Design of a Power Saving Industrial Conveyor System

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Abstract—This paper looked at the design of a power saving conveyor system which involves sizing, selection and cost benefit analysis of its installation. This paper focuses on factors that cause high belt power consumption and costs which are high starting torque and more operating hours hence there is design of drive control system consisting of soft starters and variable speed drives to reduce starting torque and load detecting switching system to reduce number of operating hours. The average power savings considering all the factors of reducing the system operating hours to the average of 12 hours a day and drive control system that reduces the starting power were calculated to be 47%. The annual costs of power consumption were reduced from $86212 to $40520 resulting in the payback period after investing to be 8 months. After doing cost benefit analysis it was ascertained that installation, operation and maintenance costs of the designed system are less than that occur on the initial system hence the design is worthy to install since it results in cost savings and increase in system life. The are some recommendations for the designed system which are clean ventilated environment to promote adequate cooling, belt protection against overload to avoid stops and also soft starters, variable speed drives and sensors protection against overvoltage and overcurrent so that the drive control system will not fail.

Index Terms—Design, soft starter, automation, control, conveyor, variable speed drive

I. INTRODUCTION

Conveyor systems are material handling mechanisms that allow quick efficient transportation of material from one point to another. Belt conveyors involve energy conversions from electrical to mechanical energy. The system had a number of benefits which promoted industry such as reducing transportation costs, move loads of all sizes and weights and safety features that prevent accidents. Although the system mentioned advantages it needs further developments such as improving efficiency and reducing energy losses and costs.

A: BACKGROUND

Most industrial conveyor systems have continuous operation without stopping for the reason of avoiding high power consumption during starting and stoppage of the system. High starting power will result high starting torque and shock loads giving rise to problems of short belt life due to more tension and also leads to more energy costs. In order to reduce these negative effects there should be a power controlling system and design of a belt with good strength qualities.

B. PROBLEM STATEMENT

High power wastage and belt failure due to high starting torque.

C. AIM

Design of an automated power saving industrial conveyor system.

D. PROJECT OBJECTIVES AND JUSTIFICATION

1. OBJECTIVES

- Design a system that start the conveyor belt at low power consumption
- Increase conveyor system performance in terms of output torque and power
- Increase average belt life

2. JUSTIFICATION

This design will have significance for the industry as its goal is to reduce power consumptions thus reducing energy cost. Low power consumption and low starting torque will result in reduction in shock loads and abnormal belt tensions hence the average belt life will be increased. The system will have speed control therefore for any load the speed will be adjusted to its safe speed that matches with its power demanding. The researchers automated the system and this reduces accidents since there will be less human interference.

II. METHODOLOGY

Industrial visit to local industries in Zimbabwe, design and calculations using AutoCAD and Mat lab software are used.

A. TECHNICAL SPECIFICATIONS

Belt normal speed \( v = 500 \text{ fpm} \)
Belt weight \( W_b = 17 \text{ lbs/ft} \)
Belt length \( L = 2,400 \text{ ft} \)
The belt is horizontal hence \( (H) \text{lift} = 0 \)
Capacity \( Q = 3,400 \text{ tonnes per hour} \)
Troughing spacing \( S_f = 3 \text{ Ft} \)
Belt width = 48 inches.
Ambient temperature = 60°F
Material to be conveyed = iron ore at 150 lbs./cu ft. 10-in. maximum lumps
Drive = lagged and grooved head pulley, 220-degree wrap
Final tensions:
Te = 16,342 lbs
T2 = 5,720 lbs
T1 = 22,062 lbs
Tt = 7,032 lbs

Troughing idlers = Class E6, 6-in. diameter, 20-degree angle
Return idlers = rubber-disc type, Class C6, 6-in. diameter, 10 ft. spacing
Cw = 0.35 from table 1
Wm = (33.3Q)÷V = (33.3×3400)÷500 = 226.4 lbs. per ft.
For 60°F, Kt = 1.0 as shown in tables 1 and 2.

III. DETAILED DESIGN

When choosing and dimensioning a motor the relevant parameters of all elements in the chain of energy flow, starting with the actual load, must be determined with relative accuracy. In order to do a proper selection of a motor it is necessary to find an ideal motor for the kinematic task at hand. An undersized motor will fail in continuous duty and an oversized motor causes unnecessary expenses and may run uneconomically.

A. CALCULATION OF MOTOR POWER AND TORQUES

Taking the effective tension in the belt from specifications mentioned in methods section.
Te = LKt(Kx + KyWb + 0.015Wb) + Wm(LKy + H) + Tac
Te = 16,342 lbs.

