DESIGN AND FABRICATION OF PILE CAGE WELDING MACHINE

A Final Year Project Report

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In Partial Fulfillment
of the Requirements for the Degree of
Bachelors of Mechanical Engineering

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by

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ABSTRACT

With the perpetual increment in volume of infrastructure development across the globe, the need for creation of efficient and cost effective ways of optimization of construction procedures has become inevitable. Specifically, after the initiation of One Belt One Road initiative and the China Pakistan Economic Corridor project, the need of efficient construction methods has become relevant for Pakistan and the South Asian region. Piling forms the backbone of the construction practices with an enormous amount of human resource, capital and time being invested in formation of pile cages and their drilling into the soil. The economics of infrastructure industry is therefore highly impacted by the efficiency of this process. Hence it remains to be an area of significant improvement for the engineers and developers. Currently, this pile cage formation process is done by laborers expending a huge amount of energy and time in this process. This project aims to develop Pakistan's first prototype of a full-scale pile cage welding machine. The project includes analytical and CAD design of pile cage welding machine, simulation of critical components on FEA software, fabrication of machine and final testing of machine and the cages produced for further improvement in quality of the cages produced and their usage in the industry. The literature review section includes the references for the similar work done earlier, the basis of design and calculations and motivation for the need of developing this machine. The methodology section breaks down the product into its various components and then discussed the design procedure for each one of them. The simulation results in FEA software are shown in the conclusion section of the report. The report also highlights the need of development of this machine by considering the economic analysis of the machine. The cost benefit analysis strengthens the need of product development. The expected results and conclusions of the project are also discussed and further improvements are suggested where needed. The report is designed so as to give the reader an insight into the work done besides making them aware of the work done in past regarding this product and in the related industry. The possibilities of further attachments and additions to the product are also discussed in the results section of the report.

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ABBREVIATIONS

PCWM	Pile Cage Welding Machine

NOMENCLATURE

μ	Coefficient of friction
α	Angular acceleration

CHAPTER 1: INTRODUCTION

Piles are long cylindrical structures that are pushed into the ground and act as a stable support for the structures built over them. Piles are used in the foundations of megastructures where there is a need of comprehensive reinforcement of the strata. The pile consists of steel rebars of various lengths and diameter joined together by a winding wire and welded at the joints to form a cage like structure.

Motivation:

The piles cages are manufactured by human resource employed at the site of the project and make use of physically generated force in bending and winding of the cages. This is particularly lucrative for the business owner or the construction company who is undertaking the project since the cost of labor in countries like Pakistan is very low and the work hours of the labor are not defined as such. Therefore, the owner can make the local labor work for hours and succeed in the creation of piles in large numbers. However, there is a limitation to the number of cages that can be developed with the help of hand. This is particularly highlighted in large scale projects where the work is needed to be continued for 24 hours of the day and there is a constraint on the volume of the labor that can be hired on the project site for such huge amount of work.

The situation explained above is relevant to the Pakistani construction industry when it comes to the China Pakistan economic Corridor project where the pace of construction work has to be upgraded to meet the targets set by the governments of the two countries. In addition to this, there are multiple contracts and sub projects that are awarded to the same company and the distribution of labor becomes an actual issue in such projects. Moreover, the mega nature of these projects suggest a widespread use of piling in these projects so there is a need to develop a machine that can fasten the process of piles manufacturing and thus help achieve a significant breakthrough in the construction industry of Pakistan.

Issues with the Human made Pile Cages:

Before we fully establish the need of development of a pile cage machine, there is a need to understand why switching from human made pile cages to machine made pile cages is actually helpful for the industry. Therefore, we take a look at the issues that are connected with the human made cages that are developed in Pakistan so far:

- The cages developed take a significant amount of time to get manufactured. This is due to the fact that the bending forces and pulling forces have to be applied by a laborer and hence there is an upper limit to the time reduction that can take place while producing the cages.
- The cages produced are not of "good quality". There are issues with the winding of the joints where there are incidents of wound joints opening up since the winding is done manually with a steel wire wound by human hands. Also there is a non-uniformity in the pitch of the steel rebar cages where pitch is defined as the distance between the two winding wire components along the latitude.
- The strength of wound joints remains to be an issue since the force is manually applied without any standardization and joints are wound in a completely manual manner.

Pile Cage Welding Machine Basic Structure:

Pile Cage Welding Machine (PCWM) consists of a steel structure divided into three main units [1] namely Pulling head, Winding head and Rebar Loading section. The pulling head is the stationary head that pulls the cage while it is rotating and welds are being made. The Winding head is the moving head that traverses as the cage is formed. The rebar loading section consists of structure that supports the rebar while they are made into the cage formation. [2] The whole assembly is made to move on rack formation that forms the base of the machine. Three motor sets are used in the machine for producing two types of motion namely the rotational motion and the linear feed of the cage.

Existing Market:

Currently, there is no pile cage welding machine in Pakistani construction industry. The machine is widely manufactured by various vendors in Chinese industry. The major constraint in procurement of this machine is the extremely high cost and limitations in logistics of the product. Therefore this prototype remains to be the first of its kind in Pakistani market.

Deliverables of the Project:

The project revolves around following three major objectives:

- <u>Design of Pile Cage Welding Machine</u>

  To complete the design calculations in all respects, set the dimensions of the physical components and get them cross checked via software to ensure proper manufacturing.

- <u>Fabrication of Pile Cage Welding Machine</u>

  To fabricate and assemble the machine and its components in light of the dimensions and structure formed in CAD software.

- <u>Testing and improvements in Pile Cage Welding machine</u>

  To produce cages on the machine and test them against quality and reliability parameters and make efforts to improve their quality.

Dimensions of the cage:

The machine is designed to make a cage of minimum diameter 450 mm and a length of 4 m. The machine is equipped so that the diameter of the cage may be increased to another value and the length of the cage can be conveniently increased by the addition of periodic support structure that holds the structure in place while the cage is being formed. The rebar used in this prototype weigh a total of 450 kg and the motors are designed to give an RPM of 7 and an angular acceleration of 0.73 radian per squared seconds.

Sellability of the product:

The ultimate sellability of the product lies in the following factors:

- Pakistan's first indigenous pile cage welding machine
- Low maintenance cost of the machine
- Compact structure and easy to transport
- Significant reduction in time required to produce cages
- Reduction in human resource employed to produce cages

Improvements:

The improvements may be incorporated after the initial review to further enhance the quality of the cages produced by the machine and introduce attachments that allow the machine to produce cages of variable sizes and pitch.

The piles installed in seismic regions need careful attention since the piles are flexible structures and we have to make sure that the applied frequency never coincides with the natural frequency so as to avoid resonance.

CHAPTER 2: LITERATURE REVIEW

This section discusses the literature that was consulted at the onset of the project and relevant studies performed worldwide on this topic that might affect the performance of the pile cage welding machine.

Foundations, Piles and their Types:

Foundations are the structures that form the base of the buildings and other structures. [3]

Types of Foundations:

Foundations are classified as:

- Deep foundations:

These foundations transfer the load of the structure to a subsurface layer or to a range of depths according to the magnitude of load it bears.

