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Original Article

Design and Implementation of a Chip Separation Mechanism and Software for A Machine Tool System

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Abstract - *Metal cutting or machining is the process of eliminating undesired material from metal in order to produce accurate components. This essential procedure, vital for contemporary items, operates with a diverse range of materials such as metals, ceramics, and semiconductors, guaranteeing precise shape, smoothness, precision, and integrity of the surface. During high-speed machining, chips are produced at a rapid pace, which requires the use of cutting oil to provide lubrication and cooling. The objective of this project is to create a chip removal system that can effectively gather and separate chips and cutting fluid. This system is essential for modern machine tool systems that require a high level of precision. Gaining a comprehensive understanding of the mechanics involved in removing material is crucial for achieving cost-effective machining. The chip removal mechanism is engineered to efficiently manage substantial chip and coolant oil quantities within a limited area, accomplished by modifications to the screw conveyor architecture. The drawing and 3D modeling processes make use of AutoCAD and Pro-E software to make use of the parametric capabilities. In addition, software programming utilizing Visual Basic .NET is employed to analyze factors in order to improve productivity and optimize production processes*.

Keywords - *Metal cutting, High-speed machining, Precision machining, Material removal mechanisms, Screw conveyor parametric features, Software programming, Visual Basic dot Net.*

1. Introduction

The recycling of metals has emerged as a paramount problem in contemporary industrial progress. The supply of rare earth metals continues to decline while the expense of mining grows with greater depths of excavation. While not all metals are recyclable, the bulk of them may be utilized until they reach their maximum recyclable lifespan. Ferrous metals and non-ferrous metals are materials that include iron in their compounds, causing them to be attracted to magnetic fields. Non-ferrous materials are substances that do not have a magnetic attraction but yet show certain properties when they come into contact with magnetic fields. Due to this characteristic of metals, they may be classified as either magnetic or non-magnetic [1].

Material removal operations are frequently required to provide the needed level of dimensional precision, geometric features, and surface quality qualities in components, especially those with intricate geometries that cannot be cheaply or efficiently manufactured using shaping methods [2]. Material removal refers to the process of eliminating undesired material from the surface of an item. However, this process typically takes a longer time and results in the generation of waste in the form of chips. Additionally, it may have a negative impact on the quality of the surface created. The utilization of material removal processes and machines is essential in the field of manufacturing technology. The current cutting agent has a long history of usage in the metal processing industry and has grown into a broad spectrum of products. Cutting solvents are divided into two categories: based on oil solutions and solutions containing water [3].

Since its introduction in the 1700s, the lathe has spurred the continual development of several techniques. We currently possess a wide range of computer-controlled equipment, along with novel approaches that utilize lasers and other energy sources such as electrical, chemical, thermal, and hydrodynamic. Because of its many uses in the biological, commercial, and medical fields, the physical separation of elements and cells has generated much attention [4].

The cutting process fluid systems are currently prevalent in modern machine tools to improve process efficiency. Because there is little visual vision through the course of machining, the effect of the cutting agents on the various cutting force elements and the ensuing transfer of heat is a complicated physical phenomenon that is difficult to investigate experimentally [5]. With the use of this technology, contaminants from synthetic joints may be extracted and separated, leading to the separation of combined wear debris and the outstanding extraction-rate capture of wear debris pictures. It makes it possible to look at how synthetic joint implantation wears and offers insightful data on how well the newest synthetic joint implants under study wear [6]. Figure 1 shows the categorization of material removal techniques.

