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Design of Automated Pipe Cutting Machine

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Abstract- **This paper emphasis on the design of automated pipe cutting machine to reduce human efforts for repetitive work of cutter pieces of pipes as well as provides a convenient fixture to support and hold the pipes/rods during cutting operation. To maintain a low cost automation, the pneumatic circuit is designed as compressed air supply is normally available at many workshops. The clamping arrangement can be varied according to need of operations suitable.**

The overall machine is compact in size, light weight, modular and flexible to be used in small works jobs that need batch production. The setup overall configuration can be adopted by a semi skilled worker easily and can vary the operations by making certain small changes. The machine even has the potential to add up a PLC system to control its overall work with ease and with less effort provided. This machine has the potential to adopt higher level of automation if desired in future.

I. INTRODUCTION

The proposed machine is capable of cutting hollow metal bar/pipes of any size. Also it can cut numerous pipes at the same time of different lengths and sizes. This machine is a fully automatic pipe cutting machine along with provision of automatic pipe feeding and counting system.

A simple layout and tricky operational enables this type of machine to work practically at low cost, low maintenance, low capital investment in less space. It may be forecasted that in future this machine may have its unparalleled place in the industry. Advanced micro controller technology,
interact with the device through the human-machine interface.

A. Need of Work

In manual pipe cutting process, length of the pipe to be cut out is marked with the help of measuring tape or scale and then it is to be properly hold against the cutting tool. These cutting tools are operated manually and then force is applied against the pipe for which there is requirement of more human efforts. In manual cutting process there is more chances of errors to be occurred.

B. Objectives

1) To reduce human errors in the pipe cutting process.
2) To reduce the time required for cutting process.
3) To make the machine flexible i.e. provision for cutting number of pipes at a time.
4) To make the machine modular i.e. provision of counting for number of pipes to be cut.
5) To make the marking system accurate.
6) To make the machine compact and portable.

C. Construction & Components

1. Conveyor Belt : It is used to feed the pipe into the cutting machine
2. Sensors: These are used to sense the pipe to its cutting length, to start the compressor and to start the cutting process.
3. Compressor:It provides pressurized air to the pneumatic arm to provide to and fro movement of the piston inside the pneumatic arm..
4. Cutting Blade: It is used to cut the work piece of desired length size.
5. Motor: It is used to run the conveyor belt and cutting blade..
6. Microcontroller: ALF VEGARD RISC (AVR) microcontroller is used to control the operations.

