INTERNATIONAL JOURNAL OF MULTIDISCIPLINARY RESEARCH AND ANALYSIS

ISSN(print): 2643-9840, ISSN(online): 2643-9875

Volume 08 Issue 06 June 2025

DOI: 10.47191/ijmra/v8-i06-50, Impact Factor: 8.266

Page No. 3490-3497

Conceptual Design: A Case Study of Integrated Gearbox and Pulley-Belt System for Fish Feed Pelletizer

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ABSTRACT: The conceptual design of the power transmission system for a fish feed pelletizer was developed. The development carried out using the modified Pahl and Beitz systematic design methodology, which provides a structured framework for engineering problem-solving through clearly defined stages. Preliminary works has obtained the pelletizer machine power was 1.55 kW to yield 80-85 kg pellet per hour, for suitable of small to medium-scale fish farming operations. The screw extruder rotational speed was 100-110 rpm. A conceptual design of the power transmission system was developed and guided by identification and weighting of evaluation criteria applied to alternative designs. The primary criteria identified were performance, cost, safety, maintainability, availability of components, and manufacturability. There was also a constraint in power availability that limited to single phase electricity. The power transmission system was decomposed into standard machine elements namely belt drives, chain drives, gear trains, and shaft couplings**.** This development resulted an integrated gearbox and pulley belt with combination ratio were 1:10 for gearbox and 1.5:1 for pulley-belt, as a power transmission system of the fish feed pelletizer.

KEYWORDS: conceptual design, pahl and beitz, pelletizer, gearbox, pulley-belt

I. INTRODUCTION

The design of mechanical systems for agricultural machinery, such as fish feed pelletizers, demands a structured and methodical approach to ensure optimal functionality, reliability, and manufacturability. The Pahl and Beitz design methodology provides a systematic framework for engineering design, progressing from the clarification of the task to the embodiment and detailing of the solution [1]. When applied to the development of an integrated gearbox and pulley-belt transmission system, this approach facilitates a clear understanding of functional requirements—such as torque transmission, speed reduction, and mechanical efficiency—within the operational context of pelletizing processes. The gearbox component addresses the need for torque amplification, while the pulley-belt system provides adaptability in drive ratio and vibration dampening—both crucial for the consistent extrusion of feed pellets under varying loads [2]. By employing function structures, morphological analysis, and evaluation matrices as proposed by Pahl and Beitz, the design process systematically explores multiple solution principles and enables an objective selection of the most suitable concept. This structured method enhances not only the technical performance but also the maintainability and scalability of the fish feed pelletizer system. This case study explores the conceptual design of an integrated gearbox–pulley belt transmission system for a small-scale fish feed pelletizer. The design process follows a systematic methodology based on the framework proposed by Pahl and Beitz (2007), beginning with the clarification of functional requirements such as torque amplification, speed reduction, compact form factor, and ease of maintenance. The gearbox is selected to provide the necessary torque to compress and extrude feed material through the pelletizer die, while the pulley-belt system is incorporated to enable flexible speed adjustments and ease of alignment between the motor and gearbox. The integration of both mechanisms aims to optimize performance, reduce mechanical strain on individual components, and simplify the drive system layout.

Several advantages arise from this integrated transmission design. Firstly, gearboxes are capable of delivering high torque outputs at relatively low speeds, which is essential for the pelletization process [2]. Secondly, pulley-belt systems offer the benefit of smooth power transmission, vibration damping, and easier speed variation by changing pulley diameters without modifying the entire gear train [3]. Additionally, belts can accommodate minor misalignments, which reduces stress on bearings and shafts. However, this system is not without drawbacks. Belt drives are prone to slippage and wear over time, requiring periodic tensioning and replacement. Moreover, the combination of gearbox and pulley increases the complexity of the design and can result in higher initial cost and space requirements compared to a single-mode transmission system. In high-load conditions, belt-driven systems may also exhibit reduced efficiency due to energy losses from friction and stretching [4].

