FEDERAL UNIVERSITY OF TECHNOLOGY MINNA

CREATIVE MECHANICAL ENGINEERING DESIGN IN A CHANGING WORLD

By

ENGR. PROF. EVUDIOVO APHA PETER EGBE
B.Eng (Mechanical) UNIBEN, M.Eng (Mechanical) UNIBEN,
PhD (Mechanical) Minna, MNIMechE, MNSE, R. Engr. (COREN)
Professor of Mechanical Engineering

INAUGURAL LECTURE SERIES 76

7TH APRIL, 2021

ISSN 2550 - 7087

2550 7087

global links communications
+234 805 6074 844, +234 703 6446 818

FEDERAL UNIVERSITY OF TECHNOLOGY
MINNA

CREATIVE MECHANICAL ENGINEERING DESIGN IN A CHANGING WORLD

By

ENGR. PROFESSOR EVUDIOVO APHA PETER EGBE
B.Eng (Mechanical) UNIBEN, M.Eng (Mechanical) UNIBEN,
PhD (Mechanical) F.U.T., Minna, MNIMechE, MNSE, R. Engr. (COREN)
Professor of Mechanical Engineering

INAUGURAL LECTURE SERIES 76

7TH APRIL, 2021

This 76th Inaugural Lecture was delivered under
the Distinguished Chairmanship of:

Professor Abdullahi Bala, FSSSN
Vice-Chancellor
Federal University of Technology, Minna

ISSN 2550 - 7087

Published by:
University Seminar and Colloquium Committee,
Federal University of Technology, Minna.

7th April, 2021

Design + Print:
Global Links Communications, Nigeria
✆: 08056074844, 07036446818

Engr. Professor Evudiovo Apha Peter Egbe

B.Eng (Mechanical) UNIBEN, M.Eng (Mechanical) UNIBEN,
PhD (Mechanical) Minna, MNIMechE, MNSE, R. Engr. (COREN)
Professor of Mechanical Engineering

CREATIVE MECHANICAL ENGINEERING DESIGN IN A CHANGING WORLD

1.0 INTRODUCTION

I consider it a great privilege to present this inaugural lecture. When I left academics for the industry, twenty-nine years ago it did not cross my mind that God planned this pathway for me. Therefore, I give God all glory for this honour to present this lecture.

I would like to begin this lecture by quoting a design axiom: "Your decisions, good or bad, affect everyone downstream." While this axiom may be true in everyday life, it is particularly important in engineering design decisions and it summarizes a guiding light to creative design.

An inaugural lecture provides a scholar the opportunity to present his contribution to knowledge and its relevance to sustainable development of the society. I shall in this lecture elucidate my contributions to knowledge under the chosen theme.

1.1 CREATIVITY

The Platonic school described creativity as fundamentally unexplainable and that it results from divine inspiration (Gaut, 2012; Kronfeldner, 2009; Stokes & Paul, 2016). The Romantic tradition continued with the Platonic interpretation of creativity (Bridy 2012; Sawyer 2012). In the Romantic view, creativity is the mark of genius and the 'creative person' is an extraordinary individual who possesses the mysterious gift of creating something that ordinary people are not capable of. The irrational view of creativity as a phenomenon, the causes and mechanisms of which cannot be described nor measured is shared also by later thinkers, such as Kant (Pluhar, 1987), Schopenhauer (Gaut, 2012), Hausman (Kronfeldner, 2009) and Miller through his view on creative geniuses (Miller, 1996).

Sternberg (1999) studied the life and products of very creative persons and came to a conclusion that the processes behind every creative product can be explained in terms of ordinary cognitive processes. Weisberg (1993) submitted that scientific discoveries and works of art which seem inexplicably creative to the vast majority of people, can instead be shown to have come through the determination, skill, and hard work of their creators. Thomas Edison invented the electric bulb but he succeeded after failing 99 times. He expected the unusual but worked hard at it until he got it.

Thus to this end creative activity is simply a special class of problem-solving activity characterized by novelty, unconventionality, persistence, and difficulty in problem formulation. The assumption behind this statement is that there is no difference in the thought processes of the ones we recognize as 'geniuses' and of ordinary people. It is just that the first have better heuristics (Simon, 1985).

1.2 ENGINEERING

According to Professor Ralph J. Smith (Emeritus Professor of Electrical Engineering at Stanford University, California), "Engineering is the application of science to the optimum conversion of the resources of nature to the uses of humankind." Engineers Council for Professional Development, in United States, gives a broader definition of Engineering as the creative application of scientific principles to design or develop structures, machines, apparatus, or manufacturing processes or works utilizing them singly or in combination; or to construct or operate the same with full cognizance of their design; or to forecast their behaviour under specific operating conditions; all with regard to an intended function, economics of operation and safety of life and property.