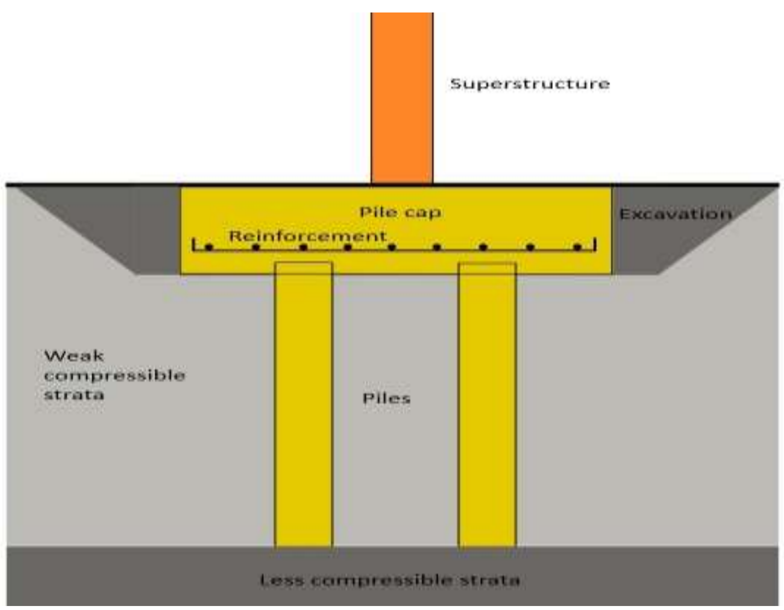


Figure 1: Overview of Piling

- Shallow foundations:

These foundations transfer load to a location near the surface of the ground rather than subsurface or larger depth surfaces.

Piled foundations are used in following situations [4]:

- When the layer of soil holding the structure is weak and we have to make the load rest on the stronger lower surface.
- When the structure has very large load or the load concentration is high.

Types of Pile Foundations on the basis of structural behavior:

Pile Foundations are divided into two types based on their structural behaviour : [5]

End bearing piles

The end bearing piles are designed so that their bottom end rests on hard surface and thus they act to transfer load to the strata.

Friction piles

Friction piles work differently in a way that the load is being transferred to the lateral sides of the pile all along its length by the action of friction force.

Piles can be soil compactor piles where the structures are pushed into the ground to compact the soil underneath in an effort to increase the strength of the soil.

Piles are integral structural component of the infrastructure and thus it needs to be carefully constructed and designed before they are pushed into the structure of the soil.

Methods of Pile Construction:

There are various ways in which the piles are constructed, the salient ones are enlisted below: [6]

- Cast-in-place piles
- Precast driven piles

Cast-in-place piles are those in which a steel tube of thin wall is paced into the ground and then the ground is removed and steel reinforcement structure is moved into the sheet. [7] Precast driven piles are those in which a prefabricated steel cage is forced into the ground either using hammering or using a pile driver. This project is concerned with the formation of pile cage and can be used primarily in both configurations.

Pile Load Testing:

Figure 2: Pile Load Test

Pile Load testing is done in order to test the piles for their bearing capacity. In this load testing, a set amount of load in the form of blocks of known mass are placed where the piles are to be tested for bearing capacity. Various defection meters are placed in the pile to check for static deflection. If there is deflection beyond the set threshold, the pile is rejected for load bearing capacity otherwise it is approved. The test is usually conducted 28 days after the casting of piles and normally are categorized into two types namely initial and routine tests.

Loadings and modes of failure:

Different types of stresses are involved in the loading condition of the machine namely normal stress and shear stress. The various modes of failure involved include ductile failure, buckling, excessive bending and excessive deflection.

When the rebars are loaded onto the loading section, the members are subjected to shear loading. Due to rotation of the machine, an additional force is induced due to moment of inertia of the bars. The friction force causes a load at the star attachment on the ends where the structure is supported. This force has a maximum value equal to half of the weight of the rebars.

Shapes of the Rebar Cages:

The rebar cages can be made in various shapes namely conical, square, triangular, pentagonal and hexagonal. The machine can be developed for a number of cage shapes and configurations by allocation of proper attachments [8]. This machine is designed to produce

Figure 3: Pile Rebar Cage

circular cages of known minimum diameter and can be modified to produce cages of various higher diameters within a limit.

Welding types employed:

The cages can be manufactured using a number of welding types namely arc welding, gas welding, TIG, MIG and spot welding. A few manufacturers make use of robotic welding arm to increase the rate of production and accuracy of the welds formed.

Steels types and their properties [9]:

Properties	Carbon Steels	Alloy Steels	Stainless Steels	Tool Steels
Density (1000 kg/m3)	7.85	7.85	7.75-8.1	7.72-8.0
Elastic Modulus (GPa)	190-210	190-210	190-210	190-210
Poisson's Ratio	0.27-0.3	0.27-0.3	0.27-0.3	0.27-0.3
Thermal Expansion (10-6/K)	11-16.6	9.0-15	9.0-20.7	9.4-15.1
Melting Point (°C)			1371-1454	
Thermal Conductivity (W/m-K)	24.3-65.2	26-48.6	11.2-36.7	19.9-48.3
Specific Heat (J/kg-K)	450-2081	452-1499	420-500	
Electrical Resistivity (10-9W-m)	130-1250	210-1251	75.7-1020	
Tensile Strength (MPa)	276-1882	758-1882	515-827	640-2000
Yield Strength (MPa)	186-758	366-1793	207-552	380-440
Percent Elongation (%)	10-32	4-31	12-40	5-25
Hardness (Brinell 3000kg)	86-388	149-627	137-595	210-620

Table 1: Steels and their properties

Carbon Steels and their Types:

Carbon Steels are broadly classified as [10]:

- Low Carbon Steel
- Medium Carbon Steel
- High Carbon Steel

Low carbon Steel is commonly known as the mild steel. It has a carbon percentage of 0.04-0.3 % and is widely used in the industry. It is available as rebars, sheets and in various precast forms. The project is based on mild steel stricture and the cage is also built out of mild steel. This is in conformation with the global construction practices.

Types of Gears:

The whole assembly is bound to move on the surface of some track. This can either be bounded track made out of I beam or rack and pinion mechanism. Since we have to incorporate a motor for linear motion, rack and pinion makes the best choice for use as track.

Figure 4: Rack and pinion

Rack and pinion consists of a pair of teethed components that mate to convert the rotational motion of the gear wheel into the linear motion of the rack. Since only one teeth is in contact, the frictional force in rack and pinion mechanism is smaller in magnitude.

Types of Chains:

A power transfer mechanism is required to transfer power from the motors to the flange of the pile cage welding machine. The available options include chain mechanism, gear mechanism, simple belt mechanism and toothed belt mechanism.

We are using a chain drive for transmission of power from motor to the flange due to very large diameter of the chain and ease of usability in chain mechanism. Chains consist of plate, roller and pin all assembled to form one link which is in turn attached to other links to form a complete chain drive.

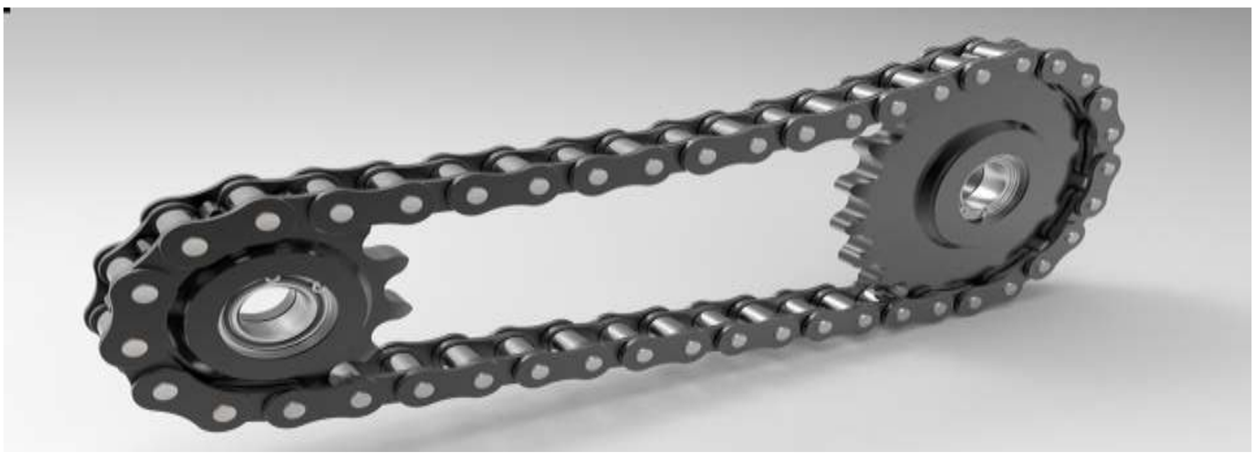


Figure 5: Chain sprocket assembly

Following are the major types of chains used in the industry:

- Roller chain.
- Detachable chain.
- Pintle chain.
- Silent chain.
- Leaf chain.
- Laminated metal chain

In this project, we have made use of roller chain for attachment of flange with the motor output. The links are lubricated using external lubricating oil and provide reasonable efficiency of power transmission ranging above 30%.

