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Design, Manufacturing, Testing and Optimization of Nick Milling Machine – A case study

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***Abstract* - A milling machine is a machine tool used to machine solid materials. The Nick Milling Machine used in Bearing Department of a well known Engine Manufacturing Ltd. Company in Pune, operates on work provided by the compressor. The input air pressure provided to this machine is about 5 Bar. This compressed air is used for operating the punch bringing about the actual nicking operation. A nick is required on each bearing halve for joining the two bearing halves. After completion of the punching operation, the exhaust (waste) air is given out to the atmosphere (approximate 4.5 Bar) . Some additional compressor work is required for applications like alignment of the bearing , cleaning of the bearing surface, cutter surface cleaning etc. after cutting the nick on the bearing halve, since the exhaust (waste) air from the nick milling machine is approximate 3 Bar obtained at receiver outlet considering piping loses . Instead of using additional compressor work for the above said actions, we can reuse the same exhaust air with the help of efficiently designed receiver, distributor system, piping system, inlet and outlet nozzles corresponding to exhaust air pressure (approximate 3 Bar) and corresponding to the above mentioned applications.**

***Keywords* - Nick Milling Machine, Bearing, Air Collector, Non Return Valve, Distributor System, Thin Cylinder**

I. INTRODUCTION

The main aim of our project work is to Optimize the performance of the Nick Milling Machine used in the Bearing Department by reusing the exhaust air after the punching operation and thereby saving the compressor work.

II. NICK MILLING MACHINE

A. *Information of Nick Milling Machine :*

A milling machine is a machine tool used to machine solid materials. Milling machines are often classed in two basic forms, horizontal and vertical, which refers to the orientation of the main spindle. Milling machines can perform a vast number of operations, from simple (e.g., slot and keyway cutting, planing, drilling) to complex (e.g., contouring, die sinking). In the vertical mill (which is the type of milling machine under consideration), the spindle axis is vertically oriented. Milling cutters are held in the spindle and rotate on its axis. The spindle can generally be extended (or the table can be raised/lowered, giving the same effect), allowing plunge cuts and drilling.

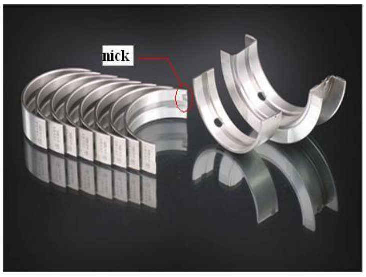

Fig 1 : Nick Milling Machine.

Fig 2 : Nick on Bearing Halve.

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B. ***Specifications of Nick Milling Machine :***

DIMENSION : 2400 mm x 2830 mm x 1830 mm
WEIGHT : 3500 kg
ELECTRIC POWER CONSUMPTION : 3 PHASE x 380 V x 50 HZ
POWER CONSUMPTION : 13.5 KW
AIR CONSUMPTION : 0.7 m^3/min
AIR CYLINDER : STROKE – 100 mm
LENGTH – 100 mm
SIZE OF THE FRAME HOUSING THE CYLINDER (MAIN FRAME) : W970 x L1160 x H1580
ELECTRIC PANEL SIZE : W400 x L900 x H1400