The words engine and ingenious are derived from the Latin root word ingenerare which means to create. The early English verb engine means to contrive. The two top priorities for man have always been food and security. This explains why the oldest known devices contrived or conceptualized by man are farming and war implements. Engineering devices such as catapult, simple lever date to ancient time before immergence of modern day engineering as we now know it. Standards of engineering practice are maintained through the efforts of professional bodies (in Nigeria, Council for Regulation of Engineering, COREN) with all members acknowledging a responsibility to the public over and above responsibilities to their employer or to other members of their society.

The function of the scientist is to know, while that of the engineer is to do. Scientists add to the store of verified systematized knowledge of the physical world, and engineers bring this knowledge to bear on practical problems. Engineering science is based principally on physics, chemistry, and mathematics and their extensions into materials science, solid and fluid mechanics, thermodynamics, transfer and rate processes, and systems analysis.

The engineer must solve problems as they come, and their solutions must satisfy conflicting requirements. Efficiency costs money, safety adds to complexity, and improved performance increases weight and cost. The engineering solution is the optimum solution after accounting for so many conflicting factors and the result must be the most desirable under the prevailing circumstances. It should be the most reliable within a given cost/weight limit, the simplest that will satisfy certain safety requirements, or the most efficient for a given cost. In many engineering problems the social costs are significant.

Engineers employ two types of natural resources-materials and energy. Materials are useful because of their properties: their strength, ease of fabrication, lightness, or durability, their ability to insulate or conduct, their chemical, electrical and acoustical properties. In an ever changing world in terms of population growth and development there is need for the development of new materials that can meet increase in complexity of problems facing the engineer. The second natural resource, includes fossil fuels (coal, petroleum and gas), wind, sunlight, hydro-power and nuclear fission. Both energy and materials are limited and expensive. This places responsibility on the engineer to manage the resources with great discretion to the benefit of the public. Also since most materials and energy resources are nonrenewable, engineers in the twenty-first century must concern themselves with the continual development of new resources as well as the efficient utilization of existing ones (Smith, 2021).

1.3 MECHANICAL ENGINEERING

Mechanical Engineering is the branch of engineering that combines engineering physics and mathematics principles with materials science to design, analyse, manufacture and maintain mechanical systems. It is arguably the oldest and broadest field in engineering family since military engineering started off in designing engines to haul stones (like King Solomon) and catapult which are mechanical devices or machines. Mechanical engineering has given birth to so many daughters, just to name a few: materials engineering, metallurgical engineering, auto engineering, agricultural engineering, production engineering etc.

Prior to the twentieth century, mechanical engineers required only the knowledge of mechanical parts and assembly. The twentieth century witnessed a drastic change that added electrical components, followed by electronic components and computer programming to the consideration of mechanical engineering designer in succession (Ullman, 2010). The coming of the computer has also improved technology for manufacturing processes, materials development, design process and performance analysis.

The complexity of mechanical devices has grown rapidly over the last 200 years. Figure 1 shows the increase in complexity of mechanical design over a period of 200 years (from 1800 to 2000 AD). The more complex the device becomes the more the number of components required. There is also increase in complexity in terms of field of knowledge and materials requirement. The increase will continue as microcomputers and artificial intelligence becomes increasing consideration of the mechanical engineer.

