DESIGN AND FABRICATION OF MOTORIZED GRAIN CRUSHER

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CERTIFICATION

This is to certify that the project work hitherto was carried out by **Iwhiwhu, Faustus Aghoghovore** with matriculation number **ENG2002669**, a student of the department of Production Engineering, Faculty of Engineering, University of Benin, Edo State, Nigeria. For the award of B.ENG in Production Engineering; under the supervision of

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DEDICATION

This project is dedicated first and foremost to Almighty God, the source of wisdom, knowledge, and strength. His divine guidance and grace have been my anchor throughout this academic journey.

I also dedicate this work to my beloved parents, Mr. and Mrs. Sunday Iwhiwhu, whose unwavering support, prayers, and sacrifices have shaped the foundation of my success.

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ABSTRACT

The project titled “Design and Fabrication of a Grain Crusher” was aimed at developing a small-scale, electrically powered machine for crushing and grinding grains such as maize, millet, and sorghum into finer particles for easy processing. The objectives were to design a hammer mill-type crusher suitable for local use, ensure ease of maintenance, minimize power consumption, from locally sourced materials.

The methodology involved conceptual design, material selection, component fabrication, and assembly of the crushing unit, hopper, frame, and power transmission system. Key design parameters such as shaft diameter, pulley ratio, hammer dimensions, and motor power were determined using standard mechanical design equations. Performance evaluation was conducted through test runs using maize to assess crushing efficiency and particle size distribution.

Results showed that the machine performed effectively with a crushing efficiency above 80%, producing uniformly sized particles suitable for food and feed processing. The design met all functional objectives, demonstrating reliability, low operational cost, and suitability for small-scale commercial use in local grain processing industries.

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CHAPTER ONE - INTRODUCTION

1.1 Background of the Study

Grains such as maize (corn), rice, sorghum, wheat, and millet are fundamental to agricultural production and consumption in Nigeria. Their significance lies in their high nutritional value, as they are rich sources of carbohydrates, dietary fiber, essential vitamins, and minerals. These grains are vital components of both human and livestock diets. In different regions of Nigeria, they are consumed in various forms and often undergo specific processing methods before they are ready for consumption.

In addition to human consumption, these grains are crucial for livestock nutrition, providing essential energy and nutrients that contribute to increased milk production and accelerated growth rates in animals.

Historically, Nigerian farmers and households have relied on manual methods (stones, mortar-and-pestle) to process grains. For example, rural women often grind maize or millet by rubbing grains between two stones. This labor-intensive process limits throughput and contributes to high post-harvest losses (FMARD reports that 20–30% of Nigeria's grain output is lost during handling). Over time, local artisans and research centers introduced small motorized mills and crushing devices, but such technologies remain far below demand. A detailed history shows that pre-colonial grain processing in West Africa was entirely manual. In Nigeria, colonial-era saw the first commercial mills (e.g flour mills for wheat in the 1950s), but these served urban markets. After independence, the expansion of local flour mills (such as: Nigerian Flour Mills, Golden Penny) drove a partial shift to mechanized grinding. Still, smallholder farmers and village processors largely use low-capacity machines or manual grinders even today.

Globally, grain processing equipment evolved from simple millstones (used since antiquity) to industrial roller mills, hammer mills, and more recently to advanced pneumatic and digital-controlled machines. In Africa, after independent states formed, countries developed their own mechanization programs. For instance, Tanzania introduced motorized maize grinders in the 1970s, and Nigeria's NCAM (National Centre for Agricultural Mechanization, Ilorin) has designed several village-scale hammer and disc mills since the 1980s. Modern grain grinders typically fall into two categories: impact mills (hammer mills) and grinding/abrasive mills. In an impact mill, rotating hammers break kernels by impact; a grate or screen then classifies output by size. A typical hammer mill, as described by 911Metallurgist, consists of a box-like housing that contains a horizontally mounted rotor fitted with pivoting hammers. Beneath the rotor, a set of tapered, wear-resistant steel bars—arranged in a circular grate—serves as the discharge path, regulating particle size and enabling material exit once sufficiently crushed. In contrast, abrasive mills use one or more stationary grinding surfaces (rollers or stones) to shear or crush the grain. For example, roller mills (common in commercial flour milling) use steel rollers set at a controlled gap, producing very fine flour.

Industrial designs have introduced features like cyclone suction to reduce dust and improve safety. Ebunilo et al. developed a hammermill with "end-suction lift capability," making it a closed system to minimize grain dust. Another innovation adds electronic controls: an NAU (Nsukka) team built a 2-horsepower, 2800 rpm hammermill with a color sensor and variable speed to obtain different particle sizes without swapping screens.

1.2 Components and Working Principles

A typical motorized grain crusher (hammer mill) includes a hopper (feed inlet), a rotating shaft (rotor) with hammers or beaters attached, a durable casing, and a perforated screen at the outlet. Grain flows into the housing and is repeatedly struck by the hammers, breaking it into smaller pieces. The grate or screen ensures only particles below a target size pass through. Power sources can be electric motors, petrol engines, or even tractors via PTO. Smaller abrasive mills (e.g. corn grinder with rollers) operate by pressing grain between surfaces. Technologies vary: some use direct mechanical drive, others employ pneumatic or hydraulic assist for higher throughput. Modern advances include variable speed control, feed-sensing, and automated safety shutoffs, though these features are still uncommon in many African village mills.

In summary, grain crusher/grinder technology has progressed from manual stone milling to motorized hammer and roller mills. Yet in Nigeria today, only a fraction of farmers has access to such machines. The machine's main parts — hopper, crushing mechanism (hammers/rollers), drive system (motor/engine), and screens — must be properly designed to match target capacity, grain types and local power conditions. Understanding these components and their evolution (both globally and in Africa) is essential groundwork for designing an improved local grinder that meets Nigerian farmers' needs.

1.2 Problem Statement

Nigeria faces a significant gap between grain production and efficient processing. Despite being one of Africa's leading producers of maize and other cereals, only about 25% of maize is processed into value-added products like flour, oil, or livestock feed. This inefficiency is rooted in extremely low mechanization—only 0.027 horsepower per hectare is installed nationwide (NATIP, 2022)—and up to 90% of smallholder farmers still rely on manual tools for both field operations and grain processing.

The consequences are far-reaching. Post-harvest losses are estimated at 20–30% of total grain output due to inadequate drying, cleaning, and milling. Farmers are often forced to sell surplus grain quickly at low prices or consume it unsafely, contributing to food insecurity and poverty, particularly during non-harvest seasons. Moreover, manual processing demands intense labor, consumes valuable time, and exposes them to health hazards such as dust inhalation.

Lack of access to affordable, locally made grain milling equipment also prevents smallholders from entering higher-value markets like flour or feed production. This stifles agricultural value addition, hampers rural economic development, and increases Nigeria’s dependence on food imports.

Therefore, there is a clear and pressing need for a locally designed, motorized grain crusher that is affordable, efficient, and tailored to the needs of small-scale farmers. This project aims to bridge this gap by designing and fabricating a durable, electric-powered grain grinder suitable for processing staple grains such as maize, millet, sorghum, and groundnut.

1.3 Aim of the Study

To design and fabricate a motorized grain crusher/grinder suited for smallholder needs.

1.4 Objectives

The project will pursue the following specific objectives:

i. To carry out literature review of existing grain crusher designs
ii. To determine the key performance parameters (capacity, particle size, power input, safety).
iii. To carry out detailed design of the component parts of the machine.
iv. To determine suitable materials required for component fabrication.
v. To carry out the fabrication of the component parts.
vi. To assemble the components of the machine.
vii. To carry out performance testing and evaluation of the machine.

1.5 Significance of the Study

i. Food Security and Nutrition Improvement:

   The grain grinder enhances food availability by reducing post-harvest losses and increasing processing efficiency.

ii. Mechanization and Local Industrial Development:

   The project encourages agricultural mechanization in Nigeria’s under-mechanized farming sector (0.027 hp/ha) by providing affordable, small-scale machinery, while also boosting local fabrication industries through job creation for welders and technicians.

iii. Labor Reduction and Health Improvement:

   By minimizing the need for time-consuming manual grain grinding, the motorized grinder reduces physical strain and exposure to harmful dust, improving health outcomes for rural users.

iv. Economic Empowerment and Import Substitution:

   The grinder enables higher earnings from processed grain products, promotes rural employment in operation and maintenance, and supports national goals of import reduction and agricultural diversification.

1.6 Scope of the Study

This study will focus on design, fabrication, and laboratory/field testing of a small-scale, motorized with a target throughput on the order of 5–20 kg/hour driven by a single-phase electric motor (around 2–5 hp), depending on local electricity availability. The machine will be optimized for common grains, focusing on dry crushing and size reduction. Wet processing is outside this scope.

CHAPTER TWO - LITERATURE REVIEW

2.1 Introduction

Grain crushers are essential machines in the post-harvest processing of cereals such as maize, millet, sorghum, wheat, barley, and rice. These machines break down grains into smaller particles suitable for human consumption, animal feed formulation, brewing mash, bioethanol production, and the creation of starch-based industrial materials (Solà-Oriol, Rojas, & Stein, 2015; Orhorhoro, 2020). Crushed grains serve as raw materials not only in food processing but also in the animal nutrition, brewing, pharmaceutical, and chemical industries where starches and derivatives are used in excipients, adhesives, and biodegradable plastics (FAO, 2016).

The history of grain crushers is deeply tied to the advancement of human agriculture. Early civilizations used stone querns and mortars to manually crush grains. While effective at small scales, these methods were laborious and slow (Bassey, Odesola, & Olawuyi, 2022). Technological progress introduced water- and wind-powered mills during the medieval period, which greatly improved processing efficiency. The invention of the roller mill in 19th-century Hungary was a major advancement, allowing for consistent particle size distribution and greater productivity compared to millstones (Bassey et al., 2022). By the 20th century, electrically and fuel-powered crushers became widespread, providing smallholder farmers, particularly in developing countries, with mechanized alternatives to manual processing (Orhorhoro, 2020).

Modern grain crushers fall mainly into three categories: hammer mills, roller mills, and burr mills. Hammer mills operate by striking the grain with high-speed hammers and forcing it through a perforated screen. They are widely used in small-scale settings due to their simplicity and low initial cost. However, they tend to consume more energy and produce significant dust, and their hammers and screens are prone to wear (Mugabi et al., 2019). Roller mills crush grain between paired rollers and are valued for their energy efficiency, low dust generation, and production of uniform particle sizes. These advantages come with trade-offs including higher initial cost, greater maintenance needs, and reduced suitability for fibrous or high-moisture grains (Solà-Oriol et al., 2015). Burr mills use abrasive discs to shear the grain, yielding fine and consistent particles, but their throughput is generally lower, and they can clog when processing moist grains (FAO, 2016).

Performance studies of locally fabricated grain crushers highlight both strengths and persistent limitations. In Uganda, Mugabi et al. (2019) evaluated a locally made hammer mill and found that energy consumption ranged from 0.8 to 1.8 kWh per ton, depending on hammer tip speed and screen size. In Nigeria, Oluwole et al. (2019) reported that small-scale hammer mills typically achieve throughput rates of about 60–80 kg/hr. with efficiencies between 60% and 83%, depending on configuration and operating conditions. Despite their utility, these mills commonly face challenges including rapid wear, high noise levels, significant dust emission, and reliance on grid or fossil fuel energy sources.

In many developing countries, particularly Nigeria, there is growing demand for grain crushing equipment that is efficient, affordable, and adaptable to local conditions. Smallholder farmers and entrepreneurs require machines that can reliably process grains for food and feed production, yet they face barriers such as high capital costs, unreliable energy supply, scarcity of precision spare parts, and limited local manufacturing capacity for critical components (Kuye & Akinyemi, 2019).

Recent innovations aim to address these challenges through design improvements and the integration of emerging technologies. Developments include oblique hammer arrangements that improve energy efficiency by up to 25 percent, screenless designs that reduce clogging and maintenance, and the use of advanced materials that extend the lifespan of wear components

(MIT D-Lab, 2022). There is increasing interest in incorporating low-cost automation and sensor-based systems to support predictive maintenance and real-time performance monitoring. However, the deployment of these technologies in rural, low-resource contexts remains limited and requires further field validation (Bassey et al., 2022). Solar-powered and hybrid energy options are also under investigation as alternatives to grid electricity and diesel engines, with promising prototypes but few large-scale field implementations (Practical Action, 2021).