Where:
Kt= ambient temperature correction factor
Kx= idler frictional resistance factor
Ky=carrying run factor
Wb=weight of the belt
Wm=weight of the material
Tac =total tension rom conveyor accessories
H = height

Belt HP = \frac{3800}{16242 \times 500} = 0.3366

Drive pulley HP = \frac{3800}{200 \times 500} = 0.38

Where v is the belt velocity and 33000 is a constant derived from pounds of effective tension.

For calculating horse power for a motor shaft add 5% for speed reduction loss = 0.05(247.61 + 3.03) = 12.53

Horsepower at motor shaft = 263.17 HP then select (select 300 HP, 1,750 rpm, motor)

Motor rated power = 300 HP

From table 2 select nameplate voltage or rated voltage = 415v

Motor current = \frac{415 \times 1.75 \times 0.97 \times 0.82}{392A} \times 392 = 392A then take 400A

Foe 415volts motor corresponding full load current =390A (NHP Electrical Engineering Products Pty Ltd, 2013)

B. BELT PULLEYS

Drive pulley
Taking the belt with from specifications w=48 inch=1.2 m
Select USC drive pulley corresponding to belt width from the catalogue

TABLE III: DRIVE PULLEY SELECTION TABLE (RULMICA, 2009)

<table>
<thead>
<tr>
<th>Belt width</th>
<th>Pulley type</th>
<th>Diameter mm</th>
<th>Weight Kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>400</td>
<td>USC</td>
<td>320</td>
<td>59</td>
</tr>
<tr>
<td>500</td>
<td>USC</td>
<td>400</td>
<td>111</td>
</tr>
<tr>
<td>650</td>
<td>USC</td>
<td>520</td>
<td>191</td>
</tr>
<tr>
<td>800</td>
<td>USC</td>
<td>520</td>
<td>250</td>
</tr>
<tr>
<td>1000</td>
<td>USC</td>
<td>520</td>
<td>250</td>
</tr>
<tr>
<td>1200</td>
<td>USC</td>
<td>620</td>
<td>361</td>
</tr>
</tbody>
</table>
From table above select USC drive pulley of:
Diameter =0.62m
Weight =270kg

- Idler Pulleys
Taking belt width from specifications w = 1.2m
Select USF idler pulleys from the catalogue corresponding to belt width

<table>
<thead>
<tr>
<th>Belt width (mm)</th>
<th>Pulley type</th>
<th>Diameter</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>400</td>
<td>USF</td>
<td>190</td>
<td>37</td>
</tr>
<tr>
<td>500</td>
<td>USF</td>
<td>270</td>
<td>51</td>
</tr>
<tr>
<td>650</td>
<td>USF</td>
<td>320</td>
<td>69</td>
</tr>
<tr>
<td>800</td>
<td>USF</td>
<td>400</td>
<td>121</td>
</tr>
<tr>
<td>1000</td>
<td>USF</td>
<td>400</td>
<td>153</td>
</tr>
<tr>
<td>1200</td>
<td>USF</td>
<td>520</td>
<td>270</td>
</tr>
</tbody>
</table>

From table above selecting USF idler pulleys of:
Diameter= 0.52m, Weight=270kg

C. GEAR BOX SELECTION
When selecting a gear box there is need to find reduction ratio

\[ \text{Reduction ratio} = \frac{\text{Input rpm}}{\text{Output rpm}} \]

The motor input speed = 1750 rpm
\[ \frac{\pi \times D \times N}{60} \]

Output rpm is found from \( v = \frac{60 \times N}{\pi D} \)

Where \( D \) is the effective diameter of the driving pulley =620mm

Effective diameter = 620+24=644mm

Where the 24mm is added to compensate for lagging pulley
\[ v = \text{belt speed} = 500 \text{ft/min} = 2.54 \text{m/s} \]
\[ \frac{60 \times 2.54}{\pi \times 0.644} = 75.32 \text{ rpm} \]

Reduction ratio= 75.33 \ giving 23:1

Calculating starting time:
Accelerating torque taken from speed torque curve is 180% of full load torque

For drive efficiency of 95% horse power motor shaft to operate a loaded conveyor =263.17hp

Taking from specifications in methodology
Let Force of acceleration of loaded conveyor at belt speed 500fpm be \( Fa \)
\[ Fa = \frac{HP \times L \times 33000}{v} - \frac{P \times 33000}{v} \times 0.95 \]