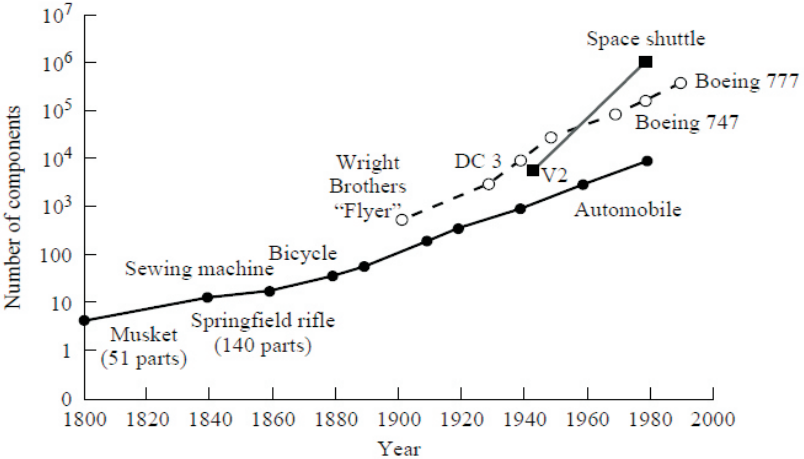


Figure 1: Increasing complexity in mechanical design

Source: *Ullman, 2010*

1.3.1 Mechanical Engineering Design

Engineering design is the process of devising a system, component, or process to meet desired needs (Yousef & Tamer, 2011). According to Engineering Design Council, UK, Mechanical design process is the use of scientific principles and technical information along with innovations, ingenuity or imagination in the definition of a machine, mechanical device or system to perform pre specified functions with maximum economy and efficiency. The outcome of a design process is a marketable product that satisfies the need of customers.

Customer satisfaction is key to the success of any product and by extension the success of the design process. The metrics by which customer satisfaction is measured includes satisfactory performance of desired task, noise level, vibration level, weight or volume, life expectancy, aesthetics/ergonomics and cost. It is difficult to satisfy all competing metrics in all design projects, hence some form of compromise is inevitable, with priority given to those metrics that have higher control on the performance and customer satisfaction with the particular product.

The place of customer satisfaction cannot be overemphasized. On assumption of duty as Production Manager in a plastic industry in 1993, I guided the production team to optimize the operating conditions of moulding temperature and cooling rate in order to reduce rejects and improve production. This was because Egbe and Onyepke (1991) had established that the operating conditions of temperature, cooling rate and clamping pressure affects the mechanical properties of injection moulded thermoplastic products. Optimization led to production increase from below 70 to 100 pieces of 50 litre jerry cans per shift. Despite increase in production the distributors wanted more of our products because of quality. Management wanted to satisfy them and demanded to know what else could be done apart from moulding condition control. After a brainstorming session with my team, I demanded a change in raw materials from mere poorly sorted plastic regrind to pelletized materials. There was foot dragging because of cost but eventual change resulted in drastic jump in production to an average of 250 pieces per shift. Our distributors were very happy but competitors could not sell and one of them wrote a petition with fake name from an empty plot address in Ikeja, that the trade mark of our product was stolen from him. Alagbon Police squad acted without investigation and only gave up after over 24 hours of harassment, upon seeing original purchase papers/agreement for the plastic mould. It was after this experience that distributors informed me that Royale Poly Product had the best 50 litre mould in the market due to preferred shape of the product and stability when piled up and hence the high demand in preference to similar products. This claim by distributors agrees with the concept that consumers typically buy the more creative products, the ones that “delight” the customers and go beyond expectation of functionality (Horn & Salvendy 2006; Elizondo, *et al*. 2010).

2 CREATIVE MECHANICAL ENGINEERING DESIGN

A creative solution to a problem must meet two criteria: it must solve the problem in question, and it must be original. Solving a problem involves understanding it, generating solutions for it, evaluating the solutions, deciding on the best one, and determining what to do next. Thus, creativity is more than just coming up with good ideas. The second criterion, originality, depends on the knowledge of the designer and of society as a whole.

To be a creative mechanical designer, a person must have knowledge of existing mechanical products. Additionally, part of being creative is being able to evaluate the viability of ideas. Without knowledge about the domain, the designer cannot evaluate the design. Knowledge about a domain is only gained through hard work in that domain. Thus, a firm foundation in engineering science is essential to being a creative designer of mechanical devices.

New ideas are born from the combination of parts of existing knowledge. The ability to decompose and manipulate this knowledge is an important attribute of a creative designer. Another attribute of creative engineers is the willingness to take an intellectual chance. Fear of making a mistake or of spending time on a design that in the end does not work is characteristic of a non-creative individual. Thomas Edison tried hundreds of different light bulb designs before he found the carbon filament. Creative designers have more than one approach to problem solving. If the process they initially follow is not yielding the desired solution, they turn to alternative techniques.

Creativity improves with practice. Most designers find that they have creative phases in their career (periods when they have many good ideas). During these times the environment is supportive and one good idea builds on another. However, even with a supportive environment, practice enhances the number and quality of ideas.

2.1 CREATIVE MECHANICAL ENGINEERING DESIGN PROCESS

Things remain the way they are until someone feels dissatisfied about the prevailing state and takes action to change it. Thus design starts when a person or a group of persons feels dissatisfied about a situation and decides to do something about it. Such dissatisfaction may be a mere feeling that something is not right as in discomforting environment or quantifiable indices as in noise level/vibration of a machine, surface finish, weight or volume differential, life cycle etc. For example the need to do something about a production line may arise from customer dissatisfaction about quality, increase in demand, market competition, running cost, or life expectancy.