Types of Rollers:

Rollers are employed in the project for the attachment of flange with the structure of the winding and pulling heads. Rollers are classified into following types:

- Mechanical rollers
- Hydraulic rollers

Mechanical rollers are used in the project since they are easily available in the market and have the strength to withstand reasonable magnitudes of loads without failing. The roller consists of metallic wheel having a bearing installed in the middle and grooved surface where a guided object can move all along its path. The cross section of the guided path in the roller can be either circular or square. We have employed a circular path for the trajectory in rollers due to its fine clearance and lower resistance due to friction.

The rollers are attached to the structure using pins of comparable diameter congruent with the bearing used.

Figure 6: Roller configurations

Bearings and their types:

Bearing are required to ensure smooth rotation of pins in the rollers. The bearings are selected so that they can bear the loads without failing in shear. Following are the major types of bearing used:

- Rolling element bearing
- Plain (Journal) Bearing

Plain bearing consist of simple circular or straight cavity that allows for smooth relative motion of two parts.

Figure 7: Plain bearing

Types of Motors:

Motors are classified as:

- AC motors
- DC motors

Since the AC motors have higher life expectancies and are rugged in their usage so they are being used in the project along with the use of variable frequency drive (VFD) for controlling various parameters of the motors.

Figure 8: VFD

Economic Analysis:

Economic analysis form a major component of the product development since economy forms a major part of the motivation of the project. A major reason for no machine being procured by the construction companies in Pakistan is economics. The weight of the machine is very large and thus a huge amount is charged as custom clearance duty by the Government while importing the project from China.

- Project Expenses:

Following are the major expenses that are projected to be incurred in the project during development of PCWM prototype:

COST BREAKDOWN		
Expenditure head	**Description**	**Cost**
Material (Mechanical)	Channel,Girders,Rollers	400000
Material (Electrical)	Motors,Drives,PLC,DB	150000
Total Material cost	**includes electrical and mechanical material**	**550000**
Labor Charges	2*personnel @120,000 for 4 months	480000
Labor charges (miscellaneous)	includes machining and support staff cost	70000
Total Labor charges	**includes total labor**	**550000**
Utilities cost	Electricity expended on project	50000
Support services	includes welding rods and equipment used at site	100000
Logistics	includes project transportation	75000
Total cost		**1325000**

Table 2: Expense breakdown

- <u>Cost Saving Calculations:</u>

This section makes a mention of cost saving calculations that are expected to be harvested from the development of PCWM.

COST SAVING ANALYSIS		
Title/Cost head	**Unit**	**Quantity**
Labor dedicated to make cage conventionally	number	8
Labor required to make cage using PCWM	number	2
Labor rate/Hour	PKR	125
Cost saving per cage	PKR	750
Avg. number of cages per year	number	3000
Total saving	**PKR**	**2250000**
Cost saving in USD	**USD rate @140 PKR**	**16071.42857**

Table 3: Savings breakdown

Assumption made that it takes equal time (1 hour) to make cage with and without using machine and cost saving lies in terms of labor reduction

- <u>Payback Period:</u>

The payback period for the project is projected to be 0.52 years.

NPV Calculation - - Pile Cage Welding Machine						
Data is in 1000$						
Outflows	**Capital**	**Yr 1**	**Yr 2**	**Yr 3**	**Yr 4**	**Yr 5**
Cost of project (capital & expenses)	(9.46)					
Depreciation of Capital Invested		(0.63)	(0.63)	(0.63)	(0.63)	(0.63)
Total Costs		**(0.63)**	**(0.63)**	**(0.63)**	**(0.63)**	**(0.63)**
Inflows						
Cost Saving		16.07	16.07	16.07	16.07	16.07
Total savings		**16.07**	**16.07**	**16.07**	**16.07**	**16.07**
Net Operating Cash Flow		15.44	15.44	15.44	15.44	15.44
After Tax Operating Cash Flow		**10.50**	**10.50**	**10.50**	**10.50**	**10.50**
Add Back Depreciation		0.63	0.63	0.63	0.63	0.63
Capital Investment	**(9.46)**					
Total	**(9.46)**	**11.13**	**11.13**	**11.13**	**11.13**	**11.13**

Net present value analysis for the project is indicated above, where the values are in USD.

Table 4: Net Present value

CHAPTER 3: METHODOLOGY

Pile Cage Welding Machine consists of following major components:

- Pulling head
- Stationary head
- Rebar loading section

The figure shows these sections pictorially:

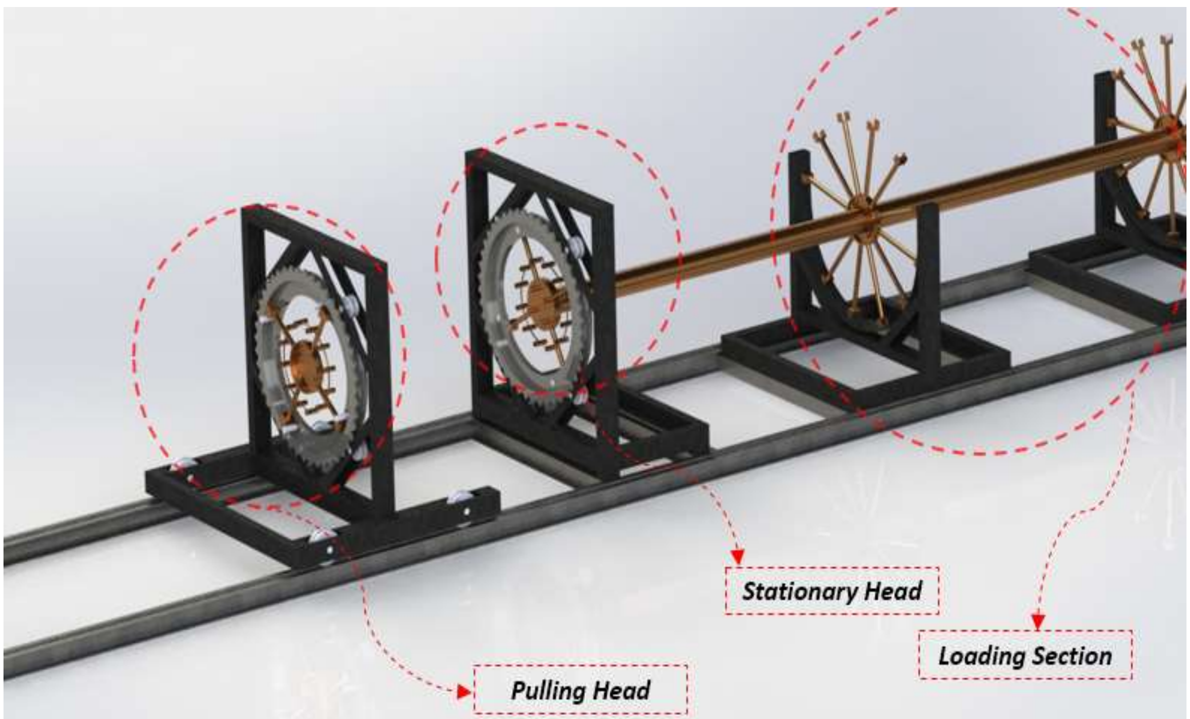


Table 5: PCWM layout

Stationary head does not move while the pulling head moves towards the stationary head as the cage is produced.