III. BRIEF ABOUT THE PROJECT :

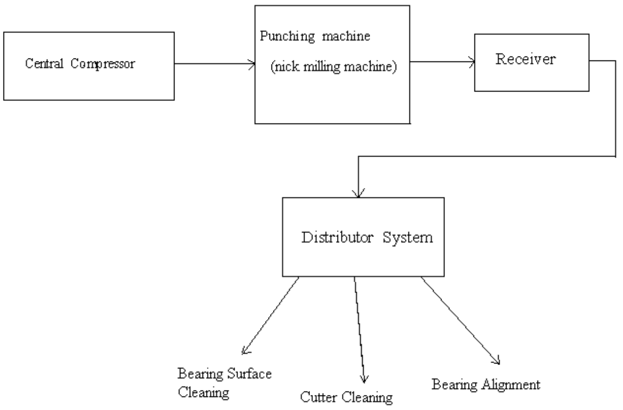

Fig 3 : Layout Diagram of Modified System

Some additional compressor work is required for purpose of alignment of the bearing or cleaning of the bearing surface etc. after cutting the nick on the bearing halve, since after completion of the punching operation, the exhaust (waste) air from the nick milling machine is given out to the atmosphere (approx 3 Bar) . Instead of using additional compressor work for the above said actions, we can reuse the same exhaust air (after punching operation) with the help of efficiently designed receiver, distributor system, piping system, inlet and outlet nozzles corresponding to exhaust air pressure (approx 3 Bar) ; and corresponding to the required applications discussed subsequently.

IV. AIR COLLECTOR :

The exhaust air (pressure approx 3 BAR) coming out from the main punching cylinder (pneumatic) of the nick milling machine, is collected in the air collector shown in the figure above. This is done with the help of exhaust air pipes whose one end is connected to the pneumatic cylinder and the other to the Air Collector. Before application of the modified system, the exhaust air would be let off into the atmosphere directly through the air collector. The modified system for Optimization of Nick Milling Machine is connected to this Air Collector.

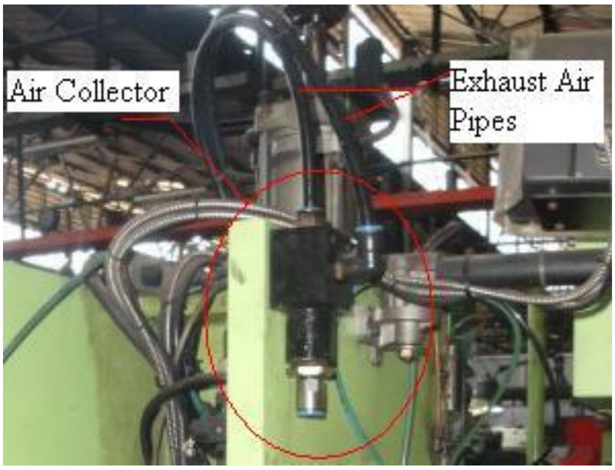

Fig 4 : Air Collector

V. PARAMETERS RELATED TO PNEUMATIC CYLINDER :

PARAMETERS AT THE INLET:
AIR PRESSURE (P1) : 4.9 BAR
TEMPERATURE (T1) : 19˚ C = 292 K
AIR VOLUME (V1) : ?
MASS FLOW RATE (m1) : ?

PARAMETERS AT THE OUTLET :
AIR PRESSURE (P2) : ?
TEMPERATURE (T2) : 15˚C = 288 K
AIR VOLUME (V2) : $\left(\frac{\pi}{4}\right) * (D^2) * L$

$= \left(\frac{\pi}{4}\right) * (100^2) * 100$

$= 785.3981 * (10^{-6})\ m^3$

MASS FLOW RATE (m2) : ?

CALCULATIONS :
(a) FOR POLYTROPIC PROCESS :

$$\left(\frac{T2}{T1}\right) = \left(\frac{P2}{P1}\right)^{(n-1/n)}$$

$$\left(\frac{288}{292}\right) = \left(\frac{P2}{4.9}\right)^{(1.3-1)/1.3}$$

P2 = 4.617756 BAR

(b) SIMILARLY :

$$\left(\frac{T2}{T1}\right) = \left(\frac{V1}{V2}\right)^{(n-1)}$$

$$\left(\frac{288}{292}\right) = \left(\frac{V1}{785.3981 * (10^{-6})}\right)^{(1.3-1)}$$

$V1 = 750.10484 * (10^{-6})\ m^3$

(c) TOTAL WEIGHT OF INCOMING AIR (W1) :
$W1 = \rho * V1 * g$
$= 1 * 750.1048 * (10^{-6}) * 9.81$
$W1 = 7.3585 * (10^{-3})$ kg