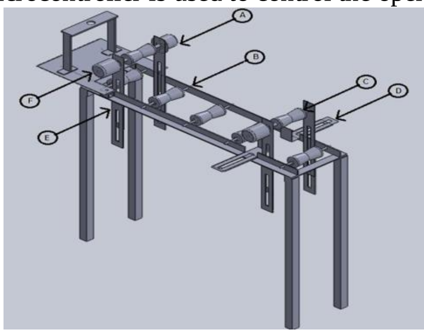

Fig 1: Constructional Details

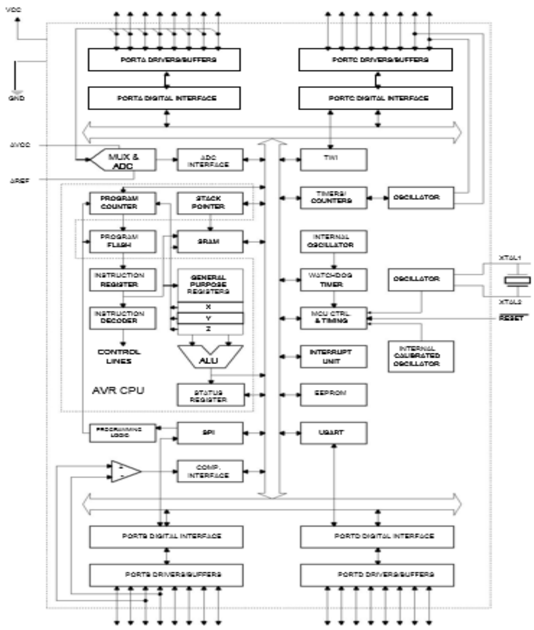

Fig.2: Block Diagram

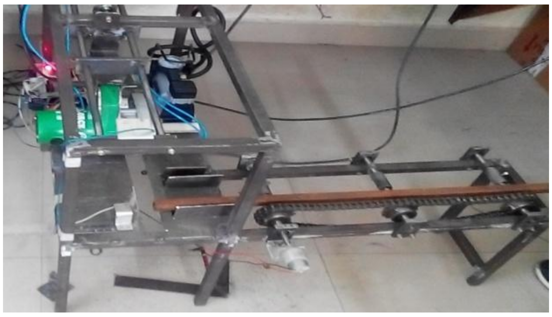

Fig 3: Front View of the fabricated model

Fig 4: Top View of the fabricated model

II. DESIGN CALCULATIONS

A. Cutter Design

The cutter design is based on the calculations of the PVC pipe selected
Considering outer diameter = 48.11mm
Shear stress =(Shear force/Shear Area)
So, Shear Force = 32.312*(π/4)(48.11²-39.79²)
= 21824.89N= 21.824KN
This is minimum required cutting force
For machine design, radius of cutter should be more then diameter of pipe
Hence, selecting Cutter of 5inch diameter i.e. 127mm, α=rake angle=10°, Clearance angle = 70°
Fc=22KN cutting force required
Ft, tangential force= Fc/2 = 11KN
Resultant Force, R = 24.59KN = 25KN
f, Friction force = Fcsinα+Ftsinα, f=14.65KN
Normal Force, N = Fccosα-Ftsinα
N=21.67KN;
ß= n¯¹(14.65/19.75)=36.56°
Ø= 45-(1/2(ß-α)=13.28°
Shear force, Fs= FccosØ-FtsinØ
Fs= 18.88KN
Force perpendicular to shear plane
Ns= FcsinØ- FtcosØ
Ns=5.64KN
Cutter Calculations
Power = Resultant force*Cutting speed=R*V
V=450 for plastic, data book
So, P=1.8KN
P= (2πNT)/60
T=15.25Nm
Also, V= (πDN)/1000
N= (450*1000)/ (127*π)
N=1127.86rpm required for milling but for cutting operation rpm required is comparatively low.

B. Gear Drive

Speed of pinion=N_p=30 Rpm
Velocity ratio ,$(N_p/N_g)=(t_g/t_p)$= 3
Assume Teeth on pinion,
t_p=23 teeth
Teeth on gear,
$t_g = 3 \times t_p$
t_g = 69 teeth ,
normal pressure angle = $\varphi_n = 20°$
$\tan \varphi_n = \tan \varphi \times \cos\Psi$
where, φ = pressure angle in tangential plane,
Assume 15°
φ_n = pressure angle measured in normal plane
$\varphi = \tan^{-1}(\tan 20/\cos 15) = 20.64°$
Since, $N_g = N_p / 3$,
= 30 / 3
=10 rpm
Formative no. of teeth
$t_{fp} = (t_p/\cos^3\Psi)$
= 23/cos³15
= 25.52
$t_{fg} = (t_g / \cos^3\Psi)$
= 69 / cos³15
= 76.56

C. Design Power:

$P_d = P_r \times K_l \times K_w$
where, K_l = load factor, light shocks and 8 hrs per day =1.25
K_w = lubricating and wear factor
Assume, scant lubrication K_w=1.25
= 12 x 1.25 x 1.25
= 18.75 watts
Tangential load,
$F_t = (P_d/V_p)$
where, $V_p = (\pi \times D_p \times N_p)/(60 \times 1000)$
$D_p = m_t \times t_p = m_n \times t_p/\cos\Psi$
$V_p = (\pi \times (m_n/\cos 15) \times 23 \times 30)/(60 \times 1000)$
$= 0.037m_n$
$= 18.75 / 0.037m_n$
$= 506.75/m_n$
Beam Strength,
$F_b = S_o \times C_v \times y \times b \times m_n$
where, $b = 10\ m_t/\tan\Psi$
$C_v = 0.4,\ 0<N_p<1000$
S_o = For pinion, SAE 1045= 210 MPa
For gear, cast steel 0.2%carbon heat treated=196 mpa
y = Lewis form factor, 20° full depth
$= 0.485-(2.87/t_f)$,
$y_p = 0.372$
$y_g = 0.447$
$S_{op} \times y_p = 78.12$
$S_{op} \times y_g = 87.612$
$b = 10 \times m_n/(\cos\Psi \times \tan\Psi)$
$= 10 \times m_n/(\cos 15 \times \tan 15)$
= 38.63