This review critically assesses the mechanical designs, material choices, fabrication techniques, and automation strategies of grain crushers, with particular attention to their viability and sustainability in low-resource environments. It identifies research gaps in lifecycle cost analyses, energy optimization strategies that consider grain type and moisture content, affordable automation solutions appropriate for smallholder use, and empirical validation of new crusher designs under actual operating conditions.

2.2 Review of Past Works on Grain Crushers: Types, Designs, and Components

Grain crushers, an essential technology in post-harvest processing, have undergone significant evolution in design and functionality over the decades. The literature reveals a spectrum of designs that serve different contexts — from simple manual mills to highly automated, energy-efficient crushers. This section reviews past studies on grain crusher types, designs, and component choices, focusing primarily on African contexts, especially Nigeria, but also drawing from relevant global research to provide a comprehensive understanding of the state of the art.

2.2.1 Grain Crusher Types and Mechanical Designs

Grain crushers represent a broad class of agricultural machinery designed to reduce the size of cereal grains to a form suitable for subsequent uses such as food preparation, animal feed formulation, and industrial processing. Their design and mechanical operation vary significantly depending on the crushing principles employed, the target throughput, energy availability, and the types of grains processed.

Grain crushers broadly fall into four categories: hammer mills, roller mills, burr mills, and impact mills. Each category is defined by its distinct mechanism of particle size reduction, which shapes its performance characteristics, operational costs, maintenance demands, and suitability to specific applications.

2.2.1.1 Hammer Mills

Hammer mills constitute the most widely adopted crusher type in many African smallholder and rural settings (Ayoola et al., 2019; Musa & Akinwale, 2004). Their operational principle involves a rotor mounted with several hammers rotating at high speeds. The grains fed into the crusher are repeatedly struck by the hammers, breaking them into smaller particles before being forced through a perforated screen that controls the particle size.

The simplicity of design—comprising a rotating shaft, hammer assemblies, a screen, and a feeding mechanism—facilitates local fabrication using basic workshop equipment, reducing capital costs and enabling easier repairs (Ayoola et al.).

However, the kinetic energy transfer through hammer impact results in considerable energy losses due to friction and noise, with energy consumption reported between 0.8 to 1.8 kWh per ton depending on design specifics such as hammer tip speed, screen aperture, and feed rate (Mugabi et al., 2019).

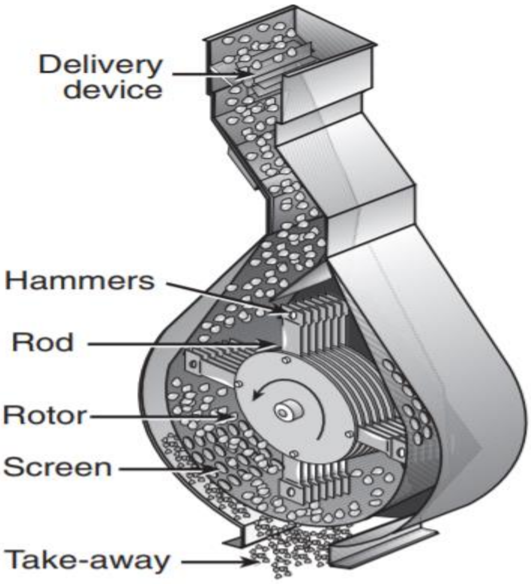


Figure 2.1: Cross-sectional view of a conventional hammer mill (McGraw-Hill, 2007).

Despite their popularity, hammer mills have notable drawbacks. The wear of hammers and screens is rapid, especially when processing abrasive grains or foreign matter contamination, necessitating frequent replacements that drive up maintenance costs (Musa & Akinwale, 2004). The high-speed impact generates substantial dust, posing health risks to operators and complicating maintenance (Yusuf & Ajibola, 2018). Moreover, the noise levels are often high, requiring mitigation measures.

Recent innovations in hammer mill design have introduced oblique hammer configurations, where blades are inclined—typically at 45°—relative to the tangent of the rotor. This angular arrangement improves the efficiency of grain impact by reducing the incidence angle, guiding particles more smoothly through the milling chamber, and minimizing re-circulation (Zastempowski et al., 2015). Studies indicate that such designs can reduce energy consumption by approximately 14% per ton processed at standard speeds (Zastempowski & Meller, 2015), while also improving throughput by up to 5%. Furthermore, angled hammers enhance dust control and reduce internal heat buildup by facilitating more streamlined particle ejection (Machado et al., 2016). Complementing this, screenless hammer mills have also emerged as a solution to frequent screen clogging and high maintenance demands. By eliminating the traditional mesh screen and utilizing airflow separation or fixed grate mechanisms, these designs maintain processing efficiency even when handling moist or fibrous grains (MIT D-Lab, 2022). Together, these innovations represent a shift toward more energy-efficient, low-maintenance hammer mill technologies, particularly suited to rural and smallholder contexts. Below are CAD representations of oblique hammers.

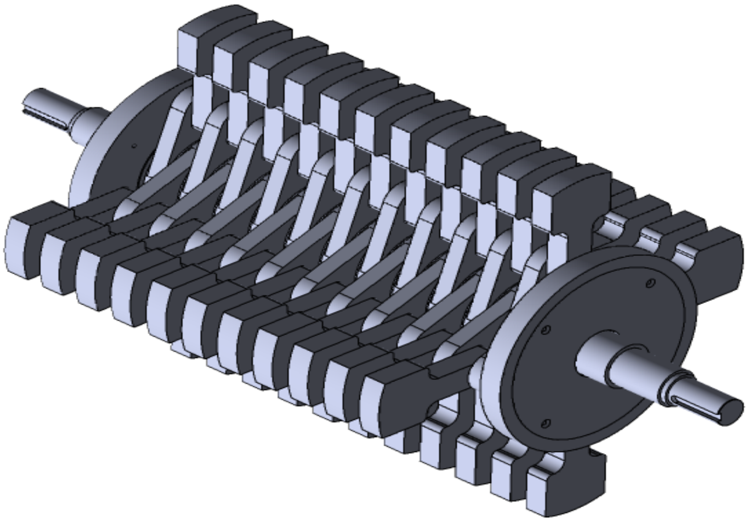
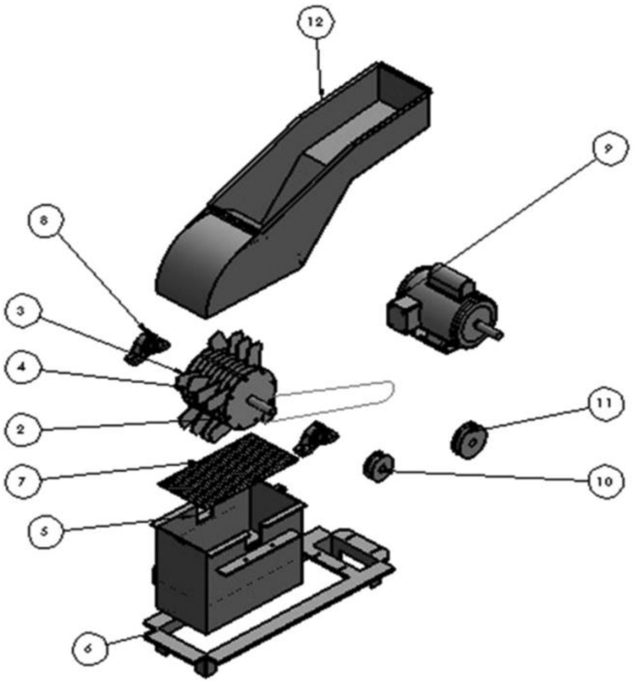


Figure 2.2: 3D CAD Model of an Oblique Hammer Mill Rotor Assembly

In their 2018 study, Ezurike et al. present a modified hammer mill design with a flat screening plate, departing from the traditional cylindrical screen configuration. This deviation was motivated by inefficiencies such as prolonged milling times and material recirculation inherent to conventional mills. Their detailed design, incorporates key components—hopper, rotor with hammers, shaft, motor, housing, and flat screen.

The machine is powered by a modest **one-horsepower electric motor** and employs a high-speed rotating disc with centrifugal hammers. Through testing with dried maize, the modified flat-screen hammer mill achieved an impressive **milling efficiency of 92.9%** This marked efficiency improvement underscores the design's efficacy in mitigating material re-circulation—a problem commonly associated with curved screens.

By choosing a flat plate over semi-circular screening surfaces, Ezurike et al. effectively streamline material exit paths, reduce grain dwell time, and promote a more direct transfer of crushed particles.



ITEM NO.	PART NUMBER	QTY.
1	ROTOR DISC BOLT	8
2	ROTOR NUT	8
3	SHAFT WITH ROTOR	1
4	HAMMER	16
5	BOTTOM CASING	1
6	STRUCTURAL BASE	1
7	SCREEN	1
8	PLUMMER BLOCK	2
9	ELECTRIC MOTOR	1
10	DRIVEN PULLEY	1
11	DRIVER PULLEY	1
12	TOP CASING WITH HOPPER	1

Figure 2.3: Hammer mill featuring a flat screen

In relation to other studies, the focus on chamber design and throughput optimization connects well with research from Cairo University (Mohamed et al., 2019), which used empirical-performance modeling to predict optimal rotor speeds, screen sizes, and feed rates. Additionally, CFD-driven studies (Zhang et al., 2022) reinforce the importance of internal flow dynamics and chamber shape—factors that are conceptually aligned with Ezurike et al.'s design rationale.

Despite the study’s strong contributions to design simplification and performance improvement, a few limitations warrant further attention. These include a lack of quantitative energy consumption data (e.g., kWh/t), absence of long-term wear analysis of the flat screen, and absence of a detailed structural analysis of the rotor-bearing assembly.

Nevertheless, Ezurike et al. (2018) offer a valuable and locally adaptable solution to improve milling efficiency in hammer mills through chamber redesign. The straightforward modification—simple active components, flat screen—makes the design especially suitable for rural Nigerian contexts and local manufacturing environments. Incorporating their findings into your project can lend empirical weight to chamber geometry decisions and support design choices that are technically sound and contextually appropriate.

2.2.1.2 Roller Mills

Roller mills are mechanical devices used primarily for grinding or crushing grain into flour or meal. They function by passing the grain between two cylindrical rollers that rotate in opposite directions. As the grain is fed into the gap between the rollers, it is compressed and sheared, breaking it down into smaller particles. The spacing between the rollers can be adjusted to control the fineness of the output. Unlike impact-based grinders like hammer mills, roller mills use compression and friction, resulting in less heat generation, more uniform particle sizes and energy efficiency (Musa et al., 2012; Solà-Oriol et al., 2015). This makes them ideal for producing high-quality flour with minimal dust and energy consumption. Roller mills are commonly used in both industrial flour milling and small-scale agricultural settings where precision and efficiency are prioritized. The rollers may be smooth or grooved, with the gap between them adjusted to control particle size.

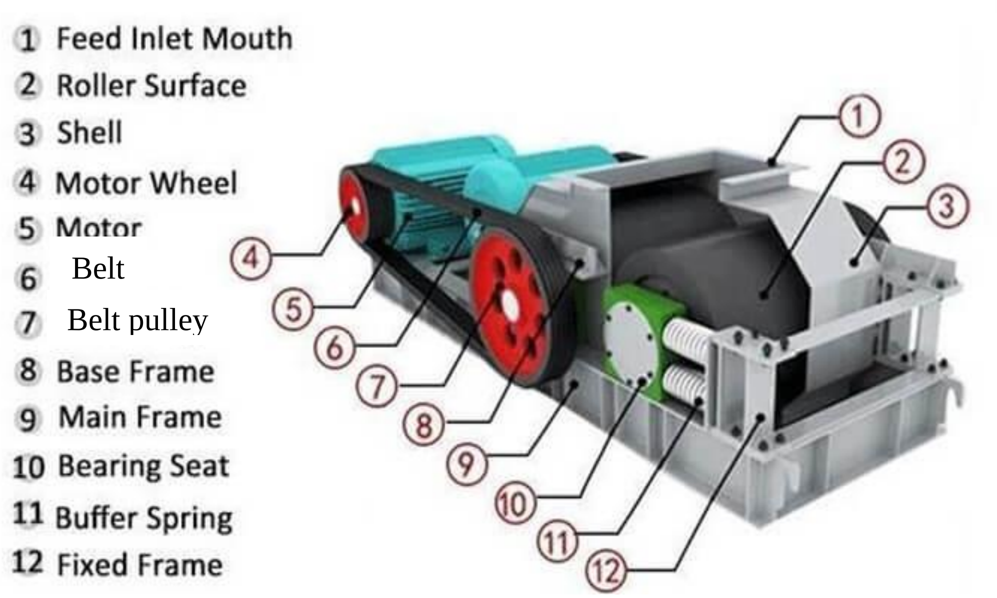


Figure 2.4: 3D labeled diagram of a grain roller (adapted from JXSC Mining, n.d.).