Where:
1. HP is rated power
2. \( v \) is belt speed
3. \( P \) is actual motor shaft power
4. 1.8 and 0.95are accelerating torque percentage of full load torque and drive efficiency estimation respectively
5. 33000 is a constant derived from pounds of effective tension
\[ \frac{300 \times 1.8 \times 33000}{500} - \frac{263.17 \times 33000}{500} \times 0.95 \]

\[ Fa = 17358 \text{N} \]

Total equivalent mass= \[ \frac{32.2}{32.2} = 23880 \text{ slugs} \]

Calculating starting current
\[ \text{Starting current} = \frac{VOLTS \times 1.73 \times \text{EFFICIENCY} \times \text{POWER FACTOR}}{HP \times 746} \]

Current at starting HP is the value of starting power= 540 HP

\[ \frac{540 \times 746}{768.926} \]

Calculating starting current
\[ \text{Starting current} = 415 \times 1.73 \times 0.87 \times 0.82 = 705 \text{ amps} \]

D. VARIABLE SPEED DRIVES
Components of variable speed drives:
- Rectifier- Converts Ac power to fixed or adjustable dc power
- Inverter- produces controllable AC power output at desire voltage and frequency.
- Regulator- modifies inverter switching characteristics so that the output frequency can be controlled.

Considerations when selecting a variable speed drive:
- Motor type –squirrel cage induction motor
- Motor rated HP= 300HP
- Torque load Type-constant torque
- Starting methods – soft starting

Select a Variable voltage inverter (VVI) of following specifications from adjustable speed drives catalogue (Richard Okrasa, 1997)
- Efficiency= 93%
• Rated voltage = 380V AC
• Rated frequency = 60 Hz
• Output frequency range = 0.5 Hz to 60 Hz

The System is being protected against input voltage overload, output overcurrent and motor load.

Fig. 2. Variable speed operation in a closed loop control system

E. LOAD DETECTION SWITCHING SYSTEM

The load detection method to be used is through beam mode switching system. It consists of a transmitter and a receiver. A transmitter sends a beam of radiation to the receiver and the load is detected if the beam between the transmitter and the receiver is interrupted the output of the receiver switches state. In this case when load is placed on the belt it interrupts the beam thus switching on the system. A counting timer is used to set the on time delay in order to avoid stops when the load moves away from sensor detecting range. The timer starts counting when the load is placed on the belt and after the time that the material travels to the end has elapsed it will confirm if the sensor is detecting another load, if there is another load it resets and starts counting again until the sensor detects no load.

- Calculate the time moved by the load from loading point to the discharge chute
  
  BELT LENGTH

  Time t = BELT SPEED

  t = \( \frac{500 \times 60}{2400} \) = 288 seconds take 300 seconds ON delaying time

  Sensing range

  The transmitter and the receiver are placed at loading point across belt width
  Belt width = 1.2 m
  Take load detecting range to be 2m.
  Select Through beam sensor with inbuilt timer on delay 5 mins and load detection range 3m.

F. ENERGY SAVINGS

Power savings is achieved by:

- Reduced operating hours by provision of auto system switching
- Reduced starting current, voltage thus starting power with gradual system acceleration by use of a variable speed drives

G. OPERATING HOURS

The initial systems operate continuously the whole day giving 8760 hours per year

The designed system has average operating hours of hours per day giving 4380 hours per year.

Calculating Operating Annual energy consumption:

\[
\text{Annual energy consumption} = \frac{\text{Power consumed} \times \text{hours} \times 1.73 \times \text{Power factor}}{1000}
\]

Power consumed by belt = 185 kW, Power factor = 0.82

Initial system operating annual energy consumption= \( \frac{185000 \times 8760 \times 1.73 \times 0.82}{1000} \) = 2298983 Kilowatts-hours per year

Designed system operating annual energy consumption= \( \frac{185000 \times 4380 \times 1.73 \times 0.82}{1000} \) = 1149492 kilowatts-hours per year.

The annual operating energy consumption is being reduced by 50%

H. REDUCED STARTING CURRENT AND CONTROLLED ACCELERATION

The starting current at full load will be at minimum of 390A for motor of rated voltage 415V

The soft starter enables the system to start at a minimum current and the variable speed drive accelerates the conditions suitable for the system.

Starting current for the initial system = 705A calculated in later. Corresponding power = 540 HP

The designed system can start at minimum of 390A

Corresponding power = Voltage x current x 1.73 x PF

Power = 307 HP

The starting power is being reduced from 540 HP to 307 HP.
This is from 180% to 102% rated power and starting power is reduced by 43%. Average reduction in energy consumption = \frac{43 + 50}{2} = 47%.

