(b)

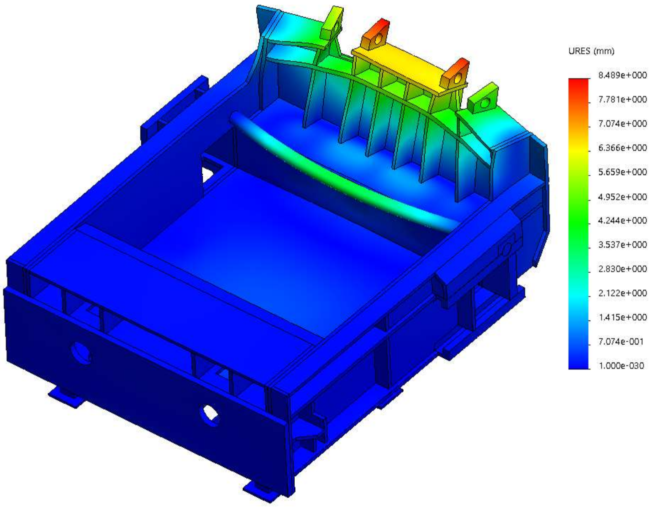
Figure 3.9 continues

The maximum element size for analysis is 100 mm and the smallest element size is 20 mm. Therefore, the total number of nodes is 166296. The total number of elements is 88427. Various mesh types have been tested for scrap press analysis. However, the most appropriate results were obtained when curvatured-based mesh was used. The results of the analysis are given for curvature-based mesh.

FE analysis of the first model was performed. The stresses resulting from the analysis of the first step are shown in figure 3.10 (a). Figure 3.10 (b) shows the total amount of deformation.



(a)

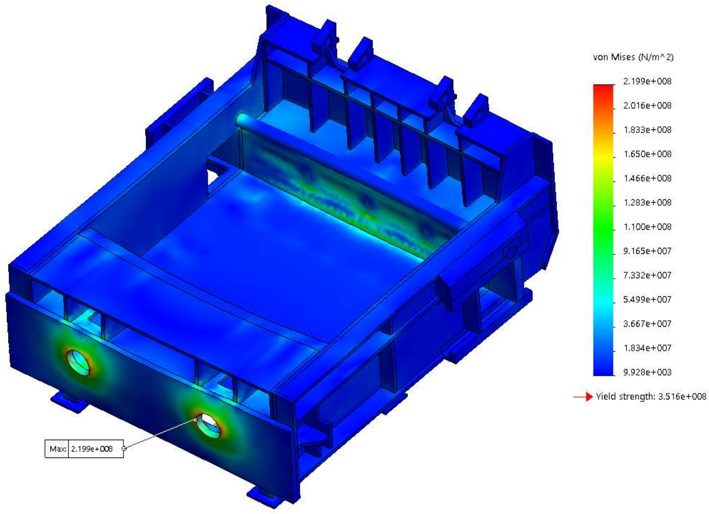


(b)

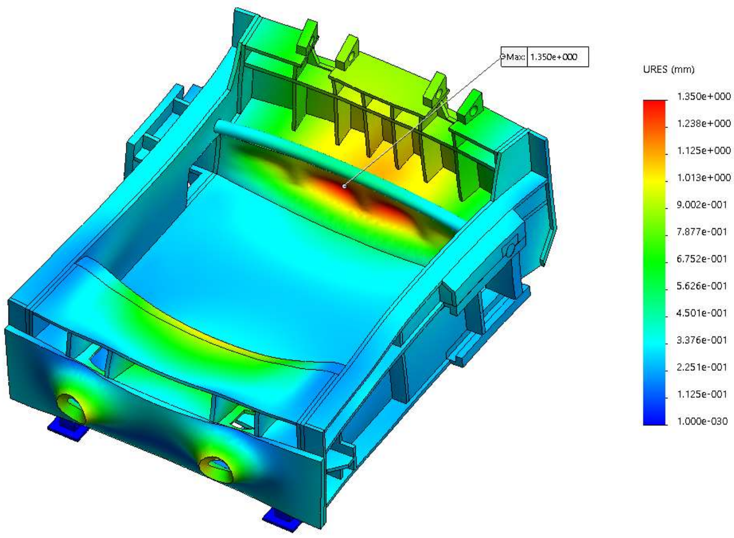
Figure 3.10 (a) Step-1 vonMises stress distributions (b) deformed shapes of HP3 60x60 3500x2500