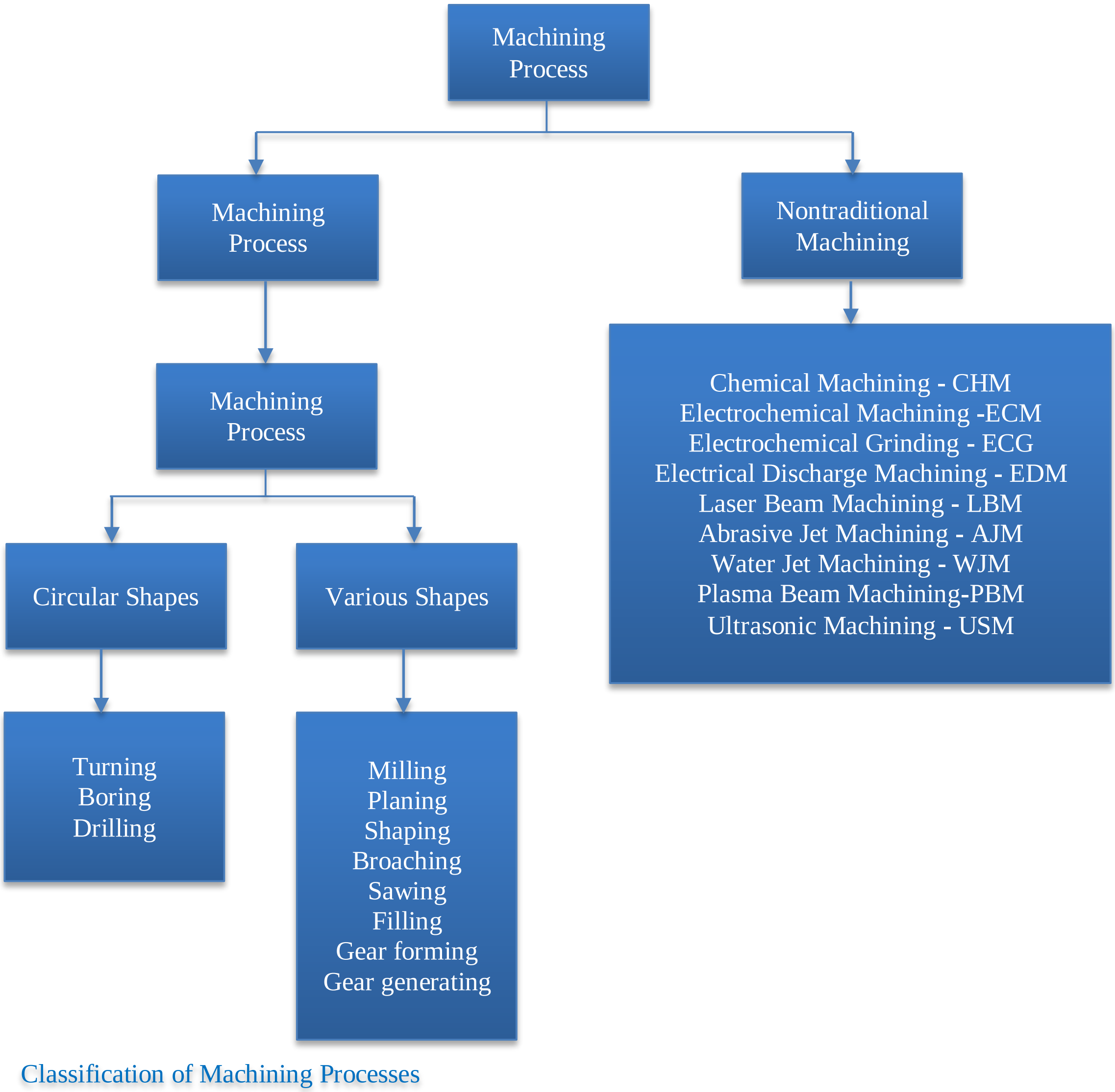


Fig. 1 Overview of material removal processes

2. Literature Review

Regarding waste produced in machinery, such as metallic chips seen in Figure 2, the metallurgical and equipment industries commonly utilize remediation and post-generation treatment methods, also known as eco-efficiency. Nevertheless, there is an increasing inclination to adopt approaches that prioritize the enhancement of production processes to reduce waste formation, optimize processes, and improve the efficient utilization of raw materials and energy (known as eco-effectiveness). These innovative methods allow the industry to recycle solid waste more effectively, even garbage that was previously intended for disposal in landfills, resulting in nearly total recycling [7].

