ICMIEE20-275

A Comprehensive Analysis of Bucket Wheel Conveyor for Lifting and Conveying Granular Materials

Shahanaz Akther Sathi[1] , *Dipta Das Pranta*[1] , *Supti Saha*[1] , *Jawat Kabir Fahim*[1] , *Hayder Hossain Rahat*[1], *Toukir Ahmed*[2,*]
[1]Department of Mechanical & Production Engineering, Ahsanullah University of Science & Technology, Dhaka-1208, BANGLADESH
[2*]Lecturer, Department of Industrial & Production Engineering, Rajshahi University of Engineering & Technology, Rajshahi-6204, BANGLADESH

ABSTRACT
In the modern world, it is of great importance to transfer materials from one place to another without the help of the workers and reduce the life threats. The objective of this research work is to design and construct a machine that can lift and convey granular materials without the help of manpower. Over and above, this machine is not only confined in transferring coals but also can be used in glass manufacturing industries, construction sites, foundry shops which will increase the company's profit. This was designed based on some assigned themes and also according to the steps of product design like Market Analysis by surveying, Quality Function Deployment (QFD), Functional Decomposition, Specification and Design Analysis, Material Selection Process, Manufacturing Process Selection, Cost Analysis. In Market Analysis a survey was performed to know the customer requirements. Ensuring the customer requirements and technical requirements a relation was made between these two requirements by QFD. Then the design of the machine was specified. In addition, the material and manufacturing processes were selected. Moreover, a cost analysis was done based on break-even analysis. Ensuring these factors, this analysis was able to reduce production time. A prototype of the machine was made to test the overall production time based on the budget. From the cost analysis, it was found that the per-unit cost of the machine will be 21,146 BDT and the estimated profit will be 26,97,500 BDT if the sell is 600 units. As it is a prototype, it can convey materials upto 2.3 tons/hour. But with some modification & further development the capacity of this machine can be increased more. Also when the full scale industrial model is produced a whole new array of functions can be added to the machine. For a bigger machine the capacity will increase 5 times more than 2.3 tons/hour as the power of motor will also increase.

Keywords: Bucket Wheel Conveyor, Black Box Model, Cluster Function Structure, Stress Analysis, QFD.

1. Introduction

Bucket Wheel Conveyor (for granular materials) is a machine that is capable of loading and unloading materials at the same time without or with the very least manual labor. In various industries or working fields, traumatic injuries pose significant problems and can range from common hazards like fires, electrocution to death. Conventionally, manual material handling or lifting task leads to physical discomfort, fatigue, pain, or injury to the musculoskeletal system which in turn causes workplace accidents, and also productivity is less in manual handling [7]. The machine was designed for the simple purpose of eliminating the excess hassle of workers in respected factories and lessen the life threats mentioned or even eliminate them.

This product can be functioned in two ways, which are loading materials and transferring the materials to another spot. Two purposes, the wheel assembly and the conveyor can be served by the parts of our machine. The buckets attached to the wheel had scooped up materials from one place while the wheel rotated and dropped them onto the conveyor belt. The load was transferred by the conveyor to a designated location.

In manual handling, it takes time for the workers to carry materials from one place to the desired place but time can be saved by using this machine. Thus, the production rate will also increase. For coal transferring this machine also can be used. Coal dust also has been a significant threat, affecting coal workers' pneumoconiosis or 'black lung' and severe obstructive respiratory disease. Permanent brain damage, fracture, or perhaps death may include severe injuries. So, this machine can be used to reduce these risks as workers aren't exposed to hazardous conditions for a long time as much as they were before

The construction of this product started with a basic 2D sketch of what the machine might look like based on its functions and requirements. Then the parts needed for the machine such as motors, conveyor belt, roller, sheet metal were brought together and provided to a machine shop. A final 3D sketch was also provided to the shop and the required functions of the machine were discussed. After about 5 weeks of work, frequent visits to the shop, and some minor adjustments, the machine was up and running.