A breakdown of each head is given below:

STATIONARY HEAD:

Following are the major parts of the stationary head:

- Rotating Core Flange
- Rotating Core Collar
- Rotating Core Sprocket
- Groove Ring
- Frame
- Roller

Rotating Core Flange:

The rotating core flange forms the heart of the flange that rotates in either of the two heads i.e. pulling head and stationary head. It consists of a ring of mild steel that supports the load of the rebars during cage formation.

Figure 9: Rotating core flange

Rotating core flange is the component that forms the hub of rotating part of machine.

- Calculations:

Force (N)	Thickness (m)	Area (m^2)	Shear Stress (Pa)
225.63	0.0009	0.0000045	50140000

Table 6: Flange calculations

The thickness of the core flange is 9 mm and internal diameter is governed by the diameter of the pile cage. The allowable stress obtained by using a factor of safety of 2 comes out to be 50 MPa, which is half of 0.4 times the yield strength of 250 MPa. The calculated shear stress comes out to be 50 MPa which is just at the verge of our threshold value.

Rotating Core Collar

Rotating core collar is a collar that is welded onto the surface of the core of the flange. This collar strengthen the core and allows for the attachment of a guided path for the roller movement on the core flange as well as the welding of a toothed gear component on the core of the flange.

The thickness of the available collar that is compatible with the given configuration is 18 mm while internal diameter that is governed by the diameter of the cage and thickness of the core of the flange is 780 mm. The allowable stress obtained by using a factor of safety of 2 comes out to be 75 MPa, which is half of 0.6 times the yield strength of 250 MPa. While the value for the calculated bending stress comes out to be 71 MPa, which is within the safe limit.

Rotating core collar calculation:

Below is a breakdown of calculations leading to the determination of specifications of the collar:

Figure 10: Rotating core collar

Width (m)	Thickness (m)	Mass (kg)	Moment (Nm)	Inertia (m^4)	Bending Stress (Pa)
0.095	0.018	330	153.77175	1.944E-08	71190625

Table 7: Rotating core collar calculations

The rotating core flange is critical for effective load distribution and avoidance of a situation where stress concentration regions may develop.

Groove Ring:

A ring is welded on the collar to provide for a track where the rollers can move. This ring has a thickness of 9 mm and internal diameter governed by the cage diameter and the diameter of flange and collar. The allowable stress obtained by using a factor of safety of 2 comes out to be 50 MPa, which is half of 0.4 times the yield strength of 250 MPa. The calculated shear stress comes out to be 50 MPa which is just at the verge of our threshold value.

Figure 11: Groove ring

Force (N)	Thickness (mm)	Area (m^2)	Shear Stress (Pa)
225.63	0.0009	0.0000045	50140000

Table 8: Groove ring calculations

A steel rebar is welded on the flange to serve the purpose of a ring providing track for the rollers to move.

Rotating Core Sprocket

The rotating core sprocket works to provide a medium for power transmission from motors to the flange. This flange is welded to the core and is fixed so as to make an assembly consisting of flange and toothed gear.

Figure 12: Rotating core sprocket

The thickness of the sprocket is 9 mm while the internal diameter of sprocket is 914.4 mm. The chain size used is of 80 number. The allowable strength for this chain number is 55 kN and the critical design strength comes out to be 10 kN from the input of load values. This is well within the threshold.

Frame:

The frame provides the major structural support to the whole system and forms the backbone of the head. We had to determine the section of the frame while dimensions are determined by other components.

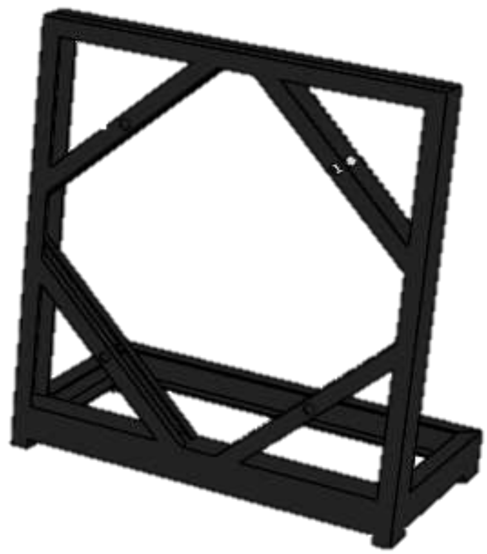


Figure 13: Frame

Breadth 1 (m)	Height 1 (m)	Breadth 2 (m)	Height 2 (m)	Moment of inertia (m^4)	Weight of Head (N)	Weight of cage (N)	Bending Force (N)	Moment (Nm)	Bending Stress (MPa)	Thickness (m)
0.05	0.05	0.046	0.046	1.2 E-07	66.28	153.33	902.52	270.75	56.306	0.003

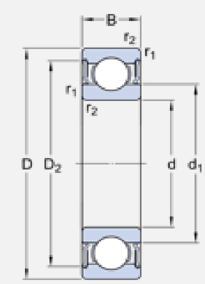
Table 9: Frame calculations

C CHANNEL				
Flange (in)	Web (in)	Thickness (m)	Inertia (m^4)	Bending Stress (MPa)
2	4	0.25	1.8 E-06	24.95

Table 10: C-Channel calculations

Rollers

Rollers are used to support the flange on the structure and thus transfer loads to the main structure. The side wall thickness is 8 mm.



d		9	mm
D		26	mm
B		8	mm
d_1	≈	14.8	mm
D_2	≈	22.6	mm
$r_{1,2}$	min.	0.3	mm

Figure 14: Roller selection guideline

	Load Applied (N)	Safety Factor (1.5) Load (N)	Bearing Selected
Flange Rollers	2815.47	4223.20	629

Table 11: Flange roller load calculations

Figure 15: Roller configuration

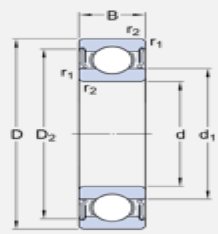
PULLING HEAD:

All the above parts are common to both the heads and thus same calculations are used with the exception of following:

- **Linear Motor Drive**
- **Base Rollers**
- **Track**

Base Roller:

The same roller selected from SKF catalogue are used here as well with a side wall thickness of 8 mm.



d		12	mm
D		32	mm
B		10	mm
d_1	≈	18.5	mm
D_2	≈	27.95	mm
$r_{1,2}$	min.	0.6	mm 16

Figure 16: Base roller and bearing selection guideline

	Load Applied	Safety Factor Load	Bearing Selected
Pulling Head Base Frame Rollers	**3649.32**	**5473.98**	**W6201**

Table 12: Base roller load calculations

Track:

An I-Beam of dimensions 4''x4'' and 2/8'' thick is used as the track for the whole assembly and the bending stress acting are 18 MPa on the cross section which are well within the range of 75 MPa.