TOTAL WEIGHT OF OUT GOING AIR (W2):
$W2 = \rho * V2 * g$
$= 1 * 785.3981 * (10^{-6}) * 9.81$
$W2 = 7.70475 * (10^{-3})$ kg

(d) MASS FLOW RATE OF INCOMING AIR (m1):

$$m1 = \left(\frac{W1}{60}\right) \text{ kg/sec}$$

$$= \frac{7.3585*(10^{-3})}{60} \text{ kg/sec}$$

$$m1 = 1.226416 * (10^{-4}) \text{ kg/sec}$$

MASS FLOW RATE OF OUTGOING AIR (m2) :

$$m2 = \left(\frac{W2}{60}\right) \text{ kg/sec}$$

$$= \frac{7.70475*10^{-3}}{60} \text{ kg/sec}$$

$$m2 = 1.28412 * (10^{-4}) \text{ kg/sec}$$

VI. SELECTION OF TUBES :

The tubes are basically used in the modified system in three areas –

(a) Connection of air collector output to receiver inlet (i.e. to NRV).

(b) Connection of receiver output to distributor system.

(c) From the distributor system to different applications.

A. *Tube System Used for Modified System :*

All the tubes selected for the modified system which is fit to the nick milling machine are being selected from the 'TUBE CATALOGUE' of FESTO company according to required parameters.

B. *Tube Range and Features :*

- Outside diameter 3, 4, 6, 8, 10, 12 and 16 mm
- Outside diameter 1/8", 5/32", 3/16", 1/4", 5/16", 3/8", 1/2"
- Standard O.D. tubing
- Operating medium
  - Compressed air
  - Vacuum
  - Water
- Materials
  - Polyamide
  - Polyvinyl chloride
  - Perfluoroalkoxyalkane
  - Polyethylene
  - Polyurethane
- DUO tube
- 2 tubes fused together.

Fig 5 : Tubes Selected

VII. VALVES AND FITTINGS :

A. *Type of Valve Selected and Fittings* :

Air coming out from the Collector is collected in the Receiver has pressure of 2.5 BAR. At the inlet of the Receiver, the fitment of a NON RETURN VALVE is a must, as failing to do so will cause the air inside the receiver to start flowing outside the receiver (i.e. in reverse direction) , due to BACK PRESSURE effect, when the pressure inside the receiver and at it's inlet become almost similar. This will affect the working cycle of the NICK MILLING machine.

B. *Parameters Needed for Valve Selection*:

(a) Mass flow rate at the valve inlet : $m = 1.28412 * (10^{-4})$ kg/sec

(b) Temperature at the valve inlet : $T = 15^{\circ}C = 288$ K

(c) Pressure at inlet of the valve (NRV) :

Pressure at valve inlet (NRV) = Pressure at pneumatic cylinder outlet – Presure loss due to friction in pipes

Pressure loss due to friction in pipes = $h * \gamma = P1 - P2$

[Where : h = head loss due to friction in pipes
$\gamma = \rho * g$ (ρ = density of fluid)
P1 = Pressure at outlet of pneumatic cylinder = 4.617756 Bar
P2 = Pressure at NRV inlet]

Also, $h = \frac{4*f*l*V^2}{2*g*d}$

[where f = 0.03 is the friction factor
L = length of the tubes = 1 m
V = velocity fluid through tube = 0.46 m / sec
g = acceleration due to gravity = 9.81 m/s^2
d = diameter of tube = 6 mm = 0.006 m]

Hence , $h = \frac{4*0.03*1*0.46^2}{2*9.81*0.006}$

$h = 0.21569$ m

$P1 - P2 = h * \gamma = h * \rho * g$

$4.617756 - P2 = 0.21569 * 1 * 9.81$

Hence, P2 = 2.501756 Bar

Thus, corresponding to the values of pressure, temperature and mass flow rate at inlet of the valve, we will now select the appropriate valve from the catalogue. The NRV that is selected is done so for 10 Bar pressure.

