CONCEPT DESIGN AND STRUCTURAL ANALYSIS OF VEHICLE LAUNCHED TRACKWAY SYSTEM

Author
HASNAIN ALI MIRZA
DME-4 (DESIGN AND MANUFACTURING ENGINEERING)
(NUST201463084MSMME62014F)

THESIS

Submitted to the Department of Design and Manufacturing Engineering in fulfillment of the Requirements for the Degree of

MASTER OF SCIENCE
in
DESIGN AND MANUFACTURING ENGINEERING

Thesis Supervisor
Dr Mushtaq Khan

School of Mechanical and Manufacturing Engineering
National University of Sciences and Technology
2016

CONCEPT DESIGN AND STRUCTURAL ANALYSIS OF VEHICLE LAUNCHED TRACKWAY SYSTEM

By

Hasnain Ali Mirza

Submitted to the Faculty of Department of Design and Manufacturing Engineering, National University of Sciences and Technology College of School of Mechanical and Manufacturing Engineering, Islamabad Pakistan, in partial fulfillment of the Requirement for the Degree of Master of Science in Design and Manufacturing Engineering

Candidate: ____

Hasnain Ali Mirza

Advisor: ____

Dr. Mushtaq Khan

Guidance and Evaluation Committee (GEC) Members:

1. Dr. Liaqat Ali
2. Dr. Hussain Imran
3. Dr. Aamir Mubashir

National University of Sciences and Technology,

School of Mechanical and Manufacturing Engineering,

Islamabad.

___ August, 2016

ABSTRACT

CONCEPT DESIGN AND STRUCTURAL ANALYSIS OF VEHICLE LAUNCHED TRACK LAYING SYSTEM

In military, movement of the troops and vehicles is carried out cross country during operations. This necessitates the use of specialized equipment's such as bridges and tracks to assist the move. Pakistan Army in 1990's made vehicle launched track laying system of 50 m length rolled over a spool and mounted on a truck to assist the movement of heavy vehicles in soft terrain. This existing vehicle launched track laying mechanism rolls/retrieves the track from the front side (in front of windscreen) of the vehicle. Army using this system in the field has communicated few problems in it which includes; obstruction in the view of operator, considerable amount of time required to lay the track, wear and tear of track and fatigue factor for crew due to manual handling of system. These factors have necessitated the need to study the entire system critically and devise a new system which can cater for the problems being faced by user.

This project will follow the new trends in assault track laying systems in the world, which will benefit in developing the new design. The scope of work in this thesis will address problems areas in the existing system and present a complete CAD assembly of the newly designed system. It will automate the process of track laying by using hydraulic power, to reduce crew members and fatigue factor. It will focus on identification of suitable materials for manufacturing of the new assembly and narrowing down most suitable material considering availability, functionality and manufacturability. Analyze functional and operational capability of new system, by carrying out engineering analysis (Mechanism analysis and Structural analysis) of critical parts in the new system. In the end the track wear and maintenance issues will be conversed to reduce failures and enhance life of track.

DEDICATIONS

To my beloved parents and family….

ACKNOWLEDGEMENT

First and foremost, I would like to thank my Almighty Allah for all His blessings and benevolence which helped me complete this incredible task in terms of integrity and completeness.

Secondly, there is long list of people without whom I would not have been to complete this endeavor successfully. I would like to communicate my special appreciation and gratitude to my advisor, Dr. Mushtaq Khan for his extended support throughout my thesis tenure. His untiring efforts and advice helped me move around the tight corners during my project work. His constant support helped me to be consistent and productive, for which he has my utter gratitude.

I would also like to pay special thanks to my co advisor Dr. Liaqat Ali whose guidance served as beacon of light and inspiration throughout my work. His professional experience proved invaluable for completing the designing and analysis phase for this project.

Special thanks to my family; my parents, my wife and children, for all the sacrifices that they have made on my behalf and who were always in my support in dire moments.

Conclusively, I would like to thank the entire honorable faculty of Department of Design and Manufacturing Engineering, whose professional approach and vision groomed me as a sound person both technically and morally.

Hasnain Ali Mirza

August, 2016

TABLE OF CONTENTS **Page No.**

LIST OF FIGURES **Page No.**

LIST OF TABLES **Page No.**

LIST OF ABBREVIATIONS

CAD	Computer aided design
PTO	Power take off
ATPs	Acceptance Test Procedures
HB	Brinell hardness
H.P	Horse power
m	Module of gear
BHN	Brinell hardness number
M	Moment
MPa	Mega pascals
rpm	Revolutions per minute
NATO	North Atlantic Treaty Organization
ITD Dte	Inspection and Technical Development Directorate
GHQ	General Headquarters
approx	Approximately
Dia	Diameter

CHAPTER – 1

INTRODUCTION TO ASSAULT TRACK-WAY

1. Introduction

In military, movement of the troops and vehicles is carried out cross country during operations. This necessitates the use of specialized equipment's such as bridges and tracks to assist the move. Pakistan Army in 1990's made vehicle launched track laying system (Assault Track-way) of 50 m length rolled over a spool and mounted on a truck to assist the move of heavy vehicles in soft terrain. **Assault Track-way** is a field expedient which is meant for laying track over soft areas i.e marshy, sandy patches or lengths of track likely to become degraded by sustained traffic. The trackway equipment enables carrying and launching of a 50 meters length of special aluminum alloy track-way duly wrapped on its spool. The track-way permits mobility to vehicles / equipment up-to 30 tons of combat weight. The launching vehicle is used for transportation as well as mechanical assisted launching / retrieval of the track-way. The launcher can easily launch / retrieve one 50 meter length in 20-30 minutes employing a crew of four to five members.

1.1 Existing System:

Figure 1.1 Existing Assault Track-way

1.1.1 Technical Specifications

• Length of each plank	-	4.572 m (14 ft approx)
• Width of each plank	-	0.257 meters (10 in)
• Length of track-way	-	50.292 meters (165 ft)
• Width of track-way	-	3.352 meters (11 ft)
• Weight of each plank	-	16 kgs (approx)
• Weight of one set of track-way	-	3400 kgs
• Carrying vehicle	-	5 Ton MAN Steyr (4x4)

1.1.2 Working

Existing system uses a winch system to wind and un-wind the track from the spool. It requires manual labor. First the track assembly is rotated on the circular turn table such that it will be at right angle to the vehicle, after this a person picks up the winch form the bottom of the vehicle, which is operated by the Power Take off (PTO). The person then delivers one end of this rope to the other person standing at the top of the vehicle at its front end on a roller support arm assembly. This end of the winch is then connected to the track-way, so that as soon as the PTO starts driving the winch assembly, then from the front side of the vehicle it moves in the front direction providing a pull to the track-way. Now, there comes a problem that as soon as the track-way comes under the wheels, it experiences a pull from the vehicle, which produces inertia in the spool. If there is no brake mechanism then it would be very difficult to control the laying process. Due to this inertia the spool will go on unwinding and this process will become out of control. So for this purpose a brake mechanism is provided on the spool to control the unwinding of the spool. In this process, driver cannot see anything in front of him. He is driving blindly. So he needs an instructor or a helper. Also the unwinding process is done by hand power (manually) until the track-way reaches under the wheels.

1.2 Problem Statement

In Military operations time is the biggest constraint and during assault operations it is the deciding factor. The problem Army faced after induction of this equipment and over 20 years of usage in the field are appended below:-

a. Cumbersome process requires specialized training of staff.
b. It requires at least 20 min for laying out the track and approximately 30 min for retrieval.
c. 5 to 6 crew members required to execute the operation.
d. Driver view is obstructed as laying and retrieval of the track-way is done from the front side of the vehicle.
e. High risk of accident and track damage is involved.

1.3 Aim

To design an effective and efficient way of laying track in the field with minimum operating time and crew.

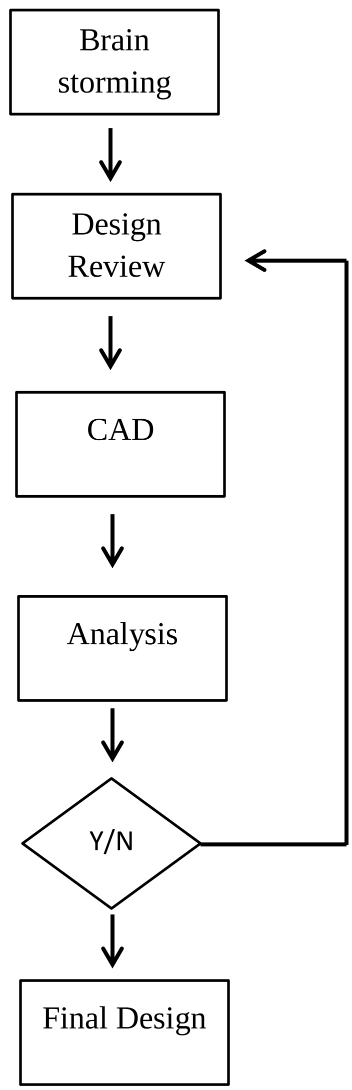
1.4 Objective

The objectives of the new design are appended below:-

a. The design must increase mechanical advantage over its predecessor by introducing hydraulic assisted system.
b. Design a system which should be simple and easy to operate. Hence requiring less amount of training for crew.
c. Enhance the visibility of the driver by rearward laying of track.
d. Reduction in operating time from 30 mins to 5 mins.
e. Enhance the safety of the crew by involving minimum risk of accident.
f. Reducing the number of crew to operate the system.
g. Provide alternate mechanism for laying of track, if hydraulic system or vehicle becomes faulty.

1.5 Methodology

This project will follow following methodology to develop new modified design, which will check its functionality as well as its structural ability to withstand the total payload.



CHAPTER - 2

DESIGNING OF NEW SYSTEM

2.1 Design Requirements

These requirements are given by the user after technical consultation with ITD Dte GHQ which serves as a base for designing the new modified system.

a. The launching and retrieving of the track way mounted on the launching assembly will be operated by hydraulic system.

b. The equipment should be capable to perform both function of transportation of track and its launching.

c. Safety system should be incorporated in the equipment to avoid any accident / mishap.

d. There should be roller bar which will guide track way on spool.

e. Installation / fitment of hydraulic pump which will take drive from PTO.

f. Fitment of hydraulic valves / leverage system in driver cabin for operation of launching system.

g. Installation / fitment of hydraulic motor which will give drive to spool through gear reduction unit.

h. Provision of hand operated mechanical system for retrieval of track way, in case of failure of vehicle hydraulic system.

i. Mounting of brackets and rollers at rear both sides which will facilitate to track way in rear lying.

j. Diameter of rear rollers both sides be increased to a suitable size not less than 6 inches.

k. All rollers shall be of appropriate material steel / chrome alloy for bearing required stresses/ loads during launching / retrieving operation.

l. Provision of proper locking system for launching system during laying / retrieval and transportation.

m. Provision of buckle for fastening of track way on spool during move.

n. Provision of proper concealed lighting at appropriate location system for night operation.
o. Grease nipples should be provided on all roller pins of turntable and moving parts.
p. Provision of tool / accessories.
q. All the attachments which are placed with vehicle tail body will be developed / manufactured on vehicle chassis developed by the firm. These includes attachments like placement of Jerri can, spare wheel attachment etc.
r. Location of attachments should remain same as in original sample.
s. Material of all the parts / assemblies will be ensured same as that of sample during manufacture.
t. Configuration / manufacture of parts / assemblies will be same as per sample.
u. Safety feature will be provided to keep the vehicle speed with in limit that it remains lesser than the laying / retrieving speed of track.
v. Arrangements for speed safety features should be placed such that they do not hinder move of individual inside cabin.