$F_b = 78.12 \times 0.4 \times 38.63 \times m_n \times m_n = 1207.11\ m_n^2$
$F_b = F_t$
$506.75/m_n = 1207.11 \times m_n^2$
$m_n = 0.74$ mm
Std. $m_n = 1$ mm
$V_p = 0.037 \times 1$
$= 0.037$ m/sec
$F_t = 506.75/1$
$= 506.75$ N
$F_b = S_o \times C_v \times y \times b \times m_n$
Where, $C_v = 4.5/(4.5+V_p)$
$= 4.5/(4.5+0.018) = 1$
$F_b = 78.12 \times 1 \times b_{min} \times 1$
$= 78.12 \times b_{min}$
$F_t = F_b$
$1002.55 = 78.12 \times b_{min}$
$b_{min} = 7.12$ mm
$m_n = m_t \cos \Psi$
$1 = m_t \times \cos 15$
$m_t = 1.03$ mm
$m_t = D/t$
$D_p = 1.03 \times 23 = 23.81$ mm
$m_t = D_g/t_g$
$D_g = 1.03 \times 69 = 71.07$mm
Check, $b_{min} > 4.5 m_t/\tan\Psi$
$4.5 \times 1.03/\tan 15$
$7.12 < 17.29$
$b_{min} = 4.5\ m_t / (\tan \Psi)$
$= 17.29$ mm
$F_{b\,(act)} = 78.12 \times 1 \times 17.29 \times 1$
$= 1351.32$ N
$F_b > F_t$, Design is Safe

Axial load,
$F_a = F_t \times \tan \Psi$
$= 506.75 \times \tan 15$
$F_a = 150.25$ N
$F_d = F_t + 21 \times V_p \times [c \times e \times b \times \cos^2\Psi + F_t] \times \cos \Psi$
$21 \times V_p + \sqrt{(c \times e \times b \times \cos^2\Psi + F_t)}$
Where, $c = 11800$
$e_{pro} = 0.025$, $e_{per} = 0.14$
$e_{pro} < e_{per}$
$F_d = 506.75 + 21 \times 0.018 \times [11800 \times 0.025 \times 17.29 \times \cos^2 15 + 506.75] \times \cos 15$
$21 \times 0.018 + \sqrt{(11800 \times 0.025 \times 17.29 \times \cos^2 15 + 506.75)}$
$F_d = 614.59$ N

Limiting wear strength,
$F_w = (K_{min} \times b \times D_p \times Q)/ \cos^2\Psi$
Where Q = size factor
$= (2 \times 69)/(69+23) = 1.5$
$F_w = K_{min} \times 17.29 \times 23.81 \times 1.5 / \cos^2 15 = 661.84\ K_{min}$
$F_d = F_w$
$614.59 = 661.84\ K_{min}$
$K_{min} = 0.928$
Std K = 1.37
$BHN_p = 350$, $BHN_g = 350$
$F_{w\,(act)} = (K \times b \times D_p \times Q)/\cos^2\Psi$
$= (1.37 \times 17.29 \times 23.81 \times 1.5)/\cos^2 15 = 845.99$
$F_w > F_d$, Design is safe
Endurance strength,
$F_{en} = S_{eb} \times b \times y \times m_n$
Where, $S_{eb\,p} = 596$
$S_{eb\,g} = 596$
$S_{eb\,p} \times y_p = 0.372 \times 596 = 221.71$
$S_{eb\,g} \times y_g = 0.447 \times 596 = 266.41$
$= 221.71 \times 17.29 \times 1$
$= 3833.36$ N
$F_{en} > F_d$, Design is Safe.
Gear Blank,
$D_o = D_p + 2m$
$= 23.81+(2 \times 1)$
$= 25.01$ mm
$D_i = D_p - (1.2 \times 2m)$
$= 23.81 - (1.2 \times 2 \times 1)$
$= 21.4$ mm
$D_p \leq (15\ m + 60)$ mm
$23.81 \leq (15 \times 1 + 60)$ mm
$23.81 \leq 75$ mm
Solid Construction,
$P = 2 \times \pi \times N \times T_d/ 60$
$12 = 2 \times \pi \times 30 \times T_d / 60$
$T_d = 3.819$ Nm
$T_d = 3.819 \text{ X } 10^3$ N-mm
$T_d = (\pi/16) \times d_s^3 \times \tau_{max}$
Where, τ_{max} = SAE 1030
$S_{yt} = 296$ MPa
$S_{ut} = 527$ MPa
$\tau_{(w/o\ keyway)} = 88.8$ MPa, $S_{yt} = 94.86$ mpa, S_{ut}
$\tau_{max(with\ keyway)} = 0.75 \times 88.8$
$= 66.6$ MPa
$3.819 \times 10^3 = (\pi/16) \times d_s^3 \times 66.6$
$d_s = 7$ mm
Std. $d_s = 7$ mm
Hub Proportion :
dia of hub = $d_h = 7$ mm
length of hub = $1.5 \times d_s$
$= 1.5 \times 7 = 10.5$ mm
Rim thichness = $t = 1.5 \times m$
$= 1.5 \times 1 = 1.5$ mm