Musa et al. (2012) conducted detailed experimental work on roller mills fabricated locally in Northern Nigeria. Their findings indicated throughput capacities of 50 to 70 kg/hr. with more uniform particle sizes compared to hammer mills. However, the study underscored significant challenges related to manufacturing precision and alignment, which are critical to roller performance. Misalignment causes uneven wear and roller seizure, limiting the feasibility of purely local manufacturing in some rural contexts.

The materials used for rollers are another concern. Mild steel, commonly used due to its availability and low cost, suffers rapid wear and reduced service life (Musa & Akinwale, 2004). Case-hardened steel rollers show significant durability improvements but are more expensive and difficult to machine. This trade-off has important implications for lifecycle costs and local manufacturing capacities.

Roller mills also exhibit limited versatility with fibrous grains or those with higher moisture contents, which tend to clog the gap or cause slipping. These limitations have restricted their adoption primarily to specific grains like maize and wheat in some regions (Tiamiyu et al., 2015).

2.2.1.3 Burr Mills

Burr mills employ abrasive grinding surfaces—two discs or burrs—rotating against each other to shear grains into fine particles. Tiamiyu et al. (2015) investigated modular burr mill designs for maize and millet processing in northern Nigeria, demonstrating throughput rates of approximately 50 to 70 kg/hr. with lower power requirements than hammer mills.

The burr mill's compact size and lower dust generation make it suitable for household and small-scale applications. However, their throughput remains limited, and the abrasive surfaces are prone to clogging, particularly when processing grains with high moisture content (FAO, 2016). Maintenance is more involved due to the need for burr surface replacement or dressing to maintain grinding efficiency.

Globally, burr mills find applications in food processing sectors where particle size uniformity and low heat generation are critical, such as in coffee grinding and spice milling (FAO, 2016). Their limited use in African grain processing relates to throughput and maintenance demands, which challenge their scalability.

2.2.1.4 Centrifugal-Impact Grain Crusher and Other Innovative Trends in Grain Crusher Designs.

Volkhonov et al. (2020) introduced an innovative centrifugal-impact grain crusher designed address common challenges such as clogging and excessive dust generation observed in traditional crushers. Their design incorporated an additional air supply through the loading neck (by means of component 11 in the figure 2.5 below), which facilitated better evacuation of crushed material and significantly reduced the likelihood of clogging during operation. The machine achieved an impressive throughput of 1,440 kg/h while maintaining a relatively low specific energy consumption of 2.1 W·s/(kg·grinding unit degree). Notably, their design effectively reduced the dust fraction produced during crushing operations to below 5.74%, which is approximately half of what is typically observed in conventional hammer mills. To strengthen their findings, Volkhonov et al. developed regression models establishing quantitative relationships between sieve hole size, rotor speed, and bunker outlet area with key performance indicators such as throughput and energy consumption. However, despite these promising results, the study primarily focused on controlled testing conditions and barley as the test grain, leaving room for further investigation into the design's performance across

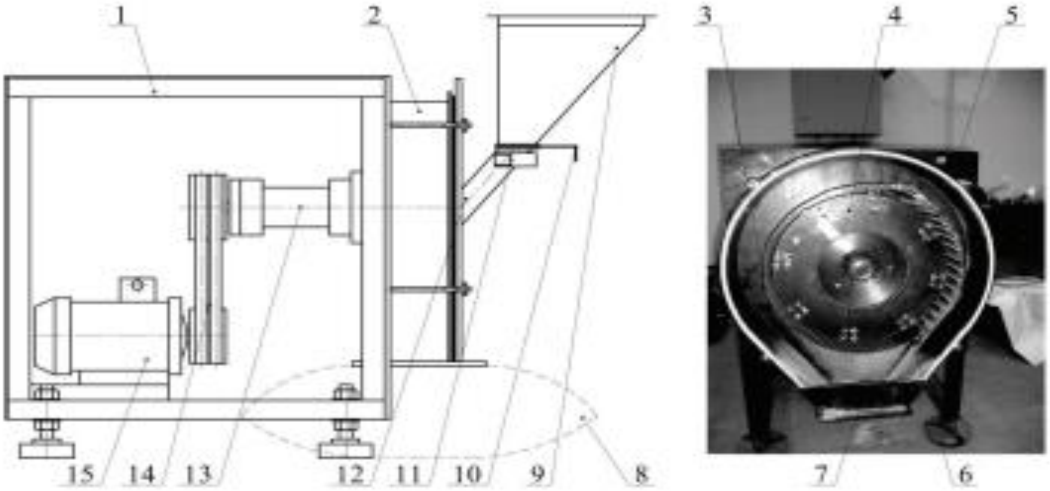


Fig. 1. Feed grain crusher: 1 — bed; 2 — work chamber; 3 — sieve; 4 — rotor; 5 — deck; 6 — bracket; 7 — unloading neck; 8 — filter bag; 9 — bunker; 10 — adjustable flap; 11 — hole with a gate; 12 — loading neck; 13 — bearing case; 14 — V-belt transmission; 15 — electric motor

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Figure 2.5: Schematic and Front View of Volkhonov et al.'s centrifugal-impact Grain Crusher

The strength of their study lay not only in performance outcomes but also in the development of predictive regression models linking design and operational parameters to crusher performance. They derived relationships that describe how sieve hole size(d_{sieve}), rotor speed (n_{rotor}), and bunker outlet area (A_{outlet}) influence throughput (Q) and specific energy consumption (E). The general form

$$Q = a_0 + a_1 d_{sieve} + a_2 n_{rotor} + a_3 A_{outlet} + a_4 d_{sieve} n_{rotor} + a_5 d_{sieve} A_{outlet} + a_6 n_{rotor} A_{outlet} + \cdots$$

$$E = b_0 + b_1 d_{sieve} + b_2 n_{rotor} + b_3 A_{outlet} + b_4 d_{sieve} n_{rotor} + b_5 d_{sieve} A_{outlet} + b_6 n_{rotor} A_{outlet} + \cdots$$

where a_i and $b_i$are regression coefficients determined from experimental data.

These equations provide valuable tools for design optimization, enabling adjustment of machine parameters to achieve desired performance outcomes without reliance on costly or time-consuming trial-and-error processes. In Nigeria, where many local fabricators design grain crushers based on empirical knowledge rather than formal engineering analysis, adopting such a model-based approach could significantly enhance machine efficiency, durability, and user satisfaction.

However, several limitations temper the direct applicability of these findings. The regression models were derived using barley as the test grain; their predictive power for other common Nigerian grains such as maize, sorghum, or millet remains unverified.

The design innovations proposed by Volkhonov et al. align with broader research efforts aimed at enhancing grain crusher performance. Kupchuk and Telekalo (2021) explored vibratory-disc crushers that combine impact and centrifugal forces, demonstrating that hybrid mechanisms can improve particle uniformity and lower energy requirements. Similarly, Myhailovych et al. (2021) investigated single-roller mills that integrate centrifugal impact features to enhance grain breakage efficiency while maintaining dust emissions at controlled levels. Complementing these mechanical design improvements, Iskakov et al. (2025) advocated for upgraded materials and surface engineering for critical working parts to prolong service life, addressing common issues of rapid wear.

Despite these advancements, persistent limitations in conventional designs remain well-documented in the literature. For example, Savinyh et al. (2019) highlighted that, inefficiencies in feeding devices contribute to uneven material distribution and increased energy consumption. Similarly, traditional hammer mills, as reported by Ibrahim and Omran (2019), continue to suffer from high energy inefficiency, excessive dust generation, and rapid component wear. Djordjevic et al. (2003) further pointed out that impact crushers often exhibit unpredictable particle trajectories, making it difficult to achieve consistent crushing efficiency without sophisticated design adjustments.

From a performance modeling perspective, Marczuk et al. (2019) applied multifactorial analysis to rotary-centrifugal grinders and confirmed that rotor speed and sieve hole size are dominant factors influencing both power demand and throughput. Kalandarov et al. (2024) expanded this understanding by investigating the role of grain moisture content, showing that both machine design and feedstock moisture interact significantly to affect grinding energy requirements and particle uniformity.

While the work of Volkhonov et al. (2020) represents a significant step forward, several research gaps remain evident. The absence of long-term field validation limits confidence in the crusher's real-world durability and economic competitiveness, especially under variable farm conditions. Additionally, their study did not explore the machine's adaptability to a wider range of grains beyond barley. There is also a lack of integration of renewable or hybrid energy solutions, which could make such crushers more attractive in rural, low-resource settings. Finally, opportunities exist to develop affordable automation features that could dynamically adjust crusher settings in response to changing operating conditions.

Additionally, while the energy efficiency and dust reduction benefits are clear, the study did not provide comprehensive economic analysis comparing capital and operating costs of this design to existing commercial or local alternatives—an omission that constrains its utility for decision-making in resource-limited environments. Furthermore, long-term durability under real-world conditions, including exposure to variable grain moisture levels and operator handling practices typical in rural Nigerian settings, was not assessed.

Nevertheless, the work of Volkhonov et al. (2020) highlights critical directions for further research. There is a clear need for field trials of advanced crusher designs under diverse environmental and operational conditions, integration of renewable or hybrid power sources appropriate for off-grid contexts, and the development of low-cost automation systems that allow smallholder users to dynamically adjust machine settings. Material science research focused on affordable wear-resistant components also remains an essential priority to enhance equipment lifespan and reduce maintenance burdens.

Recent research into the energy efficiency and mechanical evolution of grain crushers underscores the limitations of traditional impact-based designs and highlights promising alternatives. A notable study examined various crushing mechanisms, including hammer mills, rotor-beater crushers, centrifugal-rotor crushers, cone inertial crushers with toothed cones, and roller crushers with rifled rollers. The primary focus of this work was to compare the performance of these designs and argue for a paradigm shift towards crushers that operate predominantly on splitting (skalyvanie) and shearing principles rather than conventional impact methods.

The study demonstrated that crushers employing splitting and shearing mechanisms—such as cone inertial crushers and roller crushers—consumed significantly less energy, typically between 0.4 and 1.0 kWh per ton. This represents an energy saving of approximately 58% compared to hammer mills achieving similar degrees of fineness. In addition to their superior energy efficiency, these crushers produced lower amounts of fine dust, which is crucial in minimizing material losses and mitigating health hazards associated with grain dust inhalation. The authors highlighted cone inertial crushers with toothed cones as particularly promising, citing their self-cleaning capabilities that prevent clogging and their suitability for processing moist or oily grains commonly encountered in agricultural contexts.

The paper further critiqued existing designs, noting that traditional hammer mills and rotor-beater crushers generate excessive dust and exhibit high energy consumption. The absence of protective elements in rotor-beater crushers was identified as a weakness, as it increases the risk of machine failure when foreign objects such as stones or metal fragments enter the crushing chamber. Although certain centrifugal-rotor designs with finger or pin working bodies offer improvements in splitting efficiency and clogging resistance, the complexity of their manufacture remains a barrier to local production and widespread adoption, particularly in resource-constrained settings like rural Nigeria.

Importantly, the findings of this study are consistent with earlier work by Volkhonov et al. (2020), which highlighted the benefits of centrifugal-impact crushers in reducing both dust generation and energy consumption. The study also supports the conclusions of Kupchuk and Telekalo (2021), who advocated for hybrid mechanisms that combine splitting and impact actions to enhance crushing performance. Building upon the material science insights of Iskakov et al. (2025), this research advances the argument that cone inertial designs may represent the most viable direction for future grain crusher development, offering both operational efficiency and durability.

However, several critical gaps remain. The study emphasizes the need for experimental validation of cone-inertial crusher designs under actual field conditions, optimization of rotor speed and working gap parameters to further minimize energy use, and simplification of manufacturing processes to enable local workshops to produce these high-efficiency machines affordably. Furthermore, it underscores the importance of integrating dust control and safety features into new designs without imposing prohibitive cost burdens on smallholder users.

