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Design Optimization and Installation of Induction Furnace Over Oil Fired Furnace

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Abstract— By installing the induction furnace in place oil fired furnace the productivity increased and production cost is decreased. Due to high cost saving its payback period is very short. Optimization of induction furnace is done carefully in area of billet feeding. The stress given on to minimize the human labor and to gain more automation. While designing various components economy, compactness, cost reduction and weight reduction are kept in mind. Cost estimation of each component done suitably. In the end cost analysis done between oil fired and induction furnaces in order to observe differences obtained in production cost and productivity.

Index Terms— Automatic Billet Feeder, Cost Analysis, Cost Estimation, Design, Induction Furnace, Installation, Oil Fired Furnace, Optimization.

1. Introduction

The induction furnaces are more beneficial than the oil fired furnaces. So is necessary to design, optimize and install the induction furnace over the oil fired furnace in order to gain more efficiency. In this paper we have designed automatic billet feeder system for the optimization of the induction furnace. By using the automatic billet feeder system the quantity of human workers can be minimized also it contributes towards to increased productivity with time savings. The automation can be increased by adapting the automatic billet system.

2. Problem statements

Following are the problems in oil fired furnace as compared to the induction furnace-

1. High initial startup time.
2. More cycle time and less productivity.
3. Temperature cannot control precisely.
4. Effects on material properties.
5. Non-uniform flame distribution.
6. Oxidation of metal, scale formation.
7. Carbon loss of metals and emission of pollutants. Etc.

To overcome all these problems the induction furnace should be used in place of oil fired furnaces. They shold be designed, optimized and installed properly inorder to reduce production cost and increase productivity.

3. Design of various components

Density (ρ) =7850 kg/m^3

3.1 Design of Drum:-

Material C45

ρ (Density) =7850 kg/m^3
S_{ut} (Tensile Strength =600 N/mm^2
S_{yt} (Yield Strength) = 380 N/mm^2

BHN (Brinell hardness number) = 145

3.1.1 Load Calculations

1. Mass of cylinder:-
L (Length of sheet) =1000 mm
h (Thickness of sheet)=5 mm
b (Width Of Sheet) = 2016.9 mm
t (Thickness of plate)=10 mm
d (Outer diameter of drum shaft) =642mm
V_1 = Volume of Cylinder
$V_1=L\times b\times h=0.01m^3$
$m_1=V_1\times\rho=79.16$ kg
$m_1=79.16$ kg

2. Mass of pipes (24 pipes):-
Weight of pipe/m=8.10 kg
Total weight of pipe (m_2) =8.10×24
$m_2=194.4$ kg

3. Mass of plates (forward and backward):-
$V_3=(\pi/4\times L\times d^2)-(\pi/4\times L\times 24\times d_h^2)$
V_3 = Volume of Plates
d_h = Diameter of plates (Total no of plates = 24)
$V_3=(3.14/4\times 10\times 642^2)-(3.14/4\times 10\times 24\times 73^2)$
$=2.2326\times 10^{-3}\ m^3$
$m_3=V_3\times\rho$
$m_3=17.526$ kg

4. Mass of drum shaft:-
Mass (m_4) =V×ρ
=6.9115×10-3×7850
$m_4=54.25$ kg

5. Mass of ring gear (approximate):-
Mass (m_5) =V×ρ
$=4.41\times 10^{-3}\times 7850$
$m_5=34.62$ kg

6. Load:-
Mass of 1 billet=3 kg
Total no of billets can be loaded=144
Mass of 144 billets=144×3
m_6 =432kg

7. Total mass of system in loaded condition or working load:-
$m=m_1+m_2+m_3+m_4+m_5+m_6$
=79.16+194.4+17.526+54.25+34.62+432

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m=830 kg
As, Weight (W) =mg
=830×9.81
W=8136.7 N
8. Torque requirement:-
T (Torque) =W×r
Where w = load acting on system.
r = pitch circle radius of ring gear.
T = 8136.7×0.321
=2611.88 N-m