2.2 Acceptance Test Procedures (ATPs)

a. There should be no hydraulic oil leakage during visual inspection.
b. Launching / retrieving system should function smoothly without any abnormal sound.
c. Track way to be laid / retrieved and time to be noted during both operations. Laying / retrieval time should be 10 minutes each.
d. There should be no unusual noise at worm.
e. Rear roller should be hardened enough that these should function smoothly.
    1) Hardness of the roller should not be less than 150 HB
    2) Hardness of the roller pin should not be less than 130 HB
    3) Random sample may be tested for hardness.
f. Hydraulic circuit should not disturb functioning of winch (if already installed).

g. Function of the safety to control vehicle speed should be checked and ensured during laying of track way. During laying of track way, it should not be continuously touching maximum of the rollers.

h. **Paint**. Complete vehicle (less vehicle cabin) will be painted NATO Green conforming to shade 223 to BSS-381C of latest edition or matching color with vehicle cabin.

i. **Miscellaneous**

   1) All nut / bolts should be properly tightened.
   2) All hydraulic hoses should be covered with steel wire spring to avoid rubbing / friction damage where applicable.
   3) There should be no sharp edge/ burrs.
   4) Grease nipple should be provided on moving assembly / parts.
   5) Workmanship of fabrication work should be generally of good quality.

2.3 Designing of critical components

The critical components in the system are:-

a. Spur & pinion gear
b. Spur & pinion gear shaft

2.3.1 Load calculations

The basic consideration for designing this project is the total load acting on the system. Based on the total load requisite structure and auxiliary parts will be selected to optimize the functionality of the equipment.

Total mass of track	m_T	=	3400 Kgs
Force acting due to track	F_T	=	33320 N
Total mass of Spool	m_s	=	1000 Kgs
Force acting due to Spool	F_S	=	9800 N
Total Load	F	=	43120 N
Factor of safety	**FoS**	**=**	**1.25**
Design Load	$\mathbf{F_D}$	**=**	**53900 N**

Mean Dia of Spool	D_S	=	1 m
Mean radius of Spool	r_s	=	0.5 m
Torque on Spool	τ_S	=	53900 x 0.5
		=	**26.95 KN.m**
Circumference	C	=	$2\pi r$
		=	3.142m

This means a total of approximately 15 x revolutions are required to wind the track on spool from the ground and desired time to complete the job is 3 mins. Therefore **rpm N = 5**. Which will be same on spur gear $N_G = 5$

Power required for winding the track onto spool

$$P = 2\pi N\tau/60$$

Where; N = 5 rpm

and τ_S = 26.95 KN.m

Therefore **P = 14.1 KW**

We know that, 1 hp = 745.7 W

So for 14.1 KW to be transmitted the required H.P is 18.9. we say

H.P = 20hp

2.3.2 Definition of important terms

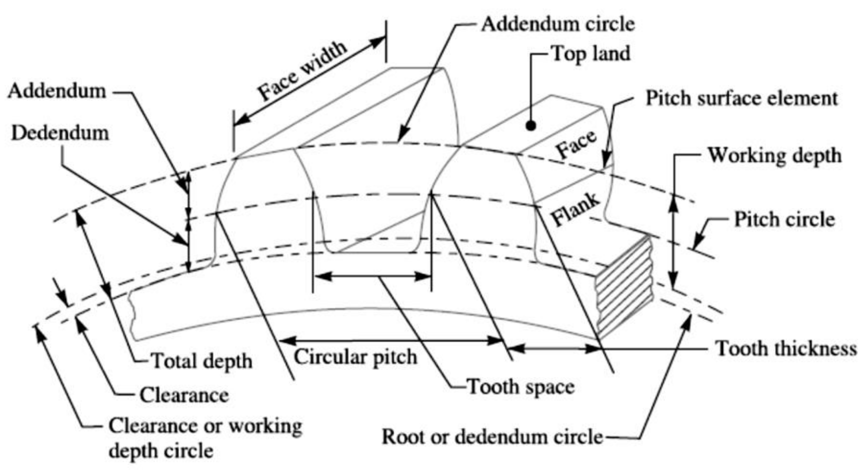


Figure 2.1 Terms used in gears

a. **Pitch circle**. The imaginary circle which gives the motion exactly like the actual gear by pure rolling action. [1]
b. **Pitch circle diameter.** As the name suggests it is dia of the pitch circle. It is very important term and the size of gear is known by its pitch circle diameter. [1]
c. **Angle of obliquity or Pressure angle**. It is denoted by φ and is the angle between the common normal of the two gear teeth at the point of contact and the common tangent at the pitch point. The normal used angles of obliquity are 14 1/2° and 20°.[1]
d. **Addendum**. The radial distance from the pitch circle of the tooth to its top surface is known as addendum. [1]
e. **Dedendum**. The radial distance from the pitch circle of the tooth to its bottom surface is known as dedendum. [1]
f. **Face width**. Axial width of the gear teeth is also known as its face width. [1]
g. **Total depth**. It is the sum of dedendum distance and addendum distance from pitch circle. [1]
h. **Working depth**. It is radial distance from the addendum circle to the clearance circle. It is equal to the sum of the addendum of the two meshing gears. [1]
i. **Clearance**. The distance taken from bottom of the tooth to the top of it radially, in a meshing gear. A circle passing through the top of the meshing gear is known as **clearance circle**. [1]

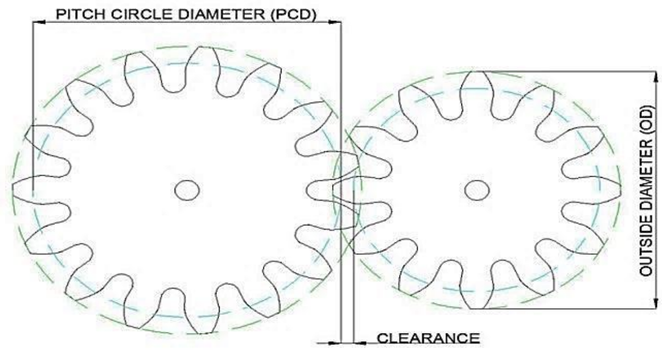


Figure 2.2 Pitch Circle Diameter

j. **Module**. The ratio of the pitch circle diameter in millimeters to number of teeth on the gear is called module and is denoted by ‘m’. If modules are equal only then the gears will mesh. Gear ISO standards and design methods are now normally based on the module e.g. a gear of module 4 has 15 teeth, its **pitch circle diameter** is: 4 x 15 = 60 mm. [1]

m = D/T

Where, D = Diameter of pitch circle in mm, and

T = Number of teeth

k. **Pitch circle or Circular pitch**. It is symbolized by ‘p_c’ and is the distance on perimeter of the pitch circle, measured from a point on one tooth to the matching point on the next tooth. [1]

Circular pitch, $p_c = \pi D/T$

Where, D = Diameter of the pitch circle, and

T = Number of teeth

Note:- If the two gears have same circular pitch they will mesh together properly.

l. **Diametral pitch**. The ratio of the number of teeths on gear to circular pitch. It is represented by ‘p_d’. [1]

Diametral pitch, $p_d = T/D = \pi / p_c$

Where, T = Number of teeth

D = Circular pitch

m. **Velocity Ratio.** Let us take D_1 and D_2 as circular pitch of gears 1 and 2 having teeths denoted by T_1 and T_2 correspondingly, then velocity ratio ω is given by equation below,

$$\omega_1 / \omega_2 = D_2 / D_1$$
$$= T_2 / T_1$$

n. **Forms of Teeth** There are commonly two types

1) **Cycloidal teeth**. A cycloid is the curve traced by a point on the circumference of a circle which rolls without slipping on a fixed straight line. When a circle rolls without slipping on the outside of a fixed circle, the curve traced by a point on the circumference of a circle is known as epicycloid. On the other hand, if a circle rolls without slipping on the inside of a fixed circle, then the curve traced by a point on the circumference of a circle is called hypocycloid. [1]
2) **Involute teeth**. An involute of a circle is a plane curve generated by a point on a tangent, which rolls on the circle without slipping or by a point on a taut string which is unwrapped from a reel. [1]

o. **Advantages of involute teeth gears.** Following are the advantages of involute gears :

1) The peculiar advantage of the involute gears system of teeth is that center distance for a couple of involute gears can be varied without altering velocity ratio, if within specified limits. But for cycloidal teeth it is not possible as cycloidal teeth require same center distance to maintain velocity ratio. [1]
2) The angle of obliquity in involute system remains constant throughout the engagement of the teeths which in turns makes them smoother and less prone to wear and tear. However the angle of obliquity in cycloidal gears, starts with maximum at beginning of engagement slowly reduces to zero at the pitch point and gradually increases to maximum again at the end of engagement. Which makes the overall engagement jerky . [1]

3) A single curve generates the flanks and face of involute whereas in cycloidal gears, dual arcs (i.e. epicycloid and hypocycloid) are required for the face and flank correspondingly.
4) Cycloidal teeth are more difficult to manufacture than the involute teeths. [1]

p. **Systems of Gear Teeth**. There are commonly four systems of gear teeth used which are appended below. [1]

1) 14 1/2° Composite teeth
2) 14 1/2° Full depth involute system
3) 20° Full depth involute system
4) 20° Stub involute system

The 20° stub involute system has a strong tooth which show excellent performance for bearing heavy loads. [1]

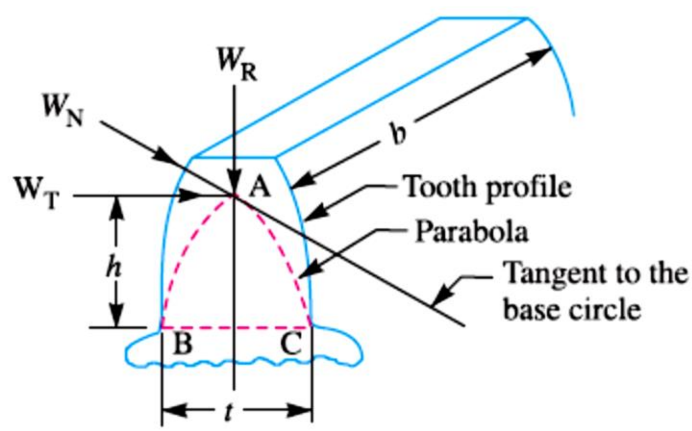


Figure 2.3 Load on tooth of a gear

q. **Lewis equation.** Contemplate that the tooth on a gear acts as a cantilever beam and under a normal load (W_N) as shown in Fig 2.3. When this normal load is resolved into its horizontal and vertical components i.e. tangential component (W_T) and radial component (W_R). The tangential component (W_T) induces a bending stress which tends to break the tooth from its base and radial component (W_R)

induces a compressive stress on the gear which is of comparatively smaller scale; therefore it's neglected due to its weak effect. Henceforth, the bending stress induced by the tangential component is being used for design calculations. The section of extreme bending stress is obtained by sketching a parabola through point 'A' which is tangential to curves B and C. In Fig. 2.3 the parabola is shown with red dotted line which acts as a beam of unvarying strength. But the teeth are bigger than this red dotted parabola at every point except point BC. So therefore we take section BC as critical section where maximum stresses will act.[1]

$W_T = \sigma_w \times b \times p_c \times y = \sigma_w \times b \times \pi m \times y$

Where,

σ_w = The permissible working stress (depends upon the material)

b = Face width

y = Lewis form factor

2.3.3 Design Considerations of Spur and Pinion Gear

For designing of gear system normally following data is given, which is as follows:-

a. Total power required to be transmitted on the system of gears.
b. Rpm of the driving gear.
c. Velocity Ration of the gears.
d. The distances between the centers of the gears.

Requirements which must be addressed in designing the gear system are appended below:-

a. Sufficient strength to cater for static loading as well as dynamic loading under normal running conditions should be considered at priority.

b. Wear characteristics of the system of gear teeths, to optimize the life expectancy of the gears.
c. Availability of space
d. Economy of the material being used.
e. Alignment and deflections of the shafts.
f. Methods for lubrication of the gears to avoid squeals.