According to Ulrich and Eppinger [5], the early design phase focuses on identifying the key functions and constraints, including power requirements, spatial limitations, and maintenance considerations. The gearbox serves as the primary torque converter, stepping down the motor speed to a level suitable for pellet extrusion, while the pulley-belt system provides a secondary speed adjustment mechanism and acts as a flexible coupling between the motor and gearbox [6]. This integration enhances adaptability by allowing speed variation through changes in pulley diameters without the need for altering the gear ratios, thereby simplifying operational adjustments.

The pulley-belt system also contributes to shock absorption and vibration damping, protecting the gearbox and other components from sudden load spikes common in pelletizing operations [7]. However, the design must address challenges such as belt slip, elongation, and the need for regular maintenance to sustain proper tension and alignment. Furthermore, the addition of pulleys and belts introduces extra points of potential failure and slightly reduces overall transmission efficiency due to frictional losses [8]. Despite these drawbacks, this hybrid transmission system offers a balanced trade-off between performance, cost, and ease of maintenance, making it an attractive option for medium-scale feed pellet production. The modularity of the system also facilitates scalability and easier repair, which are crucial in agricultural and aquaculture machinery contexts where downtime can significantly impact productivity [9].

Overall, the conceptual integration of a gearbox and pulley-belt system presents a balanced solution that leverages the torque-handling capability of gears with the flexibility and simplicity of belts, making it particularly suitable for medium-duty applications like fish feed pelletizers where cost, efficiency, and serviceability must all be considered.

II. LITERATURE REVIEW

Power transmission systems play a critical role in the performance and efficiency of mechanical equipment such as fish feed pelletizers, where reliable torque delivery, speed regulation, and operational stability are essential. Various studies have explored the application of mechanical power transmission methods in agricultural and feed processing equipment, with gear drives, belt systems, and chain drives being the most commonly used due to their simplicity and availability [10]. Gear-based transmissions are often preferred in pelletizing applications for their high torque capacity and precision, while belt drives are valued for smooth operation and shock absorption [3]. However, transmission choice is typically influenced by machine scale, load requirements, cost constraints, and environmental factors such as moisture and particulate contamination, which are prevalent in aquaculture feed production settings. The Pahl and Beitz design methodology has been widely adopted in mechanical system design due to its structured and iterative approach, enabling designers to systematically translate functional requirements into optimized technical solutions [1]. Its application in power transmission system design facilitates a rigorous evaluation of alternative solutions based on clearly defined criteria, thereby enhancing reliability and efficiency in demanding operational contexts. While prior works have addressed individual aspects of transmission design, few have explicitly combined these principles with a structured engineering methodology to optimize system performance in fish feed processing equipment.

A. Design Process

Design process model was proposed by Pahl and Beitz, who formalized the design process into four systematic stages:
product definition, concept design, embodiment design, and detail design. The design flow will be carried out as in Figure 1.