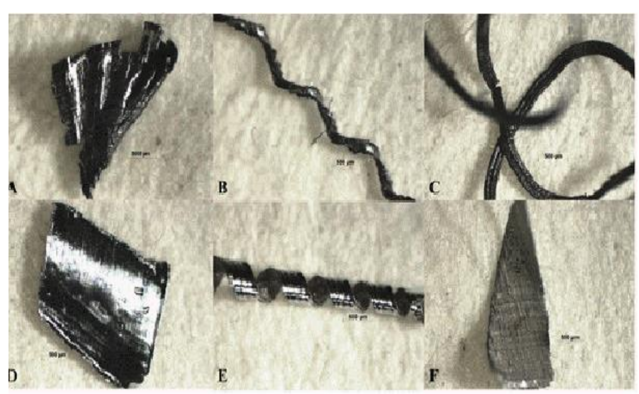


Fig. 2 Contamination of steel and aluminum chips with cutting fluid

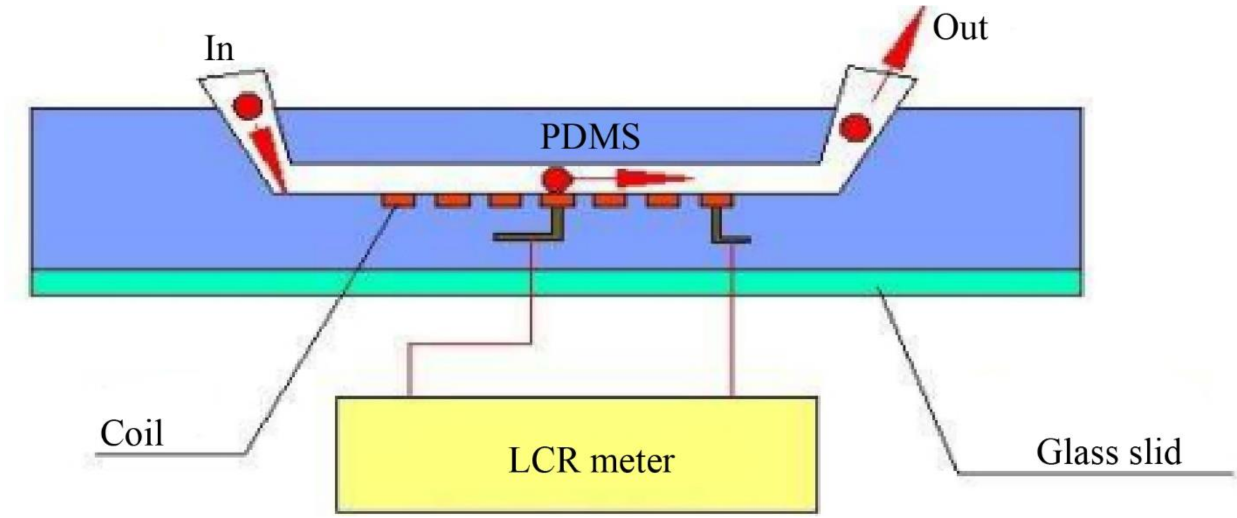


Fig. 3 Diagram of the microfluidic device that detects metal particles in hydraulic oil

According to the previously mentioned idea, when a ferrous or non-ferrous metal grain joins an inductive coil, the coil's corresponding inductance changes dramatically. The change causes the LCR meter to produce a pulse signal, with distinct signals coming from each sort of particle. Consequently, by identifying the pulse signal linked to the inductive change in the coil, it becomes possible to distinguish between ferrous and non-ferrous waste. Moreover, this technique allows for the estimation of the amount of material that is now present [8].

In scrap sorting procedures, iron-containing ferrous scrap metal typically serves as the initial material for segregation. Some examples of these metals are alloy steel, carbon steel, cast iron, and wrought iron. Recognizing that there is a common misconception that ferrous materials are magnetic and vice versa is important. The phenomenon known as ferromagnetism describes the magnetic properties displayed by certain materials.

These materials possess the capacity to either generate permanent magnets or attract them. Materials that display ferromagnetism include iron, nickel, cobalt, certain rare earth oxides, and naturally occurring minerals such as lodestones. It is worth noting that magnetite, which is present in lodestones, is technically ferrimagnetic, a feature similar to ferromagnetism. Additionally, there exist additional forms of magnetism, namely Para magnetism, diamagnetism, and antiferromagnetism, which often exhibit less pronounced effects [9].

