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.

Manuscript received March 4, 2016; revised July 23, 2016
This work was supported by the University of Johannesburg.
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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 fpm
Belt weight Wb = 17 lbs/ft
Belt length L= 2,400 ft
The belt is horizontal hence (H)lift = 0
Capacity (Q) = 3,400 tonnes per hour
Troughing spacing S*i* = 3 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 = $\frac{Te\ v}{33000}$

Belt HP = $\frac{16342 \times 500}{33000}$ =247.61Hp

Drive pulley HP= $\frac{200 \times 500}{33000}$

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= $\frac{HP \times 746}{VOLTS \times 1.73 \times EFFICIENCY \times POWER\ FACTOR}$

Motor current= $\frac{300 \times 746}{415 \times 1.73 \times 0.97 \times 0.82}$ =392A then take 400A

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

(Load Power factor)^2 $= \frac{Input\ watts}{V \times I \times 1.73}$ $= \frac{184.7 \times 1000}{415 \times 390 \times 1.73}$ =0.67

Load power factor =0.82

Motor efficiency $= \frac{HP \times 746}{V \times I \times PF \times 1.73} = \frac{300 \times 746}{415 \times 390 \times 0.82 \times 1.73}$ =0.97

Efficiency= 97%

Starting power is 180% of motor rated power =540hp

Frequency = 60 hertz

Taking number of poles to be p=4

Synchronous speed Nsync= $\frac{120fe}{p} = \frac{120 \times 60}{4}$ =1800rpm

Rotor speed Nm= 1750rpm

Slip = $\frac{Nsync - Nm}{Nsync} = \frac{1800 - 1750}{1800}$ =0.0278

S=2.78%

Full load torque = $\frac{HP \times 5252}{FULL\ LOAD\ rpm}$

Full load torque = $\frac{300 \times 5252}{1750}$

Starting torque is expressed as percentage of full load torque in this case it is (180% full load torque) (GE Industrial Systems, 1993)

Starting torque=1.8(900) = 1620 lbs per ft.

Break down torque is also expressed as a percentage of full load torque (185% full load torque) (GE Industrial Systems, 1993)

Breakdown torque = (1.85 ×900) = 1665 lbs. per ft.

Pull up torque is expressed as a percentage of starting torque since rated power is more than 145hp according to (GE Industrial Systems, 1993) it is taken as (70 % of starting torque)

Pull up torque = (0.7×1620) =1134 lbs. per ft.

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)

Belt width	Pulley type	Diameter mm	Weight Kg
400		270	46
500	USC	320	59
650	USC	400	111
800	USC	520	191
1000	USC	520	250
1200	USC	620	361

ISBN: 978-988-14048-2-4
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

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 IV: IDLER PULLEY SELECTION TABLE (RULMICA, 2009)

Belt width mm	Pulley type	Diameter	Weight
400	USF	190	37
500	USF	270	51
650	USF	320	69
800	USF	400	121
1000	USF	400	153
1200	USF	520	270

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

Reduction ratio= $\frac{\text{INPUT rpm}}{\text{OUTPUT rpm}}$

The motor input speed = 1750 rpm

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

N= $\frac{60v}{\pi D}$ 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=belt speed =500ft/min=2.54m/s

N= $\frac{60 \times 2.54}{\pi \times 0.644}$ =75.32 rpm

Reduction ratio= $\frac{1750}{75.33}$ 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= [$\frac{HP \times 1.8 \times 33000}{V}$ - $\frac{P \times 33000}{V}$]×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

Fa = [$\frac{300 \times 1.8 \times 33000}{500}$ - $\frac{263.17 \times 33000}{500}$]×0.95

Fa =0.95-[300(1.8)-263.17] × $\frac{33000}{500}$

Fa=17358N

Total equivalent mass= $\frac{768926}{32.2}$ = 23880 slugs

Fa= ma

a= $\frac{Fa}{m}$ = $\frac{17358}{3800}$ =0.77ft per sec^2

t= $\frac{(Vt-V)}{60a}$ $=\frac{500}{60 \times 0.727}$ =11.46seconds

The starting time of the system is=11.46 seconds

Calculating starting current

Current = $\frac{HP \times 746}{VOLTS \times 1.73 \times EFFICIENCY \times POWER\ FACTOR}$

