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Factors Influencing the Performance of Belt Conveyor

N V Sarathbabu Goriparti[1*], M. Aruna [2], Ch. S. N. Murthy[3]
[1]Research Scholar, National Institute Technology Karnataka, Surathkal
[2]Assciciate Professor, National Institute Technology Karnataka, Surathkal
[3]Professor, National Institute Technology Karnataka, Surathkal

***Email:** sarathyadav225@gmail.com

Abstract
Belt conveyor is used for transporting coal, ore, mineral, and other such products from one station to another. The performance of the belt conveyor system signifies the quality and cost of a transportation system. This paper involves the review of the factors influencing the performance of the belt conveyor and also reveals the possibilities of improving its performance. The factors affecting the performance (performance metrics) of a belt conveyor are power consumption, specific energy, tension force, transfer rate (material discharge rate), wear and tear of the belt, starting and stopping times of the conveyor system, etc. These metrics show the quality and behavior of the conveyor system, give recommendations for the modifications and improvements with the advancing technologies, and helps to achieve future goals of the organization.

Keywords
Belt conveyor, Transportation, Performance metrics, Transfer rate

I. INTRODUCTION

Belt conveyor is a most economical and safe transport, used to transport bulk materials like ore, minerals, coal, and other such products from one station to another in most industries and production plants. It can transport materials for small to medium distances at various transportation capacities ranging from few tons per hour to thousands of tons per hour. Calculation of design parameters is a prerequisite for the installation of a belt conveyor. DIN (Deutsche institute for normalization) 22101, ISO (International Organization for Standardization) 5048 are CEMA (Conveyor equipment manufacture association) are the standards useful for belt conveyor design and calculation [1]–[3]. These standards are also necessary information for the selection of motor and gearbox. A Good design and control procedure will improve a belt conveyor performance, even help escape the conveyor from failure

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risks. The typical failure risks of a belt conveyor system are belt slippage around the drive pulley, belt over-tension at the splicing area, motor overheat, material spillage from the belt, and pushing motor into the regenerative operation. These risks of failures can overcome with the help of advanced modeling, design, and control techniques.

A belt conveyor performance metrics may be divided into four levels: equipment, design, control, and analysis levels [4]. At the equipment level, the performance, i.e., the conveyor's efficiency, can be improved by using the high power factor units, voltage correction units, dynamic voltage restorers, harmonic balancing techniques, and eddy current reduction dampers [5]. Secondly, at the design level, the design of conveyors with optimal tensile force, design of belts with less flexure, selection of belt materials based on the material to be transported, number of plies of the belt, the thickness of the belt, and size of the drive and return drum units, the weight of the idlers, the spacing between the successive carrying and return idlers and importantly selection of the drive motor and gear units for transportation. Thirdly, at the control level, the speed and the torque are the two critical mechanical variables to control and improve a conveyor system's energy efficiency. Even though the acceleration and deceleration of the conveyor depending on the conveyor design, the dynamic behavior may also depend on the control mechanism of the conveyor, i.e., the control of the motor. In past decades, belt conveyor may be controlled by conventional speed control methods like hydraulic methods, direct on-off methods, resistance and reactive bank units, mechanical couplings, and some mechanical relay and switching units. Since the last two and half decades, electronic control raises its hand and change the industries' shape helps the automation of industries, processing, and electricity generation plants. Finally, at the analysis level, it is essential to see the availability of all conveyor equipment which is necessary for transporting the material; failure of one equipment leads to either degrade or mall function of the total system and causing loss of the entire operation. However, it is not possible to provide all the equipment all the time, since failure in equipment is often an undesired and unavoidable thing in practices. Therefore, this problem can be reduced by providing minimum repair hours. In this article, the critical metrics for performance improvement and energy efficiency were studied in all four levels.

II. PERFORMANCE INFLUENCING FACTORS

The performance influencing factors of the belt conveyor system at different levels of the belt conveyor is given in TABLE 1.

Table 1: Performance Influencing Factors of Belt Conveyor at Different Levels

Level	Performance Metrics
Equipment	Drive system efficiency, the power factor of the drive motor, utilization factor of belt and the motor.
Design	Motion resistance, Transfer capacity, friction coefficient, wear and tear of belt, a lifetime of the belt

Control	Belt speed Acceleration and deceleration times, tension force, speed power consumption, power losses (constant and variable losses), total harmonic distortion (THD), steady-state error, system gain, conveyor run-time and
Analysis	Reliability, availability, maintainability, and safety.

