BEE's National Program
on
Energy Efficiency and Technology Up-gradation in SMEs

Ludhiana Forging Cluster

Baseline Energy Audit Report
Bharat International

Submitted to

Submitted by

nsPIRE

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Brief about the Project

The project BEE's National Program on "Energy Efficiency and Technology Up gradation in SMEs - Ludhiana Forging Cluster" supported by Government agencies; Bureau of Energy Efficiency (BEE), and Ministry of Micro, Small and Medium Enterprises (MSME) and local association namely, Auto Parts Manufacturers Association - Ludhiana (APMA) aims to bring down the energy demand of forging industries located at Ludhiana by supporting them to implement and adopt Energy Efficient Technologies in their respective units.

Executive Summary

1. Unit Details

Unit Name	:	**Bharat International**
Address	:	C-27, Focal Point, Ludhiana – 141010, Punjab
Contact Person	:	Mr. Gurpreet Singh Kahlon (Cell No. 9914188832)
Products	:	Bolts, Nuts, Washers and Auto Parts
Production	:	1 – 2 Tons/day
DIC Number	:	030091200251 (Part-II)
Bank Details	:	State Bank of India; Miller Ganj Branch - Ludhiana Account Number, 10330878666, IFSC Code –SBIN0000731
TAN / PAN No.	:	PAN: AABFB09453; TAN: JLDB01169A
Contract demand	:	400 kVA

2. Existing Major Energy Consuming Technology

FO Based re-heating technology

- Conventional Technology with higher losses
- Prevailing energy consumption is 0.194 liters of FO per kg of the production

Lathes Machine

- Manually operated lathe machines for machining job work including threading, turning, grinding, drilling etc.
- Electrical motor rating of 2-3 HP with production of 40-90 pieces per hour per set of lathe machine.

3. Proposed Energy Saving Technologies with Cost Economics

Proposed Energy Savings Measures

- Replacement of FO fired re-heating furnace with 50 kW induction re-heating furnace
- Replacement of manual lathe machines by three numbers of CNC based Special Purpose Machine (SPM), two of turning and one for drilling operation