### Table V: System Components versus Costs.

<table>
<thead>
<tr>
<th>System Component</th>
<th>Costs in US dollars</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soft starter</td>
<td>4100</td>
</tr>
<tr>
<td>VSD system</td>
<td>4500</td>
</tr>
<tr>
<td>Through beam sensor switch system</td>
<td>3000</td>
</tr>
<tr>
<td>Installation</td>
<td>1000</td>
</tr>
<tr>
<td>System protection devices</td>
<td>12600</td>
</tr>
<tr>
<td>Total capital cost</td>
<td>25200</td>
</tr>
</tbody>
</table>

The initial average Annual power consumption = 1149492 kilowatt hours

Annual consumption costs in $ = Average annual power consumption \times \$KILOWATT HOUR.

According to ZESA Zimbabwe’s average electricity costs $KWh=0.075$/KWh(Zympay, 2014)

Initial system annual consumption costs= 1149492\times0.075=$86212

Average savings = 47%

Annual savings = 0.47 \times$86212= $40520

Capital invested =\$25200

Payback period = \frac{25200}{40520} \times 12 \text{ months} = 8 \text{ months}

### Table I: Wrap Factors (CW) (CEMA, 2006)

<table>
<thead>
<tr>
<th>Type of pulley drive</th>
<th>Angle of wrap in degrees</th>
<th>Automatic take up bare pulley</th>
<th>Automatic take up lagged pulley</th>
<th>Manual take up bare pulley</th>
<th>Manual take up lagged pulley</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single, no snub</td>
<td>180</td>
<td>0.84</td>
<td>0.80</td>
<td>1.2</td>
<td>0.8</td>
</tr>
<tr>
<td>Single with snub</td>
<td>200</td>
<td>0.72</td>
<td>0.42</td>
<td>1.0</td>
<td>0.7</td>
</tr>
<tr>
<td>Single with snub</td>
<td>210</td>
<td>0.66</td>
<td>0.38</td>
<td>1.0</td>
<td>0.7</td>
</tr>
<tr>
<td>Single with snub</td>
<td>220</td>
<td>0.62</td>
<td>0.35</td>
<td>0.9</td>
<td>0.6</td>
</tr>
<tr>
<td>Single with snub</td>
<td>240</td>
<td>0.54</td>
<td>0.30</td>
<td>0.8</td>
<td>0.6</td>
</tr>
<tr>
<td>Dual</td>
<td>380</td>
<td>0.23</td>
<td>0.11</td>
<td>0.5</td>
<td>0.0</td>
</tr>
<tr>
<td>Dual</td>
<td>420</td>
<td>0.18</td>
<td>0.08</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

### Table II: Estimated Average Belt Weight, Multiple- and Reduced-Ply Belts, lbs/ft (CEMA, 2006)

<table>
<thead>
<tr>
<th>Belt Width</th>
<th>Material Carried, lbs/ft3</th>
<th>30-74</th>
<th>75-129</th>
<th>130-200</th>
</tr>
</thead>
<tbody>
<tr>
<td>18</td>
<td>3.5</td>
<td>4.0</td>
<td>4.5</td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>4.5</td>
<td>5.5</td>
<td>6.0</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>6.0</td>
<td>7.0</td>
<td>8.0</td>
<td></td>
</tr>
<tr>
<td>36</td>
<td>9.0</td>
<td>10.0</td>
<td>12.0</td>
<td></td>
</tr>
<tr>
<td>42</td>
<td>11.0</td>
<td>12.0</td>
<td>14.0</td>
<td></td>
</tr>
<tr>
<td>48</td>
<td>14.0</td>
<td>15.0</td>
<td>17.0</td>
<td></td>
</tr>
<tr>
<td>54</td>
<td>16.0</td>
<td>17.0</td>
<td>19.0</td>
<td></td>
</tr>
<tr>
<td>60</td>
<td>18.0</td>
<td>20.0</td>
<td>22.0</td>
<td></td>
</tr>
<tr>
<td>72</td>
<td>21.0</td>
<td>24.0</td>
<td>26.0</td>
<td></td>
</tr>
<tr>
<td>84</td>
<td>25.0</td>
<td>30.0</td>
<td>33.0</td>
<td></td>
</tr>
<tr>
<td>96</td>
<td>30.0</td>
<td>35.0</td>
<td>38.0</td>
<td></td>
</tr>
</tbody>
</table>
IV. CONCLUSION
The design system components were sized according to standard practice and were capable to meet the objectives of the projects. The project will boost industry with greater profit margins by reducing the power costs and maintenance costs. The system component such as variable speed drives and soft starters requires careful monitoring for protection against overcurrent and overvoltage. From cost benefit analysis the project investment has shorter payback period thus making it more beneficial.

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REFERENCES