Fig 6 : Non Return Valve

C. ***Fittings :***

Fittings are basically necessary for connecting the tubes with different pneumatic systems. In the case of our modified system, we use fittings for connections between Collector outlet tube and NRV; and Receiver outlet to inlet tube of Distributor System 1. Like the tubes, these fittings as well are selected from the standard available fittings manufactured by FESTO Company. Also, using these fitting equipments helps in reducing leakages to a great extent.

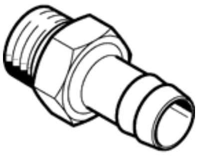

Fig 7 : Fitting 1 and Fitting 2

VIII. AIR RECEIVER :

A . *Basics of Pressure Vessel* :

A pressure vessel is a closed container designed to hold gases or liquids at a pressure substantially different from the ambient pressure.
The definition of a pressure vessel varies from country to country, but involves parameters such as maximum safe operating pressure and temperature.

B. *Thin – Wall Cylinder Theory*:

• Thin-wall theory is developed from a Strength of Materials solution which yields the state of stress as an average over the pressure vessel wall.
• Use restricted by wall thickness-to-radius ratio:
According to theory, Thin-wall Theory is justified for $(\frac{t}{r}) \leq (\frac{1}{20})$
In practice, typically use a less conservative rule, $(\frac{t}{r}) \leq (\frac{1}{10})$

State of Stress Definition:
1. Hoop Stress, σ_t assumed to be uniform across wall thickness.
2. Radial Stress is insignificant compared to tangential stress, thus, $\sigma_r = 0$.
3. Longitudinal Stress, σ_l
Exists for cylinders with capped ends;
Assumed to be uniformly distributed across wall thickness;
This approximation for the longitudinal stress is only valid far away
from the end-caps.
4. These cylindrical stresses (σ_t ,σ_r ,σ_l) are principal stresses (σ_t ,σ_r ,σ_l)which
can be determined without computation of Mohr's circle plot.

C. *Analysis of Thin Walled Cylinder Section* :

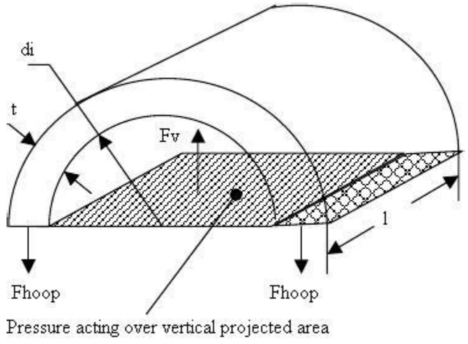

Fig 8 : Thin Walled Cylinder

The internal pressure exerts a vertical force, *FV*, on the cylinder wall which is
balanced by the tangential hoop stress, *FHoop*.

$F\,V = pA\,proj = p\,\{(d\,i)(1)\} = pd\mathit{i}$
$F\,Hoop = \sigma_t\,A\,stressed = \sigma_t\,\{(t)(1)\} = \sigma_t\,t$
$F\,y = 0 = F\,V - 2\,F\,Hoop = pdi - 2\,\sigma_t\,t$
Solving for the tangential stress,
$\sigma_t = \frac{p*di}{2*t}$ [Hoop Stress]

Comparison of state of stress for cylinder under internal pressure verses external pressure:

Internal Pressure Only :
$\sigma_t = \frac{p*di}{2*t}$ [Hoop Stress]
$\sigma_r = 0$ [By Definition]
$\sigma_l = \frac{p*di}{4*t}$ [Capped Case]

External Pressure Only :
$\sigma\,t = \frac{p*do}{2*t}$ [Hoop Stress]
$\sigma\,r = 0$ [By Definition]
$\sigma\,l = \frac{p*do}{4*t}$ [Capped Case]

D. *Receiver Calculations*:

From Practical Considerations point of View, and Available Space :

Receiver Parameters :

Outer Diameter (do) = 112 mm
Inside Diameter (di) = 102 mm
Inside Radius (ri) = 51 mm
Thickness (t) = 5 mm

Now, $\left(\frac{t}{ri}\right) = \frac{5}{51} = 0.09804$

As the above ratio is less than 0.1, hence we select THIN CYLINDER.