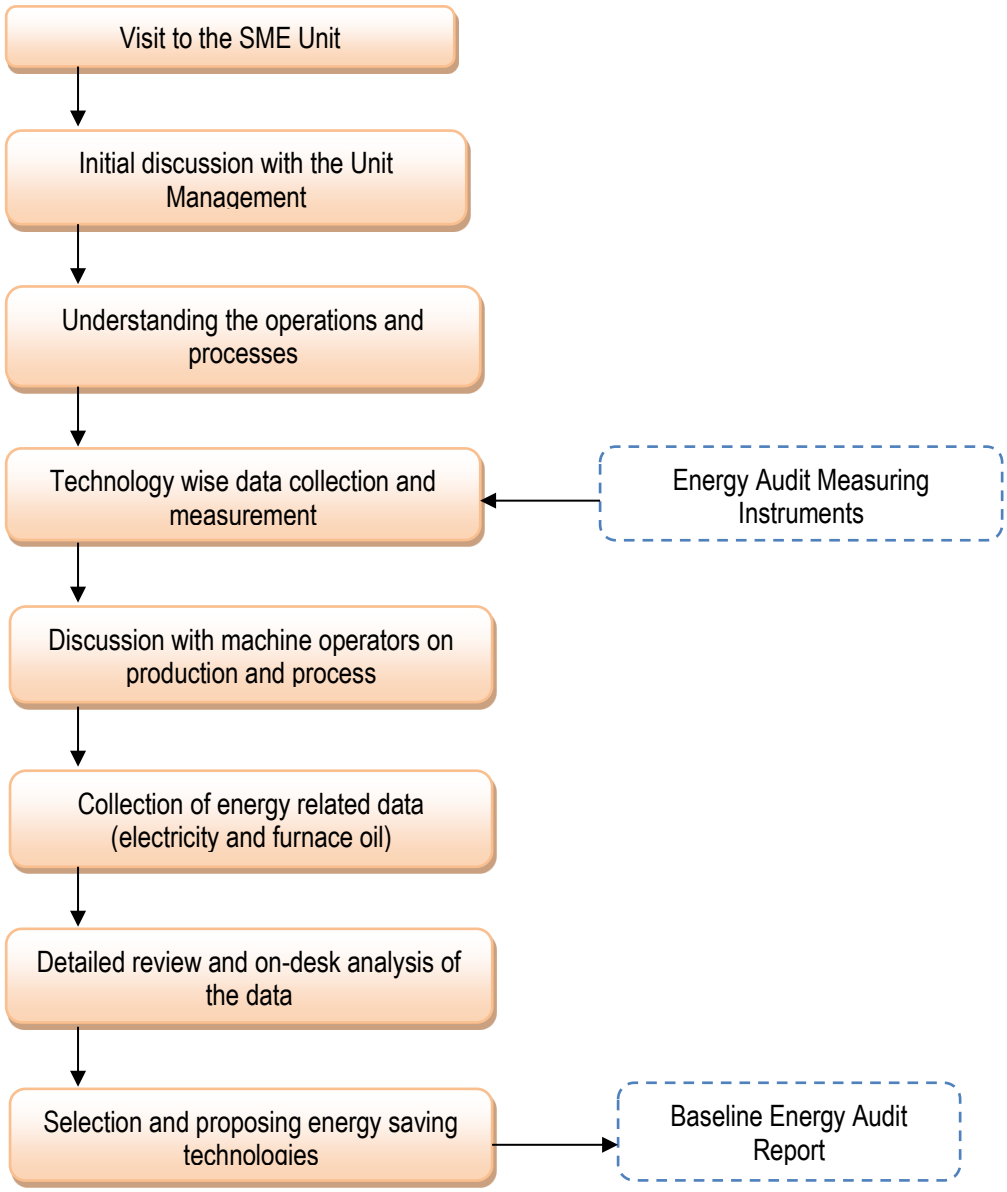
Table 1: *Cost Economic Analysis*

Proposed Technology	Estimated Energy Savings (%)	Savings (in Rs.)	Investment (in Rs.)	Simple Payback period (Years)
Induction re-heating furnace (50 kW)	73	628,128	936,510	1.5
SPM machine – Turning (2 Nos.)	81	389,412	1,100,000	2.8
SPM machine- Drilling	73	65,880	350,000	5.3
Total		**1,083,420**	**2,386,510**	

Introduction

1.1 ENERGY AUDIT METHODOLOGY

The primary objective of the energy audit was to quantify the existing fuel consumption pattern and to determine the operating efficiencies of existing systems. The key points targeted through energy audits were determination of specific fuel consumption, various losses, operation practices like hot metal temperature, production, fuel consumption, scale formation etc. Pre – planned methodology was followed to conduct the energy audits. Data collected at all above steps was used to calculate various other operating parameters like material feeding rate (Kg/hr), fuel firing rate, specific fuel consumption (kg/tonne), etc.



1.2 ABOUT THE UNIT

M/s Bharat International was started it commercial production in 1996 and is engaged in manufacturing of different types of bolts, nuts, washers and auto fasteners in various sizes as per the requirements of various customer spread in Pan India basis. The manufacturing unit is located at C-27, Focal Point, Ludhiana – 141003, Punjab.

The raw material used by the unit for making bolts and other auto components include Mild Steel, EN8, and EN15.

The daily production of the unit lies in the range of 1 to 2 tons per day. The unit is using two different forms of energy for various process and utility applications in premises, those are:

- Furnace Oil (FO), and
- Electricity

The average monthly FO consumption is 673 liters, whereas, the average monthly electricity consumption comes around 46,900 kWh. The unit spends around Rs. 49,075/- monthly on purchasing the FO @ Rs. 73 per liter. The average electricity bill of the unit is Rs. 3,33,032/- per month. The FO is purchased from local supplier and electricity is taken from Punjab State Power Corporation Limited.

To manufacture the products, the unit has installed two open type FO based re-heating furnace, one batch type and one continuous type; forging press, pressing machine, grinding/ facing/ trimming lathes, threading machine, cold forging hammers, nut making machines, drawing machine etc.