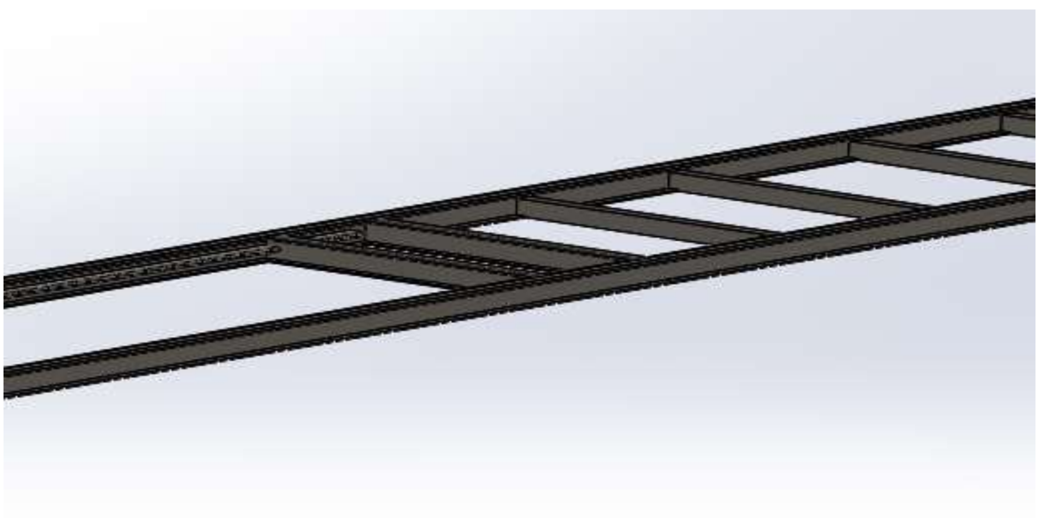


Figure 17: Track

REBAR LOADING SECTION:

It has following parts namely:

- **Connecting Pipes**
- **Star Arrangement**
- **Frame**

Connecting Pipes:

The connecting pipes run through the core of the machine and support the base load and structure of the machine.

Figure 18 : Connecting pipe CAD model

The connecting pipe has a length of 4 m in total made from two pieces of 2 m each and diameter 4.5” while the thickness of the pipe is 0.25 “.

The whole load of the manufactured cage is transferred to the body of the machine through the connecting pipe, so it holds immense significance in the overall structure of the machine and hence needs to be designed accordingly.

Main Shaft Ro (m)	Thickness (m)	J (m^4)	I (m^4)	Shaft Weight (N)	Bending Moment (Nm)	Bending Stress (MPa)	Torsion (Nm)	Torsional Stress (MPa)
0.025	0.003	2.5 E-07	1.29 E-07	1.04 E+02	1.17 E+02	23.03	90.25	8.873

Table 13: Connecting pipe calculations

Star Arrangement

Star arrangement is made to hold the rebars in position while in loading section. It consists of a pipe of diameter 1’’ connected about a spoke and the thickness of the pipe is 1/8”.

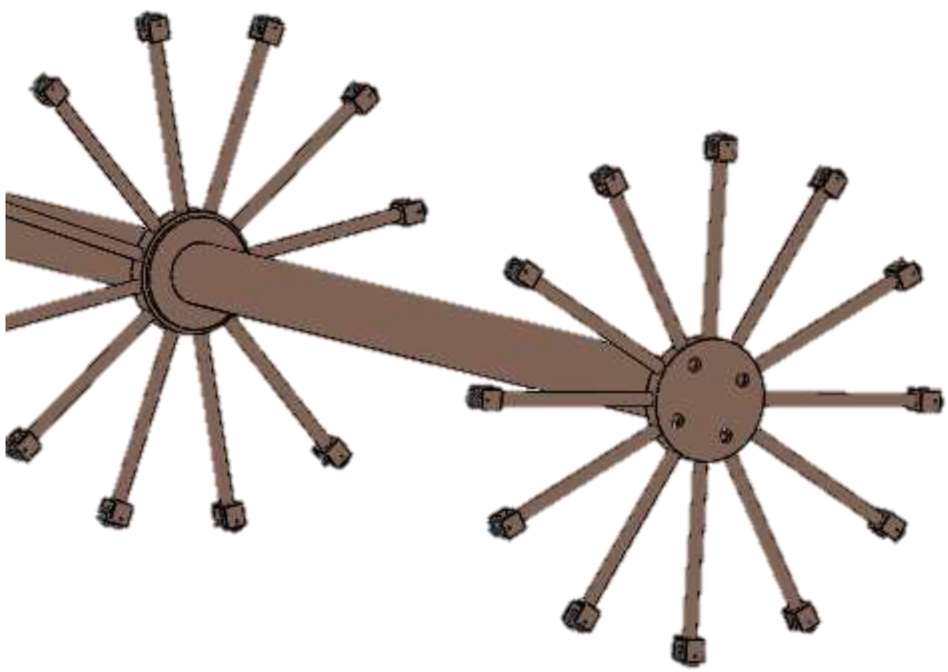


Figure 19: Star arrangemnt CAD model

Ro (m)	Thickness (m)	I (m^4)	Moment (Nm)	Bending Stress (MPa)
0.0127	0.003175	8.17 E-08	112.815	17.53

Table 14: Star arrangement calculation

Motor Selection:

The motors are selected for the most severe loading conditions and their determination involves two types of torques:

- Initial torque to overcome inertia
- Maintenance torque

Figure 20: AC motor

The initial torque and maintenance torque are given by:

$$\tau = I * \alpha$$

$$\tau = F * r_{\text{center of mass}}$$

Figure 21: Torque formulae

The motor selection is a critical phase in this project since the components are sturdy and the performance of final product is directly controlled by the motor operation. Below is the calculation for selection of motors:

Mass (kg)	Weight (N)	Radius (m)	Inertia (m^4)	ω (rad/s)	α (rad/s^2)	Torque (Nm)	Power (W)	Power (hp)	Friction force (N)	Torque due to friction (Nm)
700	6867	0.317	70.56	0.52	0.174	12.31	2691.63	3.60	686.7	218.0273

Table 15: Motor torque calculations

The motors are selected for the peak loads and their horse power comes out to be 4 hp at operating RPM of 4-7.

Gears:

Gears are used in the track where rack and pinion mechanism converts the rotary motion into linear motion so that the linear motion of the cage may be achieved through the motors. The linear actuators are expensive and not easily available while the motors are easily available and present less maintenance and troubleshooting problems. Rack and pinion mechanism is a tested technology for converting the rotary motion to linear motion and is rugged in nature too, thus catering to the needs of our product.

Overall Thickness	1 in
Diamertral Pitch	10
Pitch Line To back	1.333 in
Length	6 ft

Table 16: Gear specifications

The efficiency of this rack and pinion will directly affect the power consumption of the machine and in turn, decide the economic benefit of Pile Cage Welding Machine.

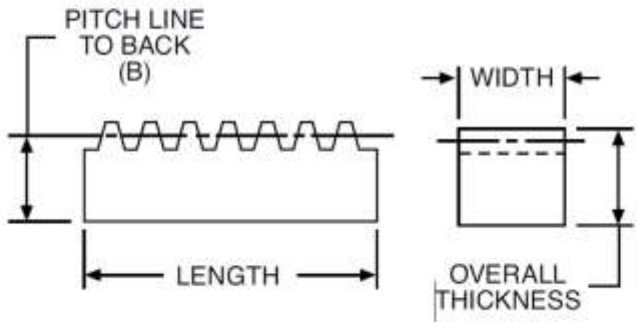


Figure 22: Motor selection guidelines

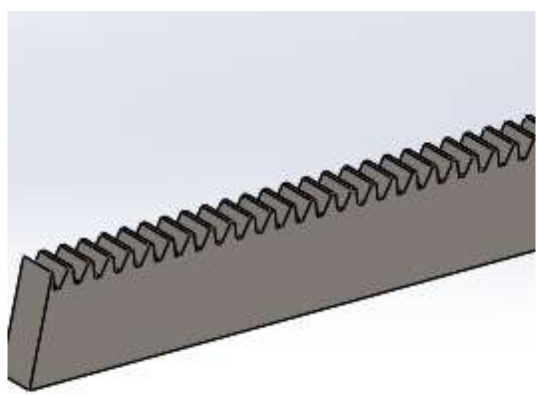


Figure 23: Rack CAD model

The selection of rack and pinion set is a complementary process where the selection of one determines the specifications of the other component.