For the purpose of material selection (for greater factor of safety), we consider internal pressure to be 10 BAR (Actual internal pressure in receiver = 2.5 BAR).

Thus,

$$\sigma_{all} = \sigma_t = \frac{pi * di}{2 * t}$$

$$= \frac{10 * 0.102}{2 * 0.005} [\text{Newton} / m^2]$$

$$= 102 \quad [\text{Newton} / m^2]$$

Considering the overall parameters, allowable stress in the receiver and the economic point of view, we select MILD STEEL as the material for the receiver.

IX. DISTRIBUTOR SYSTEM :

The air coming out from the outlet of the receiver (approx 2.5 BAR) is provided at the input of the 'Distributor System'. The Distributor System basically distributes this air to the individual channel of the different applications. Since three applications are to be operated (Bearing alignment, Bearing cleaning and Cutter cleaning).

For this purpose, considering the pressure of the available air coming inside the distributor i.e. at the outlet of the receiver, appropriate Distributor Systems (which meets the required parameters of pressure, temperature etc. values) of FESTO COMPANY is selected.

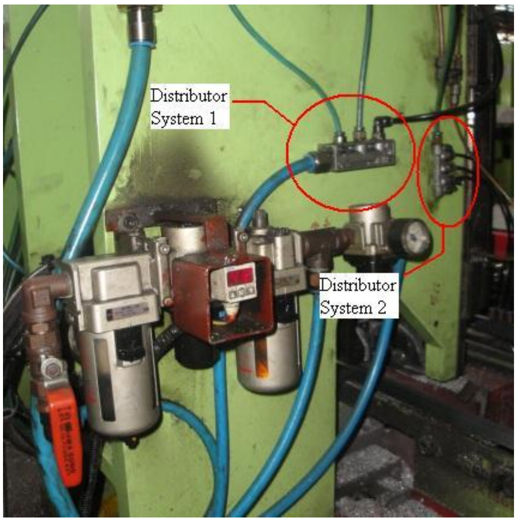

Fig 9 : Distributor System

For these Distributor Systems,

No. of inlet ports : 1

No. of outlet ports : 3

Air coming out from the Air Receiver is supplied to the Distributor System 1which has three outlets. Each of these outlets is connected to to a tube. Air coming out form these tubes is utilized for different applications as follows :

(a) Tube 1 ; Provided for Bearing Surface cleaning application.

(b) Tube 2 : Provided for Cutter Cleaning application.

(c) Tube 3 : Provided to the inlet of Distributor System 2 .

NOTE : Distributor System 2 is also a '1 inlet port – 3 outlet port' type of Distributor System. Tubes connected to the outlet of this system (3 in no.) are used for the purpose of Bearing Alignment by being connected to the Alignment Strip. 3 Tubes are used for the Bearing Alignment Application so that the alignment can be easily done by smooth and uniform air flow.

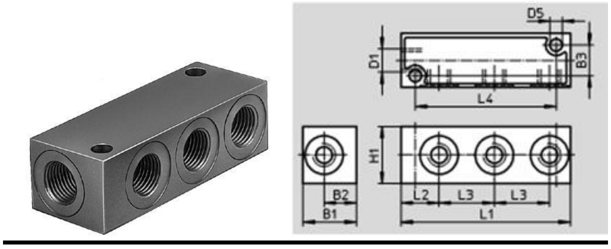

Fig 10 : Layout of the Distributor System used.