According to the assessment of the energy consumption data collected, the specific thermal energy consumption and specific electrical energy consumption is 0.02 liters per kilogram production (183.06 kcal/kg) of product and 1.25 kWh per kilogram (1075.60 kCal/kg) of product respectively. The total specific energy consumption, in terms of kCal comes to 1258.65 kCal/kg of product. Details of annual electrical and thermal energy consumption and specific energy consumption details of the unit are presented in table 1.1 below:

Table 1.1: ***Specific Energy Consumption and Energy Cost Details***

SN	Parameter	Value
1	Daily Production (Tons/day)	1.0 ~ 2.0 (average 1.5 tons per day considered for calculation)
2	Monthly electrical energy consumption (kWh)	46901.00
3	Monthly thermal (FO) energy consumption (liters)	673.00
4	Specific electrical energy consumption (kWh/kg)	1.25
5	Specific electrical energy consumption (kCal/kg)	1075.60
6	Specific thermal energy consumption (liters / kg)	0.02
7	Specific thermal energy consumption (liters / kg)	183.06
8	Specific energy consumption (kCal/kg)	1258.65
9	Electrical energy cost (Rs./kg)	8.75
10	Thermal energy cost (Rs./kg)	1.31
11	Total energy cost (Rs./kg)	10.06

Note:

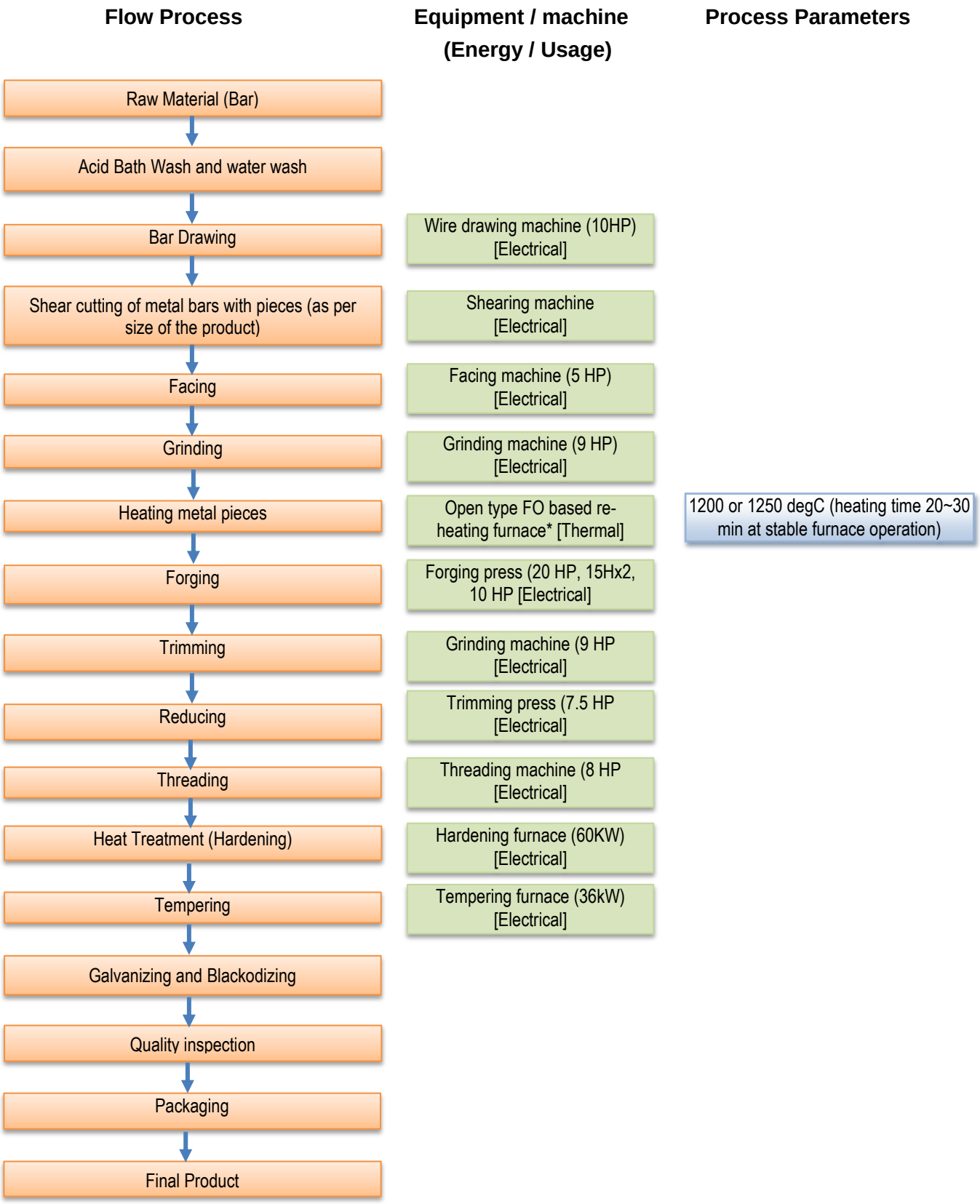
^1: Specific gross calorific value of FO is considered as 10,200 kcal / liters