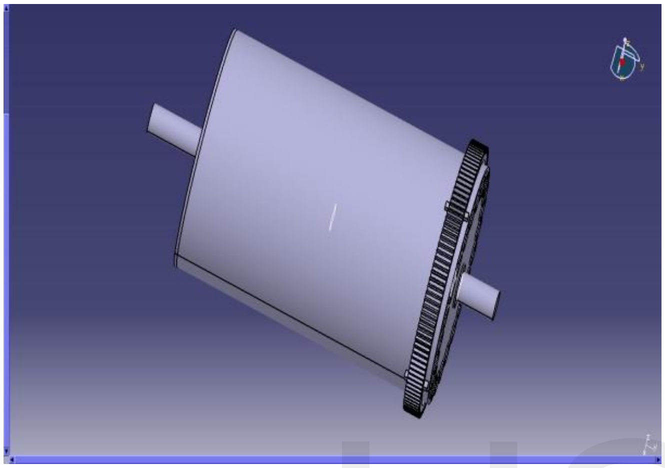

Fig. 1 (Drum)

3.2 Design of Cover Plate:-
Material C45
ρ =7850 kg/m^3
S_{ut}=600 N/mm^2
S_{yt}=380 N/mm^2
B.H.N. =145
Dimensions-
PCR (Pitch circle radius) =277.721 mm
OD (Outer diameter) =642mm
Thickness of plate= 10mm
Internal diameter=80mm
Diameter of slots=75mm
No. of slot = 1

3.3 Design of Drum shaft:-
d (Outer diameter of the shaft)=642mm
d_g (Diameter of gear)=720mm
G (gear ratio) =6
L (Length of the shaft) =1000 mm
W (Total weight) =8×10^3 N
V (Speed) =8.33m/s
τ_s (Shear stress)=50 N/mm^2
σ_t (Tensile stress)=115 N/mm^2
k_b (Load correction factor)=2
k_t (Theoretical stress concentration factor)=1.5
ϕ=20°
F_t (Tangential force) =7255 N
F_r (Radial force) = 2640.60 N
F (Resultant force) = 720060 N
M (Maximum bending moment on shaft) =1158.81 N-mm
T_e (Equivalent torque) =4551.16×10^3 N-mm
Me (Equivalent bending moment) =3434.39×10^3 N-mm
By maximum shear stress theory
$\tau_{max}=16T_e/\pi d^3$
$50=16\times4551.16\times10^3/\pi d^3$
d=77.39mm
By maximum principal stress theory.
$\sigma_{tmax}=32M_e/\pi d^3$
$115=32\times3434.39\times10^3/\pi d^3$
d=61.55mm
From above equations greater value is selected.
d=77.39mm
Take d=80mm
Material selection.
Alloy steel 50Cr1V23
S_{ut}=190-240 kgf/mm^2
S_{yt}=180 kgf/mm^2
BHN=500-580

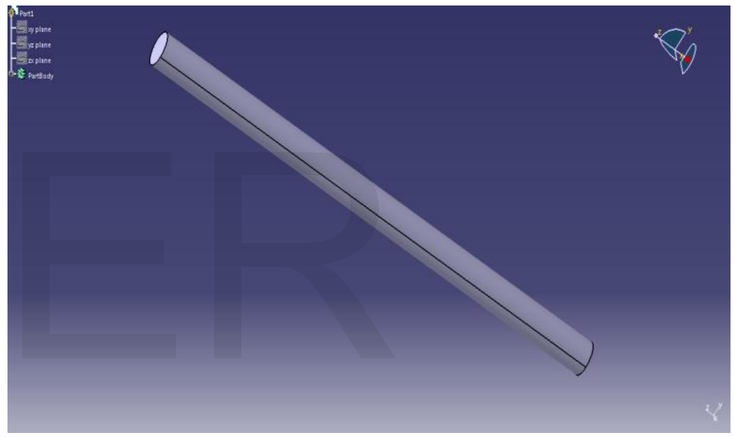

Fig. 2 (Drum Shaft)

3.4 Design of Ring Gear and Pinion
T (Torque) =2611.88 N-m
N=100rpm
M (Module) =6mm
Z_p (Number of teeth on pinion) =20
Z_g (Number of teeth on gear) =120
P (Power) =7500 W
N_f=1.5
ϕ (Pressure angle) =20°
e (Tooth error)=15×10-3mm
c (Dynamic factor)=11400e
Material selected C45.
S_{ut}=600 N/mm^2
S_{yt}=380 N/mm^2
BHN=460

Effective load
V (Speed) = 0.628 m/s
F_t (Tangential load) = P/V =11936.62 N
C=11400e =11400×15×10^{-3}

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C=171 N / mm

$F_{t(max)}= k_a.k_m.F_t$

$=1\times1\times11936.62 =11936.62$ N

F_d (Dynamic load) =1805.038 N

$F_{eff}=k_a.k_m.F_t+F_d$

$=1 \times1\times11936.62+1805.038$

=13741.658N

Beam strength.