The life cycle of a product is broadly grouped into four, namely: product development, production and delivery, use, and end of life. The design engineer must understand and give adequate consideration to all the phases in the life cycle of the product. For example, the designer must factor into the product easy maintenance course, safety guard or fool proof guide.

2.2 PRODUCT DEVELOPMENT

Engineering design process is an iterative decision-making process that applies the basic sciences, mathematics, and engineering sciences to optimally convert resources to meet a stated need. The fundamental elements of the design process are: Establishment of needs, project planning, specifications, synthesis (conceptual design) and analysis, construction of prototype, testing, and evaluation. Figure 2 show the over view of the design process.

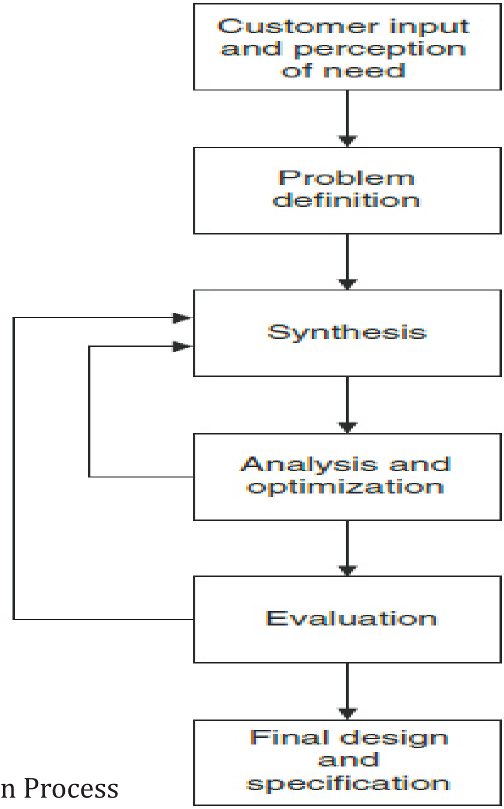


Figure 2: The General Design Process
Source: *Myer, 2014*

2.2.1 Establishment of Need

There is a distinct difference between statement of the problem and definition of the problem. For example the need to design an oil pump for the petroleum down-stream sector in Nigeria was stated at the beginning in Egbe (2013), but the definition of the problem was more detailed as shall be shown later in this lecture. The definition of problem is more specific and must include some minimal specifications of the object that is to be designed. Identification of need is the starting point of a design process. In the case of an existing product such as a CT scanner a market demand for more detail X-rays and faster scanning is a statement of the problem, as it remains vague. However, if how much more X-ray detail or what measurable time is required then the problem becomes defined (Ullman, 2010). The slow and labour intensive process of manually de-hulling cow pea established the need for the development of mechanised wet legume de-huller (Egbe and Roland, 2016). The primary sources for establishing product need are market forces, technology and product change. Market force refers to customer demand for new products or product features. Without a customer for the product, there is no way to recover the costs of design and manufacture. Conversely, technology push is when a new technology is developed before there is customer demand. Improvement in technology has made the need for new complex but inexpensive products inevitable. For example the lack of functional steel company in Nigeria makes the development of the motor industry not to be a viable project in the country. Product change arises from a better understanding of product behaviour after initial development and introduction into the market. Years of experience or research can bring about a demand for changes to be made on a mature product.

2.2.2 Project Planning

Planning ensures that available resources (money, people and materials) are correctly located and accounted for. Drawing up the design team is part of planning. Success of a design process depends to a large degree on the collective creativity of the design team. For medium and large scale projects, the team could have many design experts, production or manufacturing engineers and a materials engineer. However there are products, systems and subsystems that are designed by one person.

2.2.3 Definition of the Problem

The definition of the problem is more detailed than the statement of the problem. The problem to be solved must be clearly stated and some specifications must be provided in the statement. The specifications are the input and output quantities, the characteristics and dimensions of the space the object must occupy, and all the limitations on these quantities. We can regard the object to be designed as something in a black box. In this case the inputs and outputs of the box, together with their characteristics and limitations must be specified. For example, Egbe (2013) specified the anticipated flow rate of the oil pump as 24.55 litres/min at zero metre head. Similarly Egbe *et al*., (2016) specified a total mass of 48 kg per batch milling for a ball milling machine. The specifications may include the cost (especially for commercial products), the number to be manufactured, the expected life, the range, the operating temperature/general service conditions, and the reliability. Specified characteristics can include the speed limitations, feeds, temperature limitations, maximum range, expected variations in the variables, dimensional and weight limitations, etc. For example, in the design of a ball milling machine (Egbe *et al*., 2016) a literature search indicated that the speed for optimum ball milling is a function of mill diameter and grinding medial diameter (Will & Napier-Munn, 2006). Subject to available mill diameter of 129.3 mm, ball diameter of 25 mm and optimum ball milling condition, the specified speed was found to be 131 rpm, which became a design constraint.