2.3.4 Design of spur and pinion gear

Basing on following design constraints we move forward:-

a. Requirement is of large scale reduction so desired velocity ratio 10:1.
b. System of gear teeth is involute to cater for heavy loading which requires at least 14 teeth on pinion.
c. Space constraint for spur gear is dia < 1000 mm, So let us take following Data:-

DATA

Dia of Spur gear D_G = 980mm

Teeth on pinion T_P = 14 (to avoid interference)

Module: m $D_P / T_P = D_G / T_G$ = 7 (for gears to mesh properly module remains same on pinion and gear)

Therefore we can find D_P & T_G

Dia of pinion D_P = 98 mm

Teeth on spur gear T_G = 140

Circular pitch p_c = πm = 22mm

Face width b = 110 mm (As a general rule, gears should have a face width 'b' from 3 to 5 times the circular pitch 'p_c')

Velocity ratio $VR = T_G / T_P = N_P / N_G =$ 10:1

As rpm of spool is equal to rpm of gear: N_G = 5rpm

AISI 4140 Alloy steel

Tensile strength σ_{UT} = 785 MPa

Yield strength σ = 480 MPa

Young's Modulus E = 210 GPa

Brinell hardness number BHN = 200

Stress at yield point σ_o = 245 MPa

Stub Involute teeth with pressure angle $\phi = 20^o$

Rpm of Pinion can be found by:

$$N_G / N_P = T_P / T_G$$

$N_P = 5x140/14 = 28.57$

$\mathbf{N_P = 50\ rpm}$

Torque on pinion can be found by:

$P = 2\pi N\tau/60$

Where; $N = 50$ rpm

$P = 14.1$KW

$\boldsymbol{\tau}$ = **2.69 KN.m**

Pitch line velocity: υ of pinion is given by:

$\upsilon = \pi N_P D_P / 60 = 3.142x50x0.098 / 60$

$\boldsymbol{\upsilon}$ = **0.26 m/s**

Velocity factor on gear is: Cυ

For gears operating under 12.5 m/s

Cυ = 3 / (3+ υ) = 0.93

The tangential load on gear teeth due to power transmitted 14.1KW

$W_T = P\ C_s / \upsilon$

$C_s = 1.23$ Service factor

(For non-enclosed and grease lubricated gears)

= 14100x1.23 /0.26

$\mathbf{W_T}$ = **66704 N**

Design Tangential load on gear teeth obtained by Lewis Equation

$W_T = \sigma_W . b . p_c . y$

where, σ_W is permissible working stress

$\sigma_W = \sigma_o . C\upsilon$

σ_W = 245x0.93 = **227.85 MPa**

$y = 0.175–0.841/T_P = 0.175–0.841/14$ (20^o stub system)

y = **0.16**

W_T = 227.85x110x22x0.16

W_T = 88224 N

Results:- As the design tangential load is greater than tangential load due to power required. The design is safe.

Dynamic load using Buckingham equation

W_D = $W_T + W_I$

Here the tangential load (W_T) is calculated without using the service factor

W_T = P / υ

= **54230 N**

W_I = $21\upsilon\,(b.C + W_T) / 21\upsilon + \sqrt{b.C + WT}$

Where,

C is the Deformation factor and depends upon *e* (Tooth error in action)

C = $K.e/(1/E_G + 1/E_P)$ in N/mm^2

e = 0.071 as module is 7 (ref Table 28.7)

K = 0.115 for 20^o stub system

C = 857 N/mm^2

Now W_I = $21x0.26(110x857+54230)/21x0.26\sqrt{110x857 + 54230}$

= **385 N**

Therefore W_D = 54230 + 385

W_D = 54615 N

The Static Load is given by equation

W_S = $\sigma_e .b. p_c . y$

Where, σ_e is the flexural endurance limit and depends upon BHN

σ_e = 350 MPa

= 350x110x22x0.16

W_S = 135520 N

W_S should be greater then 1.5 W_D for shock loads.

The remaining specification of spur & pinion for 20° stub system are:-

Addendum	=	0.8m	=	5.6mm
Dedendum	=	1m	=	7mm
Working depth	=	1.6m	=	11.2mm
Minimum total depth	=	1.8m	=	12.6mm
Tooth thickness	=	1.5708m	=	11mm
Minimum clearance	=	0.2m	=	1.4mm

2.3.5 Designing shaft for Spur Gear

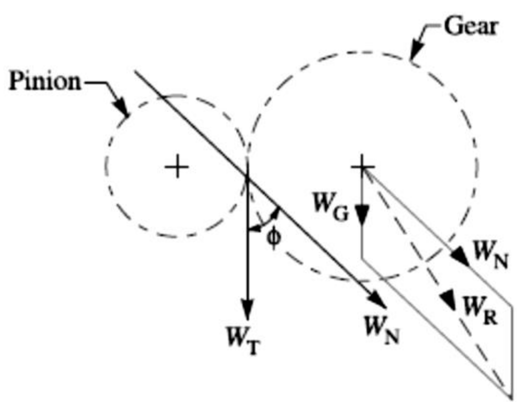


Figure 2.4 Load Acting on the Gear

First we find the normal load W_N acting between the tooth surfaces

W_N = $W_T / \cos \phi$

= 88224 / cos20

W_N = 93886 N

And weight of gear is given by:

W_G = $0.001.\ 18.\ T_G.b.m^2$ (in N)

= 0.001x18x140x110x49

= **13583 N**

Now the resultant load acting on the gear

W_R = $\sqrt{{W_N}^2 + {W_G}^2 + 2W_N W_G cos\,\phi}$

W_R **= 106751N**

Moment on the gear shaft

M **=** W_R x

Assuming that the gear is overhung on the shaft and taking the overhang as 50 mm, therefore bending moment on the shaft due to the resultant load,

M = 5337550 N.mm

And twisting moment on the shaft

T = $W_T D_G / 2$

= 88224x980/2

= 43229760

Equivalent torque

T*e* = $\sqrt{M^2 + T^2}$

= 43558025 N.mm

The dia of gear shaft is given by

T*e* = $\pi\, \sigma\, d_G^3 / 16$

Where σ is shear stress for material of gear shaft which is say 100MPa

$\mathbf{d_G}$ **= 130 mm**

2.3.6 Design of Pinion Gear Shaft

W_N = $W_T / \cos \phi$

= 88224 / cos20

$\mathbf{W_N}$ **= 93886 N**

And weight of gear is given by:

W_G = 0.001 18 T_P.b.m^2 (in N)

= 0.001x18x14x110x49

= 1358 N

Now the resultant load acting on the gear

W_R = $\sqrt{{W_N}^2 + {W_G}^2 + 2W_N W_G \cos\phi}$

W_R = 95163 N

Moment on the pinion shaft

M = W_R x

Assuming that the gear is overhung on the shaft and taking the overhang as 50 mm, therefore bending moment on the shaft due to the resultant load,

M = 4758150 N.mm

Twisting moment on the shaft

T = $W_T D_P / 2$

= 88224x98/2

= 4322976 N.mm

Equivalent torque

Te = $\sqrt{M^2 + T^2}$

= 6428694 N.mm

The dia of pinion shaft is given by

Te = $\pi \sigma d_p^3 / 16$

Where σ is shear stress for material of pinion shaft which is say 100MPa

d_p = 69 mm

2.3.7 Design Summary

Serial	**Parameter**	**Spur Gear**	**Pinion Gear**
1.	Pitch circle dia	980 mm	98 mm
2.	Outer circle dia	990.2 mm	109.2 mm
3.	Root circle dia	966 mm	84 mm
4.	Addendum	5.6 mm	5.6 mm
5.	Dedendum	7 mm	7 mm
6.	Working depth	11.2 mm	11.2 mm
7.	Total depth	12.6 mm	12.6 mm
8.	Clearance	1.4 mm	1.4 mm
9.	Tooth Thickness	11 mm	11 mm
10.	No of teeths	140	14
11.	Dia of shaft	130 mm	69 mm
12.	Module	7	7
13.	Circular Pitch	22 mm	22 mm
14.	Face width	110 mm	110 mm
15.	Pressure angle	20^o	20^o
16.	Torque	26.95 KN.m	2.69 KN.m
17.	Pitch line velocity	0.26 m/s	0.26 m/s

Table 2.1 Design summary of spur and pinion gear

2.3.8 Construction of spur and pinion gear

The construction of the gear is different according to the sizes and its application. Once dedendum circle diameter is somewhat larger than the shaft diameter, then the pinion gear teeths are made integral with shaft. If the circular pitch of the pinion is less than or equal to (14.75 x module + 60 mm), then pinion is constructed solid with uniform thickness equal to the face width as in our case we follow the later. Large gears are provided with arms, which reduces their weight considerably and secondly to join the hub of gear and its rim. The number of arms of large gear i.e spur gear depends upon circular pitch of the spur gear. The table 2.2 below shows the data below.

Ser	Circular pitch	Arms
1.	0.5m	4 or 5
2.	0.5 to 1.5 m	6
3.	1.5 to 2 m	8
4.	2 m & above	10

Table 2.2 Number of arms for spur gear

Hence as per the design summary table mention at 2.3.6 above the pinion is made solid and spur is made having 6 arms.

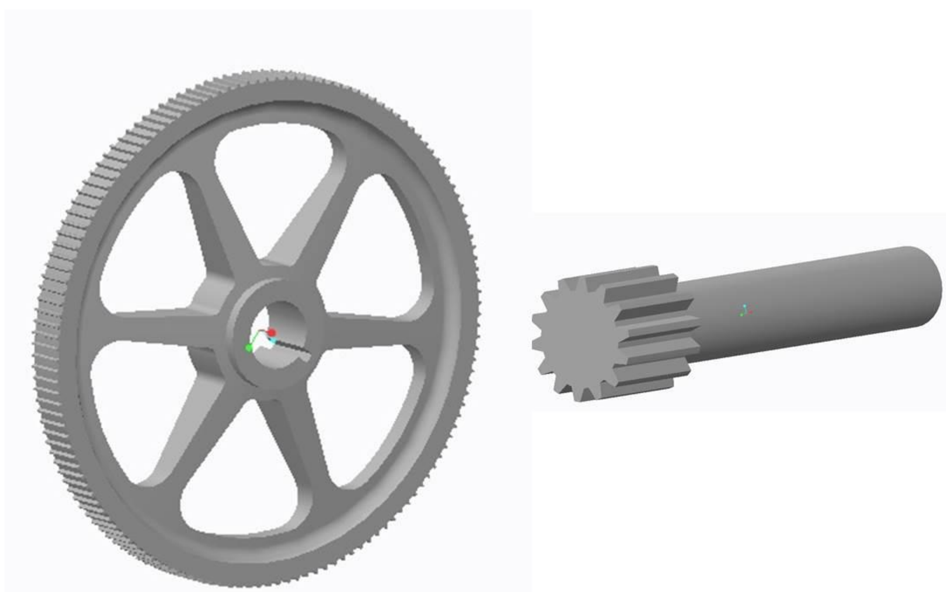


Figure 2.5 Designed Spur and Pinion Gear

So the final isometric view of reduction gear assembly will be as shown in CAD below