At starting current HP is the value of starting power= 540 HP

Starting current= $\frac{540 \times 746}{415 \times 1.73 \times 0.97 \times 0.82}$ =705 amps

Select soft starter with below features from soft starter selection guide:

- Operation voltage = 400-575V AC
- Operating current range= 4-1800A
- Start time = 1 -225 seconds
- Stop time = 0 – 225 seconds
- Ambient temperature= 0 -40 degrees Celsius
- X Design standards ICE 60947-4-2, EN 60947-4-2 (NHP Electrical Engineering Products Pty Ltd, 2013).

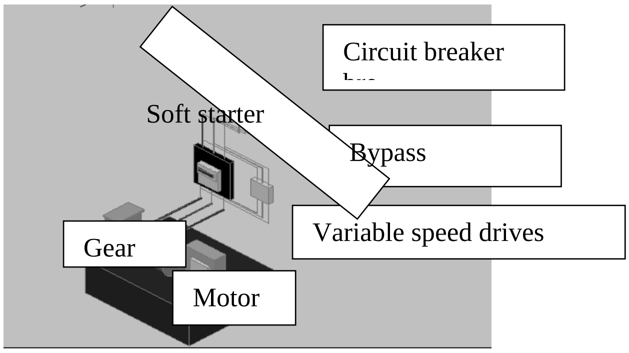

Fig. 1. Soft starter components connection to the motor and a gear box

D. VARIABLE SPEED DRIVES

Components of variable speed drives:

- Rectifier- Converts Ac power to foxed 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%

ISBN: 978-988-14048-2-4
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

- Rated voltage =380V AC
- Rated frequency =60 Hz
- Output frequency range= 0.5 Hz to 60Hz

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

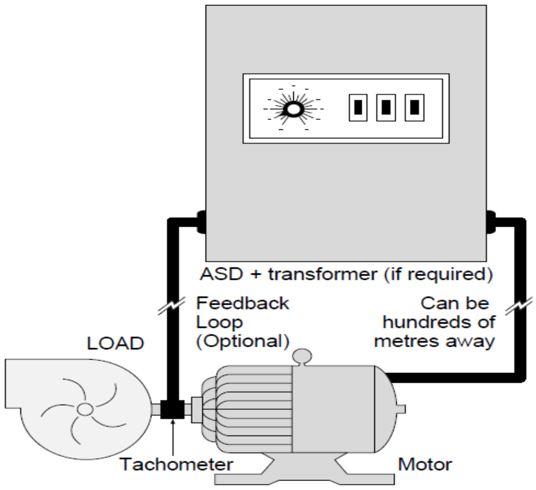

Fig. 2. Variable speed operation in a closed loop control system

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

Time **t**= $\frac{\text{BELT LENGTH}}{\text{BELT SPEED}}$

t= $\frac{2400}{500}$ ×60

t= 288 seconds take 300seconds

So the counter should count up to 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 5mins and load detection range 3m.

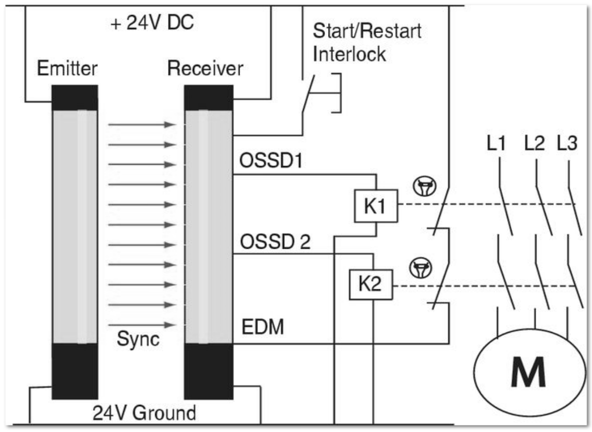

Fig. 3. Through beam switching system connection to the motor

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:

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 already calculated in last chapters