There are many implied specifications that result either from the designer's particular environment or from the nature of the problem itself. For example ASTM D 1238 standard (2005) specified die outer diameter of 9.55mm ± 0.005mm, inner diameter: 2.095mm and die height: 8mm ± 0.025mm for a standard melt mass flow rate (MFR) (Teran & Egbe, 2018). In this particular case the constraints make it possible to compare results obtained for different thermoplastic materials. The manufacturing processes that are available, together with the facilities of a certain plant, constitute restrictions on a designer's freedom, and hence are a part of the implied specifications. In designing a plastic mould, for example, the clamp of the moulding machine has a fixed dimension to which the mould must conform and hence this dimension became a specification for a metallic plastic mould design (Egbe, 2016).

However note that excessive specifications limit design creativity as the liberty to think outside the box becomes restrained. The ability to write a good set of engineering specifications is proof that the design team understands the problem. There are many techniques used to generate engineering specifications. One of the best and currently most popular is called *Quality Function Deployment (QFD)* (Ullman, 2010). What is good about the QFD method is that it is organized to develop the major pieces of information necessary to understanding the problem: **(1)** Hearing the voice of the customers; (**2)** Developing the specifications or goals for the product; **(3)** Finding out how the specifications measure the customers' desires; **(4)** Determining how well the competition meets the goals; **(5)** Developing numerical targets to work toward.

Figure 3 shows the steps in QFD method which was developed in Japan in the mid-1970s.

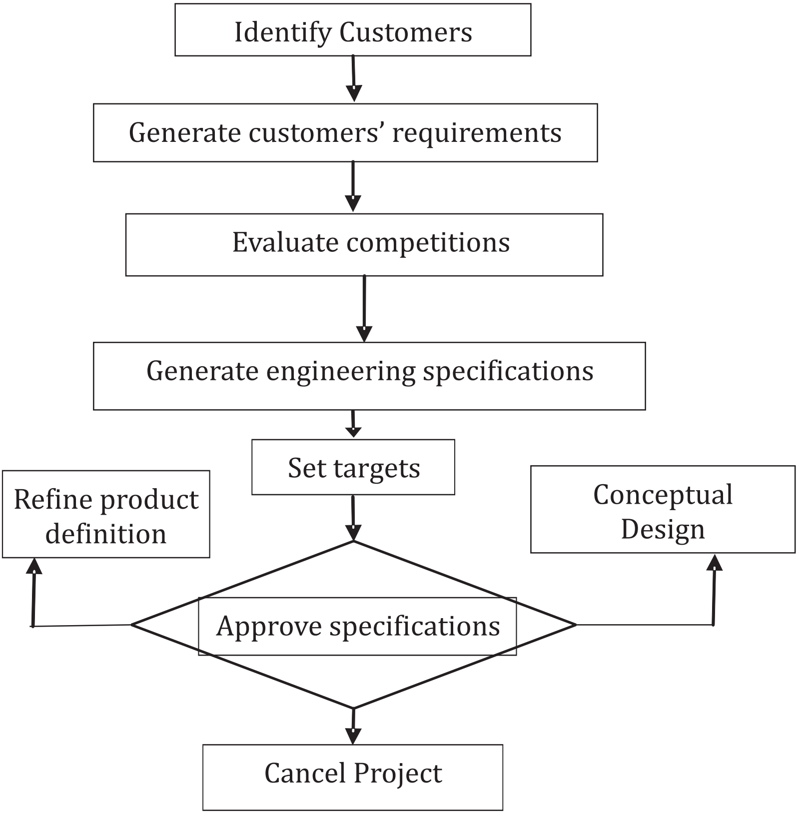


Figure 3: Product Definition Phase of Mechanical Design Process

Source: *Ullman, 2010*

Using this method, Toyota was able to reduce the costs of bringing a new car model to market by over 60% and to decrease the time required for its development by one-third (Ullman, 2010). It achieved these results while improving the quality of the product. Ullman, (2010) revealed that a survey of 150 U.S. companies showed that 69% used the QFD method and that 71% of these began using the method since 1990. Note the following:

No matter how well the design team thinks it understands a problem, it should employ the QFD method for all original design or redesign projects. In the process, the team will learn what it does not know about the problem. For example, you cannot design a car door that is "easy to open" when you do not know the meaning of "easy." Is it measured by force, time, or what? If force is a critical parameter, then is "easy" 30 N, 60 N or 90 N? The answer must be known before much time and resources are invested in the design effort.