In step-1 analysis, high stresses are observed in the Back part. The stress value is 401.1 MPa. The maximum deformation occurs in the same area. The maximum displacement is 8.49 mm. Deformation value should be reduced.

Step-2 analysis are performed by selecting the same mesh size. The stresses according to the vonMises criterion are shown in figure 3.11 (a). Figure 3.12 (b) shows the total amount of deformation.



(a)

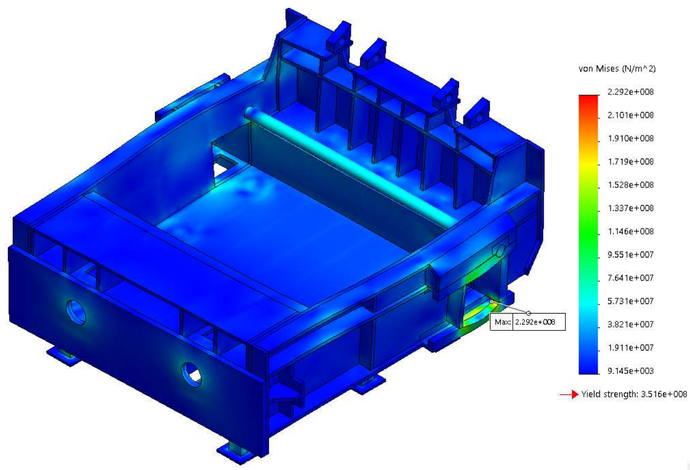


(b)

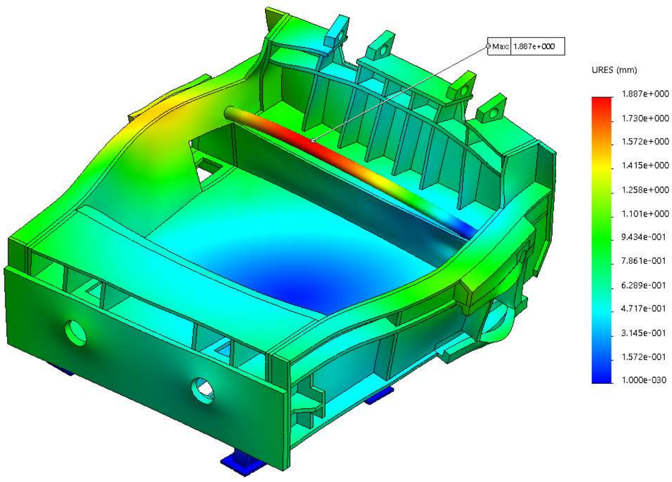
Figure 3.11 (a) Step-2 vonMises stress distributions (b) deformed shapes of HP3 60x60 3500x2500

In step 2, the highest stresses occur in the front part. The stress value is 219.9 MPa. The maximum deformation occurs in the same area. The maximum displacement is 1.35 mm. it should be taken into consideration that the stresses in the actual operating conditions of the system will be lower than the analysis values. Therefore, no improvement is required for step-2.

Step-3 analysis are performed by selecting the same mesh size. The stresses according to the vonMises criterion are shown in figure 3.12 (a). Figure 3.12 (b) shows the total amount of deformation.



(a)



(b)

Figure 3.12 (a) Step-3 vonMises stress distributions (b) deformed shapes of HP3 60x60 3500x2500

In step-3 analysis, the maximum stress value is 229.2 MPa in the right part. The amount of deformation was analysed as 1.88 mm in the same area. Step-3 analysis results show that there is no risk in this step for the machine. This is because high-strength materials (HARDOX) are used in the maximum deformation zone.