CHAPTER 4: RESULTS AND DISCUSSIONS

A parametric study was carried out for the angular acceleration and the plots for Von Mises stress and deflection were plotted. Parametric study shows the relationship of angular acceleration with the Von Mises stresses and the deflection and give us a fair indicator of the performance. The parameter variation is shown below:

Variable Parameter selected: Angular Acceleration of the motors

Range of the variable parameter: 0.733-0.091 rad/sec^2

Performance parameters observed: Von Mises stresses, Deflection magnitude

Range of deflection: 0- $1.997*10^{-4}$ m

Range of Von Mises stresses: $5.77*10^{-5}$ – $6.77*10^{7}$ Pa

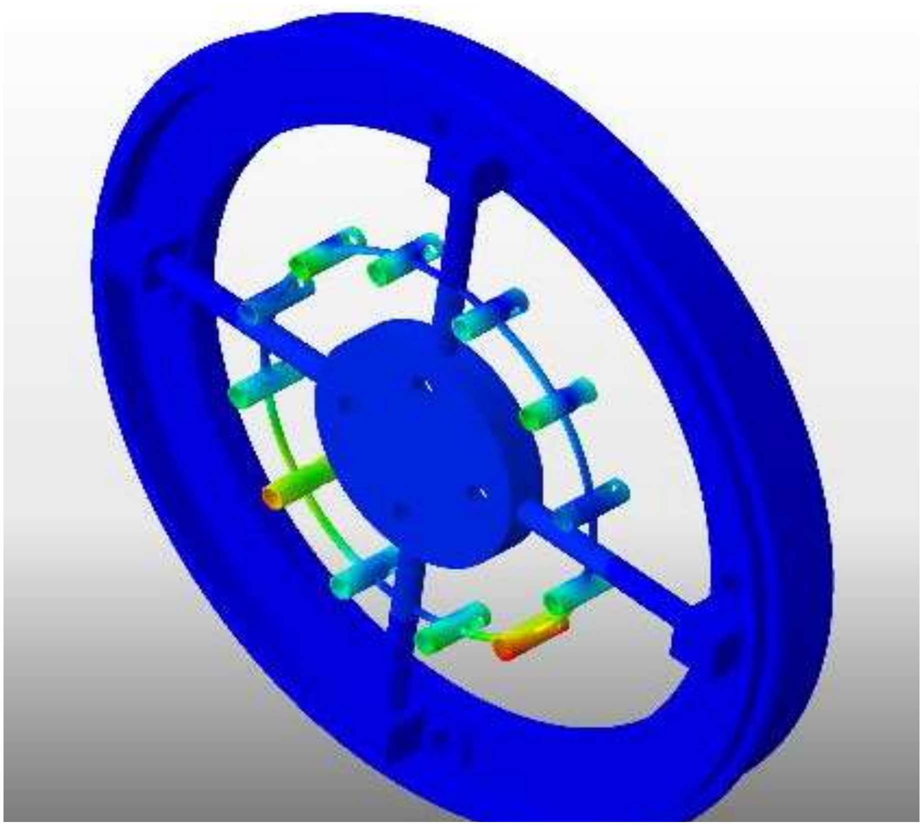


Figure 24: FEA characterization

Von Mises Plots:

Figure 25: Von Mises Plot at α = 0.733 rad/s2

Figure 26: Von Mises Plot at α = 0.366 rad/s2

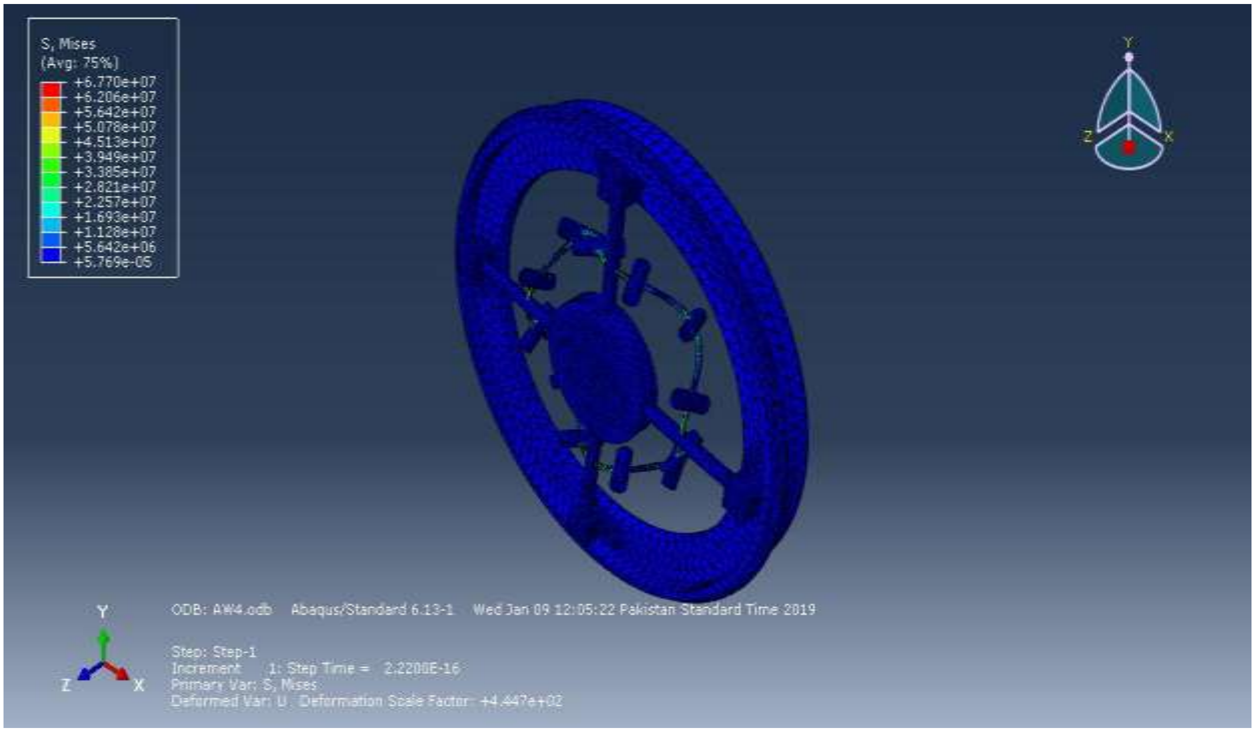


Figure 27: Von Mises Plot at α = 0.182 rad/s2

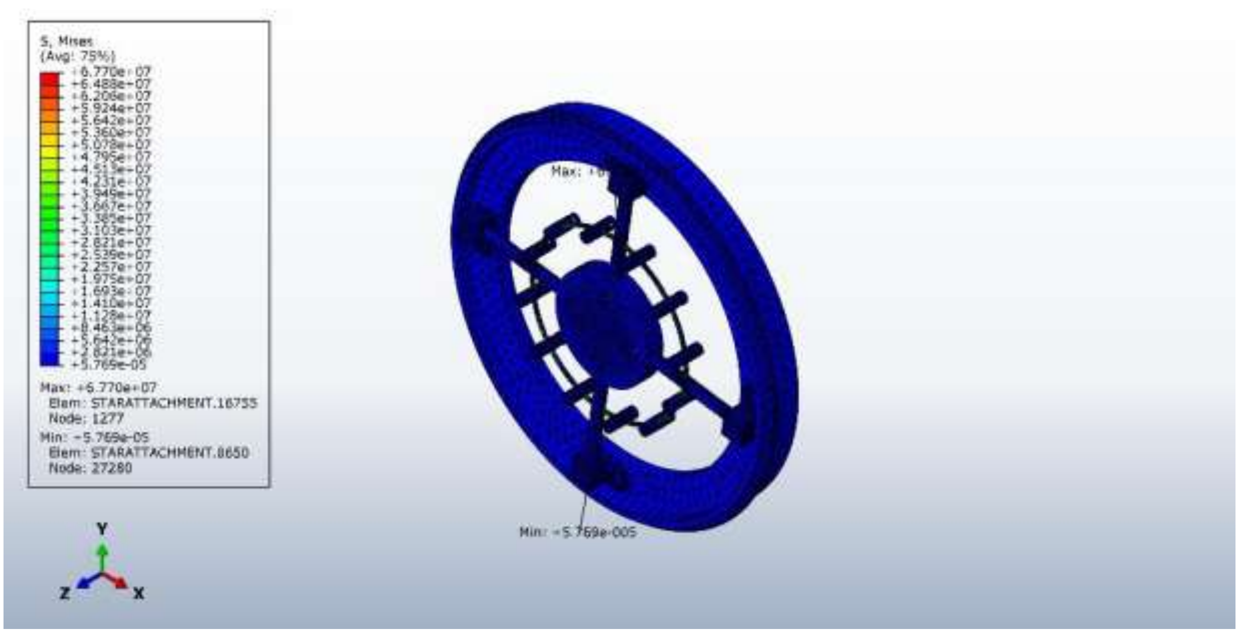


Figure 28: Von Mises Plot at α = 0.091 rad/s2

Deflection Plots

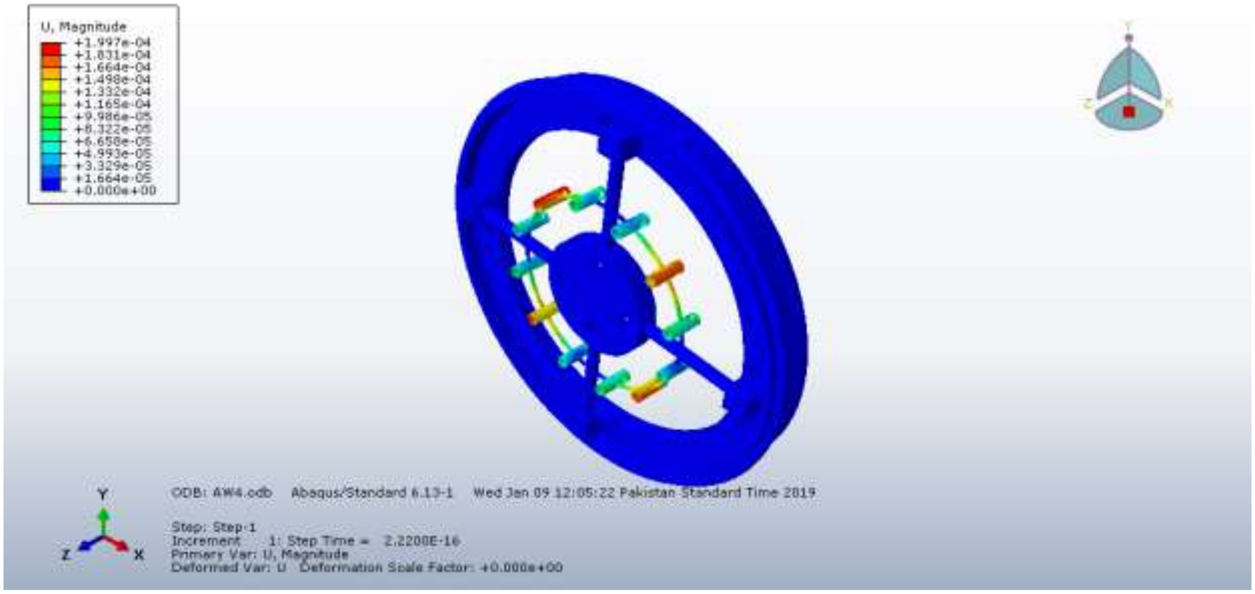


Figure 29: Deflection Plot at α = 0.733 rad/s2

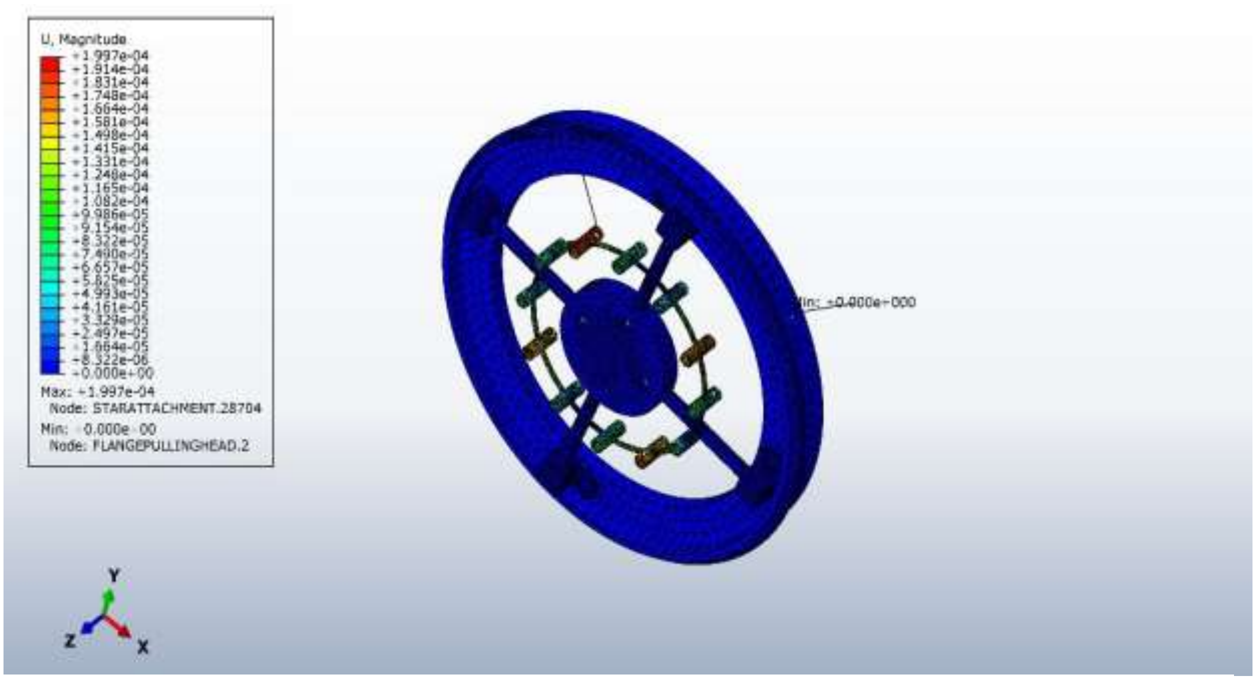


Figure 30: Deflection Plot at α = 0.366 rad/s2

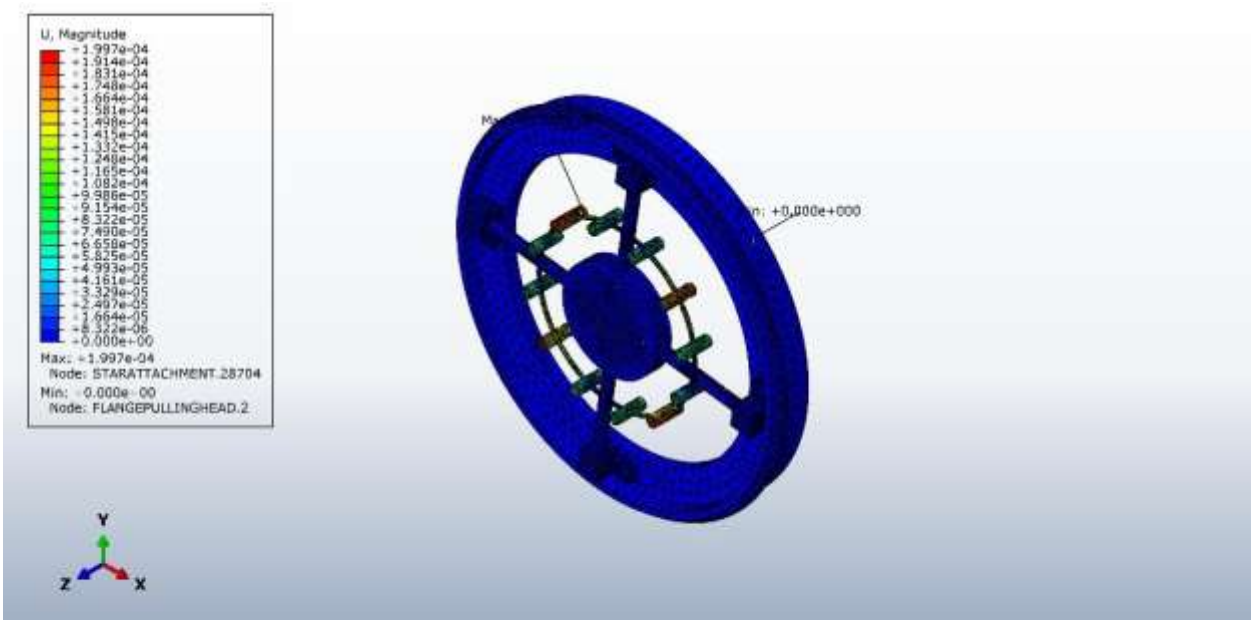


Figure 31: Deflection Plot at α = 0.182 rad/s2

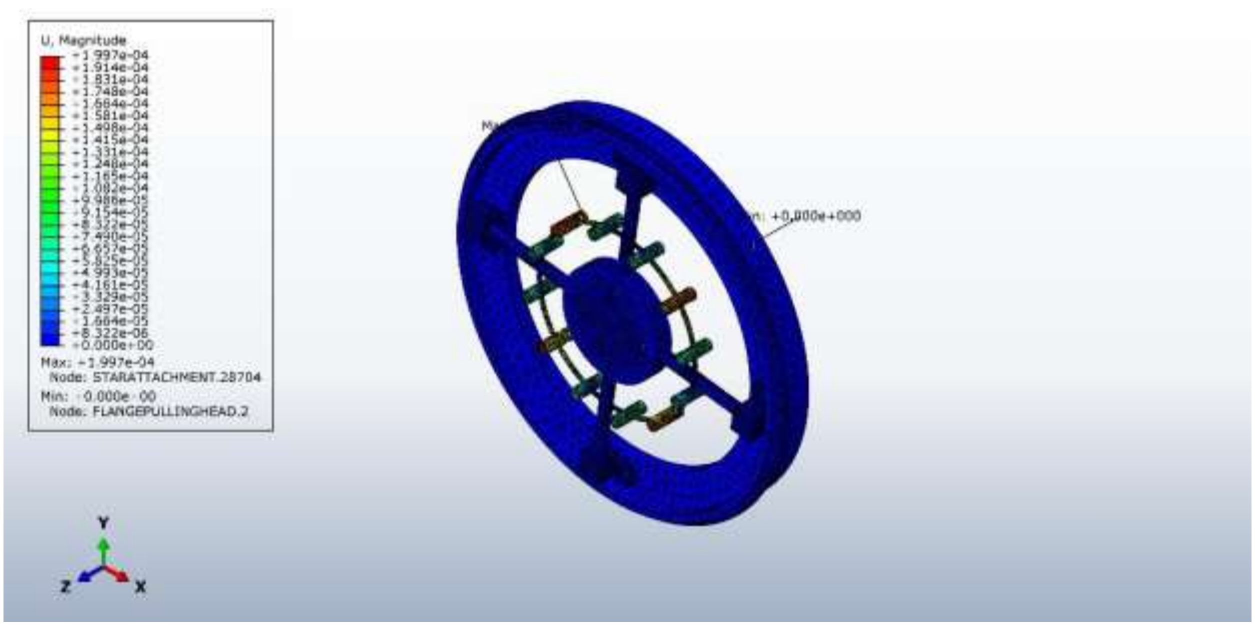


Figure 32: Deflection Plot at α = 0.091 rad/s2

The Von Mises stresses come around 67 MPa and are closer to the values obtained as a result of analytical calculations. This validates the results. The feedback of the committee regarding the meshing was cleared later on by the use of structured meshing techniques. The convergence has been established in the simulation and the results validate the analytical solution of the system

Final Product Images:

Following are the images of final product displayed at SMME Open House 2019 on 30th April, 2019.

Figure 33: Final Product (I)

It is worthy of mentioning here that the project was awarded the "2nd Best Industrial Project award" at SMME Open House 2019.

Figure 35: Final Product (II)

Figure 34: Final Product (III)

CHAPTER 5: CONCLUSION AND RECOMMENDATION

With ever increasing development in Pakistan, large civil structures will be built to support the growth in form of industry, transportation networks and large buildings. All of these developments will induce a large demand for steel cage, for which the current system is not efficient enough. Pile cage welding machine aims to alleviate this problem by development of a local product adapted to local conditions.

The basic objective of this project was to develop the

1. Design calculation
2. Identify manufacturing hurdles
3. Highlighting fabrication problem
4. Identify critical processes in manufacturing that have key role in performance of the machine