^2: Thermal equivalent for one unit of electricity is 860 kCal/kWh.

^3: The unit operates for 25 days a month.

1.3 PRODUCTION PROCESS OF PLANT

The typical production process adopted at manufacturing of forged products at the unit is presented below:



*The unit have installed two induction based re-heating furnace of 30 kW and 40 kW capacity.

1.4 PRESENT TECHNOLOGIES ADOPTED

The list of equipment's installed to manufacture the forged products in the unit and their connected load is captured and mentioned below.

S.N.	Equipment	Energy Source	Connected load	Year of Installation
1	Drawing Machine	Electricity	10 HP	1996
2	Facing Machines	Electricity	5 HP	1996
3	Grinding Machines (5 Nos.)	Electricity	9 HP x 5	1996
4	Induction Re-heating Furnace (2 nos.)	Electricity	30 kW, 40 kW	2013
5	FO Re-heating Furnace (3 Nos.)	Furnace Oil	40 ~ 45 Liters per hour	1996
6	Forging Press (4 Nos.)	Electricity	20 HP, 15 HP x 2, 10 HP	1996
7	Trimming Press	Electricity	7.5 HP	1996
8	Threading Machine (4 Nos.)	Electricity	8 HP	1996
9	Hardening Furnace	Electricity	60 kW	NA
10	Tempering Furnace	Electricity	36 kW	NA
11	Transformer (2 Nos.)	Electricity	10 kVA, 18 kVA	NA

Study and Observations

2.1 RE HEATING FURNACE (FURNACE OIL FIRED)

2.1.1 Present Process

M/s Bharat International has installed a Furnace Oil (FO) fired batch type reheating furnace to heat the metal pieces for forging. In a batch type re-heating furnace, the metal pieces are kept inside the furnace and heated for a period of 30 – 45 mins. depending upon the size/shape of the metal piece and final product to be formed. The metal piece to be forged is heated to a temperature of 1150~1200 deg. C. After that, the heated metal piece using tong is kept on the forging die having the cavity of the product to be formed. The hot metal piece then forged on the forging press into the product. A performance assessment of the FO fired reheating furnace was undertaken to assess the hourly production as well as the specific energy consumption in terms of kilogram of FO per kilogram of production. The trail data recorded is tabulated below;

Table 2.1: *Fuel consumption and Production data of Furnace Oil based re-heating furnace*

Time (from – to)	Input (No. of Pcs.)	Output (No. of Pcs.)	FO consumption (L)	Remarks
9:35 – 9:55	0	0	0	The cold furnace was pre-heated. FO tank level measurement (20 inch)
9:55 – 10:45	65	0	5.13	Furnace charged (Lot-1) with Tank level measurement (19.25 inch)
10:45 – 11:10	0	65	0	Lot-1 forged (started -10:45 completed – 11:10)
11:10 – 11:35	65	0	0	Furnace charged (Lot-2)
11:35 - 12:00	0	65	8.51	Lot-2 forged (started – 11:35 completed – 12:00) with Tank level measurement (18 inch)
Total	**130**	**130**	**13.64**	**FO consumption is 13.64 liters for 130 nos. of pieces forged**