As both gear and pinion are made of some material, pinion is weaker than gear in bending .Hence it is necessary to calculate the beam strength of pinion teeth.

$Y_p= 0.484-(2.87 / Z_p)$

$Y_p=0.3405$

$\sigma_b= S_{ut} / 3 =600 / 3$

=200 N / mm^2

$F_b=\sigma_b\times b\times m\times y_p$

$=200\times60\times6\times0.3405$

$F_b=24516$ N

The factor of safety available against bending failure is given by

$N_{fb}=F_b / F_{eff}$

=24516 / 13741.658 =1.784

Since available factor of safety is greater than required therefore design is safe against bending failure.Thus material selected C45 (S_{ut}=600N / mm2 BHN=460) is suitable for design.

Dimension of gear pair.

m (Module)=6mm

Z_p (Number of teeth on pinion) =20

Z_g (Number of teeth on gear) =120

b (Face width)=10×M=10×6=60mm

d_p (Diameter of pinion)=$m\times Z_p=6\times20=120$mm

d_g (Diameter of gear)=$m\times Z_g=6\times120=720$mm

a (Centre distance)=$(d_p+d_g) / 2=420$mm

h_a (Addendum)=6mm

h_f (Dedendum)=1.25×m=7.5mm

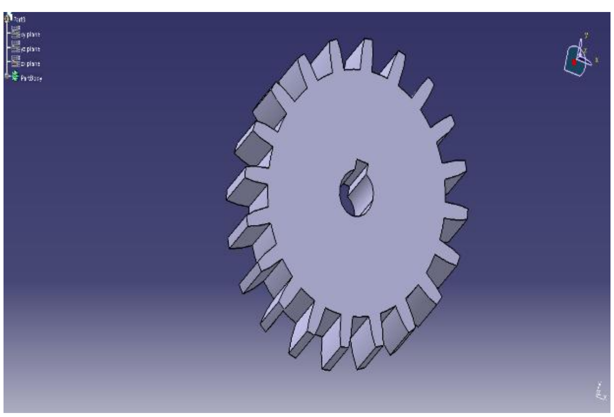

Fig. 3 (Pinion)

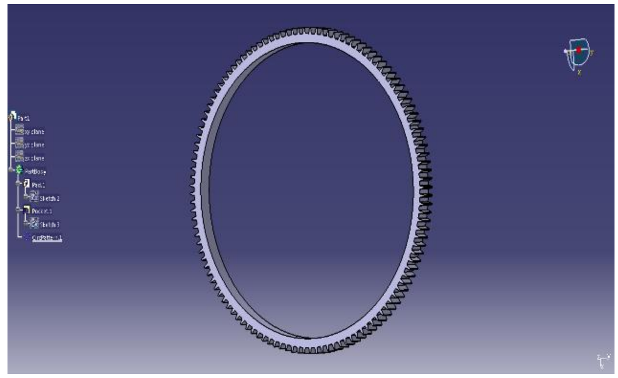

Fig. 4 (Ring Gear)

3.5 Design of Pinion Shaft

Material C45

S_{ut}=600N / mm^2

S_{yt}=600N / mm^2

$K_b=1.5$, $K_t=1$, $N_f=1.5$

$\sigma_{all} =S_{yt} / N_f$

=600 / 1.5 =400N / mm^2

σ_{all} =400 N / mm^2

$\tau_{all}=0.55\ S_{ut} / N_f$

$=0.55\times600 / 1.5$

=200N / mm^2

τ_{all}=200N / mm^2

Maximum bending of shaft.

M=FL / 4 =8188.95×380 / 4

M=777.95×10^3 N-mm

Equivalent torque on shaft.

$T_e=3054.26\times10^3$N-mm

$M_e=2305.08\times10^3$N-mm

Design of shaft by Max-shear stress theory.

$\tau_{max} =16T_e/\pi d^3$

$200=16\times3054.20\times103 / (\pi d^3)$

d=43.26mm

Design of shaft by maximum principle stress theory.