The QFD method can be applied to the entire problem and any sub-problem. For example the design of a door mechanism in the previous point is a sub-problem in automobile design. It is important to first worry about what needs to be designed and, only after that is understood, that attention is given to how the design will look and work. Cognitive capabilities generally lead the designers to assimilate the customers' functional requirements (what is to be designed) in terms of form (how it will look); these images then become favored designs and get locked onto them. The QFD procedure helps overcome this cognitive limitation.

This method takes time to complete. In some design projects, about one-third of the total project time is spent on this activity. Ford spends 3–12 months developing the QFD for a new feature. Experimental evidence has shown that designers who spend time here end up with better products and do not use any more total time when compared to others who do a superficial job here. Time spent here saves time later. Not only does the technique help in understanding the problem, it also helps set the foundation for concept generation.

2.2.3 Conceptual Design

Jensen *et al.*, (2009) submitted that the concept generation step provides great opportunity for students and engineers to enhance their creativity. It is important to first understand the function of a device, before designing its form. Conceptual design focuses on function. A concept is an idea that is sufficiently developed to evaluate the physical principles that govern its behavior. Confirming that a concept will operate as anticipated and that, with reasonable further development, it will meet the set targets, is a primary goal in concept development. Concepts must also be refined enough to evaluate the technologies needed to realize them, to evaluate their basic architecture (form), and, to some limited degree, evaluate their manufacturability. Concepts can be represented in a rough sketch or flow diagram, a proof-of-concept prototype, a set of calculations, or textual notes – an abstraction of what might someday be a product. Enough detail must be developed to model performance so that the functionality of the idea can be ensured. A popular axiom in design says “function before form”.

Function relate to description of what the product will do while form deals with how the product will do it. Both the function of the system and sub-systems must be identified. A clear understanding of the function is important to generation of creative concepts. Ullman, (2010) defines function as the logical flow of energy (including static forces), material, or information between objects or the change of state of an object caused by one or more of the flows. For example in order to change a flat tyre an individual must wedge the car, locate the jack properly under the car, jack a little, slack the wheel bolts, complete jacking up, replace flat tyre with a good one, fasten the bolts in correct order, jack down, ensure full fastening, remove the jack and the wedge. This is a simple example of energy, information and materials flow. However as simple as this example is, the energy, materials and information interaction must be correct for a successful performance. The functions associated with the flow of energy can be classified both by the type of energy and by its action in the system. The types of energy normally identified with electromechanical systems are mechanical, electrical, fluid, and thermal.

In the design of an internal gear pump, the twin gears (shown in Figure 5) interact with the fluid to generate pressure energy (Egbe, 2013). The inlet and discharge ports interact with the oil in motion and there characteristics affect optimum flow. The functions of the inlet and outlet ports could be reversed if the interaction of electrical energy with the pump is reversed. Thus the function of every component or subunit in a design must be understood at least in part before concept generation.

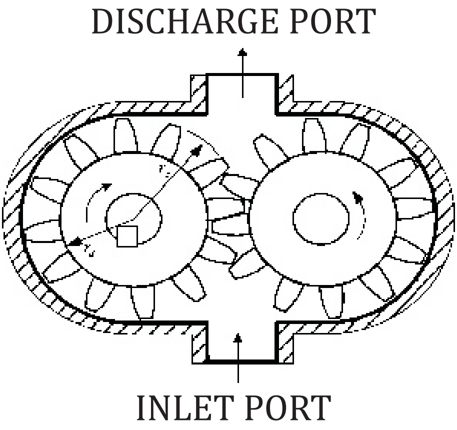


Figure 4: Internal Gear Oil Pump

Source: *Egbe, 2013*

The function of a restricted slit gate in injection thermoplastic mould is to allow plastic melt to flow into the cavity and the dimension is subject to principles of fluid flow in engineering science. Egbe (2016) indicates that flow rate is directly proportional to the width, height and pressure difference across the gate and inversely proportional to the viscosity of the melt and length of the gate (see Figure 5).