All maximum stress values obtained from the analysis of the initial model's parts are shown in Table 3.5:

Table 3.5 Maximum stresses (MPa) in parts of frame

Part	Initial design		
	Step-1	Step-2	Step-3
Bottom	68.5	177.5	132.2
Left	**279.9**	93.8	115.4
Right	278	85.2	**229.2**
Front	9.83	**229.2**	57.3
Back	**401.1**	155.9	102.7
Shaft	**355.6**	78.35	144.3

The maximum deflections in the frame are given Table 3.6:

Table 3.6 Maximum deflections (mm) in the frame

Initial design		
Step-1	Step-2	Step-3
8.5	1.4	1.9

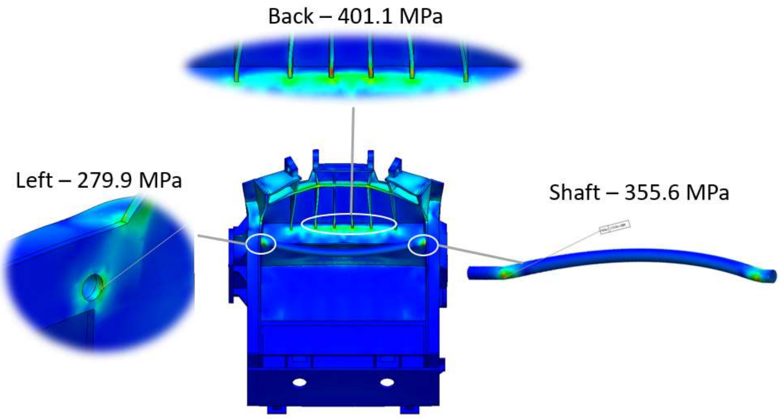
The deformed shapes and stress distributions for the first design are shown in the Figures. The colours show the voltage distributions from zero to maximum corresponding to blue to red respectively. The deformation scale for the figures is 100. Stresses are reported to be sensitive to mesh types and dimensions.

Stresses were high for the initial design. The iterative procedure shown in Figure 3.2 was used to obtain the final design. Thickness of the plates where high stresses accumulate, and the thickness values selected in the Excel file were changed and new trials were conducted.

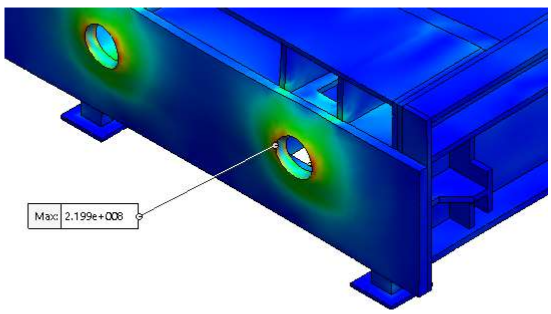
3.3.3 Improvement of Results

In the first model, which is formed over the production model, high stresses occur. these stresses are above the material strength in some critical regions. It should be aimed to reduce stresses in these critical regions. Stress-critical regions can be detected from Table 3.5. These regions are indicated in bold font in the table. For Step-1, the left, right and shaft are critical. The front for step-2 and the right for step-3 are other critical regions.

The critical points seen in Step-1 are seen in the Figure 3.13 (a). The critical points seen in Step-2 are shown in the Figure 3.13 (b). No improvement will be made in Step-3 due to the high strength of the region where maximum stress is released. However, the improvements will also have an impact on this region.



(a)



(b)

Figure 3.13 (a) Critical regions on frame from Step-1 (b) critical regions on frame from Step-2

Considering the critical points, improvements to the back part of the frame are also shown in the Figure 3.14.