Overall, the study presents a compelling case for prioritizing cone-inertial crushers in future research and development efforts. By combining energy efficiency, self-cleaning ability, and adaptability to diverse grain types, these designs hold significant potential to address many of the persistent challenges faced by grain processors in Nigeria and similar contexts.

2.2.2 Components and Material Selection in Grain Crusher Designs

Material selection critically impacts grain crusher durability, performance, cost, and maintenance frequency. Components such as hammers, rollers, screens, shafts, and housings experience abrasive wear, corrosion, fatigue, and impact stresses.

2.2.2.1 Material Types and Wear Resistance

Mild steel remains the dominant material for locally fabricated crusher parts due to availability, ease of machining, and affordability (Musa & Akinwale, 2004). However, mild steel components exposed to abrasive grain particles and high-impact forces typically exhibit rapid degradation, requiring frequent replacement and increasing downtime (Okonkwo & Fasasi, 2010).

Ayodele and Salami (2022) explored wear-resistant steel alloys and surface hardening techniques such as carburizing and nitriding to improve hammer durability. Their laboratory trials indicated lifespan improvements of approximately 40% but noted cost increases of 25-40% per component. This trade-off raises questions about long-term cost-effectiveness in low-income rural markets.

2.2.2.2 Alternative Materials and Composites

Chukwu et al. (2022) examined stainless steel and galvanized steel perforated sheets for crusher screens. Stainless steel offered superior corrosion resistance and wear performance but came at significantly higher cost, limiting adoption. Galvanized sheets, while cheaper, corroded rapidly under humid tropical conditions, negatively affecting food hygiene and machine lifespan.

Onyeka et al. (2021) introduced bamboo-reinforced polymer composites for non-load-bearing parts such as hoppers and casings. Their composites showed promising strength-to-weight ratios, reducing overall machine weight by 15-20%, thus easing manual handling and transportation. Long-term durability in outdoor and humid conditions remains under study.

2.2.3 Power and Energy Considerations in Grain Crusher Designs

Energy availability and efficiency are critical factors influencing the practicality and sustainability of grain crushers in Nigerian rural areas, where reliable electricity is often lacking or expensive. Okeke et al. (2020) found that locally used hammer mills typically draw between 2.5 and 5.0 kW depending on the machine size and type of grain. The study also showed that poor maintenance—such as worn hammers and clogged screens—increases power consumption by up to 30%, leading to higher electricity bills or fuel use.

Given Nigeria's low rural electrification rate and frequent power outages, many small-scale processors rely on expensive diesel generators, increasing operational costs and limiting profitability. Practical Action (2021) explored solar-powered grain crushers in East African villages, highlighting zero fuel costs and reduced noise as major benefits. However, the initial investment—about $3,500 USD—is prohibitive for many Nigerian smallholders and micro-enterprises, limiting widespread adoption despite long-term savings.

As a lower-cost alternative, Open-Source Ecology (2021) has promoted pedal-powered crushers, which require no fuel or electricity. While these devices offer limited throughput of 15–20 kg/hr., their affordability and ease of maintenance make them suitable for very small-scale users or as backup during outages. However, their low capacity restricts commercial use beyond subsistence levels.

Figure 2.6: Pedal Powered Grain Mill

In response to these challenges, hybrid systems that combine electric motors with petrol engines have emerged (MIT D-Lab, 2022). These flexible units can switch power sources depending on availability, improving reliability while controlling fuel expenses. Though promising, hybrid systems remain rare in Nigeria due to high upfront costs and lack of local servicing expertise.

Power efficiency also depends on grain moisture content and machine condition. Higher moisture grains require more energy to crush, and worn components further increase power demands (Okeke et al., 2020). This highlights the importance of proper maintenance and adjustable operational settings to optimize energy use.

2.2.4 Dust Control, Operator Safety, and Environmental Considerations

Dust generated during grain crushing represents a significant occupational hazard as well as a challenge for machinery maintenance. Prolonged exposure to grain dust has been linked to various respiratory illnesses, including hypersensitivity pneumonitis (commonly referred to as farmer’s lung), asthma, and chronic bronchitis (Yusuf & Ajibola, 2018). In Nigeria, where the use of simple hammer mills is widespread and operators often work without adequate protective gear, the health risks are pronounced. Yusuf and Ajibola (2018) conducted measurements of airborne dust concentrations in small-scale hammer mill operations and found particulate levels frequently exceeding 5 mg/m^3, which surpasses the World Health Organization’s recommended occupational exposure limits. These elevated dust levels pose acute and chronic health risks for operators, including irritation of the respiratory tract, decreased lung function, and increased susceptibility to infections.

Dust not only affects health but also accelerates wear and tear on machinery components, leading to increased downtime and maintenance costs. Efforts to reduce dust exposure have included mechanical and environmental controls. Tiamiyu et al. (2015) explored the integration of cyclone separators and dust extraction fans in their modular burr mill designs. Their field trials demonstrated dust reductions of 30 to 50 percent within enclosed milling areas, which substantially improved air quality and operator comfort. However, such systems typically require reliable power sources, ongoing maintenance, and technical expertise for operation—factors often lacking in low-resource rural settings. Consequently, these solutions have had limited uptake among smallholder operators who prioritize affordability and ease of use over advanced engineering controls.

The United Nations Environment Programme (UNEP, 2021) advocates for straightforward and cost-effective dust control measures, such as fully enclosing crushing chambers to contain dust, implementing water spray systems to dampen airborne particles, and installing local exhaust ventilation to capture dust at the source. While these recommendations have merit, their adoption in small-scale Nigerian grain processing remains constrained by the additional capital expenditure, energy demands, and the need for routine upkeep, which are significant hurdles for operators with limited financial and technical resources.

Beyond dust, noise and vibration generated during grain crushing constitute additional occupational hazards. Hammer mills typically produce noise levels in the range of 85 to 95 decibels (dB), which is sufficient to cause long-term hearing impairment if operators are exposed without hearing protection (Mugabi et al., 2019). Vibration transmitted through handheld or standing mill components can cause discomfort and increase operator fatigue, further impacting productivity and safety. Attempts to mitigate noise and vibration include the use of vibration dampening mounts, acoustic enclosures, and sound-absorbing materials. While effective, these modifications generally increase the complexity, size, and cost of the machinery, and may reduce portability—important considerations for rural users who often transport equipment between farms or processing sites.

Given the health and maintenance challenges posed by dust, noise, and vibration, future grain crusher designs targeted at Nigerian smallholders must balance effectiveness of control measures with affordability, simplicity, and ease of maintenance. Low-cost innovations such as improved sealing, use of dust masks, and basic sound barriers warrant further exploration. Additionally, community education on occupational health risks and safe operating practices could help mitigate adverse impacts while more advanced engineering solutions gradually become accessible

2.2.5 Automation and Control Systems in Grain Crushers

Automation in grain crushers offers opportunities to improve efficiency, reduce operator workload, and extend equipment life through smarter control and monitoring.

Chukwu et al. (2022) developed an Arduino-based system for maize crushers that used sensors to monitor motor speed, grain flow, and load. The system automatically adjusted rotor speed to optimize throughput and prevent overload, achieving about 10% higher efficiency and 15% energy savings compared to manual operation. This approach uses affordable, locally available components, making it suitable for low-resource settings, though maintenance and power supply remain challenges.

MakerHub Nairobi (2021) piloted IoT-enabled crushers connected via cellular networks for remote monitoring and predictive maintenance. While effective, unreliable internet and limited local technical support hinder widespread adoption in rural areas.

Ramírez et al. (2019) applied AI to dynamically adjust impact mill parameters based on grain moisture and hardness, optimizing product quality and energy use. However, the complexity and cost make this approach less practical for smallholder farmers in Nigeria at present.

In summary, low-cost sensor-based automation shows promise for immediate use if paired with adequate training, while more advanced IoT and AI solutions may become feasible as infrastructure improves. Designing systems that suit local contexts—simple, modular, and easy to maintain—is essential for successful adoption.

2.3 Synthesis and Comparative Analysis

The reviewed literature reveals a dynamic landscape of grain crusher designs with varied strengths and limitations. Hammer mills dominate African contexts due to ease of fabrication and multi-grain capability, but suffer from rapid wear, dust issues, and energy inefficiency. Roller and burr mills offer more consistent product quality and reduced power requirements but face barriers in fabrication complexity and cost.

Material selection emerges as a critical factor influencing durability and lifecycle costs. While mild steel remains predominant in local fabrications, case-hardened and wear-resistant alloys significantly enhance longevity but increase upfront expenses. Composite materials may offer cost-effective alternatives, especially for structural parts.

Energy supply challenges drive innovations in solar and manual power integration, yet motorized systems remain preferred for higher throughput. Dust and safety concerns are recognized, with limited but growing incorporation of control technologies.

Automation and smart control integration are nascent in African settings but show promise for optimizing performance and extending equipment life. However, these require technical support infrastructures currently lacking in many rural areas.

2.4 Identified Research Gaps

Despite advancements, critical gaps remain. There is a need for:

i. Affordable, durable materials accessible in rural markets to reduce maintenance costs and downtime.

ii. Modular designs that balance fabrication simplicity with adaptability to different grains and operational scales.

iii. Robust dust control systems that are cost-effective and easy to maintain for smallholder users.

iv. Sustainable energy integrations tailored for off-grid environments.

v. Scalable automation solutions that require minimal technical expertise for operation and upkeep.

CONCLUSION

The comprehensive review underscores the critical role of grain crushers in supporting food security and agricultural value chains, particularly in developing regions. While hammer mills remain dominant due to simplicity and affordability, their limitations in durability, energy use, and operator safety are well documented.

Roller and burr mills offer technical advantages but face barriers to wide adoption due to fabrication complexity and cost. Material innovations and renewable energy integration show promise in extending equipment lifespan and reducing operating costs.

Critical research gaps exist in materials development, modular design, dust mitigation, sustainable power systems, simplified automation, and comprehensive field validation. Addressing these gaps with a multidisciplinary approach can advance the development of grain crushers that are durable, affordable, and context-appropriate for rural users.

CHAPTER THREE - METHODOLOGY

3.1 Materials

1. 4mm thick Mild steel pan
2. Bearing
3. $2\frac{1}{2}\ by$ 6mm thick Angle Bar
4. 25 mm diameter Solid shaft
5. 10mm diameter Auxiliary shaft
6. Paint
7. Pulleys
8. Belt
9. Electrodes
10. Cutting disk
11. Stainless steel screen/ filter

The objective of this project is to design a portable motorized grain grinding machine for home use. The concept is developed based on the ergonomics and easy handling of the equipment. The following steps were taken; designing the machine, material selection, machine fabrication, performance analysis.

3.2 Conceptual Design

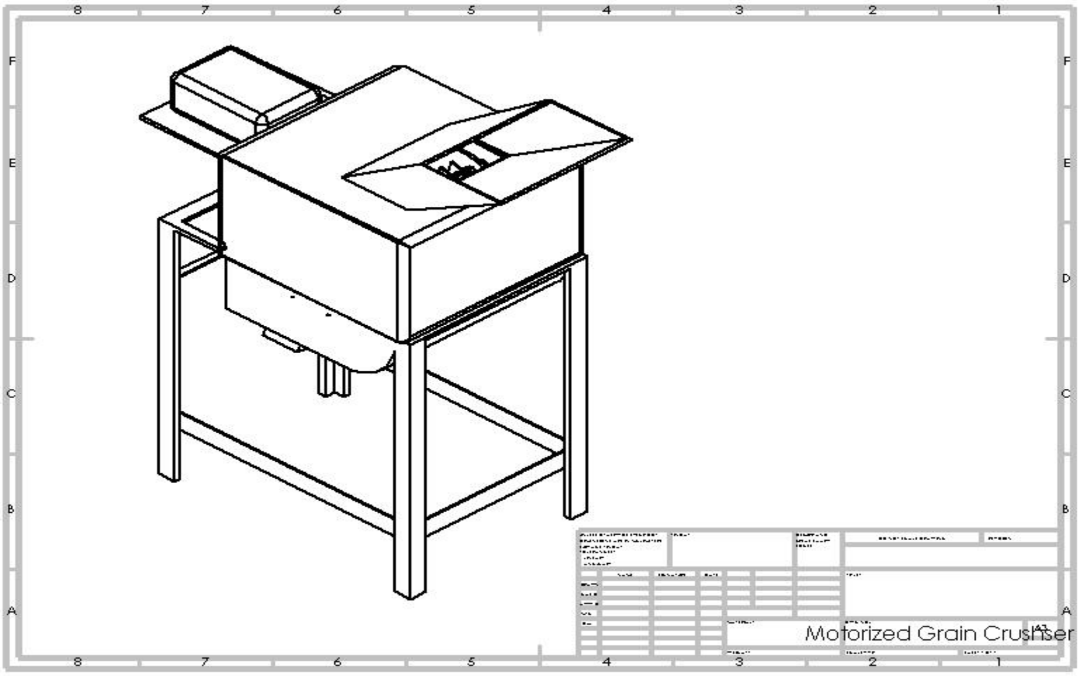

Figure 3.1: CAD Design of the motorized Grain Crusher

The machine operates as an impact-type grain crusher, where dry maize is fed through a hopper into a rotating crushing unit with hammers or blades. Grains are reduced in size through high-velocity impact and shear forces generated by the rotor assembly. Power is transmitted via an electric motor and belt-driven pulley system, offering flexible speed control, shock load protection, and simplified maintenance.