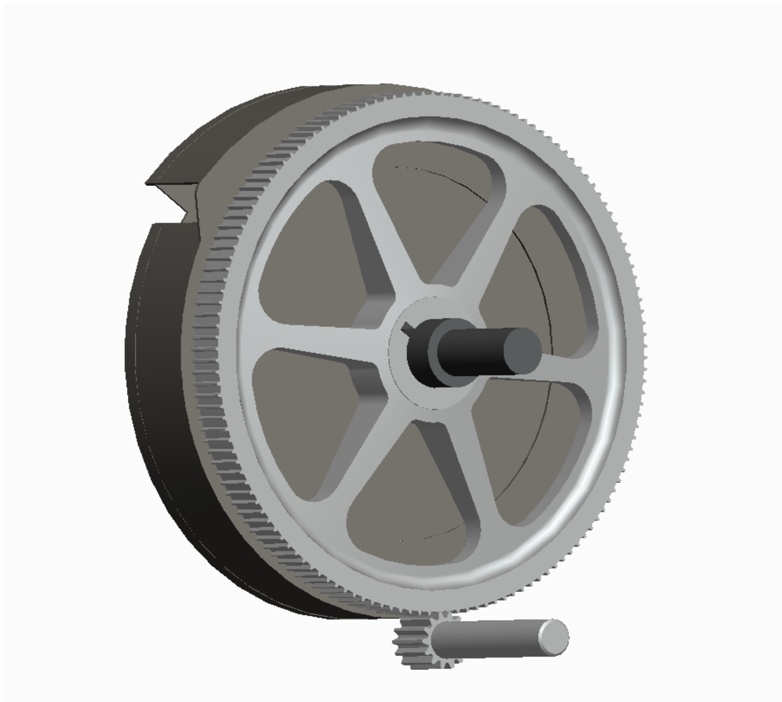


Figure 2.6 Isometric view of reduction gear assembly

2.4 Analysis

The structural analysis of the component which is under max load and bending is carried out on Ansys 15.0 to validate the design and material selected for the design. The main shaft which is connected with reduction gear assembly undergoes max deflection and torsion due to load and torque applied (as shown in fig 2.7) so if it passes the analysis in software we assume that our design is safe. After carrying out analysis following results were obtained. Complete Ansys report is attached at appendix A

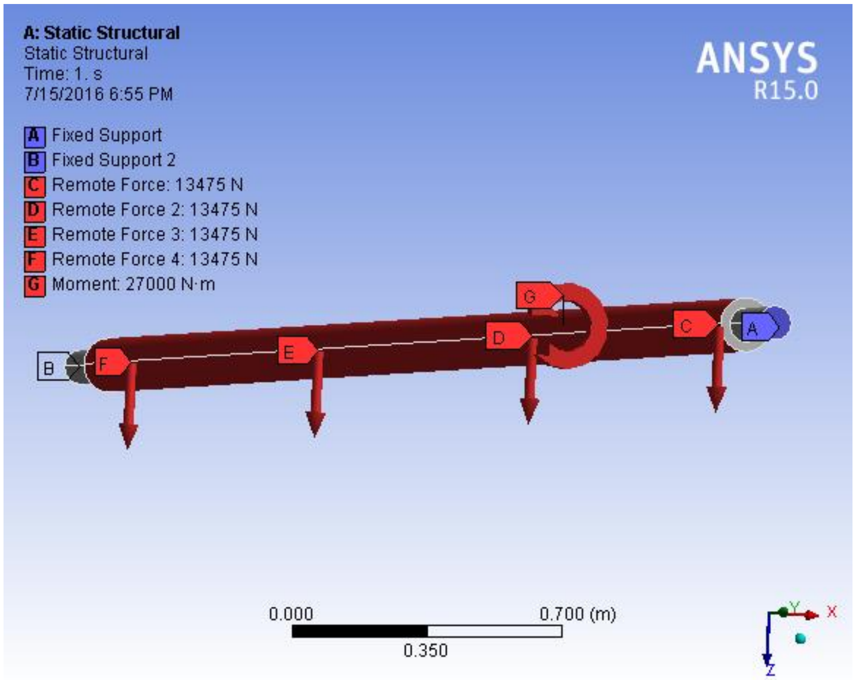


Figure 2.7 Analysis setting for main gear shaft

Type	Total Deformation	Equivalent (von-Mises) Stress	Equivalent Elastic Strain	Strain Energy
Results				
Minimum Value Over Time				
Minimum	0. m	9.7466e+005 Pa	4.5795e-005 m/m	2.0534e-002 J
Maximum	0. m	9.7466e+005 Pa	4.5795e-005 m/m	2.0534e-002 J
Maximum Value Over Time				
Minimum	1.1557e-002 m	3.0787e+008 Pa	1.4959e-003 m/m	4.8501 J
Maximum	1.1557e-002 m	3.0787e+008 Pa	1.4959e-003 m/m	4.8501 J

Table 2.3 Analysis Results

The material selected in software is AISI 4140 alloy steel (σ=480 MPa) with same physical properties as used in our calculations above and the results show that the total von mises stress of the shaft is within the elastic limits hence our design is safe.

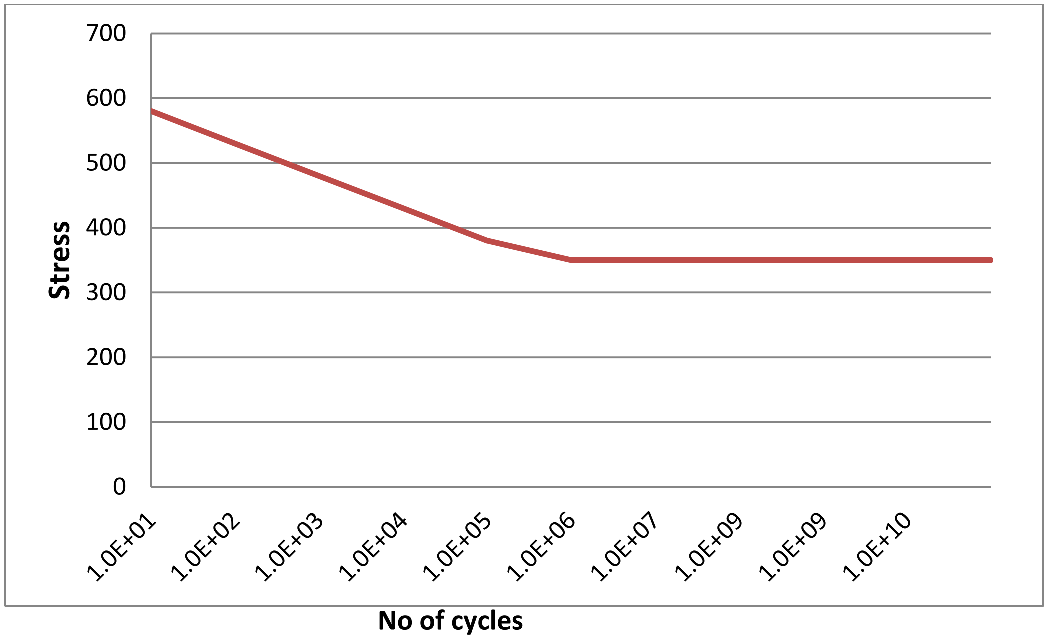


Figure 2.8 SN curve for AISI 4140

The SN curve for steel alloy is drawn from the endurance limit of alloy steel under which it shows an infinite no of cycles is taken as 40% of its ultimate tensile strength. The endurance limit σ_e AISI 4140 is 350 MPa. The maximum value of stress in our design is 308 MPa which is within the endurance limits. Hence the design of gear and shafts is for infinite number of life cycles.

2.5 Hydraulic system

The base vehicle provided for this project is 4x4 5ton MAN Steyr truck. This truck is equipped with a hydraulic winch for recovery and other military purposes. This winch is operated by hydraulic pump which takes drive from power takeoff (PTO) of the vehicle. Its control valve is placed on the chassis of the truck. Hence to give power to the reduction gear assembly designed above we use the inbuilt hydraulic system with minor modifications. These modifications include following:-

a. Place the selector control valve inside the driver cabin, so that driver can select whether to lay or retrieve the track. This control valve is a 3-way control valve operated by a lever.

b. Place a pressure release valve in between the hydraulic motor and control valve to stop operation for safety beyond designated hydraulic pressure.
c. The hydraulic motor required to operate the launching assembly shall be low speed high torque bi-directional hydraulic motors with a speed range of 20-250 rpm and torque from 2000-3000 N.m.
d. A braking mechanism should be incorporated in between the hydraulic motor and reduction gear unit for safety. Spring loaded brakes to limit the rpm of the spool.
e. A manual way should be incorporated to drive the spool, in case of failure of hydraulic system.

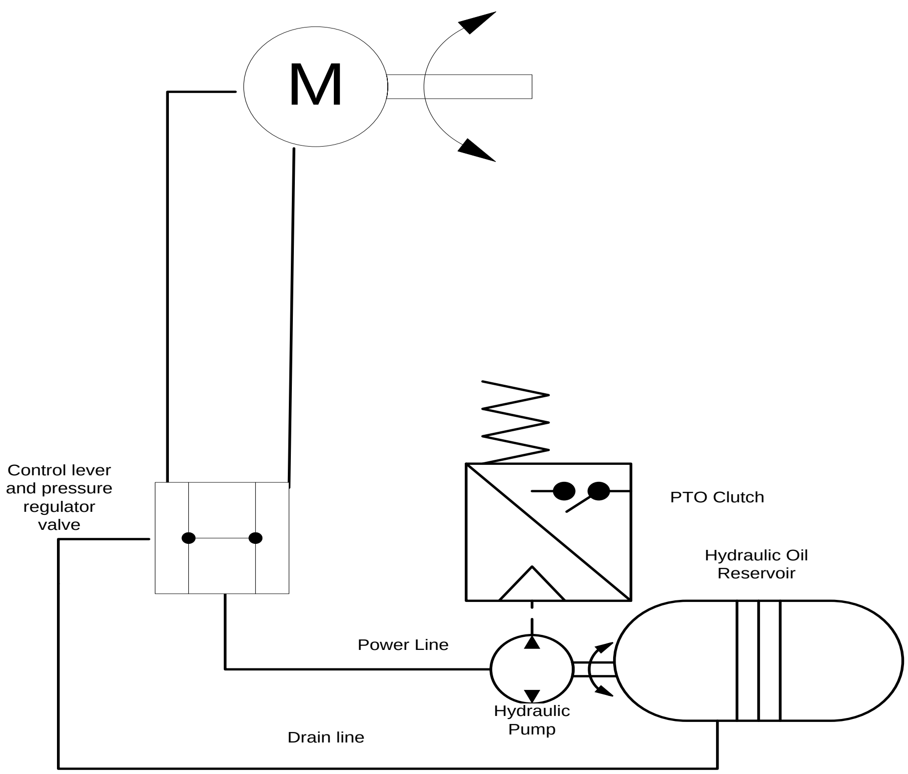


Figure 2.9 Hydraulic circuit diagram of launching assembly

2.5.1 Working of hydraulic system

The vehicle MAN Steyr is already equipped with a hydraulic winch which has following important components such as hydraulic tank and pump already installed. So therefore we place the 3-way selector valve inside driver’s cabin and connect it with the hydraulic pump. The hydraulic lines coming from pump going through the valve is connected with a bi-directional low speed high torque motor.

Hydraulic Motor is then connected with the reduction gear through a worm gear box. The reason for placing a worm gear box before pinion is to (1) increase mechanical advantage of system and (2) create means for manual handling of the system if hydraulic system becomes faulty. The manual system is operated by connecting a torque wrench in the slot available in worm gear box which will work in both clockwise and counter clockwise directions for laying or retrieving of the track-way.