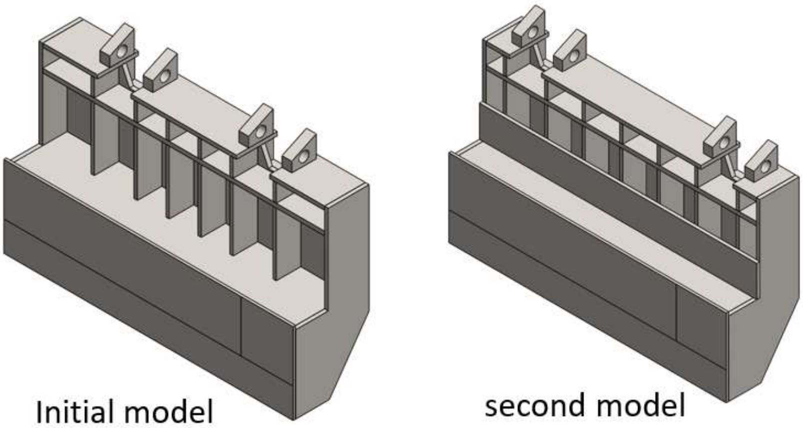


Figure 3.14 Changes to the back part of the frame

In the analysis, one of the ribs in the back was added because the highest stress was in the back parts of HP3 60x60 3500x2500. On the other hand, the plate added on the horizontal has ensured that all the ribs hold each other and show strength together. The thickness of the added rib is 40 mm. Finally, the distances of the bearing caps to which the top cover cylinders are attached to the side wall are reduced. The distance between the two caps is increased by 750 mm. This reduces the torque generated by the hydraulic cylinders.

The other part with high stresses is the shaft. The strength of the shaft material is higher. However, the shaft diameter was increased from 164 mm to 180 mm. Thus, the surface on the left part is increased and the force is distributed. Stresses were also decreased in the left part.

Considering the critical points, improvements to the front part of the frame are also shown in the Figure 3.15.

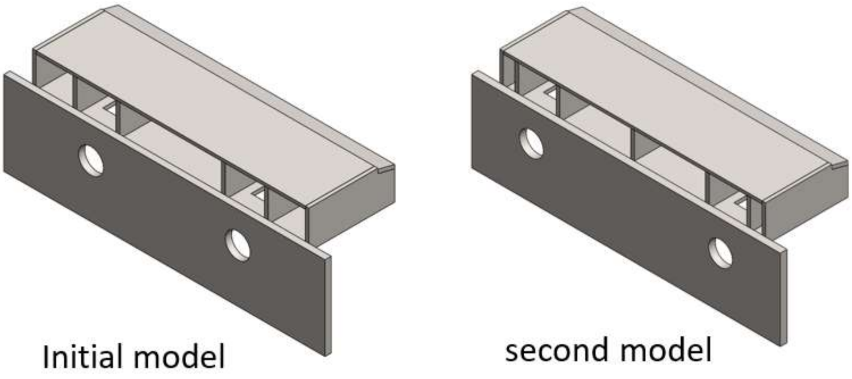
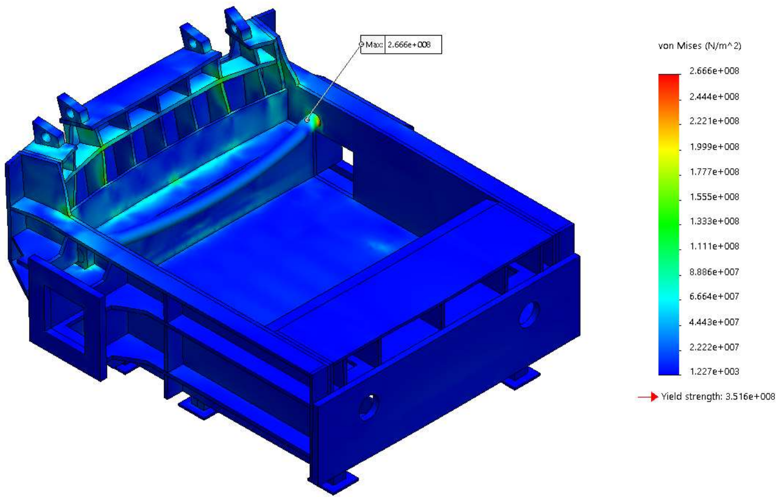