The lubricating oil system plays a crucial role in machinery, serving as its operational medium. Assessing the machine's operating state is important, and its detection capabilities can reduce the necessity of expensive equipment shutdowns for examination. Among all the crucial elements in lubricant detection, the concentration of metal particles is particularly significant. Inductance detection has become a popular approach for detecting metal particles. It uses advancements in microfabrication technology to measure the size of particles and count how many are present. Disruptions in machine function are undesirable, highlighting the importance of effective detection techniques [10].

3. Methodology

A chip separation apparatus, commonly employing a magnet, removes iron scraps and impurities from coolant oil used in various industrial machines, such as grinding, metal cutting, and rolling machines, ensuring purified oil for reuse [11]. Metal cutting involves separating a certain size of cutting layer from the workpiece under the tool's action, accompanied by high temperature, strain rate, and strain. Machine tools achieve desired component shapes by removing material in the form of chips or swarf.

With advancements like carbide tools and rapid machine tool development, large chip quantities are produced quickly [12]. Screw feeders and conveyors, prevalent in various industries, transport and mix granular materials. Efficient chip removal is crucial to prevent obstruction of tool flow, which can affect workpiece quality and pose hazards in automatic machines [13].

Conventionally, chip removal involved unsafe, inefficient methods like tank shutdowns for oil cleaning. Designing screw conveyors for efficient chip-metal transfer from cutting fluid enhances process speed and complexity while catering to high chip production rates. Different chip types, including continuous and discontinuous, require tailored removal mechanisms, with discontinuous chip removal often prioritized due to its prevalence. Despite the seemingly simple mechanism of screw conveyors, understanding particle handling physics is essential due to varied behaviors across different fields [14].