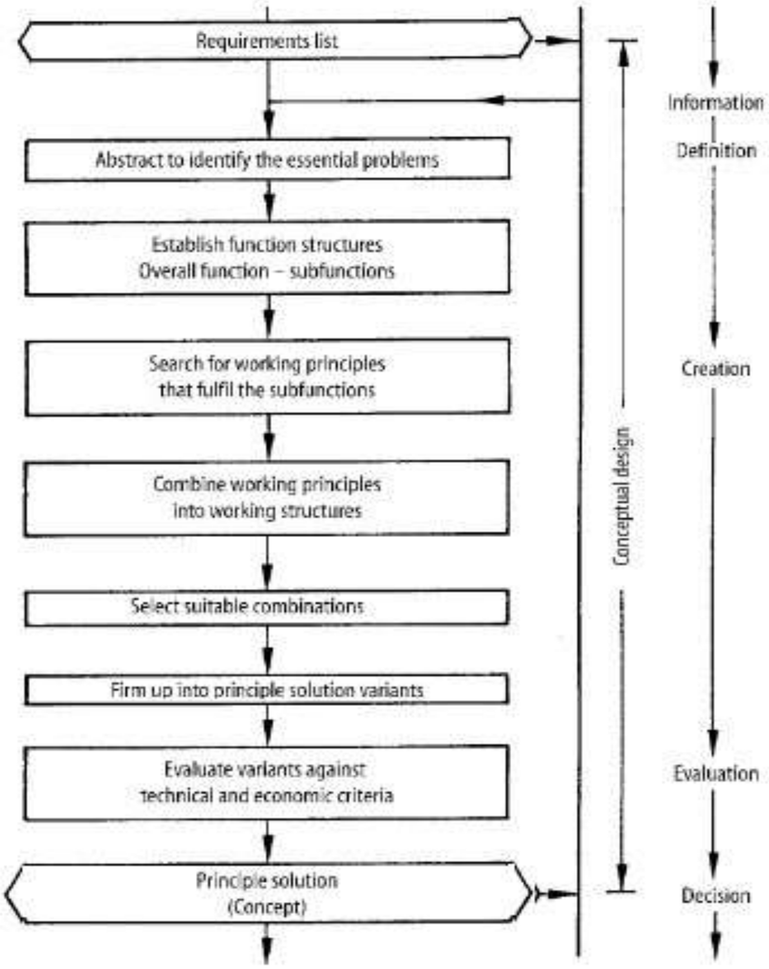

Figure 1. Steps of conceptual design [1]

As the name implies, product definition defines the product in detail so the actual design can begin, and any subsequent steps rely on these requirement definitions. Depending on the nature of the product design, this is sometimes knowns as a "**Problem definition**" or "**Product Planning**" or "**Task clarification**" [1].

Typically the product design and development task is given to the engineers and designers by either the marketing department or a client. Even if the requirement is captured in a document, the design team must clarify the requirement and start a **Product Design Specification (PDS)**. As a result of this activity, a comprehensive PDS in the form of a requirements list emphasising all technical, economic, and quality factors is produced.

Product Definition (PD) is, as the name implies, correctly identifying the requirement for the product. Therefore, product definition is the first step in Product Design Process (PDP).

There are three key steps to defining a product requirement

1. Identify requirements
2. Gather information
3. Create a Product Design Specification (PDS)

Conceptual Design is an early phase of the design process, in which the broad outlines of the function and form of something are articulated. It includes the design of interactions, experiences, processes and strategies. Within the new product development cycle, it typically sits between the product definition and embodiment design. Stages of concept design includes clarify the problem, search externally, search internally, explore systematically, reflection and choosing the concept.

By examining the trade-offs between different design choices and their impact on system performance, this study aims to provide insights into the critical design decisions that influence the overall effectiveness of a machines. In doing so, it offers valuable guidance to engineers and designers tasked with developing integrated transmission systems that not only meet operational requirements but also contribute to reduced downtime, lower maintenance costs, and enhanced energy efficiency in machines.

It is a multidisciplinary approach that has to be implemented within a working group combining different design players. Combination with functional analysis will results to a Needs Functional specification. Application of this method enabled a functional specification to be drafted for the machinery to be manufactured within scope of the project.

B. Integrated Gearbox and Pulley-belt System

Design process of power transmission can be achieved through direct drive or belt-driven systems. The performance of a machine is largely influenced by its power transmission system, which includes the integration of the gearbox-pulley-belt mechanisms. These systems are designed to transfer mechanical power from the motor to the main processing components, ensuring smooth and efficient operation.

The gearbox-pulley-belt system is a widely used configuration in machinery due to its flexibility, ease of maintenance, and cost-effectiveness. This system works by transmitting rotational power from the motor to the rollers via a combination of gears and pulleys connected by a belt. Integrated gearbox-pulley-belt systems are essential in the efficient operation of processing machinery, offering flexibility, energy efficiency, and cost savings. Despite challenges related to heat generation, wear, and maintenance, recent research continues to refine the design of these systems, improving their durability and energy efficiency. As the demand for high-quality hulling product increases, ongoing innovations will enhance the performance of gearbox-pulleybelt systems, making them an integral component of modern technology.