Figure 3.15 Changes to the front part of the frame

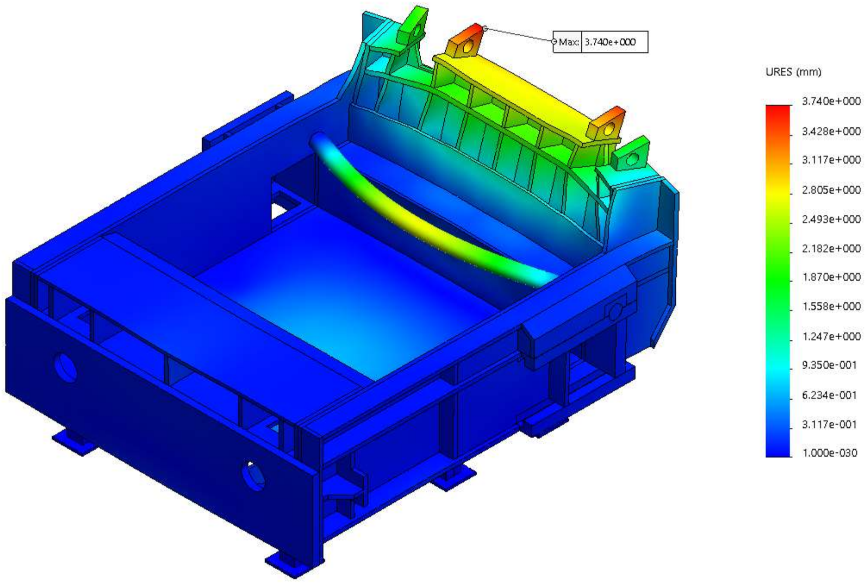
In the large plate in the front part, the stresses are maximised. Therefore, the thickness of this sheet has been increased from 80 mm to 90 mm. In order to meet the loads more balanced, a rib was added. Two ribs were cancelled.

All analysis were repeated on the model, keeping the loads constant. Step-1 analysis was performed by selecting the same mesh size. The stresses according to the vonMises criterion are shown in figure 3.16 (a). Figure 3.16 (b) shows the total amount of deformation.



(a)

Figure 3.16 (a) Step-1 vonMises stress distributions (b) deformed shapes of final design of scrap baling press

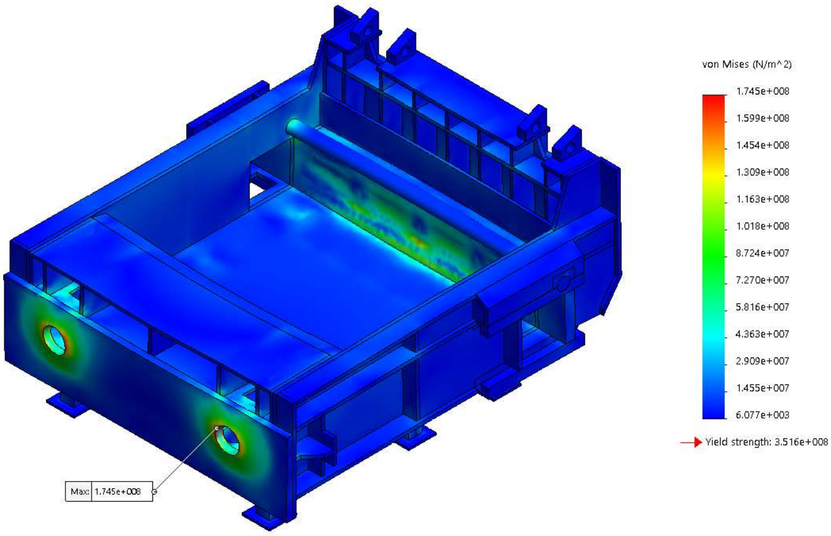


(b)