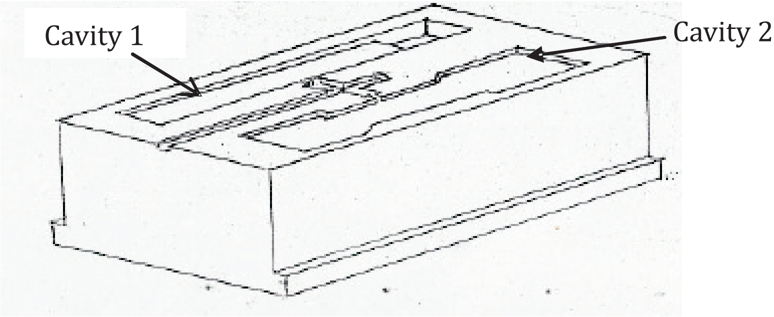


Figure 5: Cavity Plate of the Metallic Plastic Mould
Source: *Egbe, 2016*

All the factors that characterize its performance must be understood, before choosing it in preference to wide gate at conceptual design.

The same principle was used for main functions and sub-functions in the development of the ball milling machine (Egbe *et al*., 2016) shown in Plate I.

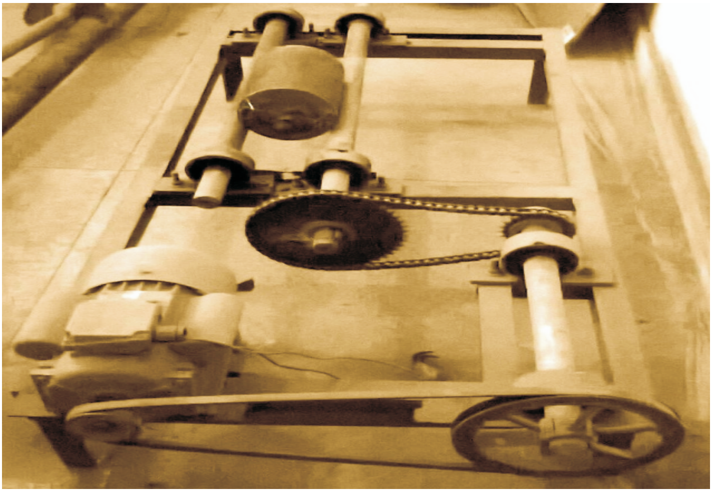
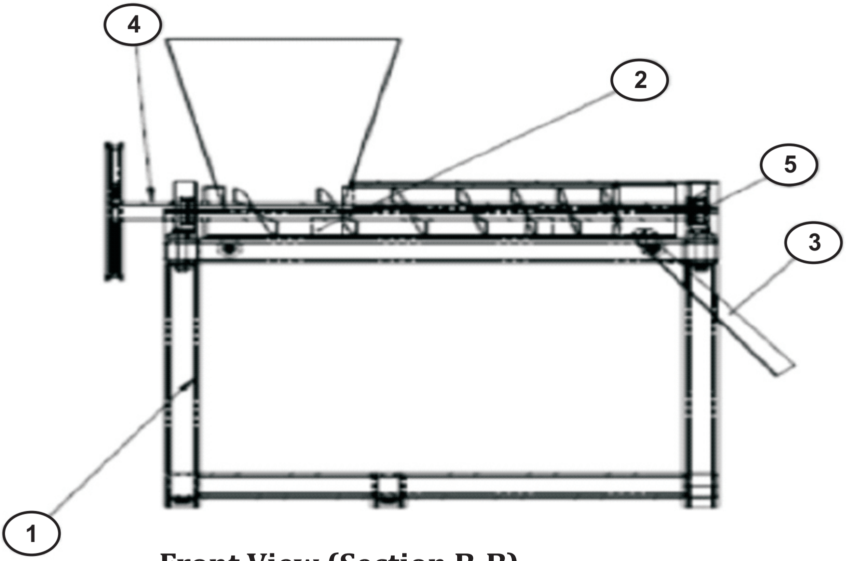


Plate I: Ball milling machine
Source: *Egbe et al., 2016*

In the case of the ball milling machine the twin rollers and the ball mill constitute two integrated subunits. There is energy, information and material interaction between the twin rollers and ball mill, while within the mill there is flow of energy, information and material between the internal surface of mill, the media and the grinding balls.

The approach discussed above was used for main functions and sub-functions of wet legume de-huller (Figure 6); Double roll crusher (Figure 7); Thermoplastic extrusion meter (Figure 8); Horizontal shaft hammer mill (Figure 9) and Dual operated single screw- driven yam pounding machine (Figure 10). Though the functions are different a correct application of a creative approach will always produce satisfactory results.