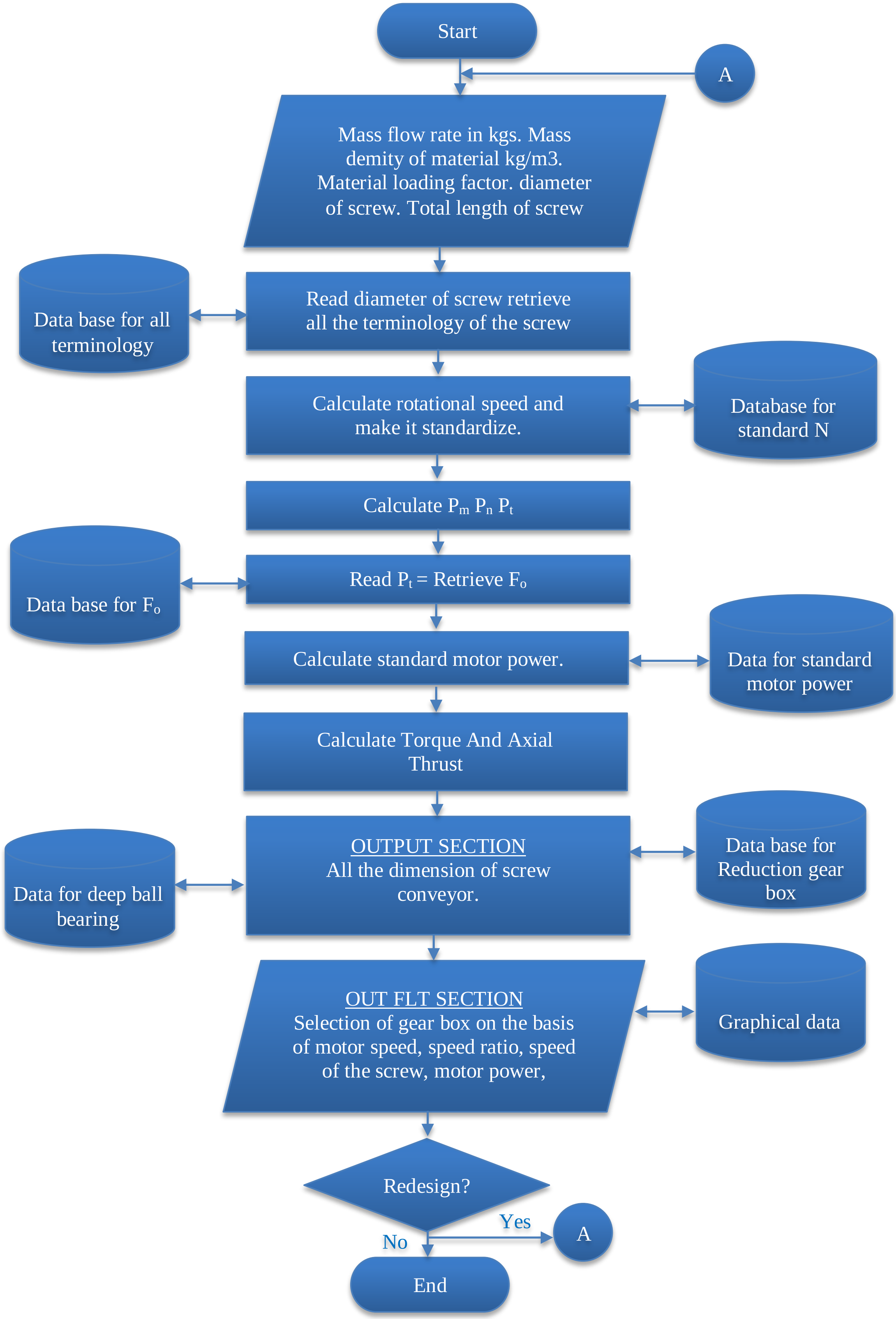


Fig. 4 Methodology flowchart

4. Assembly Drawing of Mechanism

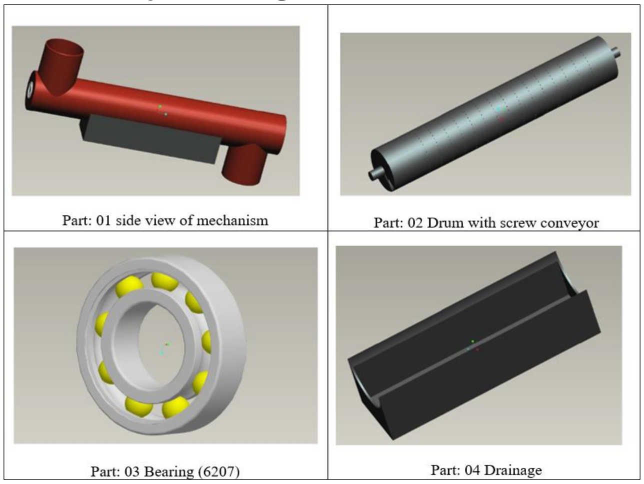


Fig. 5 Detailed drawings of chip removal mechanism (Pro Engineer) [15]

5. Design Calculation for Screw Conveyor

Each time machining is performed, a certain quantity of material is removed from the workpiece. Therefore, it is imperative to determine the volume of material that is eliminated throughout the machining process. The progress in contemporary machine tools and tooling processes, driven by the need for increased productivity, has enabled the efficient production of large amounts of metalwork parts in a shorter time. As a result, there is a higher production rate of metal swarf [16, 17]. To achieve this objective, it is important to establish an appropriate system for collecting and disposing of chips in machine tools. For example, let us consider a gear blank made of steel.

The difference between the volume of raw material used to make the blank and the volume of the final gear is equal to the volume of material that was removed during the manufacturing process. Let us suppose this volume is 20kg. Suppose we are able to produce 5 gear blanks every hour. In that case, the rate at which metal is being removed per minute is calculated by multiplying the volume of material removed per piece (20kg) by the number of pieces produced per minute (5), resulting in a rate of 100 kg/min. Assuming that in machining, 60% of the chip and 40% of the cutting fluid are eliminated, A total of 60 kg of chips and 40 kg of cutting fluid are produced.

The timing of the screw conveyor is set to rotate the Screw for 60 seconds, during which it removes 60 kg of metallic chips together with cutting fluid. The chip material used for the production can be assumed to be made from heavy materials such as steel or bronze. In this case, steel is used as the material for the screw conveyor's design.