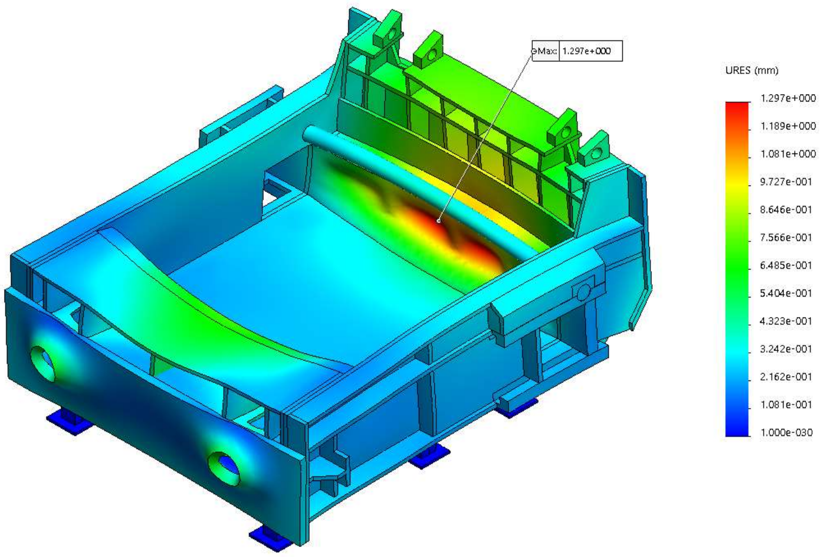
Figure 3.16 continues

In step-1 analysis of the final design, high stresses are observed in the shaft. The stress value is 266.6 MPa. The maximum deformation occurs in the back part of scrap baler. The maximum displacement is 3.74 mm.

Step-2 analysis is performed with the design of scrap baling press. The stresses according to the vonMises criterion are shown in figure 3.17 (a). Figure 3.17 (b) shows the total amount of deformation.



(a)

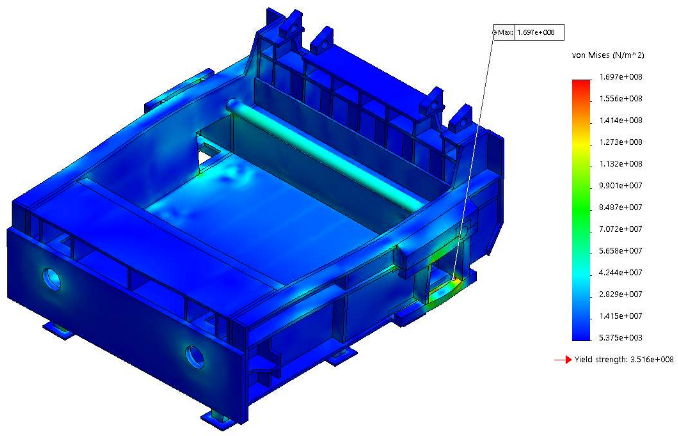


(b)

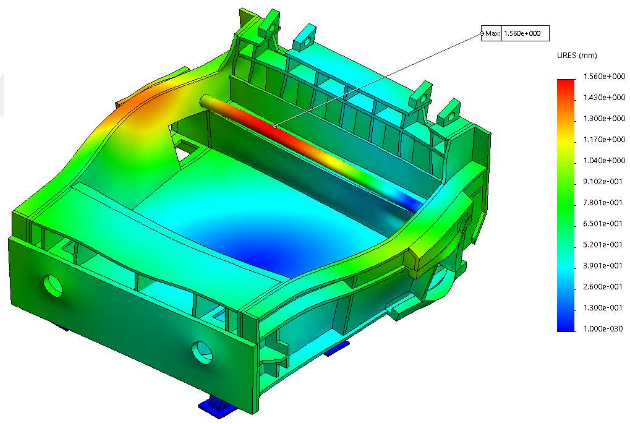
Figure 3.17 (a) Step-2 vonMises stress distributions (b) deformed shapes of final design of scrap baling press

In step-2 analysis of the final design, high stresses are observed in the front part of scrap baler. The stress value is 174.5 MPa. The maximum deformation occurs in the back part of scrap baler. The maximum displacement is 1.29 mm.