$\sigma_c=32M_e / (\pi d^3)$

$400=32\times2305.08\times103 / (\pi d^3)$

d=30.06mm

Taking larger value from above two equations.

d=45mm

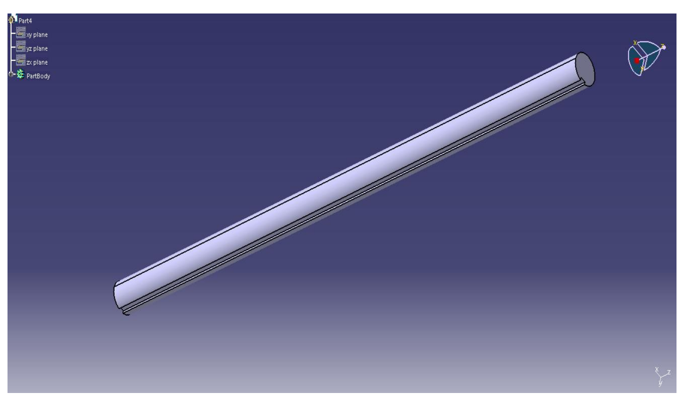

Fig. 5 (Pinion Shaft)

3.6 Design of Square Key:-

As, d=45mm
N_f=1.5
Material C45
S_{yt}=600N / mm^2
S_{ut}=600N / mm^2
W=h=d / 4=45 / 4
=11.25
Taking w=h=12mm
$\tau_{all}=0.5\times S_{ut} / N_f$
= (0.5×600) / 1.5
=200 N / mm^2
$\sigma_c = S_{yt} / N_f$
=400 N / mm²

Crushing of key:-
Considering Crushing of key
L=46.735mm
Shearing of key
L=48.68mm
Taking larger of above equations.
L=48.68mm
Taking L=50mm
Dimensions of key.
w=13mm
h=13mm
l=50mm
Quantity=5(nos)

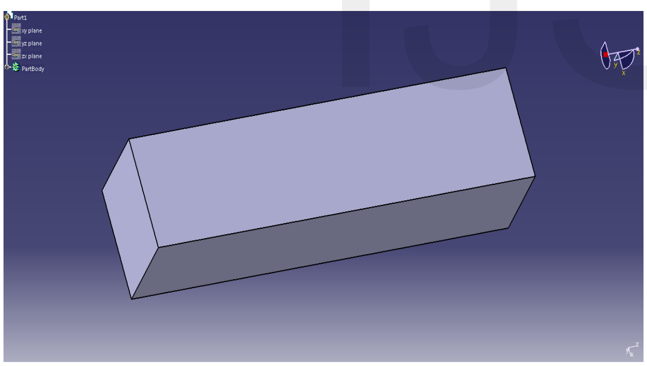

Fig. 6 (Square key)

3.7 Selection of Bearings:-

1) For drum shaft

Given data, d=80mm
Load=830 kg
Weight=3727.8 N
Axial load (F_a) =3727.8×sin45^0 =2396.18N
Radial load (F_r) =3727.8× cos40^0=2855.7 N
Bearing life in hours (Lh10) =8000 hrs. (From catalog based on application).
N=100rpm
Type- taper roller bearing
For taper roller bearing (from catalogue)
X=0.4
Y=0
Load factor (ka) =1.2
Equivalent dynamic load.
$P_e=F_r\times k_a$
=3426.8N
L_{10}=48 million revolutions.
C=10946.14N
From catalogue bearing available with 60mm bore diameter are:-

Bearing no	Basic dynamic capacity (kN)	Outer diameter (mm)	Width (B) (mm)
30215	99	110	23.75
32212	125	110	29.75
30312	168	130	33.5
32312	229	130	48.5

Table No 1 (Bearings for drum shaft)

So, bearing no. 30215 is most economic for our application therefore bearing no. 30215 is selected.
Quantity= 2(nos).

2) For Pinion Shaft

Type –taper roller bearing
Axial load (Fa) =2396.18N
Radial load (Fr) =2855.7 N
Bearing life in hrs. =8000 hrs (from catalogue based on application)
L_{10}=48 million revolutions.
C=10.946kN
From catalogue bearing available with 50mm bore diameter for calculated dynamic load are

Bearing no.	Basic dynamic capacity (C), kN	Outer diameter (mm)	Width "B" (mm)
30210	76.5	90	21.75
32210	82.5	90	24.75
30310	12.5	110	29.75
32310	172	110	42.25

Table No 2 (Bearings for pinion shaft)

Bearing no. 30210 is most economical and suitable for our application.
Therefore bearing no. 30210 is selected for system
Quantity=2(nos)