Influencing Factors at Equipment Level

Drive System Efficiency

Drive system efficiency η_{sys} is the mechanical power P_{mech} required to run the belt conveyor divided by the motor's electrical power Pele consumed. The system efficiency is given by

$$\eta_{sys} = \frac{P_{mech}}{P_{ele}} \quad (1)$$

For a belt conveyor system, drive system efficiency is the product of the drive motor, power controller, and gearbox efficiencies. Drive system efficiency is an essential metric for the belt conveyor's performance since the cost for energy directly reflects any production unit's running cost. Nowadays, manufacturers design low weight, high power density, and low loss motors with high insulation levels, which are highly suitable for highly hazardous environments like underground mines.

Power Factor

The drive motor's power factor is the ratio of active power to the apparent power (real power). The power factor is given by

$$\cos\varphi = \frac{Apparent\ power}{Active\ power} = \frac{VI\cos\phi}{VI} \quad (2)$$

Where V is the supply voltage in Volt, and I is the line current in Ampere. For a given motor drive, the power factor mainly depends on the motor winding's resistance and reactance and the type of load it carries. The motor's resistance is independent of frequency, but the reactance of the motor changes with frequency causes a change in power factor. And, most of the industrial loads like fans, pumps, compressors, and conveyors, etc., are driven by the induction motor and considered inductive loads. Inductive loads have current lagging components by their inherence. Therefore capacitor banks are installed either inside/outside the motor to compensate for the lagging current. These capacitor banks improve the power factor of motors, provide less power consumption, low losses, high torque per ampere current, and low starting current.

Utilization Factor

The utilization factor of the motor and belt are the two key issues in the successful operation of a belt conveyor system. The type and rating of the motor should be suitable for the required load. Wrong selection of motor, i.e., selection of high rating motor than required, causes high power losses in the system and degrades the system efficiency, considered under-utilized motor operation. Also, selecting low-rating motor than required causes high motor currents and damages the winding and motor. Coming to the next, the utilization of the belt, in general, the conveyors are run with a material load less than the nominal capacity of the belt, causing high power losses. The utilization of the belt is given by

$$UF = \frac{Applied\ load\ on\ the\ belt}{Maximum\ capacity} \quad (3)$$

Influencing Factors at Design Level

Motion Resistance/ Belt Tension

Motional resistance is the opposition offered by the conveyor to motion due to the following: the weight of the moving parts (rollers, idlers, and belt), the weight of the load, gradient/ inclination of the conveyor, and friction which exists among the material and belt, belt and rollers and idlers and belt, etc. Therefore, a large amount of tensile load act on the conveyor due to the above mention loads. As per DIN 22101, the motional resistance/ belt tension F (in Newton) equals to the sum of Primary tension F_p (due to all friction related resistances along the whole length of the conveyor), Secondary tension F_s (due to the friction resistance, exists only at feeder and belt cleaner units), Gradient tension F_g (due to the inclination of the conveyor) and special tension F_{sp} (due to the accessories such as skirts plies etc., generally this value is less than 1% of total belt tension).

$$F = CfL\left[m_r + (2m_b + m_l)\cos\beta\right]g + Hm_l g \quad (4)$$

Where C represents the coefficient of secondary resistance, f is the Coefficient of friction, L is the conveyor length (distance between two pulleys), m_r, m_b, m_l are the unit weight of idlers, belt, material load, respectively, β is the inclination, H is the elevation and g is the acceleration due to gravity[1]. Where material mass, m_l is calculated by

$$m_l = \frac{T}{3.6v} \quad (5)$$

Where T is material transfer rate (t/h) at a belt speed v (m/s), at constant conveyor speed, the transfer rate is directly proportional to m_l. And the mass of the idlers is calculated by the diving mass of the idler set by idler spacing.

Friction Coefficient

Friction coefficient f is a value that shows the relationship between the force of friction between two objects and the normal reaction between the objects that are involved. For a given conveyor, it mainly depends upon the speed of the belt and the load on the belt. The value of f is generally between 0.016 (clean plant) and 0.027 (unfavorable conditions). A safe design value of f is 0.023 to 0.025.

Transfer Rate

Transfer rate or material discharge rate mainly depends upon, the width of the belt and speed of the conveyor. The transfer rate is estimated by using equation (5). At a given speed, the transfer rate of the material directly a function of m_l. The value of the m_l is the product of the density of the material to be transported, the cross-section area of the belt, and the length of the belt. The material cross-sectional area is the product of the width of the belt w and trough angle of the conveyor δ.

Belt Breaking Strength

The maximum tensile strength that the belt can withstand before undergoing failure is known as belt breaking strength. This factor is used for the selection of conveyor belts. It can be calculated by

$$S_{br} = \frac{C_f P_m}{C_b v} \tag{6}$$

Where C_f is the friction factor, C_b is the breaking strength loss factor, P_m is the power at the drive pulley, and v is belt speed.