Li et al. [10] and Chen et al. [11] demonstrated that the integration of high-efficiency gearboxes with advanced pulley-belt systems can improve overall energy efficiency and reduce mechanical losses. Moreover, the use of hybrid systems, combining the strengths of different transmission mechanisms, has been proposed as an effective strategy to improve performance while maintaining cost-effectiveness [12]. These approaches are particularly relevant as machine face the challenge of operating in demanding conditions, such as high load variations and extended duty cycles.

According to Liu et al. [13], machinery system's transmission components must be able to handle fluctuations in material properties and moisture content, which can impact load demands during operation. Furthermore, Zhao et al. [12] highlighted that the power transmission system's efficiency is crucial for reducing energy consumption, as machines often operate continuously, resulting in high operational costs.

Studies have emphasized the importance of optimizing gear ratios and pulley sizes to ensure efficient power transmission. For example, research by Jiang et al. [14] explored various gear ratios and pulley sizes to reduce energy consumption and improve operational efficiency in a machine. The authors concluded that fine-tuning the gearbox and pulley specifications results in a noticeable reduction in power losses

Energy efficiency is a key concern in industrial applications. Chen et al. [11] examined energy consumption in machinery systems with integrated gearbox-pulley-belt configurations. Their study showed that a properly optimized system reduced energy consumption by up to 15% compared to less optimized configurations, which is crucial in an era of rising energy costs.

In many mechanical systems, a pulley-belt configuration is used alongside or in place of traditional gearboxes. Pulley-belt systems are often preferred for their simplicity, cost-effectiveness, and ease of maintenance. A study by Yang et al. [15] explored various pulley-belt combinations, focusing on the design of V-belt systems, which are commonly used in machine power transmission. V-belts are popular for their ability to handle variable load conditions and their ability to transmit power efficiently at higher speeds. However, the study also highlighted that V-belts are prone to slippage and stretching over time, leading to reduced transmission efficiency and the need for regular maintenance.

Liu et al. [13] provided a comprehensive comparison of belt types for mechanical systems, including V-belts, flat belts, and timing belts. The research showed that timing belts, which are toothed and designed to prevent slippage, offer superior performance in terms of power transmission efficiency and load handling compared to V-belts. However, timing belts require precise alignment and are more sensitive to temperature fluctuations, which may affect their longevity in industrial environments.

Recent research has also explored hybrid transmission systems that combine gearboxes and pulley-belt mechanisms to leverage the strengths of both systems. Zhao et al. [12] proposed a hybrid transmission system for machine, combining a planetary gearbox with a timing belt. This system allowed for a more compact and efficient transmission solution while maintaining the flexibility of variable speed control offered by the belt system. The hybrid system was found to be particularly effective in reducing mechanical losses and improving system reliability, as the gearbox handled the high-torque requirements while the belt provided smooth speed adjustments.

The transmission system plays a pivotal role in ensuring the mechanical efficiency and reliability of fish feed pelletizers. In designing such systems, the integration of a gearbox with a pulley-belt drive offers a cost-effective and versatile solution to achieve the desired torque-speed characteristics necessary for pellet formation. The gearbox provides the torque multiplication required to process feed materials under pressure, while the pulley-belt system enables flexibility in speed variation and system alignment

[3]. This integrated approach not only improves mechanical performance but also enhances maintenance accessibility and system compactness—critical for small- to medium-scale aquaculture operations. The design process involves careful consideration of power requirements, torque calculations, material selection, and alignment tolerances, ensuring the system withstands prolonged operational stresses and variable loads [4]. Moreover, selecting appropriate gear ratios and pulley dimensions is essential to maintain a balance between mechanical advantage and system efficiency. As such, the integration of gearbox and pulley-belt transmission systems in fish feed pelletizers represents an essential engineering solution to optimize performance, reliability, and scalability in feed production processes.