3.8 Material for Base Plate:-

Cast iron
ISI grade-GCI 20
Overseas nearest equivalent= DIN 1691 / GG22
Tensile strength=200 N / mm^2 (minimum)
BHN=179-223
Bending stress=3kgf / mm2
Pressure=10 kgf / cm^2

3.9 Slope of Drum / Inclination Angle of Drum:-

Material of pipe=Mild steel

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μ=static / kinetic friction co-efficient
μ=0.61(For mild steel)
We know that.
$\theta=\tan(0.61)=31.38^0$
Taking $\theta=40^0$

3.10 Specifications of Motor:-

Type-stepper motor [6].
Type code=ACS550-01-031A-2
Frame size=R2
Number of steps=24.
Power (Pn) =7.5kW or 10 hp
Current (I) = 31 A
Electronic equipments like controller (8051) and photo sensor may be used in system for positioning purpose.

3.11 Complete Assembly:-

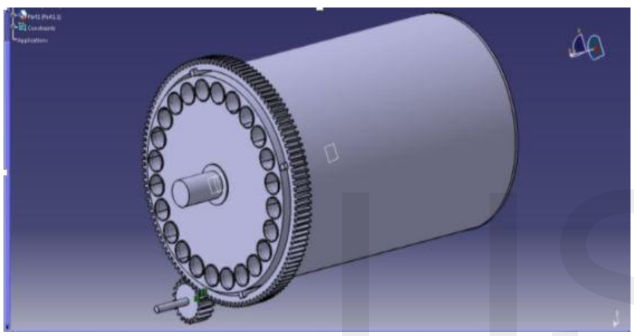

Fig. 7 (Drum Assembly)

4 CONSTRUCTION AND WORKING

1) Mount drum assembly on frame in inclined position
2) Place small frame in front and large frame at rear
3) Mount drum assembly in such a way that ring gear comes in front (near to smaller frame).
4) Then assemble pinion and stepper motor.
5) Assembly of pinion and stepper motor should be below the drum to make system compact.
6) Mount light emitter at rear end in such a way that light beam passes through the axis of pipe when pipe is at lowest bottom position.
7) Also mount receiver in same line of action at front end.
8) Mount drum assembly on frame in inclined Working.
9) Load the drum with billets.
10) Start the machine.
11) As soon as machine starts conveyor also starts to move then billets from pipes starts to slide on conveyor automatically by gravity.
12) When last billet of pipe fall on conveyor then light beam fall on receiver.
13) When light beam fall on receiver then it sends signal to controller to rotate stepper motor by 1 step (in case of 24 step motor) i.e 15 degree.
14) After receiving signal from controller, motor rotates by 1 step (15 degree) and next billet loaded pipe comes in front of light beam and it obstruct the beam to fall on receiver till last billet of pipe falls on conveyor.
15) In this way process goes on.
16) Controller program is programmed in such a way that after receiving 24 such signals m / c will stop automatically for reloading.

5 COST ESTIMATION

It is the art of finding the cost which is likely incurred on the manufacturers of the article before its actually manufactured thus if the calculation of probable cost of an article before manufacturing the tool. It also includes predetermination of quality and quantity if material and labor required.

5.1 Aims of estimation-

1. To help in deciding the methods of manufacturing.
2. To decide about the amount of overheads.
3. It helps to decide whether and particular material should be purchased from the market or from manufacturer. Etc.

5.2 Cost estimation-

Present market rate of raw material-
C45= 60 Rs / kg
Alloy steel (50Cr1V23) =72 Rs / kg
Cast iron (GCI20) = 40 Rs / kg
Mild steel (pipe) = 60 Rs / kg

5.3 Machine operation cost per hour: (Rs/hr)

1. Lathe m / c- 60 / 80
2. Milling m / c- 80 / 90
3. Grinding m / c- 70 / 75
4. Drilling m / c- 40 / 45
5. Surface grinding-85
6. Counter boring-45
7. Tapping-30
8. Welding-80
9. Cutting-40
10. Rolling-60

5.4 Raw material cost

Sr.no	Name of parts	Kg	Market rate/kg	Total cost of parts(Rs)
1	Drum shaft	55	72	3960
2	Cover plate(front and end)	35	60	2100
3	Cover plate(fixed)	17	60	1020
4	Pinion shaft	15	60	900
5	Drum cylinder	80	60	4800