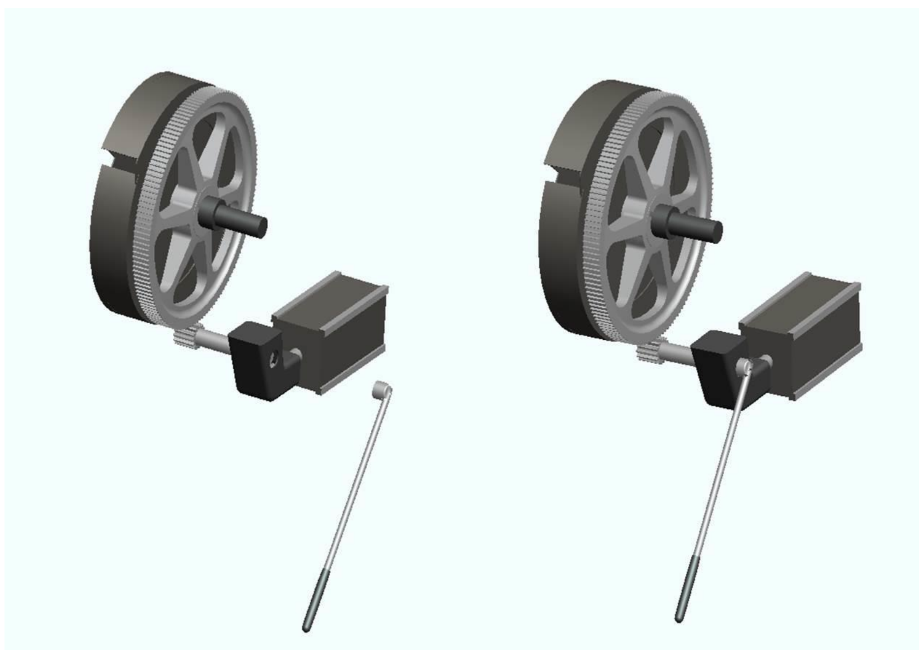


Figure 2.10 Isometric View of Manual Operation

2.6 CAD of complete system.

The complete system mounted on the truck has several components. The important components after a lot of deliberation are assembled together in Pro E to give a conceptual design of the final equipment and better understanding of its working.

Carrying position **Launching position**

Figure 2.11 Isometric view of complete vehicle

2.7 Materials

2.7.1 Materials for A-Frame

1. AISI-1025 (ASTM A29, SAE J403)

Composition	Mechanical Properties
Carbon, 0.22 - 0.28 % Manganese, 0.3 – 0.6 % Phosphorous, 0.040 % Sulfur, 0.050%	UTS, 460 - 510 MPa Yield Strength, 250-430 MPa Modulus of Elasticity, 210 GPa Bulk Modulus, 180 GPa Shear Modulus, 70 GPa

Table 2.4 Mechanical Properties of AISI-1025

Manufacturer and Suppliers

a. Model Steel Mills, Badami Bagh, Lahore

b. Peoples Steel Mills Ltd. Karachi

c. Fazal Steels I-9 Islamabad.

d. Global Steels, Gulberg Lahore

2. ASTM A-36 Steel (A-992)

A-36 steel is a structural billet steel for structural applications. The applicable thickness for A-36 steel grade as defined in the ASTM A36/A36M-08 starts from 10 mm to 60 mm.

Composition	Mechanical Properties
Carbon, 0.25 - 0.29 %	UTS, 400 - 550 MPa
Copper, 0.20 %	Yield Strength, 250 MPa
Manganese, 1.03 %	Modulus of Elasticity, 200 GPa
Phosphorous, < 0.040 %	Bulk Modulus, 160 GPa
Silicon, 0.28%	Bulk Modulus,79.3 GPa
Sulfur, 0.050%	

Table 2.5 Mechanical Properties of ASTM A-36 Steel

Manufacturer and Suppliers

a. Peoples Steel Mills Ltd. Karachi

b. Model Steel Mills, Badami Bagh, Lahore

c. Fazal Steels I-9 Islamabad.

d. Global Steels, Gulberg Lahore

In SS category 316 and 316L are also used for structural application. D-13 was also used for the same purpose. HSLA (High Strength low alloy) Steel is also used in construction.

2.7.2 Materials for Gears

1. AISI 4140

AISI 4140 grade is a low alloy steel which contains carbon, manganese, chromium and molybdenum. It is widely used in automotive industry for manufacturing of gear and engine construction, crankshafts, steering knuckles, connecting rods, spindles, intermediate gears, pumps and gear shafts. Normally heat treatment is not required.

Composition	Mechanical Properties
Carbon, 0.22 - 0.28 %	UTS, 780-850 MPa
Manganese, 0.8 %	Yield Strength, 480 MPa
Silicon, 0.2 %	Modulus of Elasticity, 210 GPa
Sulfur, 0.025 %	Izod Impact, 34
Chromium, 1.0 %	
Molybdenum, 0.2 %	

Table 2.6 Mechanical Properties of AISI 4140

Manufacturer and Suppliers

a. Millat Equipment Limited (MEL), Lahore
b. Pakistan Machine Tool Factory (Pvt) Ltd. Karachi
c. S.B Gears, Lahore

2. EN-24 (EN series)

It is Ni-Cr-Mo Steel commonly used for aircraft & automotive applications such as gears, crane shafts & heavy duty gear shaft in aircrafts & truck construction & mechanical engineering. No heat treatment is required.

3. AISI 8620 Alloy Steel

Best for gear applications, it is carburized for obtaining ultrahigh strength. This grade finds wide application in the automotive industry like ring gears, pinions, helical gears, bearing races, racks and worms.

Composition	**Mechanical Properties**
Carbon, 0.2 %	UTS, 1000 MPa
Manganese, 0.8 %	Yield Strength, 785 MPa
Silicon, 0.25 %	Modulus of Elasticity, 210 GPa
Nickle 0.55 %	Izod Impact, 41
Chromium, 0.5 %	
Molybdenum, 0.2 %	

Table 2.7 Mechanical Properties of AISI 8620 Alloy Steel

Other commonly used materials for gears are AISI 4340, 9310, 8822, 4820, 9310 and 135M.

2.7.3 Heat treatment of gear materials

a. Carburizing.

Common heat treatment practice for gear applications is Carburizing and hardening. It may also produce sever distortions and size changes, but these are to be overcome by subsequent machining. It is carried out in the presence of Rich carbon material like CO, sodium cyanide and barium carbonate etc. at 900 to 950 °C.

b. Nitriding.

It is carried out in the presence of Ammonia or Cyanide salt. It gives excellent hardening results. But it is time consuming because of relatively low temperature, therefore it is costly treatment. Not suitable for mass production.

c. Induction Hardening.

Heating is done by induction phenomenon, following by the quenching in the pre-defined medium and temperature. It is suitable for medium carbon steel. Volume production is possible but precision is cost effective. Its pre-requisite is core hardening.

CHAPTER – 3

OPERATION, MAINTENANCE & ADVANTAGES OF NEW SYSTEM

3.1 Working of New System

Now, working of this arrangement is such that the PTO drives the hydraulic pump, which in turns drives the hydraulic motor. Hydraulic motor runs the pinion of the reduction gear assembly. This pinion drives the spur gear which is bolted to the spool. In this way the torque is given to the spool, which can rotate in both clockwise and anti-clockwise direction. For this the motor used is bi-directional hydraulic motor. So that laying-out and retrieval both processes can be done.

3.1.1 Laying Process

In laying of track or unwinding process, first the launching assembly is moved perpendicular to vehicle manually by disconnecting the locking pins and rotating on turn table. Then harness is removed to set track free. The track is firstly unrolled from the spool through the hydraulic power which follows the guide roller assembly and comes near the rear tires of the vehicle. At this point hydraulic power is disconnected and the vehicle is moved in rearward direction by the driver and thus the track comes underneath the rear wheels. Here the speed of unwinding is controlled by the brake system incorporated on the reduction gear assemble which will serve as guidance for the driver to control the speed of laying. Skill of driver is required to match the speed of unwinding spool. The driver keeps the alignment of vehicle with the laying track by two means:-

a. By the fluorescent line marking on the track which serves as guide to keep the vehicle and track aligned.
b. Back view cameras with screen display inside the driver cabin.

When the complete track is laid the strings attached with spool and track is disconnected to free the track from spool.

3.1.2 Retrieval Process

In retrieval process, first the vehicle is moved on the track and put on neutral gear. The strings from spool are connected with the track. Now hydraulic motor is operated which starts rotating the spool, with the power of hydraulic system track starts rolling onto spool and moving the vehicle forward. Simultaneously the vehicle is moving forward and the track is being rolled on the spool. Here if any obstruction like rock comes underneath the track than the vehicle is moved in first gear to cross the obstruction and then again put in neutral to continue the process. When the complete track is rolled on spool it is secured by the harness. After this process the launching assembly is moved to its original location that is parallel to the vehicle body manually by rotating it on the turn table and securing it parallel to vehicle by means of locking pins.

3.2 Maintenance

1. **Definition**. All necessary work done to keep the machine into working condition is known as maintenance e.g changing of oil, lubrication, inspection, minor repairs, welding etc.

2. **Significance of Maintenance**
    a. To find out the small trouble and avoid serious trouble
    b. To get most efficient work from the machinery
    c. To get safety
    d. To extend the life of a machine
    e. To reduce the number of faults

3. **Steps of Maintenance**
    a. **Use clean washer fluid.** It is recommended that automobile window washer fluid is used without letting any dirt to get into it
    b. **Use of uncontaminated oil and grease.** Always ensure applying uncontaminated oil and grease. The containers of the oil and grease must also be clean for storage

c. **Ensure cleanliness of machine.** As our surroundings are very dusty, every effort should be made to keep the machine clean by keeping in particularly grease fittings, breathers and oil level gauges clean and avoiding foreign matters from getting into them.

d. **Be careful of hot water and oil.** Always allow engine to cool down before draining hot water and coolants. As draining these immediately after the engine stops can cause serious hazards.

e. **Inspection of foreign materials in drained oil and used filter.** Always check the drained oil and used filters for metallic particles or unwanted particles after changing them.

f. **Precautions for fuel strainer.** Do not remove fuel strainer while fueling.

g. **Oil change**. All oils must be changed in their due time or running is over as keeping the oil for long interval adversely effects the machine.

h. **Note Service meter readings.** Carry out inspection of service meter and note down its readings every day.

i. **Attach warning Sign.** The warnings sign must be placed at start / stop switch, so that no one can turn on / off the machine mistakenly.

j. **Adherence to precautions.** The precaution must be strictly adhered during the operating time of machine to avoid any untoward incident.

k. **Fire precaution.** Use nonflammable cleaner or light oil for cleaning parts. Keep flame or cigarette light away from light oil.

l. **Loose objects while operating.** The pockets must be free from any kind of loose objects, which may drop or fall onto the machinery during operation.

3.3 Advantages of new design

a. The new design has increase the mechanical advantage over its predecessor by introducing hydraulic assisted system.
b. It is simple and easy to operate and has eradicated considerably the manual handling and need of skillful operators.
c. The new system requires less amount of time to train the operator.
d. It is rearward laying of track supported by back-view cameras which has enhanced the visibility of the driver.
e. Only 2 member crew is now required to perform the task effectively.
f. The total time is reduced from 30 min to approximately 5 minutes.
g. Safety of crew members has increased due to less manual handling of system.
h. An alternate mechanism is incorporated which rotates the spool by mean of a torque wrench if hydraulic system or vehicle becomes faulty.

CHAPTER – 4

CONCLUSION AND RECOMMENDATIONS

Conclusion

This project is concerned with the conversion of winch operated mechanical system of assault track way assembly into hydraulic power systems. The existing mechanical system uses a front laying mechanism for laying of track. It is laborious and involves considerable amount of time and skill manpower for its operation. This design involves safety hazards and has caused injuries to crew members as well. The Army after its use for more than 2 decades has given the need to modify it as per the modern international track-way systems. The lead in conceptual design is taken from Faun track-ways, which are leading track-way developers in the world.