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 ×current×1.73×PF

Power = 307 HP

The starting power is being reduced from 540 HP to 307HP

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%

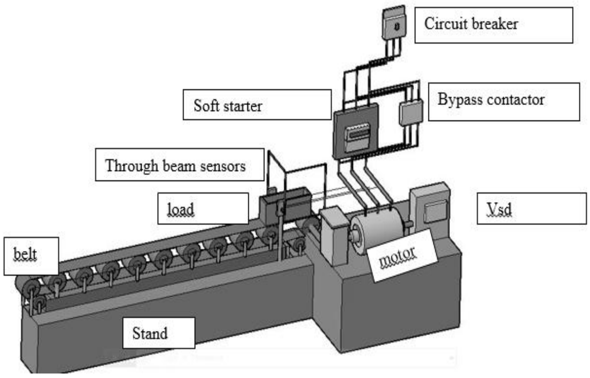

Fig. 4 Auto CAD diagram layout.

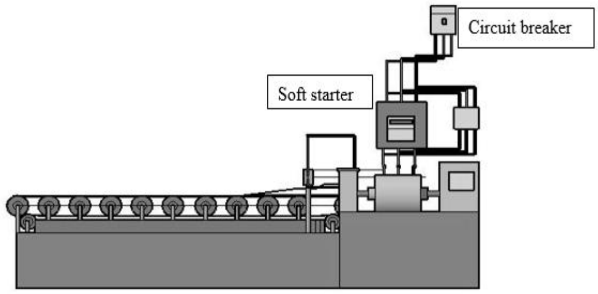

Fig. 5. Belt and power saving system

I. COST BENEFIT ANALYSIS

Break down cost of the system is calculated and shown in this section. Table V shows the average cost of variable speed drive system which is $ 4500, Soft starter is $4100 and for the through beam mode system is $3000 in US dollars(NHP Electrical Engineering Products Pty Ltd, 2013).

TABLE V: SYSTEM COMPONENTS VERSUS COSTS.

System Component	Costs in US dollars
Soft starter	4100
VSD system	4500
Through beam sensor switch system	3000
Installation	1000
System protection devices	12600
Total capital cost	25200

The initial average Annual power consumption = 1149492 kilowatt hours

Annual consumption costs in $ = Average annual power consumption $\times \frac{\$}{\text{KILOWATT HOUR}}$

According to ZESA Zimbabwe's average electricity costs $\frac{\$}{\text{KWh}}$=0.075 $/KWh(Zympay, 2014)

Initial system annual consumption costs= 1149492×0.075=$86212

Average savings = 47%

Annual savings = 0.47 ×$86212= $40520

Capital invested =$25200

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

TABLE I: WRAP FACTORS (CW) (CEMA, 2006)

Type of pulley drive	Angle of wrap in degrees	Automatic take up bare pulley	Automatic take up lagged pulley	Manual take up bare pulley	Manual take up lagged pulley
Single ,no snub	180	0.84	0.80	1.2	0.8
Single with snub	200	0.72	0.42	1.0	0.7
Single with snub	210	0.66	0.38	1.0	0.7
Single with snub	220	0.62	0.35	0.9	0.6
Single with snub	240	0.54	0.30	0.8	0.6
Dual	380	0,23	0.11	0.5	0.
Dual	420	0.18	0.08	_	_

TABLE II: ESTIMATED AVERAGE BELT WEIGHT, MULTIPLE- AND REDUCED-PLY BELTS, LBS/FT (CEMA, 2006)

Belt Width inches (*b*)	Material Carried, lbs/ft3 30-74	75-129	130-200
18	3.5	4.0	4.5
24	4.5	5.5	6.0
30	6.0	7.0	8.0
36	9.0	10.0	12.0
42	11.0	12.0	14.0
48	14.0	15.0	17.0
54	16.0	17.0	19.0
60	18.0	20.0	22.0
72	21.0	24.0	26.0
84	25.0	30.0	33.0
96	30,0	35.0	38.0

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.

Acknowledgment

I would like to thank my supervisor Professor Mbohwa for support and supervision. University of Johannesburg paid me all my trip and accommodation expenses.

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