Wear and Tear

Wear and tear is damage that naturally and inevitably occurs as a result of normal wear or aging. For given conveyor, wear exists between rollers and the inner portion of the belt. Wear can be eliminated by better belt designs, optimum tension force on the conveyor, and reasonable sag between drive and driven rollers. Further, movement of the belt on the idlers is also responsible for varying the wear; un-driven idlers may cause additional wear of the belt. The belt's wear also varied with the conveyor's speed and increased with the conveyor's speed.

Sag

Sag δ is the maximum allowable vertical distance between two adjacent idler sets obtained from a conveyor belt's catenary. It is given by [6]

$$\delta = \frac{w l_i^{\,2}}{8F_h} \quad (7)$$

Where w is the unit weight of belt and load, l_i is the spacing between the two idler sets, and F_h is the horizontal tension at the center of adjacent idler sets.

Influencing Factors at Control Level

Belt speed

In most industries and production plants, belt conveyors generally operate at a utilization factor less than unity. However, they have run at nearly nominal speed for which they design. DIN 22101 identifies some power saving by reducing the conveyor's speed employing an external frequency converter, called the speed control of belt conveyors. The electric motor manufacturers are given the motor speed in revolutions per minute, whereas belt manufacturers are given the belt speeds in meters per second. A gearbox with a gear reduction ratio of K is used to change the motor speed. The belt speed v in m/s is given by

$$v = \frac{2\pi N}{60} r \quad (8)$$

Where r is the radius of the drive pulley, and N is the motor speed after gear reduction in rpm.

Power consumption

The electrical power consumption represents a major cost factor when operating a belt conveyor system, and it is influenced by a large number of parameters like conveying length, electrical equipment used, operating technology, type of sensors, and control system used. Mechanical power required to run the conveyor P_{mech} is the product of motional resistance F and belt speed v. And, electrical power required to run the conveyor is obtained by dividing P_{mech} with drive efficiency[1]. And the value of load torque T_l is a product of belt tension F and radius of drive pulley r.

Starting

During starting, belt tension is much higher than the tension at a steady state. It is given by

$$F_{start} = F_{ss} k_s \quad (9)$$

Where F_{st} is the staring tension, F_{ss} is steady-state tension, and k_s is the start-up factor.

Acceleration

The conveyor acceleration a is given by

$$a = \frac{F_{start} - F_{ss}}{L(2m_r + 2m_b + m_l)} \quad (10)$$

The starting accelerations of small-distance (not more than 200 m), medium-distance (not more than 500 m), and long-distance (more than 500 m) conveyors are 0.1, 0.2, and 0.3 m/s^2, respectively.

Deceleration

The negative acceleration is called deceleration. The deceleration of small, medium, and long-distance conveyors are 0.3, 0.2, and 0.1 m/s^2, respectively.

Breaking/stopping

There are two types of braking used to stop the conveyor: dynamic braking and regenerative braking.

Influencing Factors at Analysis Level

Reliability

A system's reliability may be defined as the probability of the system will operate without failure under a given contain for a specified time. Its value varies from 0 to 1.

$$R(t) = 1 - F(t) \quad (11)$$

R(t) is the reliability function at time t in hours, and F(t) is the cumulative failure distribution function.

Availability

Availability is the percentage of time that a system is operating satisfactorily, and it mainly relays with two important functions: Mean time between failures (MTBF) and Mean time to repair (MTTR). MTBF is the mean of the failure distribution of a machine or component. For a constant failure rate, it is expressed as the total operating time divided by the total number of hours. And MTTR is the meantime require to repair a component, expressed as the total repair time divided by the total number of repairs. The availability of a system may be defined in terms of MTBF, and MTTR is given by

$$Availability = \frac{MTBF}{MTBF + MTTR} \tag{12}$$

III. PERFORMANCE IMPROVEMENT METHODS

Introduction of Energy Efficient Motors

Motor Efficiency is a factor influenced by the mechanical and electrical imperfection within the motor. In general, Energy-efficient motors utilize high-grade winding and core materials, have low power losses, generate less heat and noise, and produce high output for useful work. The National Electrical Manufacturers Association (NEMA) Standard MG-1.16 suggests energy-efficient motors [7].

Frequency Converters

A frequency converter is a solid-state device used for AC-AC conversion for stated voltage with different frequencies. It is used to control the speed and torque of an AC motor. Also, to convert the electrical power from one distribution standard to another. There are mainly three types of AC-AC converters, namely DC link converters, Cycloconverters, and Matrix converters. There are two types of converters with DC link: Voltage source inverter and current source inverter. Cycloconverter changes the alternating current of one frequency into alternating current of another frequency without any intermediate dc-link. Matrix converters also don't use any intermediate dc-links, converting the three phases alternating current with high power density and reliability.

Sensors and Transducers

Sensors are used to monitor the speed, motion, and alignment of the belt. They are also used to monitor the bearing and surface temperature of the drive system. Nowadays, Load cells having capacities of 5 kilograms to 500 tons are available in the market. A few of them are compression weight modules, tension weight modules, strain gauge load cell/ single-ended beam load cell, and canister/ ring load cell.