This project has resulted in an enhancement of the reliability and operating efficiency of the existing system. Improvements in the system are appended below:-

a. Laying and retrieval operations are now being carried out from the rear of vehicle instead of the front. So, driver's visibility has now increased.
b. Laying and retrieval operations are being automated by the use of a gear assembly being operated by a hydraulic motor. This hydraulic motors operated by the hydraulic pump; driven by the PTO of the vehicle.
c. We use a worm and a spur assembly. There is a possibility to use only spur assembly, but the purpose of worm assembly is to obtain high velocity ratio in less space and provide means for manual handling of system in case of hydraulic failure.
d. Hydraulic equipment such as hydraulic pump, hydraulic motor are able to provide a huge amount of power from a very small machine by using a hydraulic pressure.
e. The use of hydraulic system has resulted in less operation time.
f. The number of crew members has also been reduced as the operation is being carried out by the automated system.
g. Rear view camera and fluorescent marking on track will result in ease of operation for the driver and assist in alignment of the vehicle with the track.

h. The operation is made easy by giving the control lever in driver cabin for laying retrieving and braking of spool.

Recommendations

The future recommendation is to incorporate mechanical controls in the system. This will automate the process of laying and retrieving. The controls can be applied on limiting the minimum and maximum rpm of spool by automating the braking mechanism.

The use of auxiliary hand held control box (wired or wireless), on the outside of the driver's cabin. Whereby the crew member standing outside can override any mistake committed by the driver during the course of operation.

A complete reduction worm gear box can be used instead of spur and pinion gears. This will reduce the total weight on spool and require less amount of power to operate the system.

Project

First Saved	Sunday, June 05, 2016
Last Saved	Sunday, July 31, 2016
Product Version	15.0 Release
Save Project Before Solution	No
Save Project After Solution	No

Contents

Units

TABLE 1

Unit System	Metric (m, kg, N, s, V, A) Degrees rad/s Celsius
Angle	Degrees
Rotational Velocity	rad/s
Temperature	Celsius

Model (A4)

Geometry

TABLE 2
Model (A4) > Geometry

Object Name	*Geometry*
State	Fully Defined
Definition	
Source	D:\MS-DME 4\MS THESIS\RESULTS NEW\main shaft 130 mm.igs
Type	Iges
Length Unit	Meters
Element Control	Program Controlled
Display Style	Body Color
Bounding Box	
Length X	0.14 m
Length Y	5.198 m
Length Z	0.14 m
Properties	
Volume	7.5968e-002 m^3
Mass	596.35 kg
Scale Factor Value	1.
Statistics	
Bodies	1
Active Bodies	1
Nodes	733
Elements	300
Mesh Metric	None
Basic Geometry Options	
Solid Bodies	Yes
Surface Bodies	Yes
Line Bodies	No
Parameters	Yes
Parameter Key	DS
Attributes	No
Named Selections	No
Material Properties	No
Advanced Geometry Options	
Use Associativity	Yes

Coordinate Systems	No
Reader Mode Saves Updated File	No
Use Instances	Yes
Smart CAD Update	No
Compare Parts On Update	No
Attach File Via Temp File	Yes
Temporary Directory	C:\Users\STONE\AppData\Local\Temp
Analysis Type	3-D
Mixed Import Resolution	None
Decompose Disjoint Geometry	Yes
Enclosure and Symmetry Processing	Yes

TABLE 3
Model (A4) > Geometry > Parts

Object Name	*TRM_SRF*
State	Meshed
Graphics Properties	
Visible	Yes
Transparency	1
Definition	
Suppressed	No
Stiffness Behavior	Flexible
Coordinate System	Default Coordinate System
Reference Temperature	By Environment
Material	
Assignment	AISI 4140 Alloy Steel
Nonlinear Effects	Yes
Thermal Strain Effects	Yes
Bounding Box	
Length X	0.14 m
Length Y	5.198 m
Length Z	0.14 m
Properties	
Volume	7.5968e-002 m^3
Mass	596.35 kg
Centroid X	7.4496e-020 m
Centroid Y	-2.3824 m
Centroid Z	4.3983e-020 m
Moment of Inertia Ip1	1207.7 kg·m^2
Moment of Inertia Ip2	1.4062 kg·m^2
Moment of Inertia Ip3	1207.7 kg·m^2
Statistics	
Nodes	733
Elements	300
Mesh Metric	None

Coordinate Systems

TABLE 4
Model (A4) > Coordinate Systems > Coordinate System

Object Name	*Global Coordinate System*
State	Fully Defined
Definition	
Type	Cartesian
Coordinate System ID	0.
Origin	
Origin X	0. m
Origin Y	0. m
Origin Z	0. m
Directional Vectors	
X Axis Data	[1. 0. 0.]
Y Axis Data	[0. 1. 0.]
Z Axis Data	[0. 0. 1.]

Mesh

TABLE 5
Model (A4) > Mesh

Object Name	*Mesh*
State	Solved
Defaults	
Physics Preference	Mechanical
Relevance	0
Sizing	
Use Advanced Size Function	Off
Relevance Center	Coarse
Element Size	Default
Initial Size Seed	Active Assembly
Smoothing	Medium
Transition	Fast
Span Angle Center	Coarse
Minimum Edge Length	0.138230 m
Inflation	
Use Automatic Inflation	None
Inflation Option	Smooth Transition
Transition Ratio	0.272
Maximum Layers	5
Growth Rate	1.2
Inflation Algorithm	Pre
View Advanced Options	No
Patch Conforming Options	
Triangle Surface Mesher	Program Controlled
Patch Independent Options	
Topology Checking	Yes
Advanced	

Number of CPUs for Parallel Part Meshing	Program Controlled
Shape Checking	Standard Mechanical
Element Midside Nodes	Program Controlled
Straight Sided Elements	No
Number of Retries	Default (4)
Extra Retries For Assembly	Yes
Rigid Body Behavior	Dimensionally Reduced
Mesh Morphing	Disabled
Defeaturing	
Pinch Tolerance	Please Define
Generate Pinch on Refresh	No
Automatic Mesh Based Defeaturing	On
Defeaturing Tolerance	Default
Statistics	
Nodes	733
Elements	300
Mesh Metric	None

Static Structural (A5)

TABLE 6
Model (A4) > Analysis

Object Name	*Static Structural (A5)*
State	Solved
Definition	
Physics Type	Structural
Analysis Type	Static Structural
Solver Target	Mechanical APDL
Options	
Environment Temperature	22. °C
Generate Input Only	No

TABLE 7
Model (A4) > Static Structural (A5) > Analysis Settings

Object Name	*Analysis Settings*
State	Fully Defined
Step Controls	
Number Of Steps	1.
Current Step Number	1.
Step End Time	1. s
Auto Time Stepping	Program Controlled
Solver Controls	
Solver Type	Program Controlled
Weak Springs	Program Controlled
Restart Controls	

Generate Restart Points	Program Controlled
Retain Files After Full Solve	No
Nonlinear Controls	
Newton-Raphson Option	Program Controlled
Force Convergence	Program Controlled
Moment Convergence	Program Controlled
Displacement Convergence	Program Controlled
Rotation Convergence	Program Controlled
Line Search	Program Controlled
Stabilization	Off
Output Controls	
Stress	Yes
Strain	Yes
Nodal Forces	No
Contact Miscellaneous	No
General Miscellaneous	No
Store Results At	All Time Points
Analysis Data Management	
Solver Files Directory	D:\MS-DME 4\MS THESIS\RESULTS NEW\main shaft 130 mm\AISI 4140_files\dp0\SYS\MECH\
Future Analysis	None
Scratch Solver Files Directory	
Save MAPDL db	No
Delete Unneeded Files	Yes
Nonlinear Solution	No
Solver Units	Active System
Solver Unit System	mks

FIGURE 1
Model (A4) > Static Structural (A5) > Analysis Settings

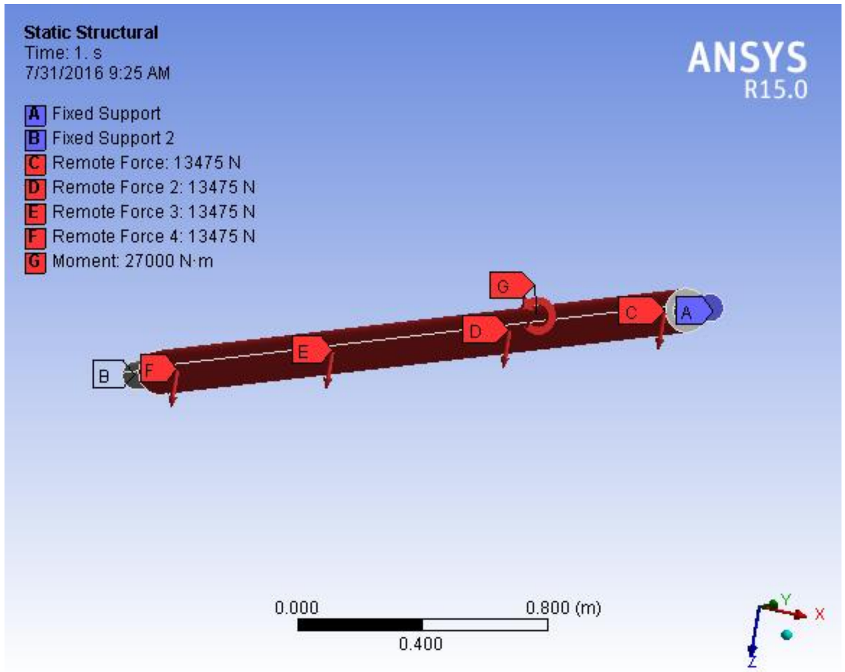


TABLE 8
Model (A4) > Static Structural (A5) > Loads

Object Name	*Fixed Support*	*Fixed Support 2*	*Remote Force*	*Remote Force 2*	*Remote Force 3*	*Remote Force 4*	*Moment*
State	Fully Defined						
Scope							
Scoping Method	Geometry Selection						
Geometry	1 Face		2 Faces				
Coordinate System			Global Coordinate System				
X Coordinate			0. m				
Y Coordinate			-0.2 m	-1.6 m	-3.2 m	-4.6 m	
Z Coordinate			0. m				
Location			Defined				
Definition							
Type	Fixed Support		Remote Force				Moment
Suppressed	No						
Define By			Components				
X Component			0. N (ramped)				0. N·m (ramped)
Y Component			0. N (ramped)				27000 N·m (ramped)
Z Component			13475 N (ramped)				0. N·m (ramped)
Behavior			Deformable				