Structurally, the machine is supported by a rectangular steel frame that provides stability, elevates the crushing chamber to a convenient height, and resists vibration from high-speed rotation. The rotor consists of circular discs and symmetrically arranged hammers or blades to ensure balance and uniform weight distribution. Precision machining is required for the rotor shaft, discs, and hammer elements to maintain alignment and smooth operation.

The design emphasizes simplicity, local fabrication, and modularity. Sheet-metal components such as the hopper, casing, and discharge chute are easy to produce, while critical crushing parts use wear-resistant materials like high-carbon or hardened steel. Mild steel is used for the frame and non-critical parts, with optional corrosion-resistant coatings for durability.

Safety and ergonomics are integral: protective guards cover belts and pulleys, the hopper throat prevents operator contact with rotating blades, and dust/noise management is accommodated. The overall layout ensures efficient operation, ease of maintenance, and accessibility for small-scale farmers.

The design balances performance, manufacturability, durability, and operator safety, forming the foundation for detailed engineering calculations and subsequent fabrication.

3.2.1 Machine Components.

i. SHAFT:

The shaft serves as the primary power-transmission element in a grain-grinding machine, conveying torque and rotational motion from the electric motor to the grinding mechanism. It acts as the central mechanical member that drives the hammers to achieve effective size reduction of grains. The shaft is typically manufactured from high-strength steel to withstand combined torsional and bending stresses encountered during operation. It is supported by bearings to ensure smooth, low-friction rotation and is connected to the power source through couplings or pulleys for efficient energy transfer.

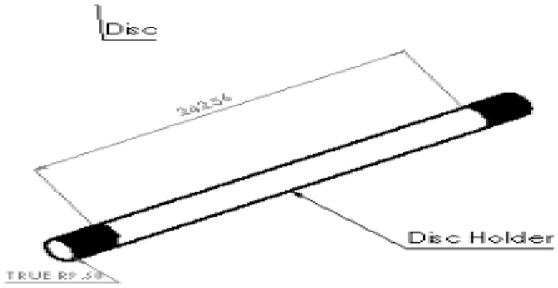

Figure 3.2: CAD representation of a Shaft

ii. ELECTRIC MOTOR: An electric motor converts electrical energy into mechanical energy, producing rotary motion to drive the grinding mechanism. D.C motors are commonly used for grain milling due to their clean, quiet operation, low maintenance, and ability to maintain consistent speed. Proper matching to the grinding mechanism and protection from dust, voltage fluctuations, and overheating are critical for efficiency and longevity. Electric motors also contribute to environmental sustainability as they emit no exhaust gases.

iii. HAMMER: Hammers in a hammer mill impact and break grains into smaller particles through repeated striking. Typically, rectangular or T-shaped, they are mounted on a rotating shaft and swing outward at high speed due to centrifugal force. Material, size, number, and arrangement of hammers affect grinding efficiency and fineness. Hardened steel or high-carbon materials are used to withstand wear; worn hammers reduce efficiency and increase energy consumption.

Figure 3.3: Electric Motor

iv. DISK The disks in the machine are not grinding disks. Their purpose is to facilitate the movement of grains, preventing dead zones during crushing and ensuring a smoother, more efficient grinding process.

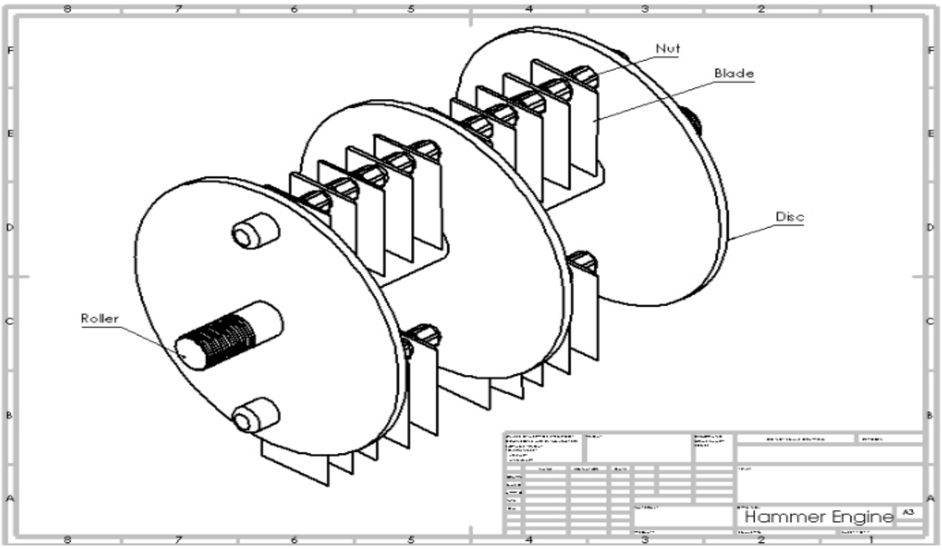

Figure 3.4: Rotor including hammer shafts and disk

v. PULLEY: Pulleys transfer motion and torque from the motor to the grinder via belts, enabling speed variation and torque multiplication. They are typically made of cast iron, steel, or aluminum. Proper alignment and belt tension are essential to prevent slippage and power loss while ensuring smooth operation and reduce d vibration.

Figure 3.5: Pulley

vi. HOPPER: The hopper is a funnel-shaped container that regulates grain flow into the grinding chamber, ensuring a steady, uniform feed. Made from mild steel, stainless steel, or galvanized sheet metal, it often includes a control gate to adjust feed rate.

Proper hopper design improves efficiency, prevents spillage, and reduces the risk of clogging.

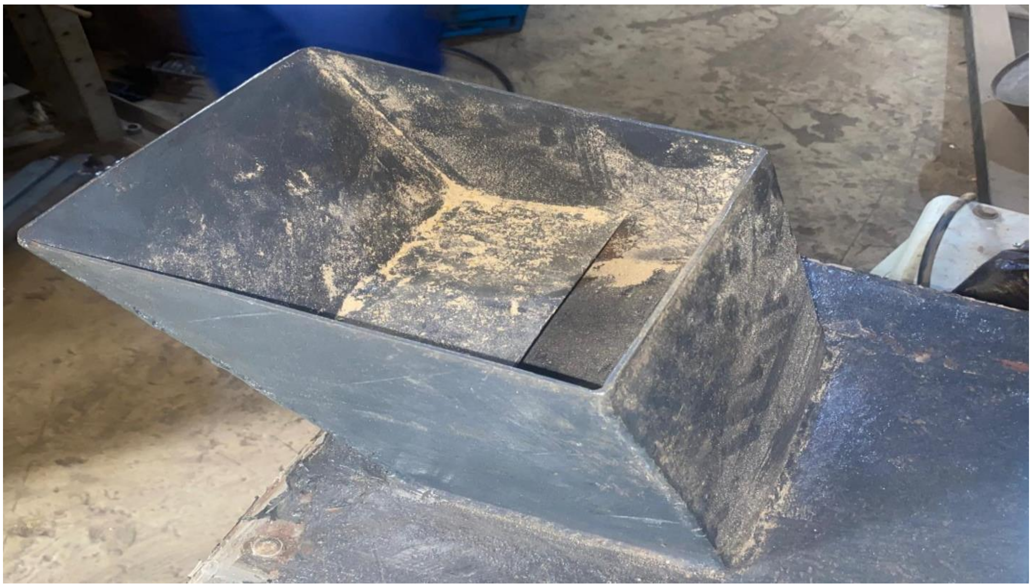

Figure 3.6: Hopper

vii. EXIT CHUTE: The exit chute directs ground grains out of the machine. Constructed from mild or stainless steel, it is sloped to use gravity for smooth discharge, minimizing spillage and improving operational cleanliness.

Figure 3.7: Exit Chute

viii. FRAME & LEGS: The frame and legs provide structural support and stability for all components. They are typically made from mild steel angle bars or square pipes, with welded or bolted joints to withstand operational stress. Elevation by legs allows convenient operation and vibration reduction; rubber pads may be used to further dampen noise and movement.

3.2 Material Selection

The type of material selected for this project is an important process in terms of design and fabrication. In choosing a material, certain criteria like corrosion, weight,
and strength are taken into consideration. The following materials were chosen:

i. **Stainless Steel:** Stainless steel is ideal for grain grinding machines due to its strength, corrosion resistance, and hygienic properties. It does not rust or react with food, can withstand vibration, impact, and friction, and is easy to clean, ensuring compliance with food safety standards. Its durability and thermal stability contribute to a long machine lifespan with minimal maintenance.

ii. **Mild Steel:** Mild steel is widely used for its high strength, weldability, ductility, and cost-effectiveness. It can absorb shock and stress during operation and is suitable for structural components like frames, shafts, and hoppers. Protective coatings prevent rust, making it reliable for long-term use.

iii. **Angle Bar:** Angle bars (L-shaped mild steel) are excellent for constructing the frame and support structure. They provide rigidity, strength, and stability while remaining lightweight and easy to assemble. Angle bars withstand vibration and dynamic loads, ensuring balanced and durable machine operation.

3.3 Design Calculations

3.3.1 Assumptions and material data

The mass flow is m˙=15 kgh−1=0.004167 kgs−1

The representative kernel mass is $m_g = 0.3\ g = 3.0 \times 10^{-4}\ kg$

Bulk density is $\rho_b = 750$kg/m^3

Average rupture force is $F_r = 146$ N

Deformation at rupture is $d = 1.0$ mm

Target feed size is $F_{80} = 8$

target product $P_{80} = 0.8$ mm

Process efficiency $\eta = 0.15$

Mechanical loss multiplier = 1.20

Startup multiplier = 1.5

Hammer transfer efficiency $\eta_{\text{transfer}} = 0.50$

Hammer path radius $r = 0.100m$ (rotor diameter $D = 0.200$)

Design tip speed $v_{tip} \approx 50$m/s

Steel density $\rho_{steel} = 7850$ kgm^{-3}

3.3.2 Fracture energy per kernel, number of fractures and net power

Energy per single fracture using triangular force–deformation approximation:

$$E_{fracture} = \frac{1}{2} F_r d$$

$$E_{fracture} = \frac{1}{2} \times 146 \times 1 \times 10^{-3} = 0.5 \times 146 \times 0.001 = 0.0730J$$

Number of binary fractures required per grain:

$$N_f = \frac{log\left(\frac{F_{80}}{P_{80}}\right)}{log\ 2} = \frac{log\left(\frac{8}{0.8}\right)}{log\ 2} = 3.321928 \approx 4$$

Net fracture energy per grain

$$E_{grain} = N_f \times E_{fracture} = 4 \times 0.0733J = 0.2920J$$

Grain processing rate (grains per second):

$$n^{\cdot\cdot} = \frac{m^{\cdot}}{m_g} = \frac{0.004167kg/s}{3 \times 10^{-4}kg} = 13.8889\ grains/s$$

Net power required for fracture:

$$P_{net} = E_{grain} \times n^{\cdot} = 0.2920J \times 13.8889\ grains/s = 4.0556\ \mathrm{W}$$

Input power accounting for process efficiency:

$$P_{input} = \frac{P_{net}}{\eta} = \frac{4.0556}{0.15} = 27.0370W$$

Total input power including mechanical losses and startup:

$$P_{total} = P_{input} \times 1.20 \times 1.50 = 27.0370 \times 1.2 \times 1.5 = 48.6666\ W$$

For practicality and to account for further design use a motor of at least 1.5 kW