Reduction in rebar and binding wire wastage is expected from the product. This will be tested by the company by practically deploying the prototype at the site and identify furthermore problems. The problems can be addressed to manufacture the product to expedite the local industry automation.

On the academic side the project offers a lot of learning and exposure to the industrial norms and practices. The development of such versatile project will provide a lot of understanding regarding Design, fabrication, Testing and motor control.

Improvements:

1) The product can be developed by integrating better design approximations to make design more robust.

a) The mechanism for restraining the flanges can be further developed for longevity of the machine.

b) The design of the diagonal channels for rollers can further be refined for better load absorption.

2) Employment of better fabrication methods for better accuracy can yield much less vibrations and better cage quality.

a) The methods used for alignment and level can be improved.

b) Use of better layout techniques can help in reducing the fitting issues.

3) Welding robot can be used to increase the cage quality further. The robot has productivity problems currently regarding the speed of cage manufacturing. The robot can be developed to overcome these problems to automate the welding process.

4) The rebar loading system can also be automated to ensure maximum productivity from the machine. The mechanism is very simple but is only worth employing for cage diameter larger than the lifting height of a person.

5) HMI or human machine interface can be used for at the site alteration of the cage specification at the site providing more flexibility. This also allows for manufacturing of variety of cage sizes without any hassle.

6) Module can be added to the system to monitor the statistics of the cage manufacturing at the site from head office for real time information from the site. This allows to make the operation leaner.

The company is furthermore interested in projects relating to construction industry to develop local industry. The project can be used a catalyst to develop academia-Industry linkage. The industry has some real problems that have to be addressed by the universities in Pakistan to carry the country forward.

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