Coordinate System		Global Coordinate System
Advanced		
Pinball Region		All

FIGURE 1
Model (A4) > Static Structural (A5) > Remote Force

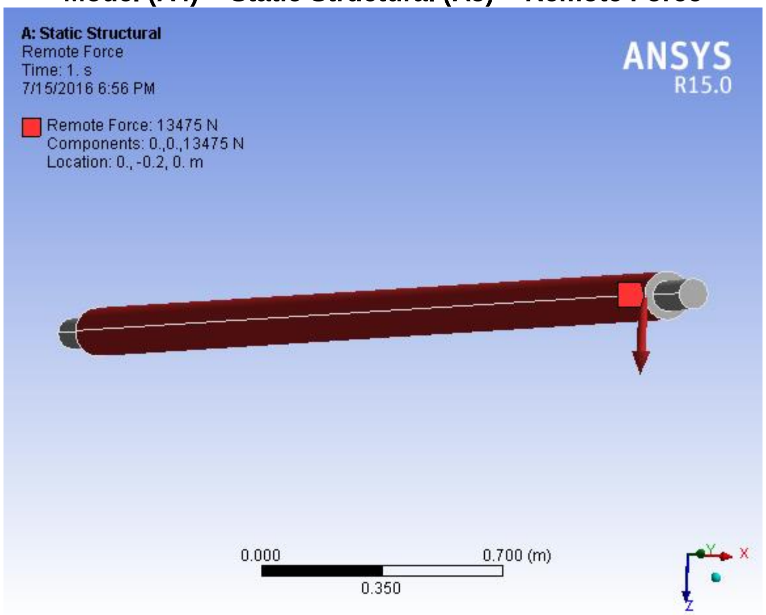


FIGURE 2
Model (A4) > Static Structural (A5) > Remote Force 2

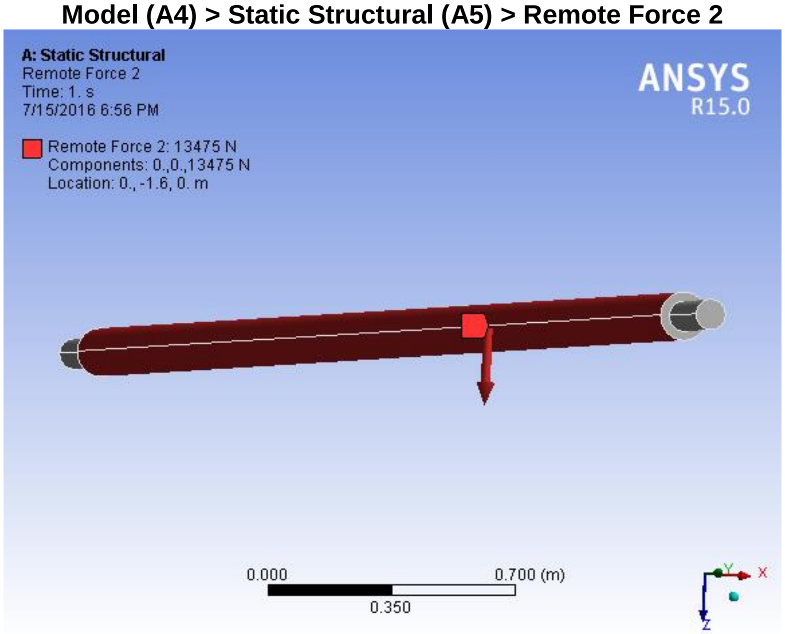


FIGURE 3
Model (A4) > Static Structural (A5) > Remote Force 3

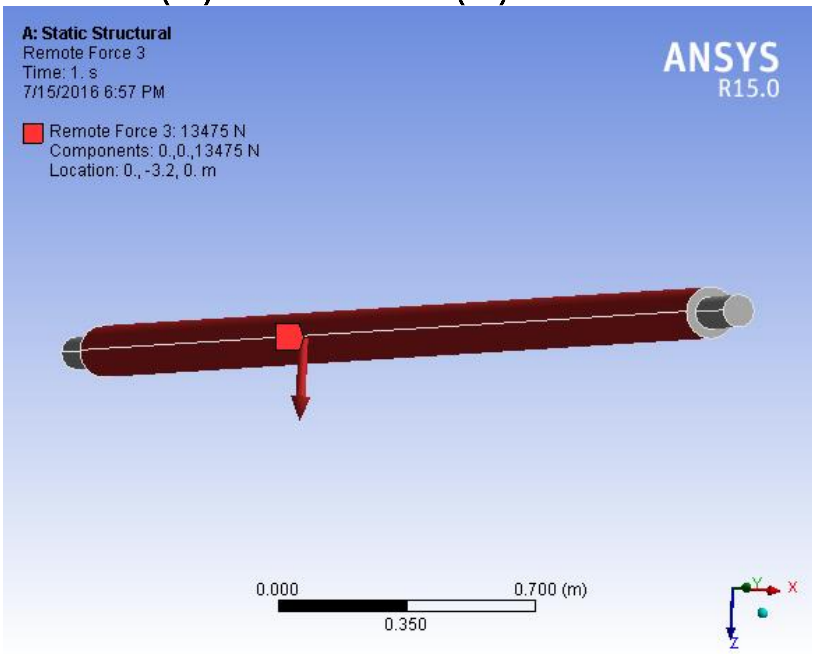


FIGURE 4
Model (A4) > Static Structural (A5) > Remote Force 4

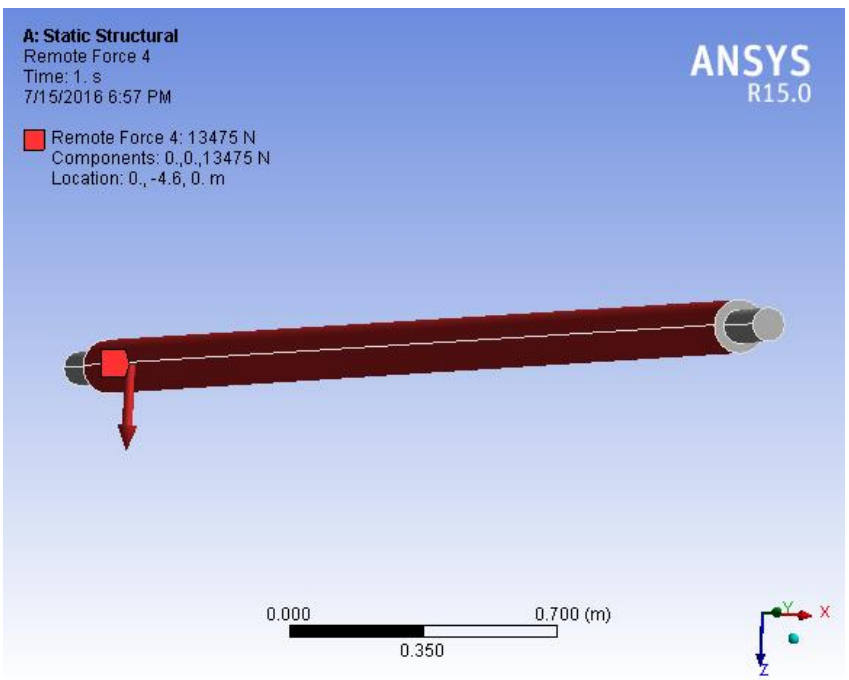
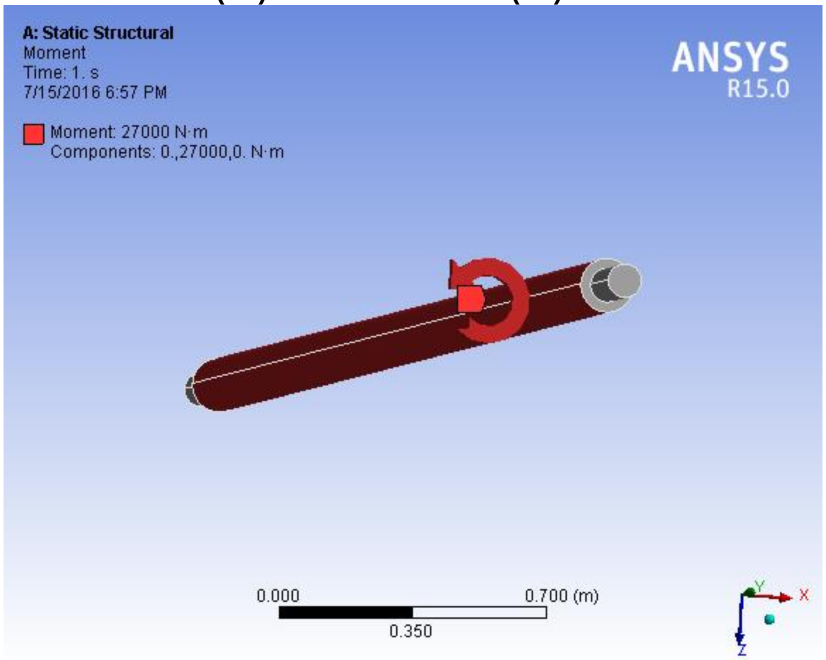


FIGURE 5
Model (A4) > Static Structural (A5) > Moment



Solution (A6)

TABLE 9
Model (A4) > Static Structural (A5) > Solution

Object Name	*Solution (A6)*
State	Solved
Adaptive Mesh Refinement	
Max Refinement Loops	1.
Refinement Depth	2.
Information	
Status	Done

TABLE 10
Model (A4) > Static Structural (A5) > Solution (A6) > Solution Information

Object Name	*Solution Information*
State	Solved
Solution Information	
Solution Output	Solver Output
Newton-Raphson Residuals	0
Update Interval	2.5 s
Display Points	All
FE Connection Visibility	
Activate Visibility	Yes
Display	All FE Connectors
Draw Connections Attached To	All Nodes
Line Color	Connection Type
Visible on Results	No

Line Thickness	Single
Display Type	Lines

TABLE 11
Model (A4) > Static Structural (A5) > Solution (A6) > Results

Object Name	*Total Deformation*	*Equivalent Stress*	*Equivalent Elastic Strain*	*Strain Energy*
State	Solved			
Scope				
Scoping Method	Geometry Selection			
Geometry	All Bodies			
Definition				
Type	Total Deformation	Equivalent (von-Mises) Stress	Equivalent Elastic Strain	Strain Energy
By	Time			
Display Time	Last			
Calculate Time History	Yes			
Identifier				
Suppressed	No			
Results				
Minimum	0. m	9.7466e+005 Pa	4.5795e-005 m/m	2.0534e-002 J
Maximum	1.1557e-002 m	3.0787e+008 Pa	1.4959e-003 m/m	4.8501 J
Minimum Value Over Time				
Minimum	0. m	9.7466e+005 Pa	4.5795e-005 m/m	2.0534e-002 J
Maximum	0. m	9.7466e+005 Pa	4.5795e-005 m/m	2.0534e-002 J
Maximum Value Over Time				
Minimum	1.1557e-002 m	3.0787e+008 Pa	1.4959e-003 m/m	4.8501 J
Maximum	1.1557e-002 m	3.0787e+008 Pa	1.4959e-003 m/m	4.8501 J
Information				
Time	1. s			
Load Step	1			
Substep	1			
Iteration Number	1			
Integration Point Results				
Display Option		Averaged		
Average Across Bodies		No		

FIGURE 6
Model (A4) > Static Structural (A5) > Solution (A6) > Total deformation

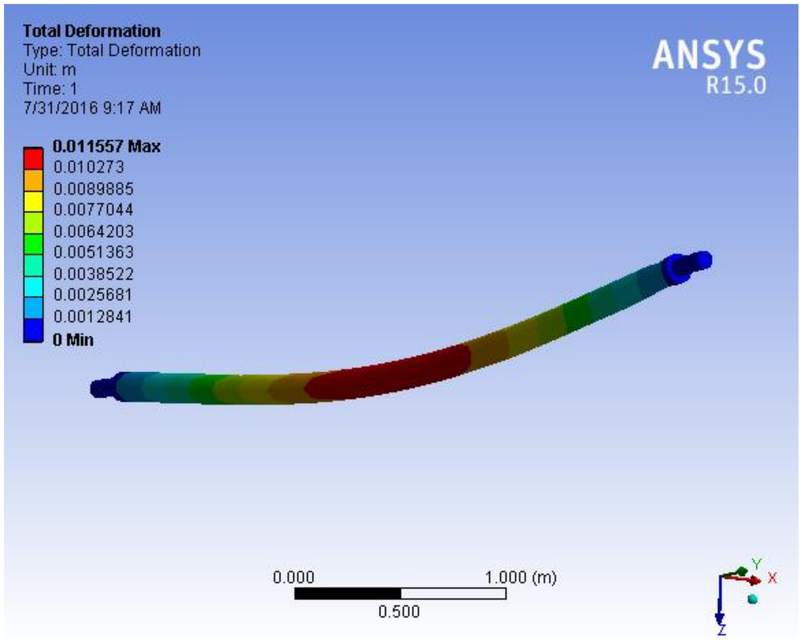


FIGURE 7
Model (A4) > Static Structural (A5) > Solution (A6) > Equivalent von misses stress