Initially, before start of the forging of the metal pieces, the re-heating furnace was pre-heated for about 20 minutes (from 9:35 to 9:55 AM). The furnace oil level in the fuel tank was measured using “Dip-Measurement” technique and it was noted that 5.13 liters of FO was consumed to pre-heat the re-heating furnace. A batch (Lot-1) of 65 metal pieces was kept inside the furnace for re-heating and was heated for about 50 minutes (with 10 minutes break due to electricity cut). The forging of (Lot-1) metal pieces was started at around 10:45 AM and completed at around 11:10 AM. After Lot-1, another batch of 65 pieces (Lot-2) was feed to the re-heating furnace. The forging of Lot-2 started at 11:35 AM and completed 12:00 PM. The total number of

pieces heated and forged during the study was 130 with fuel consumption of 13.64 liters.

In the re-heating furnace, a small local made blower was also installed to supply combustion air in re-heating furnace. The blower motor was single phase induction motor with 1 HP capacity; it operates for around 10 hours a day.

2.1.2 Observations during performance assessment of reheating furnace:

During the performance assessment study of the FO based open type reheating furnace the operation practices carried by the workers and forging process. The observations were critically reviewed and placed below.

- **Conventional Technology:**

The exiting furnace is very old installed in 1996 and was fabricated by the local manufacturer without following any design standards practises. The burner used in the furnace is also based on the conventional design having manual control option for fuel firing rate.

- **Material deterioration:**

Since the flame of the furnace directly hits the surface of the metal during the heating period varying from 20 – 30 minutes deteriorates the atomic/ grain structure of the piece and also leads to the higher scale formation due the oxidation of the metal at high temperature ultimately leading to material/ production loss. In order to attain the exact temperature profile of the material in less time, 3Ts has to be followed, Time, Turbulence and Temperature, if these three parameters can be followed in a right manner proper temperature can be archive in a minimum time, which would help in reducing the excessive heating of the material and reduction in scale loss.

- **High energy consumption:**

As per the data collected during the energy audit activity, the reheating furnace consumed around 0.02 liters of FO per kg of the production which is on the higher side, compared with the latest technologies available in the market (like induction heating furnace).

- **Low production rate:**

Since the existing furnace is open type and most of the heat of the flame goes out of the furnace leading to higher heating time and more fuel consumption. Due to the open type reheating furnace configuration, the forging metal piece takes more time to attain the desired temperature profile, thus leads to lower production and higher fuel consumption. Apart from the drawback of open type furnace configuration, the unorganized pattern of working by the labors handling the furnace is also equally responsible for lower production.

- **Environmental and Health Issues:**

The existing reheating furnace requires furnace oil as the energy which is burnt to heat the metal pieces. The burning of FO releases harmful gases like CO, CO_2, SO_X, NO_X, smoke etc. During the study, it was noted that black soot is coming out of the furnace and getting deposited in the factory walls and ceiling. The black soot is basically the unburnt carbon due to the incomplete combustion of FO, which reduces the efficiency of the furnace and enhances the fuel loss. The reheating furnace has no properly designed flue gas exhaust mechanism, ID fan and flue gas pipe, to pass the flue gases out of the unit. All these factors affect the environment and also the health of the worker handling the furnace and other operators working in the unit.

- **Lack of skilled labour:**

Another factor which is creating the problem in Ludhiana is shortage of skilled workforce. Present re-heating technology requires 2-3 workers to control and operate the reheating furnace operations to feed in / discharge of metal piece from the furnace.

- **Ideal running of forging press:**

It was noted that there is miss match between the installed / operating capacity of the furnace and forging press. As studied, in a cycle of 5 minutes, the re-heating furnace produces 10~13 heated metal pieces which were being forged in 2 minutes the remaining 3 minutes the forging press runs ideal. During this ideal running time, the forging and trimming press consumes energy instead of producing any output.

- **Choking at blower suction end:**

While studying the re-heating furnace, it was seen that the suction inlet of the blower is not working properly and there was no suction of the air.

- **Space constrained for storing fuel:**

It was observed during baseline audit, the fuel storage is a problem. The unit has space limitations and therefore finding problems with maintaining adequate and sufficient furnace oil inventory.