III. METHODOLOGY

The development of design concept of the power transmission system for the fish feed pelletizer was carried out using the modified Pahl and Beitz systematic design methodology [1], which provides a structured framework for engineering problemsolving through clearly defined stages. This methodology was chosen due to its emphasis on functionality, rational decisionmaking, and iterative development, ensuring that the resulting design would be both technically effective and economically viable. The stages are:

A. Task Clarification and Requirement Analysis

The process began with the clarification of the design task, wherein the main objective—transmitting mechanical power from the motor to the pelletizing screw extruder efficiently—was clearly defined. A detailed analysis of user needs and technical constraints was conducted. Inputs were gathered from existing pelletizer designs and operational requirements. This step led to the formulation of a comprehensive requirements list**,** categorized into functional requirements and constraints.

B. Functional Decomposition and Structure

The power transmission system was decomposed into its essential sub-functions using functional analysis. The main function of transmit mechanical energy was broken down into sub-functions, receive energy from motor, adjust speed, and ensure continuous and safe operation. This breakdown facilitated a clear understanding of what each component of the system needed to achieve, and how different transmission concepts could fulfill these roles.

C. Concept Generation

Based on the sub-functions, several conceptual solutions were generated. Transmission methods considered included belt drives, chain drives, gear trains, and shaft couplings, each offering different benefits in terms of efficiency, torque capacity, ease of maintenance, and cost. These concepts were developed into preliminary design sketches and system layouts, incorporating the potential integration with the pelletizer's motor, frame, and working units.

D. Concept Evaluation and Selection

To objectively compare the generated alternatives, a weighted decision matrix or a morphological matrix was used. Evaluation criteria were weighted based on their importance to the overall system performance. Each concept was scored against these criteria, and the total scores were used to identify the most appropriate solution.

IV. RESULT AND DISCUSSION

The conceptual design of the power transmission system for a fish feed pelletizer was systematically developed using the Pahl and Beitz design process methodology. Through task clarification, the primary goal was to transmit power from motor to screw extruder efficiently. Preliminary works has obtained the pelletizer machine power was 1.55 kW to yield 80-85 kg pellet per hour, for suitable of small to medium-scale fish farming operations. The screw extruder rotational speed was 100-110 rpm. There was also a constraint in power availability that limitted to single phase electricity.

Of the requirements, functional decomposition and structure was developed. The power transmission system was decomposed into standard machine elements namely belt drives**,** chain drives**,** gear trains**,** and shaft couplings. The evaluation for machine elements was performed to select the elements will be used. The evaluation technique was to mark each machine element by using number of plus sign to indicate the elements' more proper to criteria. The evaluation matrix shown in Table 1.

Table 1. Evaluation matrix selection of the proper machine elements

No	Criteria	Belt Drives (pulley-belt)	Chain Drives (sprocket-chain)	Gear Trains (gearbox)	Shaft Couplings (direct coupling)
1	Performance	+	++	+++	+++
2	Cost (low cost)	+++	++	++	++

3	Safety	+++	++	+++	+
4	Maintainabiity	+++	++	++	++
5	Availability of components	+++	+++	+++	+++
6	Manufacturablity	++	+	++	++
	Total plus	15	12	15	13

Table 1 shows that rank of the machine elements selection were (i) belt drives (pulley-belt), (ii) gear train (gearbox), (iii) shaft coupling, and (iv) chain drives. Based on the 2 first rank, pulley-belt and gearbox, some alternative design were generated. These atlternative design shown in Table 2.