* Corresponding author. Tel.: +88-01764282138
E-mail addresses: ahmedshotez100@gmail.com

There are some research works have been conducted on the design, modification, and analysis of different types of the conveyor system. The combination of Belt and Bucket elevators with artificial intelligence integration was designed to perform complicated tasks in a shorter time and cost-effectively [1]. The main objective of designing this system was to automate the packaging and handling of bulk material [1]. The design of a machine that combined a conveyor belt with an inclined bucket elevator was established enabling the rapid transfer of a large quantity of paddy for use in the Myanmar agricultural field. In this system, less labor is needed [2]. A discussion was done about design considerations and analyses of the belt conveyor by using three roll idlers for conveying limestone. The development of an effective belt conveyor system was accomplished that can increase productivity and at the same time reducing the risks for the workers who operate them [3]. A Work on generating design data of belt conveyor was performed for the effective transfer of crushed biomass wood whilst also preventing fatalities at the time of loading or unloading [4]. A detailed review of the design modification of the belt conveyor system was given and the use of new technologies or methods used in various applications like coal mines, food, and cement industry was also illustrated [5]. An investigation on the reasons for fracture of the bucket wheel shaft during brown-coal mine was executed. The finding from that work was the shaft heat treatment was not properly performed [6].

In previous works of literature, a systematic way of designing any machine using methods such as QFD, material, or process selection was not practiced, a cost analysis was not performed, and even in most designs, there was no mechanism by which the machine could pick up the materials from the ground. In some previous work combining two types of conveyors such as bucket elevator combined with belt conveyor has been performed, but there is no work in which the combination of bucket wheel conveyor and belt conveyor has been designed and developed. This research will provide a useful industrial design for transferring granular materials that can minimize production time and life-threats. Since some researchers combined two types of conveyors to ease the material handling of different types of material, the concept of this research work came from that.

The main objective was for this machine is to build it in a way so that it can transfer materials while reducing risk factors and life threats of workers in industries and also to reduce production time while increasing the production rate

2. Methodology

To make sure that customer's needs were met, Market Analysis was conducted. According to market analysis following features were included in the machine. Light Weight, Durability, Sustainability, High Productivity, Low Power Consumption, High Functionality these are the features of the machine.

Table 1 Total percentage of importance of technical requirements.

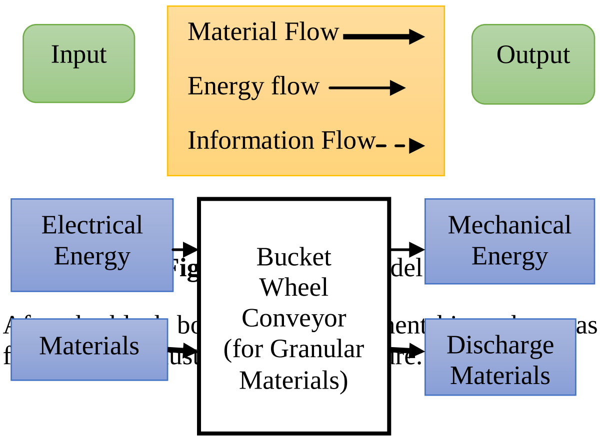
Technical Requirements	Total percentage of Importance
Motor Strength	22.09
Motor Size	2.8
Machine Design	10.2
Machine Size	8.5
Machine Weight	15.04
Material	16.4
Corrosion Resistance	10.6
Maintenance	14.4

From **Table** 1, These requirements are must for the machine. Motor strength is the most important requirement. If motor strength can be increased, the capacity of machine will be increased also. Moreover, the machine should be designed in such a way that there should not be any accident with the workers. This is how every requirements are important here. These requirements are percentage depending on the importance of requirements. This is how the design processes for the machine were done. Quality Function Deployment (QFD), functional decomposition, specification and design analysis, Material selection processes were done here. In QFD, House of Quality was done by considering customer requirements and technical requirements of the machine that was found out by us. The HOQ interprets the voice of the customer into design requirements that meet a specific target.

Table 2 Total percentage of importance of customer requirements.

Customer Requirements	Total Percentage of Importance
Light Weight	18.7
Low Cost	13.9
Safe Operation	21.5
High Production	14.6
High Functionality	9.7
High Sustainability	21.5

It is very important to know the requirements of the customers before making a machine. From **Table 2**, These customer requirements were found from a simple survey. From the survey results, percentage was calculated on the importance of customer requirements. The most important requirement was safe operation. Then sustainability of the machine was required after safe operation. So, this table was done on the basis of the requirements of the customers of this machine. After the completion of QFD, Functional Decomposition was implemented. Functional decomposition is a way of breaking down the involute quandary into simpler quandaries predicated on the tasks that need to be performed rather than the data relationships.