Soft Starters and Variable Speed Drives

Soft starter

A starter is a device that connects in series with a motor, used to regulate the high currents at starting. And soft starter is a device connected to AC electrical motors to regulate load and torque in the power train and electric current surge during start-up. The soft starter consists of electrical or mechanical devices or a combination of both. Mechanical soft starters include clutches and several types of coupling using a fluid. An electrical soft starter is any control system that reduces the torque by temporarily reducing the voltage and current input. The two important starters used for belt conveyor systems are *Hydro-viscous soft starters (HVSS).* Hydro-viscous soft starter or Hydro-viscous drive (HVD) is the drive that transmits power synchronously using oil film/ hydro-viscous shear stress [8]. *Magnetorheological soft starter (MRSS).* MRSS is a soft starter that works on the variable viscosity of Magnetorheological fluid (MR fluid). MR fluid is simply a fluid that changes its viscosity as per the applied magnetic field. The magnetic field can be varied by varying the current. As the amount of current increases, the magnetic field is increasing, so the fluid particles are trying to align themselves slowly and slowly. Now particles are showing a certain amount of force called shear stress. This property of shear stress is used in applications like dampers/brakes [9].

Variable Frequency Drive

Variable frequency drives have superior performance when compared to normal and soft starters. VFD has smooth control characteristics during starting, acceleration, deceleration, and stoping/ breaking. The drive for belt conveyors' requirements is high availability, high ability, smooth torque control, load sharing, speed variation based on load, reduced current harmonics, high power factor, and less perturbation to disturbances [10].

Programmable Logic Controllers

Programmable logic controllers (PLCs) are mainly used for industrial automation and process control. Allen Bradley, Siemens, and ABB are three of the major PLC manufacturers in the World. Underground transportation requires advanced technology and instrumentation for the sustainable growth and safety of mineworkers. Many parameters, such as belt tension, motor currents, speed, etc., need to be monitored simultaneously using suitable sensors.

Permanent Magnet Brushless Direct Current Motors

A permanent magnet brushless direct current (PMBLDC) motor is an AC motor having high power density and low weight when compared to induction and synchronous motors. Moreover, these motors don't require any brushes for commutation hence no problem of sparking and fire. Therefore they are well suited for underground mining applications.

Finite Element Methods

The finite element method (FEM) is a numerical method used to model, simulate, and analyze components/ physical systems. Some applications of FEM with belt conveyors include: analysis of dynamic transient forces propagated in a conveyor belt during its starting and stopping phases, integral analysis of conveyor pulley, and non-linear analysis and warping of tubular pipe conveyors, etc. [11].

Regression Techniques

Regression analysis is a set of statistical processes for estimating the relationships among variables. Various regression methods (also known as a method of least squares), linear, quadratic, cubic, polynomial, exponential, and logistic are available to develop regression models that could help us predict the performance of the output variables. Some of the developments with regression techniques are predicting dependence among the weight of sharp material falling on the conveyor belt and logistic regression in tracing the significance of rubber–textile conveyor belt damage [12], [13].

Reliability Studies

The reliability studies are carried with the failure data of the belt conveyor system. Failure data includes failure due to various sub-sections like belt staples, upper and lower idlers, belt tensioning system, belt, mechanical drive system, line supports, etc. Some of the developments in the reliability of belt conveyor systems are lifetime prediction conveyor belt joints, a least square method to determine the equation for wear of the conveyor belt joints, and replacement of staple joints with volcanized joints[14], [15].

Other Techniques

The other methods used for the improvement of belt conveyors are as follows: Self-adjusting apparatus for use in cleaning the surface of endless belt conveyor, leak-proof endless belt conveyor, belt conveyor with belt reinforcing member, conveyor belt wiper blade, belt conveyor idler, information-bearing belt conveyor, conveyor belt with built-in magnetic-motor linear drive, conveyor belt cleaner tensioning device, scraper assembly for a conveyor belt, steel cable conveyor belt with improved penetration and rip resistance, conveyor belt cleaner and linearly reciprocating conveyor apparatus.

IV. CONCLUSION

The study reveals the different factors that are involved in identifying the performance of the belt conveyor. These include equipment, design, control, and analysis. If these four factors can be improved in terms of their applications, then one can easily achieve better performances as such. The advancing technologies in the study considered are an application of energy-efficient motors that could help in the betterment of equipment and design. Frequency converters and variable frequency drives control the speed and torque of the drive motor that could enhance the controlling capacities of the drives resulting in the betterment of performance. Reliability studies can signify the life of the equipment and its parts; as such, we can understand the availability of the equipment/ parts for further usage, reducing the chances of failure.

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