2.1.3 Conclusion

Based on the above observations during the study and discussions with the unit management it is proposed to replace the existing re-heating technology (FO Based) with Energy Efficient Induction Reheating furnace. The benefits of the induction based EE re-heating technology are;

- Environmental cleaner technology
- Reduces specific energy consumption
- Faster operation and reduced scale formation
- User friendly technology
- Improved quality of the product output
- Higher output with fewer crop cuts or short bars

2.1.4 Cost Economics Analysis

On the day of performance assessment study, the unit was manufacturing one of their main products, namely T-bolts, all relevant data pertaining to the product manufactured was measured during the assessment study. As per the calculations, it is proposed to install energy efficient induction based re-heating furnace of capacity 50 kW, also to manufacture larger product size. To reheat the metal pieces (T-blots), the proposed furnace must be operated at 31 kW with the production rate of 75 kg/ hour. It would require 14 seconds cycle time to re-heat the metal piece of 280 gram weight (See Annexure -1 for detailed calculation sheet).

The economic comparison of FO based re-heating technology and induction technology, specific energy consumption, cost savings, investment required and simple payback period of the investment on induction technology is given in Table 2.2.

Table 2.2: *Energy saving calculation for Induction Furnace*

Parameter	Unit	Value
Furnace oil consumption on existing re-heating furnace	Liters/ hour	6.984
Production in Kg	Kg/hour	36
Specific energy consumption on FO based re-heating furnace	Liters/Kg	0.194
Cost of energy consumption (@ Rs 50 per liter)	Rs./Kg	19.0
Power consumed by proposed induction furnace (rated capacity 50 kW operating at 31 kW)	kW	31
Production in Kg	Kg/hr	75
Specific energy consumption on induction reheating furnace	kWh/Kg	0.41
Cost of energy consumption (@ Rs. 7.5 per kWh)	Rs./Kg	3.1
Reduction in energy cost	Rs./Kg	3.48
Operating hours	Hrs	8
Annual operating days	Days	300
Annual cost savings	Rs lakhs	628,128
Investment required for Induction furnace (50 kW)	Rs lakhs	936.510
Simple payback period	Years	1.5

The energy cost saved per Kg of material forged is Rs. 3.48. The investment required to implement the energy efficient induction technology based reheating furnace is estimated as Rs. 9.36 Lakhs with annual saving of Rs. 6.28 Lakhs. The simple payback period comes to very attractive as 1.5 months.

2.2 SPECIAL PURPOSE MACHINES (SPM)

2.2.1 Present Process

The unit has installed manually operated conventional machines for various components machining job work like facing, turning, grinding, drilling etc. These machine runs on electrical motors having the capacity varying from 3 HP to 10 HP with production/ machining of 1000~1500 pieces per day. The unit has installed

twelve conventional operated machines to cater to various operations like Grinding, Turning, Facing, Drilling and Threading.

Table 2.3: *List of conventional machine*

Machine	Numbers	Motor rating
Grinding Lathe	5	9 HP x 5
Turning	1	2 HP
Facing (SPM)	1	2 HP
Drilling	3	2 HP x 3
Threading machine	2	8 HP, 3 HP

2.2.2 Observations

Since these machines are manually operated, the process through which components are manufactured is very slow and time consuming. Apart from the slow process, the components manufactured are very precise and of high quality. It often observed that the machine operate ideally (without any component loaded on to the machines) and the operator is busy in doing some other work/activity. All these factors lead to valuable resource; energy, manpower, time and money..

2.2.3 Conclusion

In order to promote the energy efficiency and reduction in the overall energy cost in the factory, it is recommended to covert the existing manual machines into automatic special purpose machine (SPMs) by implementing PLC control mechanism. Since the modified machines will run on the pre-installed programming technique, the consumption of electricity will only happen when there is a function or operation done on the component. In the ideal condition the machine will remain in dead mode or no operation mode.

Apart from the pre-programmed operation, the machine will automatically load and unload the component for machining. The cycle time of the each component will be fixed in the business logic of the PLC / SPM machine, therefore, each component will take specific time for processing or machining. The SPM machines results in 30-50% percent of the energy savings depending upon the type of component, operation, material, cycle time etc. The benefits of the automatic SPM/ CNC machines are:

- Reduced energy consumption
- Faster operation and reduced down time
- Improved product quality and symmetrical product dimensions
- Higher productivity
- Environment friendly technology

2.2.4 Cost Economics Analysis

- **Turning Machine:**

The comparison of cost economic and specific energy consumption, cost savings, investment and simple payback period for old turning machine and SPM machines is given in table 2.5.