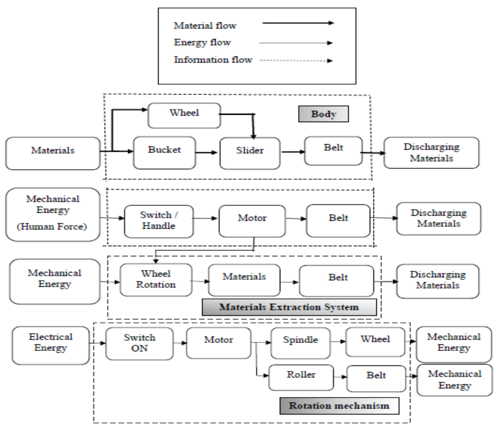


Fig. 2 The Cluster Function Structure

In the design review a 3d sketch was proposed that sums up the expected design of our product.

The components of the machine and the specifications are shown in the below table.

Table 3 Machine specifications

Criteria	Specifications
Body Frame	1.3/1 ft
Bucket Wheel	1 pc
Bucket	6 pcs
Induction Motor	2 pcs
Voltage	220 Volt
Current	24 Amp
Conveyor Belt	1 pc
Belt (length)	6 ft
Wheel (diameter)	1.6 ft

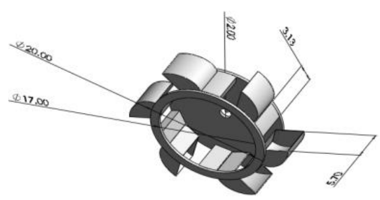


Fig. 3 Wheel with Buckets

As the model was a prototype, six buckets were used here initially. But The number of buckets can be increased for bigger machine. With the help of these buckets, the machine avails to hoist the material from ground till slider. Different types of granular materials can be carried out.

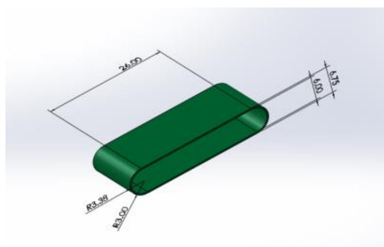


Fig. 4 Design of conveyor belt.

This conveyor belt will avail to convey the materials to the desired place. Depending on the materials the conveyor belt can be changed. This is how the whole machine will work out. The granular materials like stones, coals, sand, nuts, rice, coffee, fertilizer etc can be conveyed. Mainly, 63 microns to 5 centimeters of granular materials can be conveyed by this machine.

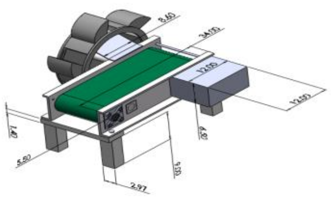


Fig. 5 Main machine assembly.

The overall design of the machine was maintained in a way so that **quality**, **safety** and **reliability** can be assured.

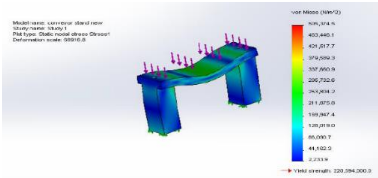


Fig. 6 Stress Analysis of stand.

Stress analysis is mainly done in every part of the machine so that the stress analysis avails to identify where structures are meeting prospects and how can amend on others .

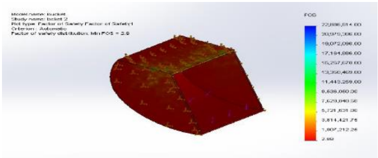


Fig. 7 Factor of safety of bucket

A factor of safety increases the safety of people and truncates the jeopardy of failure of a product.

Software Used: For the structural design, SolidWorks 2013 was used. SolidWorks is a solid computer-aided design (CAD) and computer-aided engineering (CAE) simulation computer software that predominantly runs on Microsoft Windows. Dassault Systèmes launches SolidWorks.

Detailed Engineering: Two induction motors were utilized for the conveyor belt and the wheel. The motors were additionally housed into covers composed out of sheet metal so that they are not damaged.

Material Selection Process: First, it was decided on the requisites of the application. Second, it was decided on the possible materials we can utilize in the application. Third, what vicissitudes in the material properties are needed. Lastly, which material out of the possible materials best consummates the requisites of the application given possible vicissitudes in the material properties.

Manufacturing Selection Process: Manufacturing processes are the steps through which raw materials are transformed into a final product. The manufacturing process commences with the engenderment of the materials from which the design is made.

Support: After Post engendered indispensable steps to ascertain that our product perpetuates to operate as designed and that management and staff in the respective organizations are confident, comfortable, and capable to perpetuate to prosperously operate the system when we are long gone.

Perpetual Amendment: As technology grows and more incipient machinery ameliorates, it was ascertained that our product ameliorates as time advances.