Considering the information provided, the screw conveyor's design [16]:

Mass flow rate (ms): 1.0 kg/s
Density of steel (ρ): 7850 kg/m^3
Required diameter of the Screw (D_SC): 160 mm
Total length of the Screw (l): 1000 mm
Material loading factor (k): 0.15
Material resistance coefficient (fm): 6

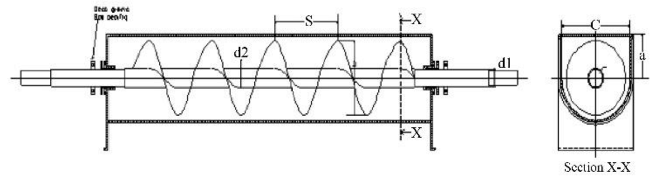


Fig. 6 Design mechanism of screw conveyor

1. Speed required for screw conveyor:

$$N = \frac{[ms \times 4]}{[\rho b \times \pi \times (D_{SC^2} - D_{SH^2})}$$

$N = 21.4\ RPM$ (for gear ratio 70)

2. The power required for screw conveyor:

$$P_f = \frac{(21.4 \times D_{SC} \times L)}{1000}$$

$$P_f = 0.0034\ KW$$

$$P_m = (F_S \times F_m \times \rho b \times g \times V_S \times L)$$

$$P_m = 0.401\ KW$$

Total power needed to get beyond the frictional obstacles between the screw conveyor's moving parts:

$$P_t = P_f + P_m$$

$$P_t = 0.404\ kW$$

Taking standard motor power,

$$P_{mot} = 0.75\ kW$$

3. Selection gearbox: Selection of the Elecon gear box has been done on the basis of the following data.
   - Motor speed = 1500 rpm.
   - Gear ratio =70
   - Screw shaft speed = 21.4 rpm
   - Power requirement = 0.75 kW

4. Torque of the screw shaft (T):

$$T = \frac{(P_{mot} \times 1000)}{(2 \times \pi \times N)}$$

$$T = 421.34\ Nm$$

5. axial thrust on the Screw:

$$P_a = (9.81 \times q \times L \times \mu)$$

$$P_a = 190.26N$$

6. Selection of deep groove ball bearing: As per the data book, for a minimum required shaft diameter of 35 mm and a

screw diameter of 160 mm, a deep groove ball bearing 6007 of series 60 is selected. The dynamic capacity of this bearing is calculated as (1250 × 9.81) = 12262.5 N. Now, this dynamic capacity is checked with respect to the load applied to the Screw [20].

$$\text{Dynamic capacity } C = P \times L^{1/3}$$

Assuming the life of the bearing LH = 10,000 hours so life in number of revolutions.

$$C = 529.90\ N$$

Here, the selected bearing 6007 of series 60 with a dynamic capacity of (1250 × 9.81) = 12262.5 N is considered, while the required dynamic capacity is 529.90 N, which is significantly lower. Therefore, the bearing is safe with respect to its dynamic capacity. The dimensions D = 62 mm and B = 14 mm for bearing 6007 are taken into account.

[7] Modified mass flow rate: [21]

$$ms = \frac{[\rho b \times \pi \times (D_{SC^2} - D_{SH^2}) \times k \times s \times N]}{4}$$

$$ms = 1.02\ {kg}/{s}$$

To achieve the desired mass flow rate of 1.0 kg/s accurately, considering the standard speed of the shaft at 21.4 rpm, a change of 0.02 kg/s is necessary. However, If accurate monitoring of the rate of flow is required, the utilization of a variable-speed drive motor becomes essential. By adjusting the motor speed, it is feasible to attain a speed of 17.04 rpm for the screw shaft, thereby achieving the required mass flow rate of 1.0 kg/s.

5.1. Software Development

Computer-Aided Design (CAD) greatly improves design efficiency by simplifying the process of creating initial designs, performing analyses, and creating drafts. Furthermore, CAD can decrease the amount of human resources needed for a certain project. In this specific scenario, we have developed a software program for material handling equipment, specifically the screw conveyor, using "VISUAL BASIC.NET" [22]. The purpose of the software is to make it easier to generate frequent results for the project.

The design of screw conveyors uses a variety of terminology and equations to indicate different dimensions. Attempting to depict all of this terminology in "C" graphics presents difficulties, and establishing a connection between this work and other graphical software like Paint or AutoCAD is not feasible. We chose "VISUAL BASIC.NET" for the screw conveyor design because of its user-friendly compatibility with other software programs.