Table 2.5: *Energy saving calculation for turning machine*

Parameter	Unit	Value
Power consumed by conventional turning machine	kW	1.5
Production on conventional turning machine	Pcs/hr	50
Specific power consumption on conventional machine	kWh/Pcs	0.03
Power consumed by SPM turning machine (motor capacity 3HP @ 60% loading)	kW	1.34
Production on SPM turning machine (Projected)	Pcs/hr	150
Specific power consumption on SPM machine	kWh/Pcs	0.009
Reduction in specific power consumption	kWh/Pcs	0.021
Percentage savings	%	70
Operating hours	Hrs	8
Annual operating days	Days	300
Annual electricity savings	kWh	7,584
Annual cost savings	Rs.	389,412
Investment required	Rs.	5,50,000
Simple payback period	Years	2.8

It is proposed to convert/ replace existing manual turning machines to automatic Special Purpose Machines (SPMs). The specific power consumption on a manual machine is 0.03 kWh/ pcs, whereas, the specific power consumption in SPM machine would be around 0.009 kWh/pcs resulting in 70% savings in electrical energy. The investment required for making an SPM machine would be around Rs 5.5 Lakhs with annual saving of Rs 3.89 lakhs. The simple payback period of the technology is 2.8 years.

- **Drilling Machine:**

The comparison between old drilling machine and SPM drilling machine on cost economic and specific energy consumption, cost savings, investment and simple payback period is given in table 2.6.

Table 2.6: *Energy saving calculation for drilling machine*

Parameter	Unit	Value
Power consumed by conventional drilling machine	kW	1.5
Production on conventional drilling machine	Pcs/hr	120
Specific power consumption on conventional machine	kWh/Pcs	0.0125
Power consumed by SPM multi spindle drilling machine (motor capacity 3HP @ 60% loading)	kW	1.34
Production on SPM multi spindle drilling machine (Projected)	Pcs/hr	300
Specific power consumption on SPM machine	kWh/Pcs	0.004

Reduction in specific power consumption	kWh/Pcs	0.0085
Percentage savings	%	68.0
Operating hours	Hrs	8
Annual operating days	Days	300
Annual electricity savings	kWh	5,784
Annual cost savings	Rs.	65,880
Investment required	Rs.	350,000
Simple payback period	Years	5.3

It is proposed to convert/ replace existing single spindle drilling machines to automatic multi spindle drilling machine - Special Purpose Machines (SPMs). The specific power consumption on a manual machine is 0.0125 kWh/ pcs, whereas, the specific power consumption in SPM machine would be around 0.004 kWh/pcs resulting in 68% savings in electrical energy. The investment required for making an SPM machine would be around Rs 3.5 Lakhs with annual saving of Rs 65,880. The simple payback period of the technology is 5.3 years.

Annexure – 1

Basic details and energy utilization pattern of Bharat International

S. No	Parameter	Value	Unit
1	Name and address of unit	M/s. Bharat International, C-27, Focal Point, Ludhiana – 141010, Punjab	
2	Contact person	Mr. Gurpreet Singh Kahlon	
3	Manufacturing product	Bolts, Nuts, Washers and Auto parts	
4	Daily Production	1 - 2 Tons/ day	
	Energy utilization		
5	Average monthly electrical energy consumption	46901.00	kWh per month
6	Average monthly thermal (FO) energy consumption	673.00	Liters per month
7	Average thermal specific energy consumption	0.02	Liter /kg of product
		183.06	kCal/kg of product
8	Electrical specific energy consumption	1.25	kWh/Kg of product
		1075.60	kCal/kg of product
9	Specific energy consumption	1258.65	kCal/kg of product
10	Electrical energy cost	8.75	Rs/Kg of product
11	Thermal energy cost	1.31	Rs/kg of product
12	Total energy cost	10.06	Rs/kg of product

Note:
^1: Specific gross calorific value of FO is considered as 10,200 kcal / liters
^2: Thermal equivalent for one unit of electricity is 860 kCal/kWh.
^3: The unit operates for 25 days a month.