Table 2. Some alternative design of power transmission

No.	Alternative Design	Description
1	Alternative I (Alt-I)	Alternative design using pulley-belt as power transmission system
2	Alternative II (Alt-II)	Alternative design using gearbox as power transmission system
3	Alternative III (Alt-III)	Alternative design using integrated of gearbox and pulley-belt as power transmission system
4	Alternative IV (Alt-IV)	Alternative design using 2-stage pulley-belt as power transmission system
5	Alternative V (Alt-V)	Alternative design using multi-stage pulley-belt as power transmission system

A conceptual design of the power transmission system was developed and guided by identification and weighting of evaluation criteria applied to alternative designs. The primary criteria identified were: performance**,** cost**,** safety, maintainability**,** availability of components**,** and manufacturability. The criteria and its description was shown in Table 3.

Table 3. Evaluation criteria and its description

No	Criteria	Description
1	Performance	The extrusion process demands consistent mechanical power to form pellets of uniform quality
2	Cost	Relatively low or high initial component costs and the long-term operational and maintenance costs
3	Safety	Ensure that all moving parts could be enclosed or shielded to minimize risks to operators
4	Maintainabiity	Users could inspect, service, and replace worn components easily.
5	Availability of components	Standard mechanical elements
6	Manufacturablity	the system could be fabricated and assembled using locally available tools and processes

From the criteria, weighting matrix was performed, as seen in Table 4.

Table 4. Evaluation of alternative design by weighting

Criteria	Weight W	Alt-I		Alt-II		Alt-III		Alt-IV		Alt-V	
		S	WxS	S	WxS	S	WxS	S	WxS	S	WxS
Performance	0.2	2	0.4	5	1	3	0.6	2	0.4	2	0.4
Cost (Low cost)	0.2	5	1	2	0.4	4	0.8	3	0.6	3	0.6
Safety	0.2	3	0.6	3	0.6	4	0.8	4	0.8	4	0.8
Maintainabiity	0.15	5	0.75	4	0.6	4	0.6	3	0.45	3	0.45
Availability of components	0.15	5	0.75	4	0.6	4	0.6	5	0.75	5	0.75
Manufacturablity	0.1	4	0.4	3	0.3	3	0.3	4	0.4	4	0.4
Total	1		3.9		3.5		3.7		3.4		3.4

In the Pahl and Beitz method, the highest score of an alternative design the weighing matrix would be the chosen alternative design, that is pulley-belt system. Nevertheles In the context of the power transmission system for a fish feed pelletizer, ergonomics plays a significant role in enhancing the operator's comfort, reducing fatigue, preventing injuries, and simplifying routine maintenance. Recognizing its importance, an ergonomic criteria were incorporated into the conceptual evaluation and design selection process in alignment with Pahl and Beitz's emphasis on user-centered design. The conseptual design dimension regarding the ergonomic criteria illustrated at Figure 2.

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According to the ergonomic aspect, there is a standard position of the human body when working. When working on a pellet machine, the human position is standing. The highest standard reach that has been determined must be ± 10 cm below the human elbow when standing. In this regard, the measurement of the height of the human elbow is 105 cm, so the maximum height of the work object is 105 cm - 10 cm = 95 cm, thus the maximum height of the fish pellet machine must be 95 cm = 950 mm. Based on Figure 2, the maximum extruder center-to-motor center distance was 590 mm. This distance became a constraint to develop a conceptual design of transmission system.

Electrical motor, which has 1450 rpm of rotational speed, was chosen as prime mover. Then the rotational speed ratio between motor and screw extruder was 1450 rpm : 100 rpm or about 14.5. This ration was too high that can cause a slippage when related to distance constraint. This lead to a single pulley-belt system could not be used for this pelletizer machine. Then combination or integration of gearbox and pulley-belt was selected, offering a high torque-to-size ratio, minimal slippage, and durability suitable for continuous operation.