Step-3 analysis is performed with the final design of scrap baling press. The stresses according to the vonMises criterion are shown in figure 3.17 (a). Figure 3.17 (b) shows the total amount of deformation.



(a)



(b)

Figure 3.18 (a) Step-3 vonMises stress distributions (b) deformed shapes of final design of scrap baling press

In step-3 analysis of the final design, high stresses are observed in the right part of scrap baler. The stress value is 169.7 MPa. The maximum deformation occurs in the back part of scrap baler. The maximum displacement is 1.56 mm.

Stress and displacement values found in the first design and final design analysis are shown in the Table 3.7 to see the effects of the improvements made.

Table 3.7 Maximum stresses (MPa) in parts of frame's initial and final design

Part	Initial Design			Final Design		
	Step-1	Step-2	Step-3	Step-1	Step-2	Step-3
Bottom	68.5	177.5	132.2	65.4	86.9	120.2
Left	**279.9**	93.8	115.4	**216.8**	78.7	118
Right	**278**	85.2	**229.2**	**216.7**	85.1	**169.7**
Front	9.83	**229.2**	57.3	8.5	**174.5**	51.2
Back	**401.1**	155.9	102.7	**196.3**	155.4	103.4
Shaft	**355.6**	78.35	144.3	**266.6**	66.2	118.3

The stresses in the back part, which were seen as critical in Step-1, were reduced from 401.1 MPa to 196.3 MPa. This part of baler shows an improvement of approximately 55%. In the other critical regions, the stresses on the right and left parts were reduced by 23%. In the shaft, the stress reduction rate is 25%.

In the initial design, in Step-2, the critical area is front part of baler. The tensile in the front part is 229.2 MPa. In the final design, this stress value was reduced to 174.5 MPa. Approximately 24% improvement was achieved.

In the initial design, in the third case, the critical region is in the right part. The stress value in the right part is 229.2 MPa. This value was reduced to 169.7 MPa in the final design. There is an improvement of approximately 26%.

Between the initial and the final design, there have been improvements in stresses. There are also improvements in deformation analysis between models. Table 3.8 shows the deformation results of two different models.

Table 3.8 Maximum deflections (mm) in frame's initial and final design

Initial design			Final design		
Step-1	Step-2	Step-3	Step-1	Step-2	Step-3
8.5	1.4	1.9	3.7	1.3	1.6

Particularly in Step-1 analysis, there are significant differences between the models. The deformation value was reduced from 8.5 mm to 3.7 mm. In Step-2 and Step-3 there is no significant deviation.

CHAPTER FOUR
CONCLUSIONS

Firstly, in this thesis, the types of industrial scrap baling presses are searched. Scrap baling machines are examined in three main groups. The grouping varies according to the number of compressions available in the scrap baling press. In all of these groups, the system is designed as mechanical, electrical and hydraulic.

The forces obtained from the hydraulic system are decisive in the design of the mechanical system. For this reason, calculations of mechanical parts which are affected by hydraulic system forces should be done carefully. Pressure should be selected for the application and system parts appropriate to this pressure should be designed.

Computer aided design (CAD) techniques are widely used in industry for product development. CAD programs offer wide range of graphical user interface (GUI) capabilities. Design is an activity which requires iterative work. It takes time and effort to accomplish iterative work by GUI only. The global competitive market forces companies to reduce the time from design to market. Design activity takes considerable time in this effort. Thus, design automation methods using parametric design approach are becoming popular.