It is possible to create graphics files in "AutoCAD 2009" and effortlessly include them in the application using software based on "VISUAL BASIC.NET." Users can avoid the need to write lengthy lines of code to specify the look and position of interface components by utilizing drag-and-drop functionality to place objects or data on the screen. This strategy streamlines the design process, allowing users to achieve results by choosing alternatives within the software program.

5.2. Design of Screw Conveyor

5.2.1. Input Section

Mass Flow Rate (kg/s)

This parameter represents the rate at which material is conveyed through the screw conveyor, measured in kilograms per second.

Mass Density of Material (kg/m^3)

The mass density indicates the amount of mass per unit volume of the conveyed material, typically measured in kilograms per cubic meter.

Material Loading Factor

The material loading factor, crucial for efficient operation, can vary depending on the material being conveyed. It can take values of 0.45, 0.30, or 0.15. A user-friendly feature is incorporated into the Graphical User Interface (GUI) of the screw conveyor, where a "Help me" option is available. By hovering the mouse cursor over the "Help me" prompt adjacent to the input box for the material loading factor, users can conveniently view the available values corresponding to different materials. This assists users in selecting the appropriate value for the specific material being conveyed.

Screw Shaft Diameter (mm)

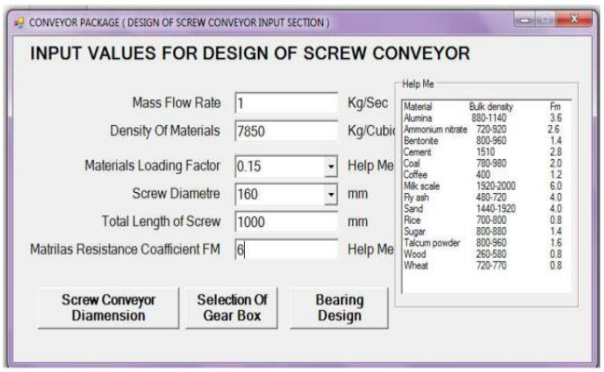
Users have the flexibility to choose the diameter of the screw shaft from a range of options provided, aligning with Indian standard specifications. The available diameters include 100, 125, 160, 200, 250, 315, 400, 500, 630, 800, 1000, and 1250 mm, catering to various application requirements.

Material Resistance Coefficient (Fm)

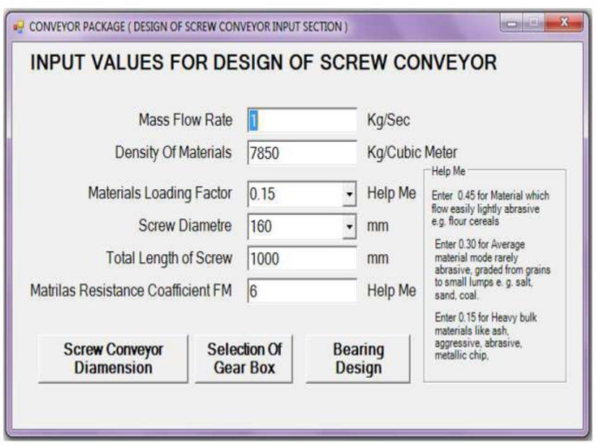
The material resistance coefficient, denoted as Fm, is contingent upon the material being conveyed. Similar to the material loading factor, a "Help me" option is integrated into the GUI.

Users can effortlessly access different values of Fm corresponding to diverse materials and densities by positioning the mouse cursor over the "Help me" prompt adjacent to the toolbox for Fm. This feature simplifies the input process, enabling users to input the appropriate value based on the conveyed material.