Cost Analysis: This expense can include the price of components, labor, overhead (e.g., building, power), packaging, shipping, and advertising, among others. Unit cost of machine parts and its specifications are shown in the table 4.

Table 4 Unitary cost of machine parts

Components	Specifications	Unitary Cost (BDT)	% of cost
Motor 1	90 W	1900	11.27
Motor 2	60 W	1700	10.08
Coupling Bearing (3)	Cast Iron	1200	7.12
Ball Bearing (3)	Carbon Steel	600	3.56
Conveyor Belt	Composite Rubber	4500	26.70
Frame	Mild Steel	1800	10.68
Wheel Disk	Mild Steel	800	4.75
Bucket (6)	Mild Steel	1800	10.68
Stand (2)	Mild Steel	600	3.56
Roller (2)	Stainless Steel	1000	5.93
Shaft	Mild Steel	400	2.40
Bolts & Nuts (16)	Mild Steel	200	1.19
Slider	Stainless Steel	200	1.19
Supporting Rod (Spindle)	Mild Steel	150	0.9
Total		**=16,850**	**=100**

In **Table 4**, every parts of the machine and their materials with the cost is shown. The cost can be increased for bigger machine in the industry. The cost will be dependent upon the cost of the machine parts.

Lifecycle cost is an important economic analysis used in the selection of alternatives that impacts on both pending and future costs.

Table 5 lifecycle cost of the machine.

Cost Types			Variable Cost (BDT)	Fixed Cost (BDT)	
	1st Year	**2nd Year**	**3rd Year**	**Life-cycle Cost**	**Per Unit Cost**
R&D	1,39,000	12,000	12,000	1,34,000	0
Facilities Expenses	1,10,000	1,39,000	1,39,000	4,17,000	0
Production cost	2,15,000	2,15,000	2,15,000	6,45,000	17,700
Marketing cost	50,000	30,000	18,000	98,000	400
Distribution cost	30,000	30,000	30,000	90,000	220
Customer service cost	25,000	25,000	20,000	70,000	300
Overhead cost	66,500	62,500	60,500	1,89,500	0
Total Cost	**6,35,500**	**5,13,500**	**5,19,500**	**17,68,500**	**18,620**

In Table 5 lifecycle cost was calculated on basis of 3 years cost. 1st year, 2nd year and 3rd year cost was done in BDT.

Sales Scenario: A sales scenario is a method of training and preparing for future sales situations, to have an answer to any possible replication by the customer. A salesperson will go into a situation prepared for many different sales scenario options, ideally with as much erudition as possible about the customer ahead of time.

Table 6 Sales scenario of the machine.

Year	Sales
1	200
2	250
3	250

s = Sales price per unit = 25,000 BDT (assumed)
Q = number of units produced
= 700 (assumed)
TR=Total Revenue
=s*Q = 25,000 * 700 = 1,75,00,000 BDT

F= Fixed costs = 17,68,500 BDT
V= Variable cost per unit
= 18,620 BDT
TC= Total costs
= F+v*Q = 17,68,500+(18,620*700)
= 1,48,02,500 BDT
Per unit cost = 1,48,02,02,500/700
= 21,146 BDT

Sales scenario datas were assumed here. Different sales scenario options were assumed to find out possible replication by the customers. Here, it was assumed that the first year sales would be 200 and the sales can be increased for the demand of customers. Total sales scenario was assumed here 700 for 3 years.

Break-Even Analysis: A break-even analysis is a utilizable implement for determining at what point your company, or an incipient product or accommodation, will be remuneratively lucrative.

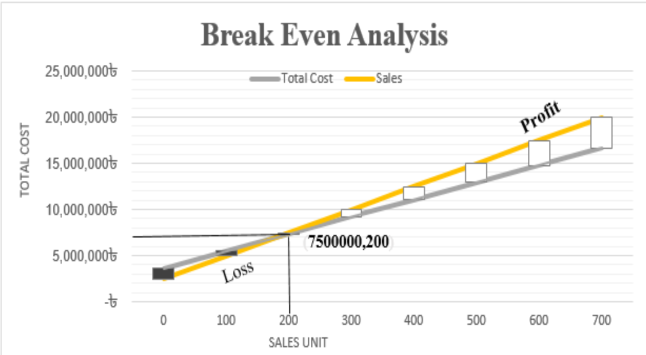


Fig. 8 Break-Even Analysis Chart

BEP_X= Break-even point in units
= F/(s-v)
= 17,68,500 ÷ (25,000-18,620)
= 277 BDT
≈ 200 units

From the chart of break even analysis it is seen that the break even point is 200. It was found from Sales unit that was assumed and total cost of machine. Break even point 200 means , profit will be gained after this point.