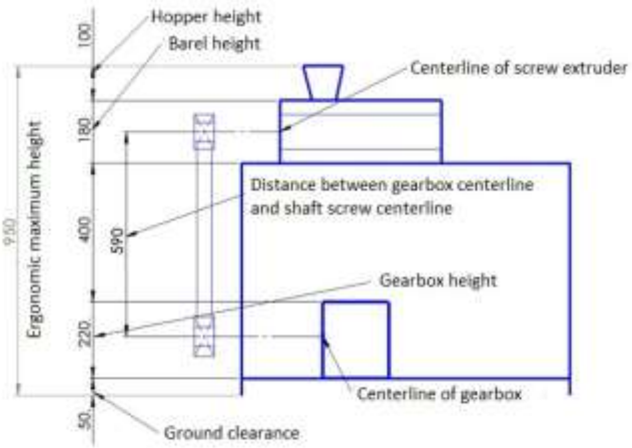

Figure 2. Conceptual design dimension of fish feed pelletizer

To analyzed for solving the total transmission ratio of 14.5, the integrated gearbox and pulley-belt was schemed shown in Figure 3. Pulley-belt type chosen was type-A belt that able to sustain 1,55 kW machine power.

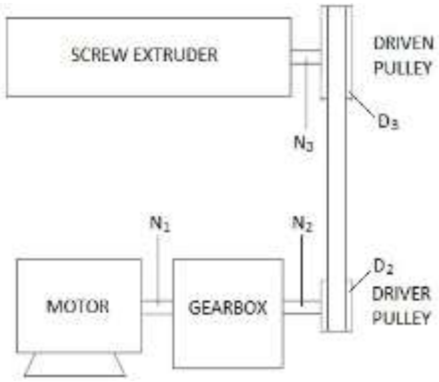

Figure 3. Conceptual design scheme of a transmission system

Refer to Figure 3, relation of rotational ratio used for combination ratio between gearbox and pulley-belt was

(1) $$\frac{N_1}{N_2} x \frac{N_2}{N_3} = \frac{N_1}{N_3} = 14.5$$

and N_2/N_3 is proportional to D_3/D_2.

N_1/N_2 and N_2/N_3 was handled by gearbox and pulley-belt, respectively. The available gearbox ratio were 1:2, 1:5, 1:7.5, 1:10. A decision matrix table was created to choose a proper ratio pair of gearbox and pulley-belt as transmission system. The combination ratio can be seen at Table 5. Table 5 was also to include recommended minimum diameter of driver pulley and as the evaluation factor.

Table 5. Decision matrix

No	Gearbox ratio	Ratio Pulleybelt	Recommended minimum diameter of driver pulley, D_2 (mm)	The diameter of driven pulley, D_3 (mm)	Decision (YES/NO) (Reason)
1	1:2	7.3:1	95	689	NO (For safety purpose, the maximum diameter for driven pulley was 250 mm)
2	1:5	2.9:1	95	276	NO (For safety purpose, the maximum diameter for driven pulley was 250 mm)
3	1:7.5	1.9:1	95	184	YES
4	1:10	1.5:1	95	138	YES

Based on Table 5 there are two selected integrated gearbox and pulley-belt was drawn, number 3 and number 4. Nevertheles, cost of 1:7.5 gearbox ratio was higher than of 1:10 ratio. Also that gearbox with ratio of 1:10 was more available. Therefore, the integrated gearbox with ratio of 1:10 and pulley-belt with ratio of 1.5:1 was chosen as a transmission system for the fish feed pelletizer.

V. CONCLUSIONS

In conclusion, the application of the Pahl and Beitz methodology enabled the development of a logical, function-oriented, and practically viable power transmission system for a fish feed pelletizer. The final concept strikes an effective balance between performance, cost, safety, maintainability, availability of components, and manufacturability, making it well-suited for implementation in small to medium-scale fish farming. The integration of belt-driven and gear-reduced mechanisms ensures a robust and adaptable system that meets both functional and economic design objectives. In this application, a gear-driven transmission system integrated with belt reduction was selected, offering a high torque-to-size ratio, minimal slippage, and durability suitable for continuous operation.

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