A procedure is offered in this study, where a Visual Basic program, Excel, and SolidWorks are integrated. A prototype model of the mechanical system under development is designed in SolidWorks by GUI, first. The geometric dimensions considered for the iterative work are entered to an Excel file. The data in the Excel file can be edited and changed for the iterative work. The modifying program developed in Visual Basic reads the data from the Excel file and automatically modifies the SolidWorks model using the application programming interface (API). The modified model is analyzed and the analysis results are evaluated. The iterative work continues until a satisfactory design is obtained. The initial design is based on experience, and usually is not satisfactory. Iterative work can continue for better optimization even a satisfactory design is reached. The procedure can be applied to develop different models of the product. The procedure was applied to design a commercial scrap bailing machine successfully. Two models which have different scrap chamber dimensions have been considered. The results for one model are presented in this thesis.

A satisfactory design considering the strength of structures can be obtained, but it should be noted that optimization is a continuing process and a better design may be possible. Optimization studies of the structure considered can continue. Also, the effect of mesh type and mesh size, and the boundary conditions in real systems on the finite element results should be investigated.

As the conditions of the analyses have a great effect on the results, the analyzes can be repeated with different mesh size and mesh type. The smaller the mesh size, the higher the accuracy of the analysis results. However, prolongation of the analysis period is a negative effect. Therefore, accurate results can be obtained without using very small mesh sizes in large bodies.

The type of analysis, such as the mesh type and size, is also important. As with the thesis work, analyzes can be made with forces and certain assumptions. However, a similar analysis can also be performed in scrap balers that are designed as multibody. The results of this analysis can be compared with each other.

Experimental studies can be performed to confirm the analyzes. The values obtained with the help of strain gauge can be handled appropriately on the machine. When the results of the experiments are found and compared with the analyzes, the analyzes will be verified.

REFERENCES

Akshaykumar, V. & Kadam, U. M. (2015). Automatic assembly modeling for product variants using parametric modeling concept. *International Journal of Engineering Research & Technology (IJERT)*, *4* (4), 79-89.

Amarnath, V. & Prabaharan, M. (2011). Structural optimization of 5ton hydraulic press and scrap baling press for cost reduction by topology. *International Journal of Modeling and Optimization*, *1* (3), 185-190.

Biber, S. (2005). Hidrolik tahrikli hurda balya preslerinde yeni "modül blok" uygulamaları. *IV. Ulusal Hidrolik Pnömatik Kongresi,* 3-10.

Bostan, B. (2011). Geri dönüşüm sektörü için hidrolik çözümler, parçalayıcı (shredder) uygulamaları. *IV. Ulusal Hidrolik Pnömatik Kongresi,* 385-408.

Halkacı, H. S. & Yiğit, O. (2004). Parametrik tasarım ve SolidWorks CAD programı ile bir uygulama. *Mühendis ve Makina*, *537*, 17-24.

Camba, J. D., Contero, M. & Company, P. (2016). Parametric CAD modeling: an analysis of strategies for design reusability. *Computer-Aided Design*, *74*, 18-31.

Li, M., Chen, Z., Sun, Y., Lin, G., Tao, Y., Li, S. et al. (2016). Design and development of Y81-1000 type heavy hydraulic scrap baling press. *6th International Conference on Advanced Design and Manufacturing Engineering,* 121-125.

Özcan, P. D. (2012). *Endüstriyel hidrolik hidrolik - pnömatik sistemler,* Retrieved May 15, 2019, from https://docplayer.biz.tr/46321976-Endustriyel-hidrolik-hidrolik-pnomatik-sistemler.html .

Shah, D. B. (2013). Parametrıc modeling and drawing automation for flange coupling using Excel spreadsheet. *International Journal of Research in Engineering & Technology (IJRET)*, *1* (2), 187-192.

Trinkel, B. (2007). *Fluid power eBook - fluid power fluid power circuits explained.* Retrieved July 12, 2019, from https://www.hydraulicspneumatics.com/ebooks/fluid-power-ebook-fluid-power-circuits-explained