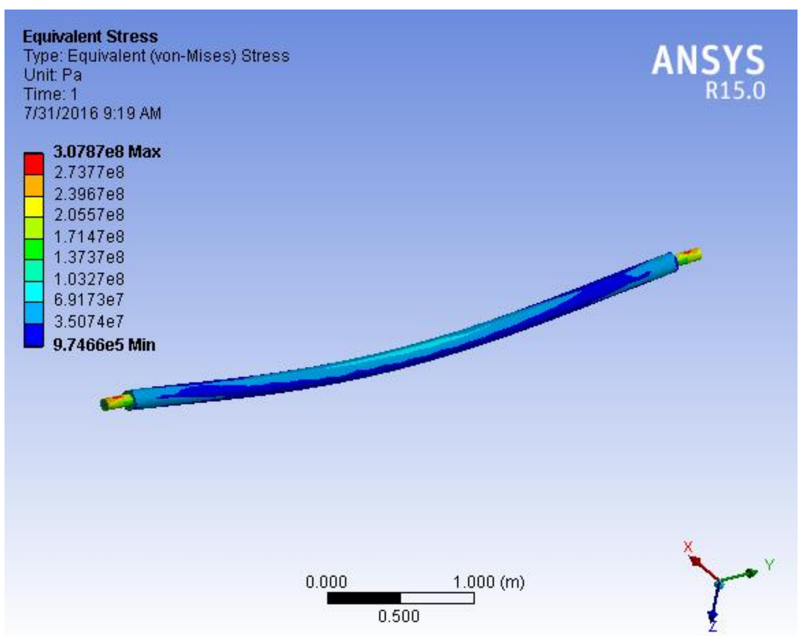


FIGURE 8
Model (A4) > Static Structural (A5) > Solution (A6) > Elastic Strain

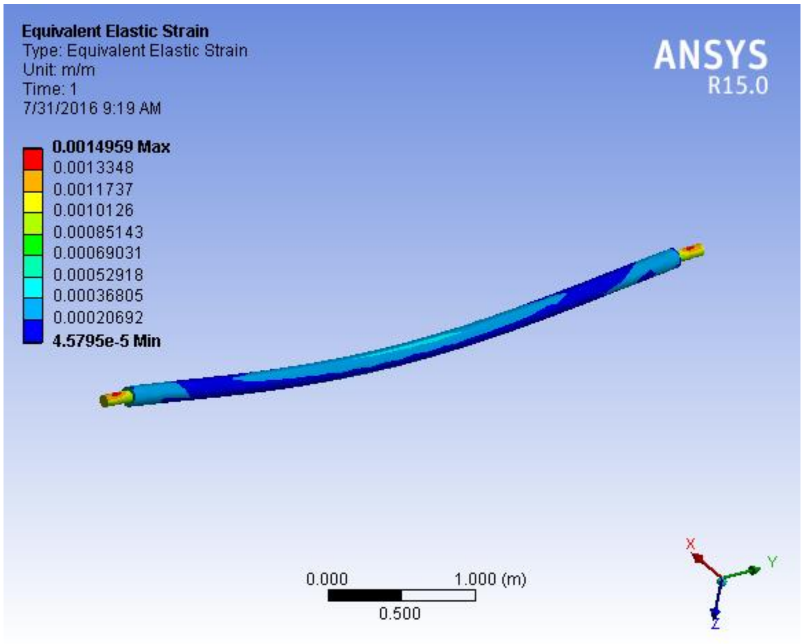
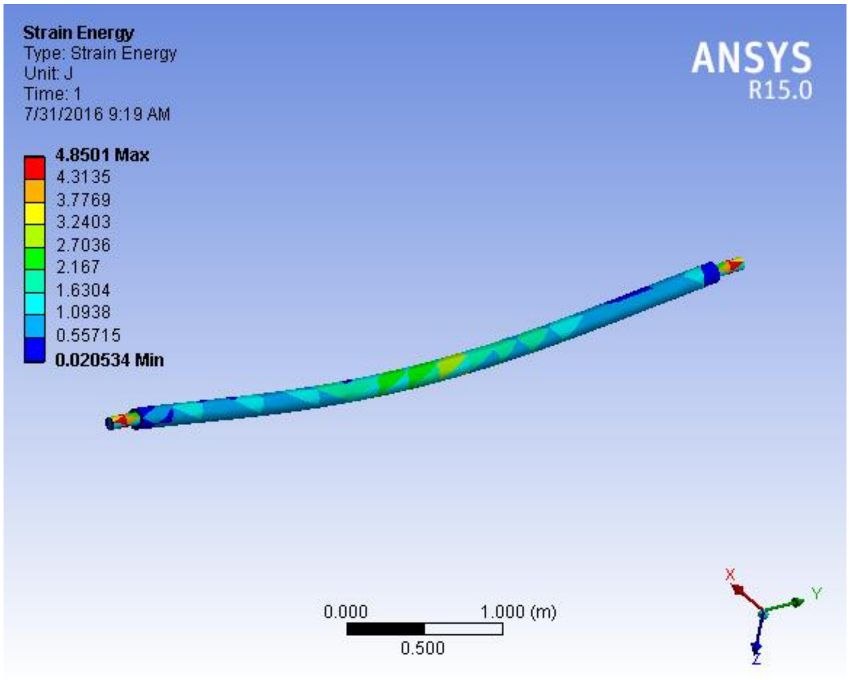


FIGURE 9
Model (A4) > Static Structural (A5) > Solution (A6) > Strain Energy



Material Data

AISI 4140 Alloy Steel

TABLE 12
AISI 4140 Alloy Steel > Constants

Density	7850 kg m^-3
Coefficient of Thermal Expansion	1.1e-005 C^-1
Specific Heat	447 J kg^-1 C^-1
Thermal Conductivity	52 W m^-1 C^-1
Resistivity	9.6e-008 ohm m

TABLE 13
AISI 4140 Alloy Steel > Compressive Ultimate Strength

Compressive Ultimate Strength Pa
7.85e+008

TABLE 14
AISI 4140 Alloy Steel > Compressive Yield Strength

Compressive Yield Strength Pa
4.8e+008

TABLE 15
AISI 4140 Alloy Steel > Tensile Yield Strength

Tensile Yield Strength Pa
4.8e+008

TABLE 16
AISI 4140 Alloy Steel > Tensile Ultimate Strength

Tensile Ultimate Strength Pa
7.85e+008

TABLE 17
AISI 4140 Alloy Steel > Isotropic Secant Coefficient of Thermal Expansion

Reference Temperature C
35

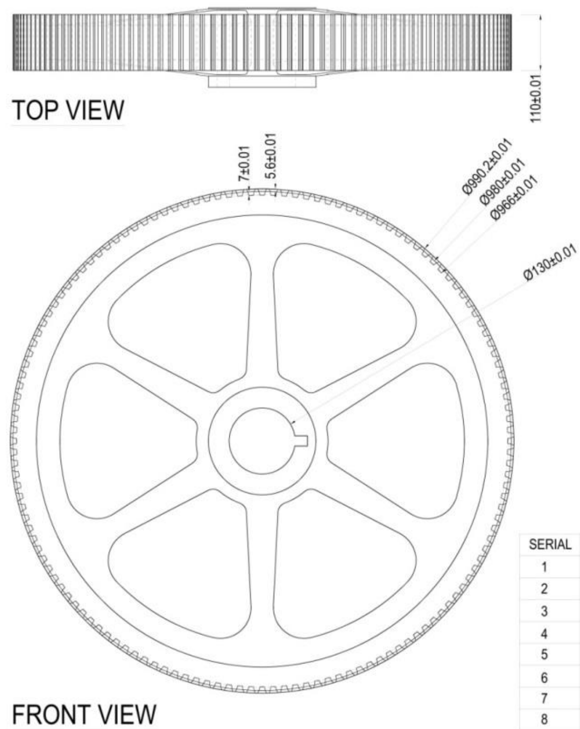
TABLE 18
AISI 4140 Alloy Steel > Isotropic Elasticity

Temperature C	Young's Modulus Pa	Poisson's Ratio	Bulk Modulus Pa	Shear Modulus Pa
	2.1e+011	0.3	1.75e+011	8.0769e+010

TABLE 19
AISI 4140 Alloy Steel > Isotropic Relative Permeability

Relative Permeability
10000

Appendix 2



TOLERANCE	UNLESS OTHERWISE SPECIFIED				
> 7	> 30	> 120	> 315	> 1000	> 2000
< 30	< 120	< 315	< 1000	< 2000	< 4000
± 0.5	± 0.8	± 1.2	± 2	± 3	± 4

ANGULAR	0-10	> 10-50	> 50-120	> 120
	± 2°	± 60'	± 40'	± 20'

SPUR GEAR

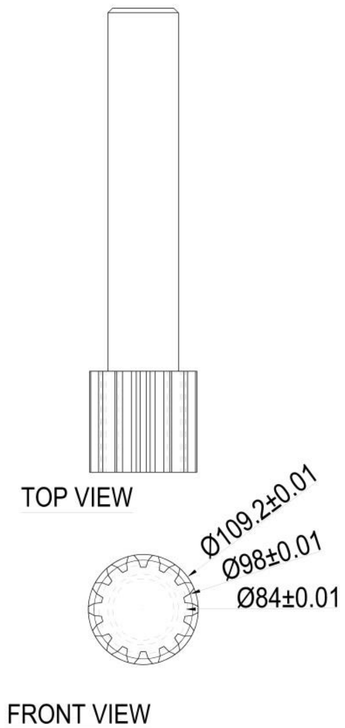
SERIAL	PARAMETER	SPUR GEAR	SERIAL	PARAMETER	SPUR GEAR
1	PITCH CIRCLE DIA	980 mm	10	NO OF TEETHS	140
2	OUTER CIRCLE DIA	990.2 mm	11	DIA OF SHAFT	130 mm
3	ROOT CIRCLE DIA	966 mm	12	MODULE	7
4	ADDENDUM	5.6 mm	13	CIRCULAR PITCH	22 mm
5	DEDDENDUM	7 mm	14	FACE WIDTH	110 mm
6	WORKING DEPTH	11.2 mm	15	PRESSURE ANGLE	20°
7	TOTAL DEPTH	12.6 mm	16	TORQUE	26.95 KN.m
8	CLEARANCE	1.4 mm	17	PITCH LINE VELOCITY	0.26 m/s
9	TOOTH THICKNESS	11 mm			

<u>**Appendix 3**</u>

TOLERANCE UNLESS OTHERWISE SPECIFIED

	> 7	> 30	> 120	> 315	> 1000	> 2000
	< 30	< 120	< 315	< 1000	< 2000	< 4000
	± 0.5	± 0.8	± 1.2	± 2	± 3	± 4

ANGULAR	0-10	> 10-50	> 50-120	> 120
	± 2°	± 60'	± 40'	± 20'



SPUR GEAR

SERIAL	PARAMETER	SPUR GEAR	SERIAL	PARAMETER	SPUR GEAR
1	PITCH CIRCLE DIA	980 mm	10	NO OF TEETHS	140
2	OUTER CIRCLE DIA	990.2 mm	11	DIA OF SHAFT	130 mm
3	ROOT CIRCLE DIA	966 mm	12	MODULE	7
4	ADDENDUM	5.6 mm	13	CIRCULAR PITCH	22 mm
5	DEDDENDUM	7 mm	14	FACE WIDTH	110 mm
6	WORKING DEPTH	11.2 mm	15	PRESSURE ANGLE	20°
7	TOTAL DEPTH	12.6 mm	16	TORQUE	26.95 KN.m
8	CLEARANCE	1.4 mm	17	PITCH LINE VELOCITY	0.26 m/s
9	TOOTH THICKNESS	11 mm			