X. APPLICATIONS OF MODIFIED SYSTEM :

A. *Allignment of Bearing Halves :*

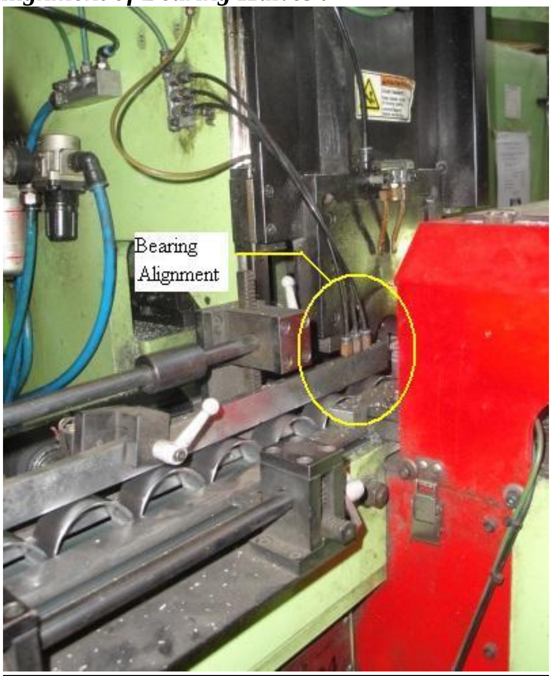

Fig 11 : Bearing Allignment

For proper NICK operation to take place inside the NICK MILLING MACHINE, the Bearing Halves while approaching the machine should be properly aligned and positioned on the conyeyor belt; as also their spacing with respect to each other should be uniform. For these purposes, the modified system can be used.

B. *Bearing Surface Cleaning* :

After the NICK Operation is performed on the Bearing Halves, when the Bearing Halves come out of the machine, and again start proceeding further on the conveyor belt, part of the air coming out of the Distributor System is utilized in cleaning the Bearing Surface at this point with the help of this Modified System which is as shown in the figure

Fig 12 : Bearing Surface Cleaning

C. *Cutter Cleaning* :

Fig 13 : Cutter Cleaning

After the Nicking operation is performed inside the NICK MILLING MACHINE, air coming out from a tube of the Distributor System 1 is used for CLEANING of the machine cutter. This helps in avoiding damage to cutter by removing the bur and scrap over it, thus increasing it's life.

XI. TESTING AND VALIDATION :

The Modified System after completion was attached after the Air Collector of the Nick Milling Machine. All the three Applications discussed were actually tested and the results were found to be in sync with the objective of each application respectively.

(a) The Bearing Halves previously would be positioned in a scattered manner, at times on the Conveyor Belt, causing sometimes the entire machine and thus the system to come to a hault abruptly, ultimately causing loss of time. But using the Bearing Alignment System helped in aligning the bearings in a linear fashion on the conveyor belt.

(b) Separate time and man power which would be wasted previously on cleaning the Bearing surface, was reduced greatly after the use of the Bearing Surface Cleaning System, whose output was also as expected.

(c) Lifetime of the Nick Milling Machine Cutter will definitely increase pertaining to it's periodic cleaning by the Cutter Cleaning Arrangement, which will help to use the cutter for a longer duration of time, reducing cost on it's maintenance as well as the cost of buying a new cutter.

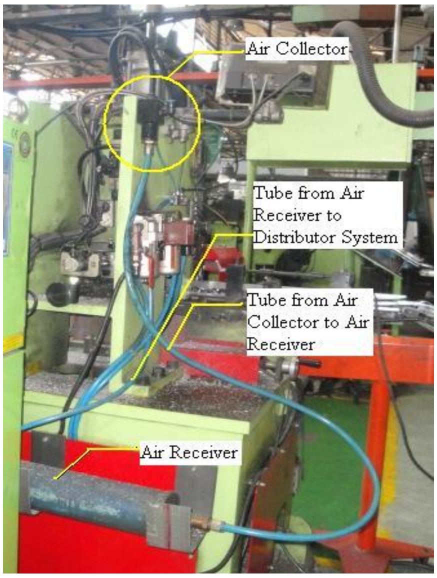

Fig 14 : Assembly of Modified System

XII. COSTING :

A. *Tubes :*

TYPE (Diameter in mm)	RATE AND LENGTH	COST
4	Rs 19 / m x 1 m	Rs 19
6	Rs 28 / m x 10 m	Rs 280
12	Rs 107 / m x 2 m	Rs 214
16	Rs 183 / m x 2 m	Rs 366