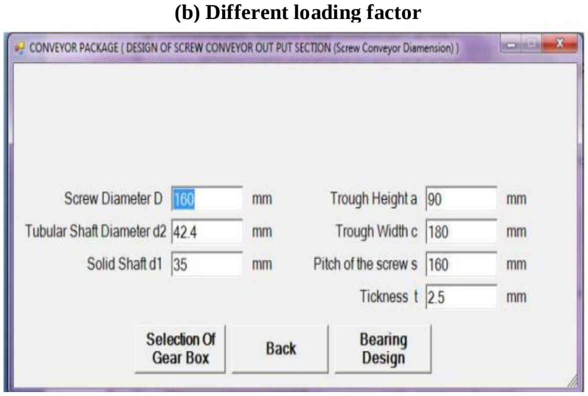
Figure 7 represents the culmination of our software development efforts, providing a comprehensive insight into screw conveyor design and optimization. It encompasses diverse aspects, including the input data necessary for initiating the design process (a), visualization of different loading factor scenarios impacting conveyor performance (b), clarification of terminology crucial for understanding screw conveyor operation (c), detailed discussion on the gearbox selection process for efficient operation (d), and examination of criteria for selecting deep groove ball bearings to ensure shaft support and smooth rotation (e). These outputs collectively form a robust framework for comprehensively understanding and optimizing screw conveyor systems, ultimately enhancing efficiency and performance in material handling applications.



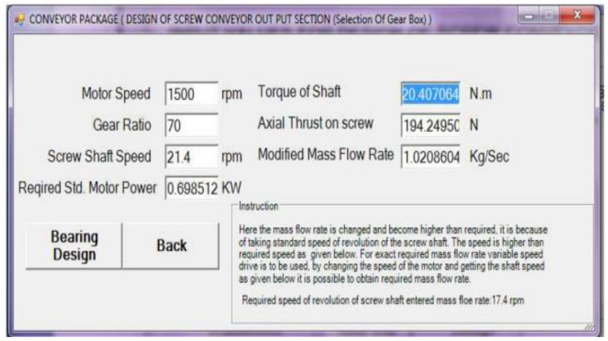
(a) Input data for screw conveyor



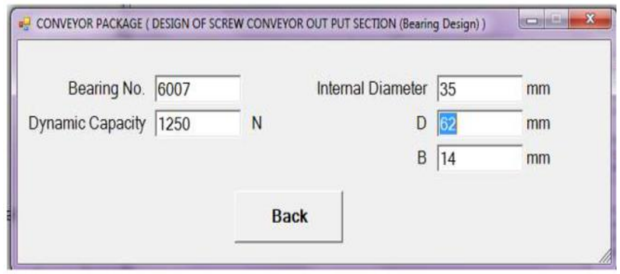
(b) Different loading factor



(c) Terminology dimensions for screw conveyor



(d) Selection of gearbox



(e) Selection of deep groove ball bearing

Fig. 7 (a-e) Comprehensive outputs from software development

6. Result and Discussion

The software developed in the presented research article yields analytical and graphical outputs essential for optimizing screw conveyor design. Analytically, it provides dimensions conforming to Indian standards, including through height, width, the pitch of the Screw, tabular shaft thickness and required solid shaft diameter. Additionally, motor specifications such as speed, required power, and gear ratio are determined alongside screw shaft speed, torque, axial thrust, and modified mass flow rate. Importantly, instructions are provided to achieve the modified mass flow rate, which may differ from the entered value. Furthermore, the software conducts safety checks for the dynamic capacity of deep groove ball bearings, offering details like bearing number, dynamic capacity, and related dimensions.

In graphical form, the software presents visual representations of screw conveyor terminology, Elecon reduction gearbox parameters, and deep groove ball bearing specifications. These graphical outputs facilitate a better understanding of the system components and aid in decision-making during the design process.

The results from the software output enhance the efficiency and accuracy of screw conveyor design, enabling engineers to optimize the system for specific requirements. This contributes to reduced manufacturing costs and improved worker safety by streamlining the chip removal process. Overall, the software provides a user-friendly interface for comprehensive analysis and design optimization, catering to varying chip removal rates and material densities.

7. Conclusion

In conclusion, this research presents a novel method for chip removal in metal-working shops, aiming to alleviate the cumbersome and time-consuming process associated with traditional methods. By employing a mechanical component such as a screw conveyor, this approach separates coolant and chips, resulting in reduced manufacturing costs and improved worker safety. The development of software related to chip removal mechanisms further enhances efficiency, offering alternative solutions for different chip removal systems utilizing screw conveyors. Notably, the software's user-friendly interface allows for easy customization and adherence to Indian standards, providing various instructions and options for input data. Additionally, it offers design data for conveying various materials, along with graphical displays of system components. Overall, this research contributes to increased productivity and cost-effectiveness in the metal-working industry.

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