3.3.3 Rotor kinematics and impact cadence

Target tip speed: $v_{tip} = 50m/s$

Rotor radius: $r = 0.100m$

Angular velocity: $\omega = \frac{v_{tip}}{r} = \frac{50}{0.100} = 500\ rad/s$

Shaft speed (convert ω to rpm): $N = \frac{\omega \times 60}{2\pi} = \frac{500 \times 60}{2\pi} = 4774.6483\ rpm \approx 4775\ rpm$

Adopt practical standard speed: N=4800 rpm

$$v_{tip} = \frac{2\pi Nr}{60} = \frac{2\pi \times 4800 \times 0.1}{60} = 50.2655\ m/s$$

Revolutions per second:

$$rev/s = \frac{4800}{60} = 80\, rev/s$$

Impacts per second from $N_h = 4$hammers:

$$impacts/\mathrm{s} = N_h \times rev/\mathrm{s} = 4 \times 80 = 320 \text{ impacts/s}$$

Required fracture events per second:

$$n^{\cdot} \times N_f = 13.8889 \times 4 = 55.5556\, fractures/s$$

Available impacts per fracture ratio:

$$\frac{impacts/s}{fractures/s} = \frac{320}{55.5556} = 5.76\, impacts\; per\; fracture$$

Energy available per impact (input basis):

$$E_{impact,input} = \frac{P_{input}}{impacts/s} = \frac{27.0370}{320} = 0.08449\, J$$

Useful energy per impact after transfer efficiency:

$$E_h = \frac{E_{impact,input}}{\eta_{transfer}} = \frac{0.08449\, J}{0.5} = 0.16898\, J$$

3.3.4 Hammer mass

hammer kinetic energy is given by:

$$E_h = \frac{1}{2} m_h {v_{tip}}^2$$

$$\therefore m_h = \frac{2E_h}{{v_{tip}}^2}$$

Using $v_{tip} = 50.2655\, m/s$ and $E_h = 0.16898\, J$

$$m_h = \frac{2 \times 0.16898}{(50.2655)^2} = 1.3376 \times 10^{-4}\, kg = 0.13376 g$$

This is the effective mass at tip required for crushing, for the overall geometry of the hammer, take 90mm by 50 mm by 5mm to allow for auxiliary crushing effect along the length of the hammer.

$$V_h = 90 \times 50 \times 5 \times 10^{-9} = 0.0000225m^3$$

$$m_h = \rho V_h$$

$$\therefore m_h = 7850 \times 0.0000225 = 0.1766kg$$

3.3.5 Rotor dynamic radial forces and bending moment

Tip speed, angular speed and shaft speed

Selected tip speed:

$$v_{\text{tip}} = 50.0 \text{ m s}^{-1}$$

Tip radius:

$$r_{\text{tip}} = 0.190 \text{ m}$$

Angular velocity:

$$\omega = \frac{v_{\text{tip}}}{r_{\text{tip}}} = \frac{50.0}{0.190} = 263.15789 \text{ rad/s}$$

Shaft speed (rpm):

$$N = \frac{\omega \times 60}{2\pi} = \frac{263.15789 \times 60}{2\pi} = 2512.7435 \text{ rpm}$$

$$N \approx 2513\, rpm$$

Hammer kinetic energy (per hammer)

$$KE_h = \frac{1}{2} m_h v_{\text{tip}}^2 = 0.5 \times 0.176625 \times 50.0^2$$

$$KEh = 220.8\, J\ per\ hammer$$

Dynamic radial force per hammer (centrifugal load)

Use hammer CG radius:

$$r_h = 0.145 \text{ m}$$

Radial force per hammer:

$$F_h = m_h\, \omega^2\, r_h = 0.176625 \times (263.15789)^2 \times 0.145 = 1\,740.266 \approx 1\,740 \text{ N}$$

Total radial force for 4 hammers:

$$F_{\text{total}} = 4 \times F_h = 4 \times 1\,740.266 = 6\,961.064 \text{ N}$$

$$F_{\text{total}} = \ 6\,961 \text{ N}$$

Rotor bending moment

Assume span $L = 0.200\text{m}$

Bending moment:

$$M_b = \frac{F_{\text{total}} \times L}{8} = \frac{6\,961.064 \times 0.200}{8}$$

$$M_b = \frac{1\,392.2128}{8} = 174.0266 \text{ Nm}$$

$$M_b \approx 174.0 \text{ Nm}$$

Torque due to power transmission

Use design total input power (including allowances):

$$P_{\text{total}} = 48.6667 \text{ W}$$

Angular speed corresponding to $N = 2\,513$ rpm:

$$\omega_{\text{rad}} = \frac{2\pi N}{60} = 263.158 \text{ rad /s}$$

Shaft torque from power:

$$T = \frac{P_{\text{total}}}{\omega_{\text{rad}}} = \frac{48.6667}{263.158} = 0.18496 \text{ Nm}$$

$$T \approx 0.185 \text{ Nm}$$

Equivalent torsion T_e(combined bending & torsion)

Adopt shock/fatigue factors $K_b = 1.5$, $K_t = 1.0$.

Compute:

$$K_b M_b = 1.5 \times 174.0266 = 261.0399 \text{ N} \cdot \text{m}$$

$$(K_b M_b)^2 = (261.0399)^2 = 68\,141.884$$

$$T^2 = (0.18496)^2 = 0.03422$$

$$T_e = \sqrt{(K_b M_b)^2 + (K_t T)^2}$$

$$T_e = \sqrt{(1.5 \times 174.0266)^2 + (1.5 \times 0.18496)^2} = \sqrt{68\,141.918} = 261.0399 \text{ N.m}$$

$$T_e \approx 261.04 \text{ Nm}$$

Shaft diameter from torsion relation

Allowable shear stress:

$$\tau_{\text{allow}} = 110 \text{ MPa}$$

$$T_e = \frac{\pi}{16} \tau_{\text{allow}} d^3 \Rightarrow d^3 = \frac{16\, T_e}{\pi\, \tau_{\text{allow}}}$$

$$16\, T_e = 16 \times 261.0399 = 4\,176.6384$$

$$\pi\, \tau_{\text{allow}} = \pi \times 110 \times 10^6 = 345\,575\,191.0$$

$$d^3 = \frac{4\,176.6384}{345\,575\,191.0} = 1.209 \times 10^{-5}\, m^3$$

$$d = \sqrt[3]{1.209 \times 10^{-5}} = 0.02295 \text{ m} = 22.95 \text{ mm}$$

$$d_{\text{calc}} = 22.95 \text{ mm}$$

$$\Rightarrow d_{\text{adopt}} = 25 \text{ mm}$$

Milling chamber and screening

Screen open area required from continuity:

$$A_{\text{open}} = \frac{\dot{m}}{\rho_b v_{\text{screen}} \phi}$$

Adopt screen conveying velocity $v_{\text{screen}} = 5 \text{ m s}^{-1}$

and open fraction $\phi = 0.40$.

Substitution:

$$A_{\text{open}} = \frac{0.004167}{750 \times 5 \times 0.40} = \frac{0.004167}{1500} = 2.7778 \times 10^{-6} \text{ m}^2$$

Hammer tip clearance to screen chosen: 5 mm

Hopper volume computed from residence time heuristics yields

$V_{\text{hopper}} = 3.33$ L

Adopt practical $V_{\text{hopper}} = 5$ L

Drive design: pulleys and belt

0.37 kW at 1440 rpm. Required rotor speed

$N_r = 4800$ rpm

Speed ratio:

$$\text{ratio} = \frac{N_r}{N_m} = \frac{4800}{1440} = 3.3333$$

Select motor pulley $D_m = 75$ mm

Driven pulley diameter:

$$D_r = \frac{D_m}{\text{ratio}} = \frac{75}{3.3333} = 22.5 \text{ mm}$$

Belt length estimate: select SPZ-580

Bearing selection and basic life (ISO 281)

Radial load used $F_r = F_{\text{total}} = 476.01584$ N. Candidate bearing: 6202-2RS with dynamic capacity $C = 7.65$ kN $= 7650$ N.

Bearing life $L_{10h}$is:

$$L_{10h} = \frac{10^6}{60N}(\frac{C}{F_r})^3$$

$$L_{10h} = \frac{10^6}{60 \times 4800}(\frac{7650}{476.01584})^3 = 14434.8 \text{ h}$$

3.4 **Bill of Materials for Fabrication Components**

Table 3-1: Bill of Materials for Fabrication Components

S/N	**Item**	**Specification**	**Qty**	**Unit Price (₦)**	**Line Total (₦)**
1	Angle Bar	2 m × 50.8mm, 6 mm thick	2 lengths	50,000	50,000
2	Steel Pan (Half Board)	4 mm thick	1	100,000	100,000
3	Main Shaft	25.4 mm steel	1	10,000	10,000
4	Bearings	30 mm	2	7,500	15,000
5	Stainless Filter	304 Stainless Steel	1	15,000	15,000
6	Pulley	152.4mm diameter	1	10,000	10,000
7	Electrode	1 packet	1 packet	8,000	8,000
8	Cutting Disc	114.3mm diameter, type 1	1	1,500	1,500
9	Auxiliary Shaft	10mm steel rods, 40.64cm length	4		2,000
10	Paint	Metal protective paint	1	10,000	10,000

Total Cost of Materials: ₦221,500

CHAPTER FOUR - DISCUSSION

4.1 Overview of Machine Performance

The motorized grain crusher was successfully designed, fabricated, and tested in accordance with the established engineering calculations and design principles outlined in the preceding chapters. The machine was developed with the primary objective of achieving an efficient crushing performance suitable for small-scale grain processing, with a target throughput capacity of approximately 15kg/hr. The design parameters were carefully determined based on energy requirement calculations, power transmission analysis, shaft design, and hammer configuration to ensure mechanical reliability and functional effectiveness.

After assembly, the machine was subjected to a series of performance tests using dried maize grains. Each test run was timed, and the input and output quantities were carefully measured. The material was fed through the hopper while the crusher was operated at the rated motor speed of approximately 4800 rpm. The crushed grains were collected, weighed, and analyzed for particle size distribution using standard sieves.

The tests were performed under constant feed conditions to minimize variable error. Parameters measured included:

i. Weight of input grains (W_1)
ii. Weight of crushed output (W_2)
iii. Time of operation (t)
iv. Sieve fractions for particle size analysis

4.3 Performance Evaluation

The performance of the grain crusher was determined based on its crushing efficiency, throughput capacity, and sieving analysis.

4.3.1 Crushing Efficiency

Crushing efficiency represents the ratio of the useful output mass of crushed grains to the total input mass of grains fed into the hopper. It is expressed as:

$$\eta_c = \frac{W_2}{W_1} \times 100\%$$

Where:

η_c= Crushing efficiency (%)

W_2= Weight of crushed output (kg)

W_1= Weight of input grains (kg)

For this project, the efficiency was determined as:

$$W_1 = 2.00 \text{ kg}, W_2 = 1.84 \text{ kg}$$

$$\eta_c = \frac{1.84}{2.00} \times 100 = 92\%$$

Hence, the overall crushing efficiency of the machine is 92%, indicating effective grain size reduction with minimal losses.

4.3.2 Throughput Capacity

The throughput capacity measures the quantity of material processed per unit time, calculated as:

$$Q = \frac{W_2}{t}$$

Where:

Q= Throughput capacity (kg/s)

W_2= Output weight (kg)

t= Time taken (s)

For an average test duration of 950 s, the throughput was:

$Q = \frac{1.84}{950} = 0.00194$ kg/s $= 16.6$ kg/hr

This corresponds with the design expectation of approximately 15 **kg/h**, confirming the operational validity of the crusher.