D. Chain Drive

1. Desing power
$P_d = P_r \times K_l = 12 \times 1.2$
Where, P_r = rated power
K_l = load factor (moderated shock,10hrs = 1.2)
= 14.4 watts
2. Power in HP = $14.4 \times 10^{-3 x}746$
=0.000019 hp
Consider hp= 0.2
Rpm = 10
Chain no. = 25
Pitch=9.525 mm
Single strand
No. of teeth = 19
3. Pitch diameter of sprocket
$D_p = p/\sin(180/t)$
$= 9.525/\sin(180/19)$

= 57.86mm

Pitch diameter for all sprocket are same

$V_p = \pi \times D_p \times n /(60 \times 1000)$

$= \pi \times 57.86 \times 10 /(60 \times 1000)$

$= 0.030$ m/sec

4. Power per strand,

   $= p^2 \times [(v_p/104)-(v_p^{1.41}/526)(26-25\cos180/19)] \times 10^3$

   = 0.211 kwatt/strand
5. No. of strand = p_d / power per strand

   $=14.4 \times 10^{-3}/0.211 = 0.06 \approx 1$
6. Approximate Dimension for roller chain,

   Roller diameter,

   $D_r = 5/8 \times p = 5.95$ mm
7. Chain width =5/8 xp = 5.95 mm
8. Pin diameter= 5/16xp=2.97 mm

E. Sprocket Design

1. Width of sprocket teeth for single strand chain

   $t_o = .58p-.15 = 5.37$ mm

   Corner relief ,e=0.125p=1.19 mm
2. Chamfer radius ,r = 0.54 x p

   = 5.14 mm
3. Outside diameter, $D_o= p[0.6 +\cot(180/t)]$ = 62.79 mm
4. Root or bottom diameter , $D_r = D_p - 0.625p$

   =51.90 mm

F. Power Transmission & Torque

Power Transmission and Torque for cutting wheel

Cutting Wheel Capacity =304mm

Cutting Wheel Speed= 3600rpm

Motor = 2.1 kW

Motor Speed = 3600 rpm

Shaft Diameter = 25 mm

Power on the cutting disc

$P_{out} = \eta P_{in}$

Assume, $\eta=1$

$P_{out} = 1 \times 2100 = 2100$ W

Torque on the disc,

$T = (60P)/(2\pi N)$

$= (60 \times 2100)/(2 \times \pi \times 3600)$

$= 5.57$ N-m $= 5.57 \times 10^3$ Nmm

ØD = 356 mm

$F_c = 59.67$ N

$T = 5.57 \times 10^3$ N-mm

III. Advantages

To operate automatic cutting process there is requirement of only one person just for the feeding of pipe at regular interval of time and have sufficient knowledge of operating the machine. Following advantages can be achieved with proposed machine:

1) High productivity.
2) Less time consuming.
3) High accuracy.
4) Less human efforts
5) Increased cutting accuracy.
6) Enhanced reliability.
7) Easy to operate, performs precisely at high speed

IV. Limitations

Pipe cutting can achieve tight tolerances. However, because of the cutting action, sheared piping is slightly out-of-round.

Other disadvantages include tooling cost—dies are custom-made for specific ID requirements and setup time, which can take one to two hours. Therefore, cutting is not cost-effective for small runs.

Moreover, inherent difficulties are encountered in designing an effective transmission of conveyor belt and pneumatic mechanism which can move the pipe cutting machine at a satisfactory speed over a broad range of pipe sizes and thicknesses.

V. Future Scope

1) Machine can be improved to perform operation on different shaped jobs.
2) With the modification in design it can be model to perform various operations.
3) It can be modified to cut the pipes and rods of larger diameter which will help to reduce the time and cost of operation.

VI. Applications

1) Oil Industries
2) PVC Pipe Manufacturing Industries etc.
3) It is used for cutting pipes for pipe fitting purpose for even household works.

VII. Conclusion

1) The proposed automated machine is compact, light weighted, less costly and reduces the total cutting cost by 30%.
2) Automated operations are faster and have greater consistency and conformity to quality specification.
3) High production rate compared to other cutting machines.

   Thus, with a high accuracy and less human effort, the pneumatically operated automatic pipe cutting machine can serve the purpose at its optimum level.

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