Table 1 : Tube Costing

Hence, Total cost for Tubing System = Rs 879

B. *Distributor System :*

TYPE	QUANTITY	COST
Type 1	1	Rs 196
Type 2	1	Rs 196
	TOTAL	Rs 392

Table 2 : Distributor Costing

C. *Fittings :*

TYPE	COST
Type 1	Rs 131
Type 2	Rs 371
TOTAL	Rs 502

TABLE 3 : Fitting Cost

D. *Receiver :*

VOLUME = π * (r^2) * L
= 3.14 * (0.005^2) * 0.75
= 5.89 * (10^{-5}) m^3

DENSITY = 7860 KG / m^3

WEIGHT = VOLUME * DENSITY
= 5.89 * (10^{-5}) * 7860
= 0.463 kg
COST = WEIGHT * COST PER Kg
= 0.463 * 42
= Rs 20
WELDING COST = Rs 30
TOTAL COST = Rs 50

E. *Total System Cost :*

SR NO.	COMPONENT	COST
1	Tubes	Rs 879
2	Valves	Rs 759
3	Receiver	Rs 50
4	Distributor	Rs 392
5	Fittings	Rs 502
	TOTAL COST	**Rs 2582 / -**

TABLE 4 : System Cost

XIII. SAVINGS IN WORK AND PAYBACK TIME :

Volume of air coming out of the pneumatic cylinder (per cycle) = 785.3981 * (10^{-6}) m^3

Volume of air coming out of the pneumatic cylinder (per minute) = Volume of air coming out of the pneumatic cylinder (per cycle) * no. of cycles per minute
= 785.3981 * (10^{-6}) * 28
= 0.02199 m^3 / minute

Mass of air coming out of the pneumatic cylinder (m) (per minute) = 0.02199 kg / minute

Saving in Compressor Work (Wc):

$$Wc = \left(\frac{n}{n-1}\right) * m * R * T * \left(\frac{p2}{p1}^{\left(\frac{n-1}{n}\right)} - 1\right)$$

[Here : n = 1.3 {Polytropic Process}
R = 0.287 KJ / Kg K
T = 15˚C = 288 K
p2 = Air Pressure coming out of the receiver
= 2.5 BAR
p1 = Atmospheric Pressure = 1 BAR]

$$Wc = \left(\frac{1.3}{1.3-1}\right) * 0.02199 * 0.287 * 288 * \left(\frac{2.5}{1}^{\left(\frac{1.3-1}{1.3}\right)} - 1\right)$$

Wc = 1.8546 watt / minute
Wc = 111.278 watt hour
= 0.111278 Kilo watt hour (KWh)
= 0.111278 KWh * 24 hrs * 26 days * 12 months
= 833.25 KWh / year

Total Energy Savings = 833.25 KWh / year * Rs. 5.5 / KWh
= Rs. 4582.875 /- per year

Payback Period = (System Cost)/((Total Energy Saving)/12)
= 6 months

XIV. CONCLUSION :

(1) Hence we designed the Modified System for optimizing the performance of the Nick Milling Machine. The saving in compressor work, electrical power required and thus cost of the system was achieved.

(2) The applications like Bearing Alignment, Bearing Surface Cleaning and Conveyor Belt Cleaning worked as per requirement increasing the Operational Efficiency of the Nick Milling Machine.

(3) The modified system also helped reduce the work load i.e. effort of the workers operating the machine. Thus all in all, the Company as well as the workers gained from this modified system.

(4) Also, this system is implemented only on a single machine of the bearing department currently. If suitably designed for the different machines (who operate pneumatically as well) in the Bearing Department, the effectiveness and savings in Compressor work, Electrical Power and ultimately in cost will be much more.

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