Induction furnace capacity and heating cycle time calculation

Induction furnace capacity calculations:

Induction furnace design standard: 2.7 – 3 kg per kW per hour

Hourly material to be heated = 75 Kg

Induction furnace capacity requirement (theoretical) = 75 / 2.7 kW/hr
= 27.78 kW/hr

As discussed with technology manufacturer, the lower design standard value of 2.7 kg per kW per hour may be suitable for the kind of operation.

Induction furnace capacity requirement (actual) (efficiency = 90%) = 27.77 / 0.90 kW/hr
= 30.86 kW/hr
= 31 kW (approximately)

Heating cycle time calculation:

Hourly material to be heated = 75 kg

Weight of the metal pieces = 280 gram

No. of pieces to be heated in an hour = 268 pieces

Heating time required per piece = 14 (13.43) seconds approximately

Keeping in view the variety of products manufactured by unit having different weight, size, geometry, and composition it is proposed to **install induction furnace of 50 kW capacity**.

Note:

*** For more accurate capacity options, induction furnace manufacturer should be consulted prior to the implementation*

Annexure – 3

Energy saving calculation for Induction furnace

Parameter	Unit	Value
Furnace oil consumption on existing re-heating furnace	Liters/ hour	6.984
Production in terms of Kg	Kg/hour	36
Specific energy consumption on FO based re-heating furnace	Liters/Kg	0.194
Cost of energy consumption	Rs./Kg	18.94
Power consumed by proposed induction furnace (rated capacity 50 kW operating at 31 kW)	kW	31
Production in terms of Kg	Kg/hr	75
Specific energy consumption on induction reheating furnace	kWh/Kg	0.41
Cost of energy consumption	Rs./Kg	3.1
Reduction in cost of energy required	Rs./Kg	3.48
Operating hours	Hrs	8
Annual operating days	Days	300
Annual cost savings	Rs lakhs	6.28
Investment required for Induction furnace (50 kW)**	Rs lakhs	9.36
Simple payback period	Years	1.5

Note:

*** The cost of induction furnace is an indicative value gathered from discussions with furnace suppliers. It may vary according to the heating requirement and the material to be heated.*

Annexure – 5

Energy saving calculation for turning machines

Parameter	Unit	Value
Power consumed by conventional turning machine	kW	1.5
Production on conventional turning machine	Pcs/hr	50
Specific power consumption on conventional machine	kWh/Pcs	0.03
Power consumed by SPM turning machine (motor capacity 3HP) @ 60% Loading	kW	1.34
Production on SPM turning machine (Projected)	Pcs/hr	150
Specific power consumption on SPM machine	kWh/Pcs	0.009
Reduction in specific power consumption	kWh/Pcs	0.021
Percentage savings	%	70
Operating hours	Hrs	8
Annual operating days	Days	300
Annual electricity savings	kWh	7,584
Annual cost savings	Rs.	389,412
Investment required	Rs.	550,000
Simple payback period	Years	2.8

Note:

*** The cost of SPM machines is an indicative value gathered from discussions with SPM machine suppliers. It may vary from operation to operation and product to product.*

Annexure – 6

Energy saving calculation for drilling machines

Parameter	Unit	Value
Power consumed by conventional drilling machine	kW	1.5
Production on conventional drilling machine	Pcs/hr	120
Specific power consumption on conventional machine	kWh/Pcs	0.0125
Power consumed by SPM multi spindle drilling machine (motor capacity 3HP) @ 60% Loading	kW	1.34
Production on SPM multi spindle drilling machine (Projected)	Pcs/hr	300
Specific power consumption on SPM machine	kWh/Pcs	0.004
Reduction in specific power consumption	kWh/Pcs	0.0085
Percentage savings	%	68.0
Operating hours	Hrs	8
Annual operating days	Days	300
Annual electricity savings	kWh	5,784
Annual cost savings	Rs.	65,880
Investment required	Rs.	350,000
Simple payback period	Years	5.3

Note:

*** The cost of SPM machines is an indicative value gathered from discussions with SPM machine suppliers. It may vary from operation to operation and product to product.*