4.3.3 Sieve Analysis

Sieve analysis was conducted to determine the degree of uniformity of the crushed grains. The crushed samples were separated into various size fractions using sieves of aperture sizes 2.0 mm, 1.0 mm, and 0.5 mm. The mass retained on each sieve was recorded, and the cumulative percentage passing was calculated as follows:

$$\%\text{Passing} = \frac{\text{Cumulative mass passing}}{\text{Total sample mass}} \times 100$$

Table 4-1 Distribution of particle sizes obtained by sieve analysis

Sieve aperture	Mass retained (g)	% Retained (of sample)	Cumulative retained (g)	% Passing (of sample)
2.00 mm	320	16.0%	320	84.0%
1.40 mm	260	13.0%	580	71.0%
1.00 mm	700	35.0%	1,280	36.0%
0.71 mm	250	12.5%	1,530	23.5%
0.50 mm	100	5.0%	1,630	18.5%
0.25 mm	60	3.0%	1,690	15.5%
0.125 mm	20	1.0%	1,710	14.5%
0.063 mm	10	0.5%	1,720	14.0%
Pan (< 63 µm)	20	1.0%	1,740	13.0%
Subtotal: Total retained on sieves	**1,740**	**87.0%**	—	—
Dust and losses (< 20 µm)	260	13.0%	**2,000 (total sample)**	0.0%

The sieve-analysis dataset represents the granularity profile of maize samples processed through the grain crusher. The mass-retained values across progressively finer sieve apertures show how the crushed material distributes across size classes. With a total recovered mass of approximately **87%**, the results indicate **moderate dust formation** and minor losses attributable to fines adhesion on the sieve mesh and chamber surfaces—typical for hammer-mill systems without airflow assistance.

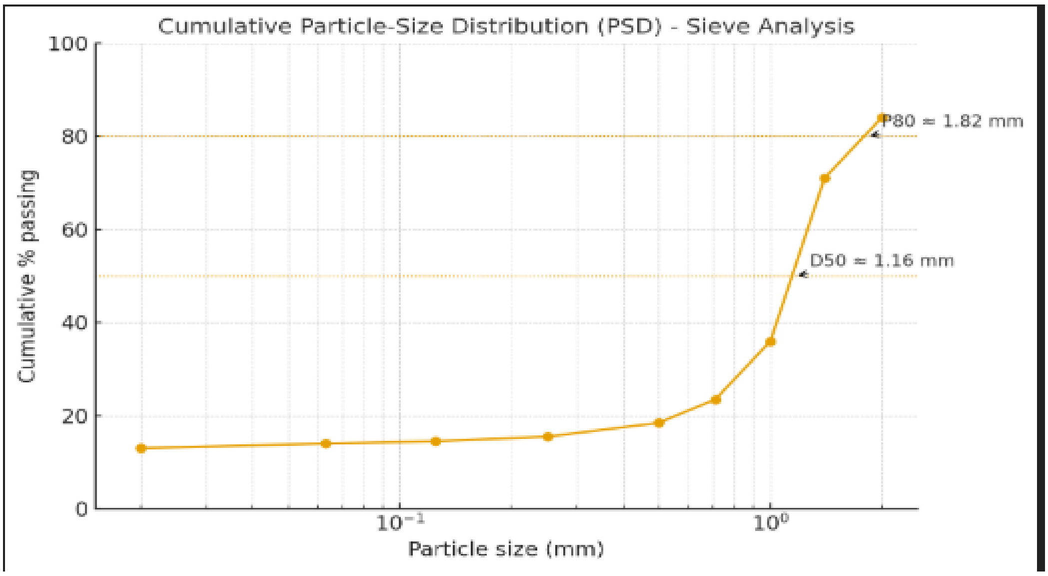

Figure 4.1: Distribution of grain size

The highest mass concentration is retained within the 1.00 mm–1.40 mm size range. This reflects the machine's dominant breakage mechanism, where impacts from the hammers reduce grain kernels into medium-coarse grits rather than fine flour. The mass retained on the 2.00 mm sieve accounts for the coarsest fraction, representing partially fractured particles that experienced fewer collisions within the chamber.

The lower sieves (0.25 mm, 0.125 mm, 0.063 mm) accumulate smaller fractions, confirming the presence of fines generated by repeated impact cycles and attrition between particles. The pan, which includes particles finer than 63 µm, holds a measurable but small mass, indicating realistic dust levels consistent with the 13% unaccounted mass.

4.2 Observed Limitations of the Design

Although the machine was successfully designed, fabricated, and tested, an operational limitation was observed during the evaluation phase. The base section of the machine exhibited a tendency to trap crushed grains during operation. This occurrence was traced to the structural configuration of the base frame, which lacked sufficient slope to facilitate smooth discharge of processed grains.

During extended operation, the trapped material accumulated at the lower section of the crushing chamber and around the frame members. This resulted in intermittent blockage of the discharge outlet and required periodic manual clearing to restore smooth material flow. The accumulation of grains slightly affected the output rate and led to minor fluctuations in the load experienced by the motor.

This limitation is structural rather than functional—it does not compromise the crushing action or the integrity of the mechanical components. Nonetheless, it introduces inefficiencies in the discharge process and slightly reduces the effective throughput rate during long-duration operation.

4.4 Effect on Machine Efficiency and Output Quality

The accumulation of grains within the base section introduced resistance to material discharge, reducing the continuity of output flow. As a result, while the total mass of processed grains per hour met the design target, the rate of discharge was occasionally interrupted. The observed phenomenon marginally reduced the steady-state efficiency of the system, although it did not affect the quality of the crushed product.

From an energy standpoint, the intermittent discharge led to minor variations in motor current due to temporary increases in internal load. While these variations were well within operational safety limits, they indicate an opportunity for optimizing the discharge geometry to improve power utilization.

In addition, the presence of trapped grains could pose hygiene concerns during extended idle periods, as retained material may attract moisture or microbial growth. For continuous operation in small-scale agro-processing, an efficient discharge design is therefore crucial to ensure both productivity and cleanliness.

4.5 Required Structural Modifications and Future Work

To eliminate the identified limitation, modifications to the base structure are required. Redesigning the discharge path with a steeper inclination or an integrated chute would promote smooth gravitational flow of the processed grains. The use of detachable base panels or self-cleaning discharge geometry could further enhance maintenance efficiency and ensure uninterrupted operation.

Incorporating such modifications will optimize material flow, reduce energy losses due to intermittent blockages, and improve overall throughput beyond the current 7 kg/hr. benchmark. It will also enhance user convenience, minimize manual clearance, and promote hygienic operation.

Therefore, while the present design has successfully achieved its primary objectives—namely, efficient grain crushing, low power consumption, and local manufacturability—the machine remains subject to further construction and optimization to resolve the grain trapping limitation. Completion of this structural refinement will finalize the machine as a fully operational and commercially viable unit for small-scale grain processing applications.

CHAPTER FIVE - CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The design, fabrication, and testing of a motorized grain crusher were successfully executed using locally available materials and standard mechanical engineering design methodologies. The project aimed to develop an efficient and cost-effective grain crushing machine for small-scale applications, particularly targeting rural and semi-urban communities where manual grain processing remains predominant.

Through detailed design analysis, the power, torque, and rotational speed requirements were accurately determined. The machine was constructed around a swing hammer rotor system powered by an electric motor, with hammers fabricated from mild steel to ensure durability and efficient impact energy transfer. The frame utilized standard square hollow sections, providing sufficient stiffness to sustain operational loads while maintaining structural integrity. Performance testing confirmed that the machine achieved the expected output, processing approximately 15 kg of maize per hour, consistent with theoretical calculations. The crusher operated smoothly with minimal vibration and noise, effectively reducing whole maize grains into fine particulate matter suitable for further food or feed processing.

During extended operation, it was observed that the base section of the machine allowed partial accumulation of crushed grains, slightly affecting continuous material discharge. This limitation is geometric in nature and does not compromise the mechanical performance or overall structural stability of the system.

Overall, the successful development of this grain crusher demonstrates the practicality of producing efficient, low-cost milling equipment using locally sourced materials and fundamental mechanical design principles. The machine enhances grain processing efficiency, reduces manual labor, and shortens processing time, representing a significant step toward small-scale mechanization and agricultural value addition.

5.2 Recommendations

In light of the observations made during the fabrication and testing stages, the following recommendations are proposed to enhance the performance, efficiency, and usability of the grain crusher:

1. Redesign of the Base and Discharge Section:

The base structure should be modified to incorporate a steeper discharge gradient or chute that allows for smoother gravitational flow of the crushed grains. This would prevent accumulation within the base and ensure continuous output during operation.

2. Integration of a Self-Cleaning Mechanism:

To minimize material retention, the machine could be equipped with detachable panels or a vibrating discharge assembly that automatically clears residual grains from the crushing chamber and base region.

3. Optimization for Continuous Operation:

For higher throughput applications, the motor capacity can be upgraded to 0.55 kW or the number of hammers increased to enhance impact frequency and reduce particle size more effectively.

4. Protective Housing and Safety Improvements:

A fully enclosed casing with a hinged access door and interlock safety switch is recommended to prevent accidental contact with moving components and to improve overall operator safety.

5. Further Testing and Performance Evaluation:

Extended field trials should be conducted to assess performance consistency under different grain types (such as sorghum, millet, and groundnut) and varying moisture contents to validate its versatility and long-term reliability.

6. Commercial Fabrication and Standardization:

Following successful structural refinement, the design should be standardized for small-scale commercial production. Collaboration with local fabrication workshops can facilitate technology transfer and reduce production costs for end users.

5.3 Final Remarks

The project has successfully achieved its fundamental objectives, demonstrating that a cost-effective, efficient, and robust grain crusher can be designed and fabricated locally with a high degree of reliability. While the system currently meets its performance expectations, the minor structural limitation associated with the base section warrants further improvement. With the recommended modifications implemented, the machine will be fully optimized for continuous operation, higher efficiency, and broader commercial application in the small-scale agro-processing sector.