3.Result Analysis

Results from QFD:

Here, an interrelationship between technical requirements and customer requirements was established. A strong interrelationship is rated by 9. Then a moderate relationship is rated by 3 and a weak interrelationship is rated by 1. The customer requirement for High Sustainability and safe operation has the highest percentage value which was 21.5% of total percentage. High functionality was the least required feature from the customer with 9.7%. From the calculation, it was found that motor strength has the highest importance which is 22.09% and the lowest was motor size with a value of 2.8%.

Results from the material selection process:
"Weighted Properties Method" was used in this material selection process.
Scaled Property, β = Numerical value of property / Maximum value in list*100
Scaled Property, β = Minimum value in list /Numerical Value of property*100
After obtaining the weighting factor (α) from a "Digital Logic Method" and scaling factor (β) from the equations above, the performance index (γ) was found.

$$\gamma = \alpha * \beta$$

The quantitative analysis was done on body frame, stand of conveyor belt, and bucket wheel with spindle using the formulas. AISI 1018 Mild steel was selected.

Results from cost analysis:
Cost analysis was carried out to determine the overall production costs and the optimum production level. From the lifecycle cost calculation, it was found that the fixed cost will be BDT 17,68,500 and the variable cost will be BDT 18,620 throughout the life cycle. After completing the cost calculation, per unit cost of the machine is found 21,146 BDT. This cost was mainly calculated by dividing total cost by total unit that was found from sales scenario. A break-even analysis was also done in which it showed 200 units of product needs to be sold to get the breakeven point and also if 600 units can be sold which is the anticipated sell, the profit will be the BDT 26,97,500.

4.Conclusion:

Developing a less workers-needed system, minimizing production time, and reducing the life threats of workers, was the main motto of designing this machine for conveying granular materials. In this machine, the section where the buckets are attached with the wheel capable of picking up the material directly from the ground without the workers' assistance. This picked up material can then be shifted automatically to the belt conveyor without any spillage using a slider. Finally, the conveyor belt plays a crucial role in this machine as it is a highly effective means of conveying granular materials. A systematic approach with different methods followed here for designing this machine. From the QFD method, it was found that the highest customer requirement is sustainability and safe operation, which is 21.5%. The cost analysis showed that this machine's per-unit cost will be 21,146 BDT and 200 units of the machine should be sold to achieve the break-even point. The only limitation is that the material has to be in a stack to collect it from the ground. The capacity calculation, overall load-carrying capacity improvement, and some design features such as the wheel's up-down motion can be added for future research work.

5.References:

[1] Taher, G. A. et al. (2014) 'Automation of Material Handling with Bucket Elevator and Belt Conveyor', International Journal of Scientific and Research Publications, 4(3), pp. 1–13.

[2] Theint, K. and Lin, T. (2018) 'Design Consideration of Bucket Elevator Conveyor', 5(2), pp. 1–4. Available at: http://www.ijirst.org/articles/IJIRSTV5I2001.pdf.

[3] 'Design of a Material Handling Equipment: Belt Conveyor System for Crushed Limestone Using 3 roll Idlers' (2014) Journal of Advancement in Engineering and Technology, 1(1). doi: 10.15297/jaet.v1i1.06.

[4] Jagtap, A. A. et al. (2015) 'Design of Material Handling Equipment: Belt Conveyor System for Crushed Biomass Wood Using V Merge Conveying System', Int. J. Mech. Eng. and Rob. Res,4(2),pp.38–48. Available at: http://www.ijmerr.com/uploadfile/2015/0415/20150415111336481.pdf.

[5] Kumar, D. and Mandloi, R. K. (2013) 'Analysis and Prospects of Modification in Belt Conveyors - A Review', International Journal of Engineering Research and Applications, 3(1), pp. 581–587. Available at: http://www.ijera.com/papers/Vol3_issue1/CL31581587.pdf.

[6] Rusiński, E. et al. (2010) 'Examination of the causes of a bucket wheel fracture in a bucket wheel excavator', Engineering Failure Analysis. Elsevier, 17(6), pp. 1300–1312.

[7] Suryoputro, M. R., Wildani, K. and Sari, A. D. (2018) 'Analysis of manual material handling activity to increase work productivity (Case study: Manufacturing company)', *MATEC Web of Conferences*, 154. doi: 10.1051/matecconf/201815401085.