6	Pipe	195	60	11700
7	I-section beam	250	60	1500
8	Ring gear and pinion	-	3000+2000	5000
9	Base plate	20	40	800
10	Bearings	4(no)	400/500	1600
11	Stepper motor	-	15000	-
	Total cost			61,880

Table No. 3 (Raw Material Cost)

5.5 Operation machining cost of each individual parts

5.5.1 Part name- Drum shaft

Sr. no.	Operation	Time(hr)	Market rate/kg	Cost(Rs)
1	Turning	4	80	320
2	Grinding	0.5	80	40
	Total cost			360

Table No. 4

5.5.2 Part name- drum cover plate (front and end)

Sr. no	Operation	Time(hr)	Market rate/kg	Cost(Rs)
1	Cutting	1×2	40	80
2	Drilling	3×2	45	270
3	Grinding	2×2	70	280
	Total cost			630

Table No. 5

5.5.3 Part name- cover plate

Sr. no	Operation	Time(hr)	Market rate/kg	Cost(Rs)
1	Cutting	1	40	40
2	Drilling	3	45	135
3	Grinding	2	70	140
	Total cost			315

Table No. 6

5.5.4 Part name- pinion shaft

Sr. No	Operation	Time(hr.)	Market rate/kg	Cost(Rs)
1	Facing	0.5	80	40
2	Turning	0.5	80	40
3	Milling	0.5	90	45
	Total cost			125

Table No. 7

5.5.5 Part name-pipe

Sr. no	Operation	Time(hr)	Market rate/kg	Cost(Rs)
1	Cutting	3	40	120
2	Welding	5	80	400
3	Grinding	6	70	420
	Total cost			940

Table No. 8

5.5.7 Part name-I-Section

Sr. no	Operation	Time(hr)	Market rate/kg	Cost(Rs)
1	Cutting	1	40	40
2	Welding	4	80	320
3	Grinding	3	70	210
	Total cost		570	

Table No. 9

5.5.6 Part name-drum cylinder

Sr. No	Operation	Time(hr)	Market rate/kg	Cost(Rs)
1	Cutting	1	40	40
2	Rolling	1	60	60
3	Welding	1	80	80
4	Grinding	1	70	70
	total			250

Table No. 10

5.5.8 Part name-base plate

Sr. No.	Operation	Time(hr)	Market rate/kg	Cost(Rs)
1	Cutting	1	40	40
2	Welding	2	80	160
3	Grinding	2	70	140
	Total cost			340

Table No. 11

5.5.9 Total machine cost:

=360+630+315+125+250+940+570+340 =3530 Rs.
Raw material cost=61,880 Rs.
Total cost=raw material cost+ machining cost
=61880+3530 =65410 Rs
Overhead charges=15% of manufacturing cost
=9811 Rs.
Indirect expenses (material handling, transportation etc)
=10% of manufacturing cost =6541 Rs.
Inspection expenses=5% of manufacturing cost

=3270 Rs.
Total cost=85000Rs. (approximate cost).
Actual cost will be greater than estimated cost.

6 COST ANALYSIS

Oil-fired furnace:-
Price of furnace oil-56.66 / litre
Oil consumption-125 lit / ton (8 hr.)
Total cost per shift-125 lit×56.66=7082.5 Rs.
Induction Furnace (400kw/hr.):-
Electricity Tariff rate-8.30 / unit
Capacity-540 kg / hr.
Power consumption per ton-770(unit) ×8.30=6391Rs. (2hr)

6.1 Result (induction over oil fired furnace)

Cost Saving per ton: 7082-6391=691(2hrs)
Cost save per shift: 691×4=2764(8hrs)
% of cost saving per shift :(2764 / 7082.5) ×100=40%
Productivity per shift: 4 ton (8hrs.).
Cost saved per day- 2764×2=5528 Rs.
Annual saving=20 lakhs (approximately).
Productivity increases four times as that of oil fired furnace. At the same time production cost reduces by 40% per shift.

7 CONCLUSION

We have observed that by installing the induction furnace over oil fired furnaces the problems faced in oil fired furnaces can be minimized. Due to installation of induction furnace productivity increases four times and also there is saving in production cost of 40%. Due to 40% cost saving its payback period is very short. Optimization of induction furnace is done by installing “Automatic Billet Feeder”. It replaces human labour and feed billets in furnace automatically. Its design and manufacturing process is made simple. While designing of its components economy, compactness and weight reduction are kept in mind.

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