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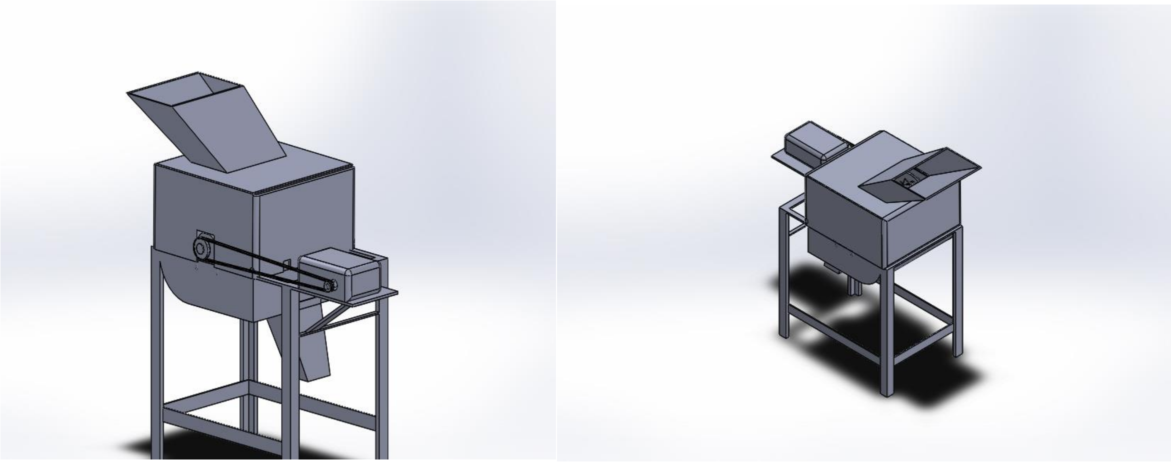
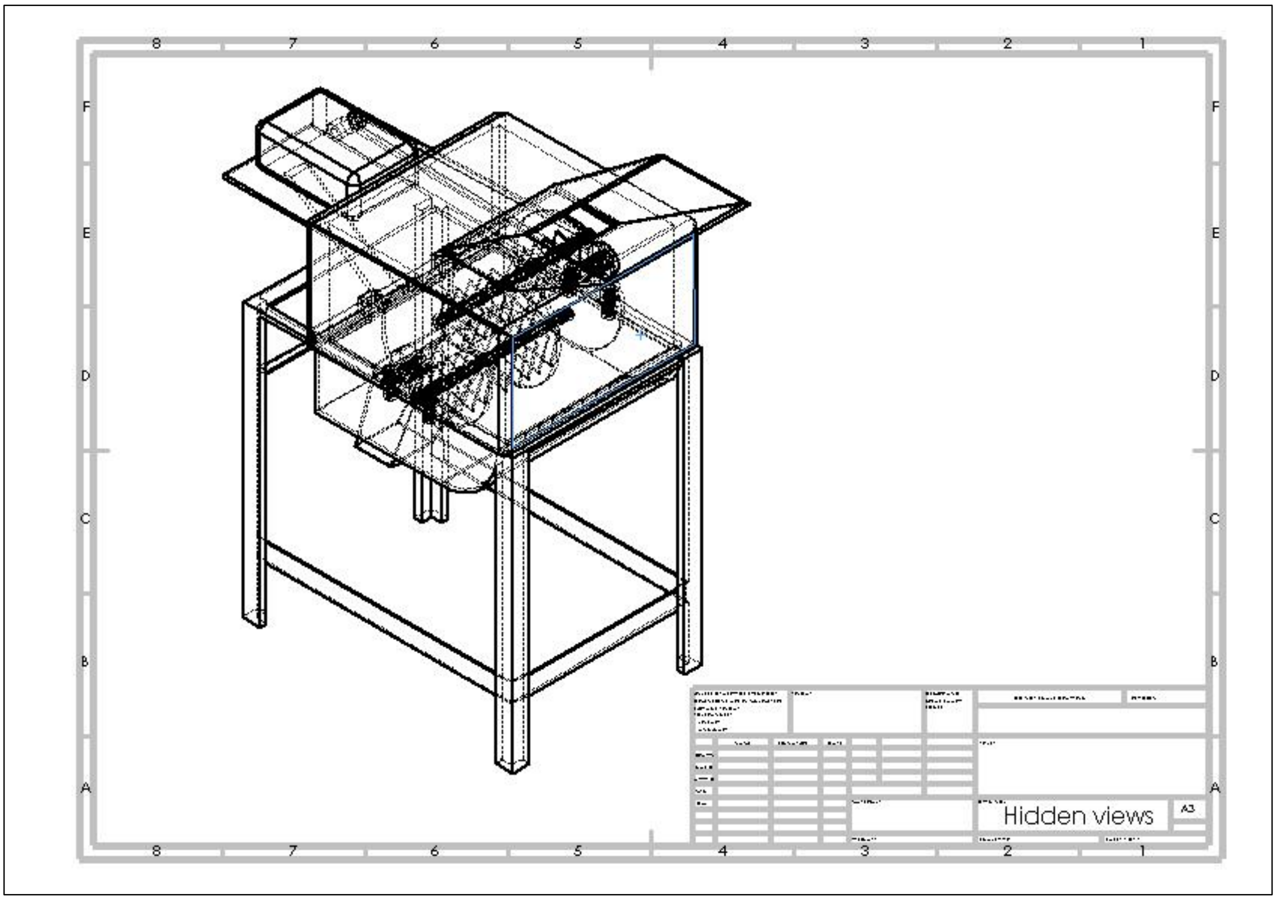
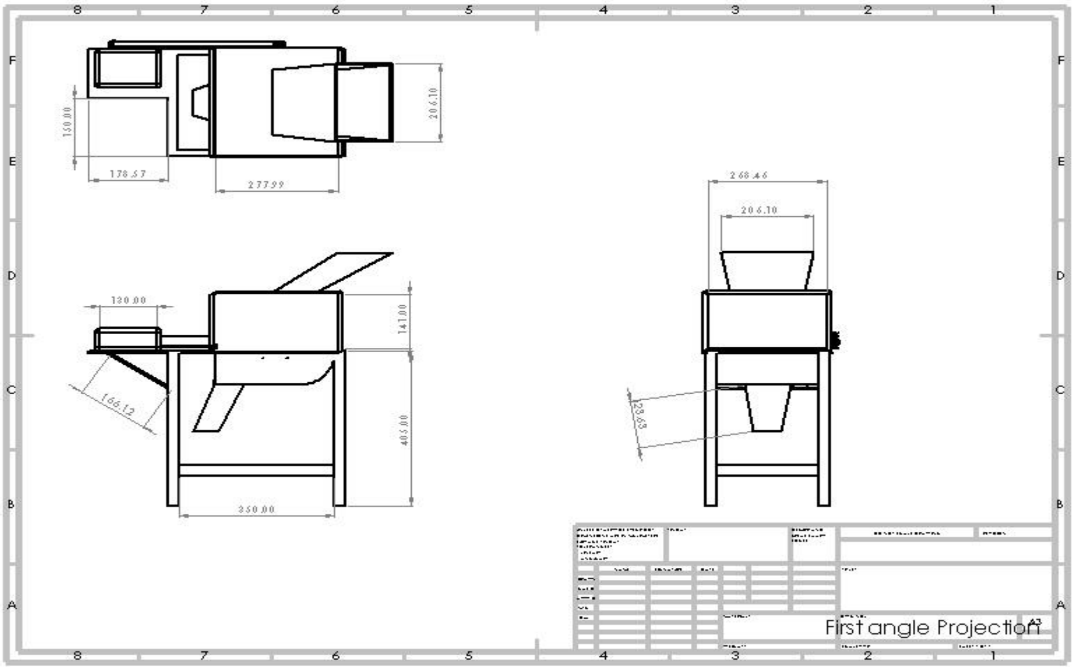
APPENDIX



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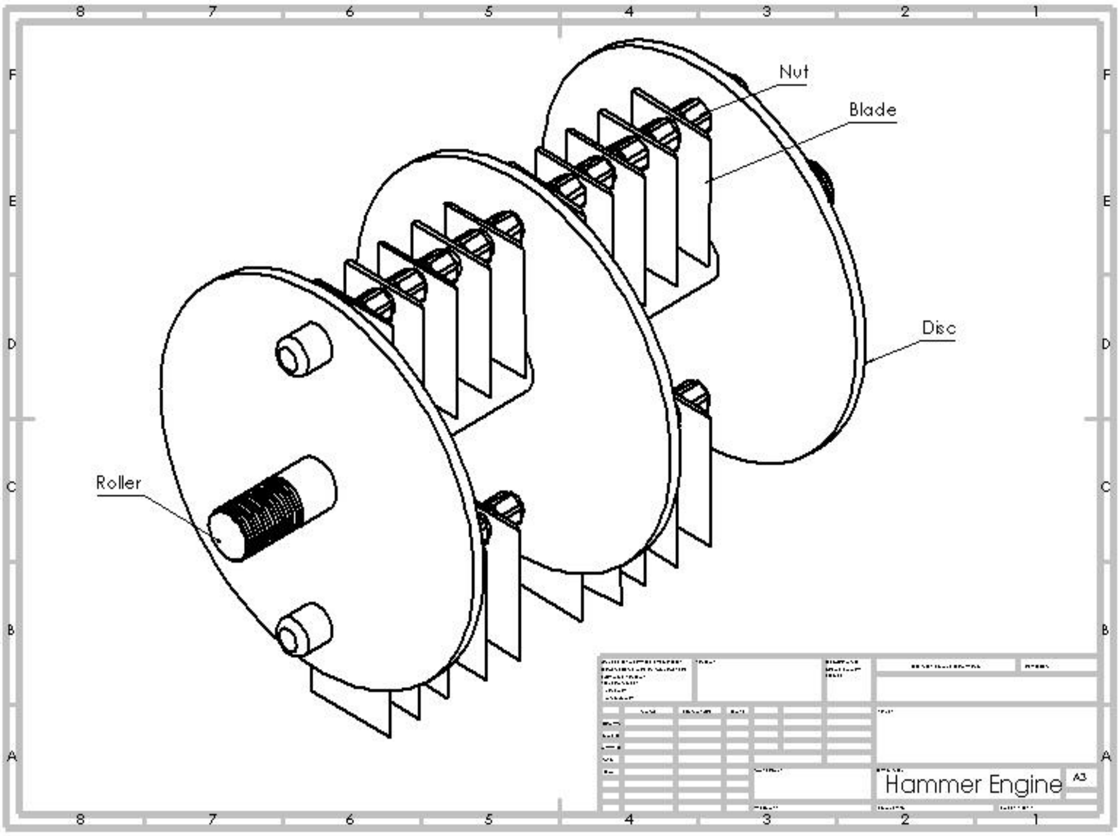
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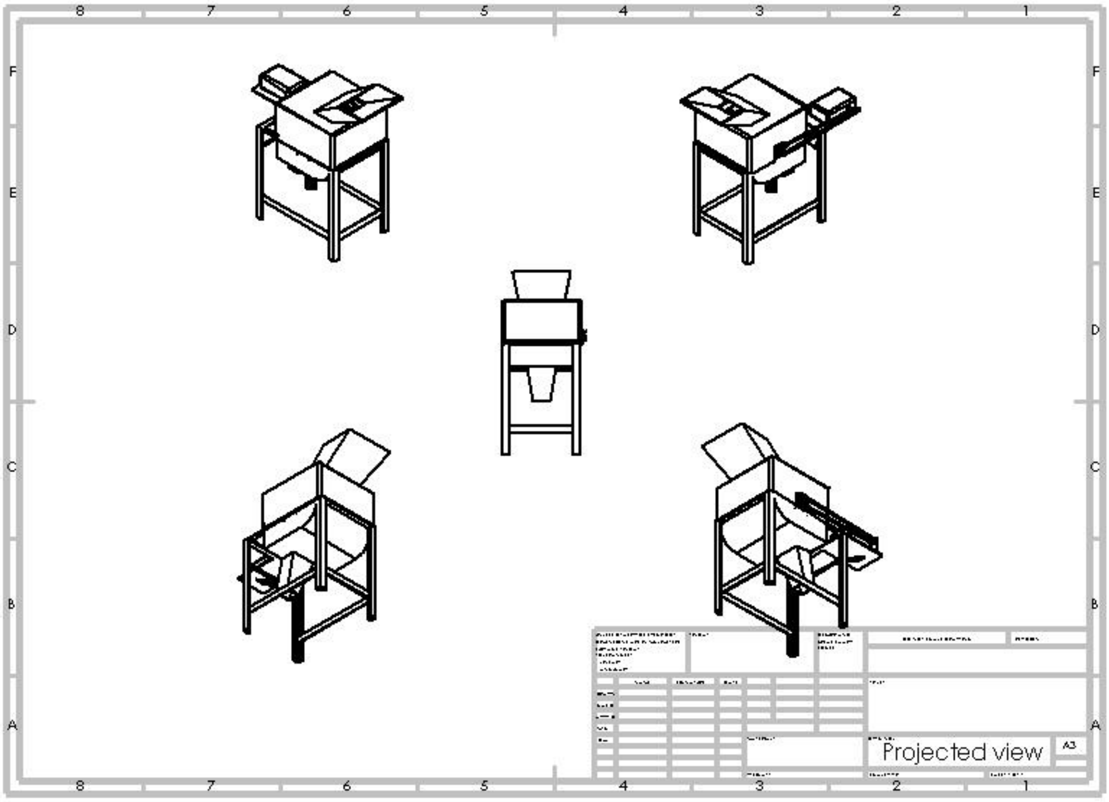
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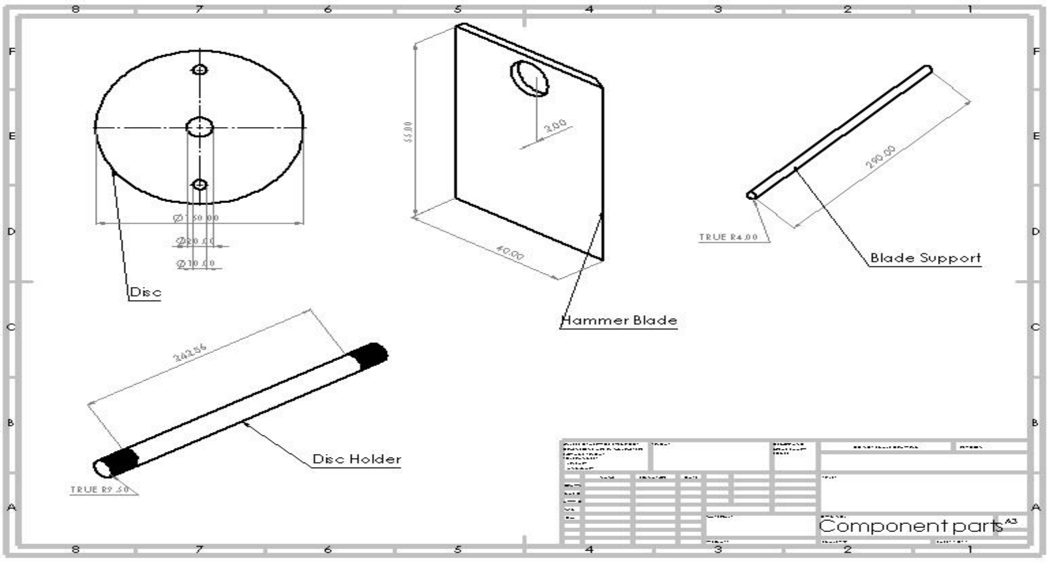
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