Front View (Section B-B)

Figure 6: Wet legume de-huller

Source: *Egbe and Roland, 2016*

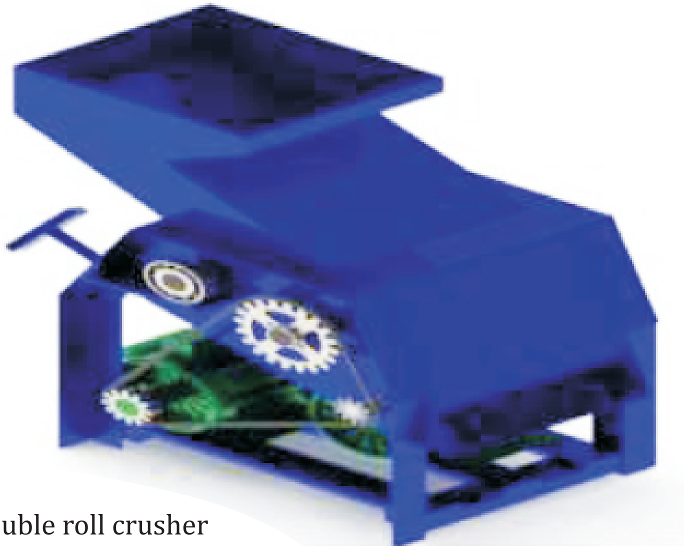


Figure 7: Double roll crusher
Source: *Egbe and Olugboji, 2016*

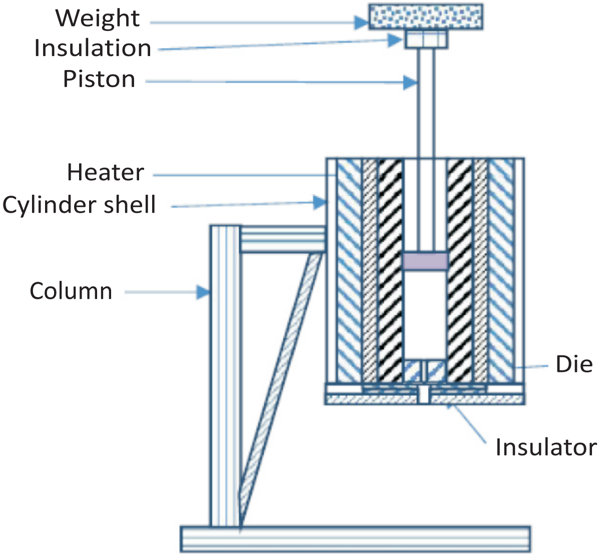


Figure 8: Thermoplastic extrusion meter
Source: *Teran and Egbe, 2018*

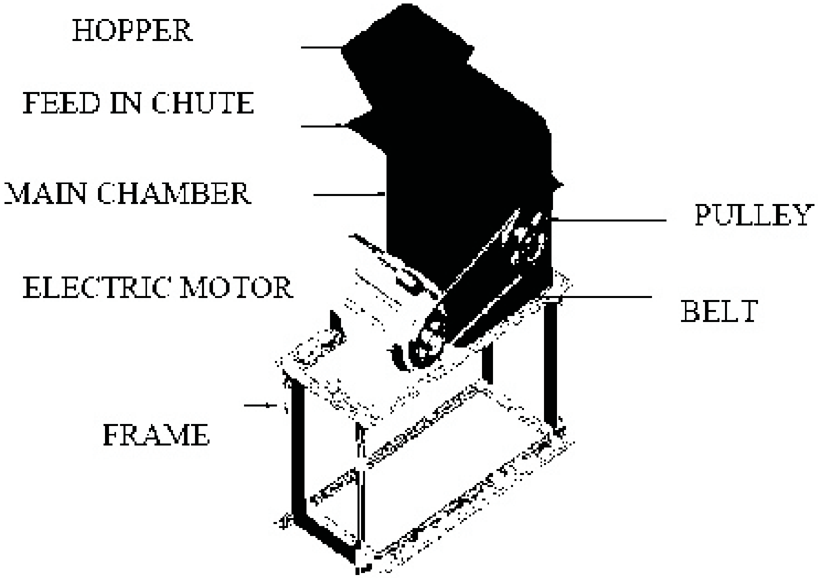


Figure 9: Horizontal shaft hammer mill
Source: *Suleiman et al., 2017*

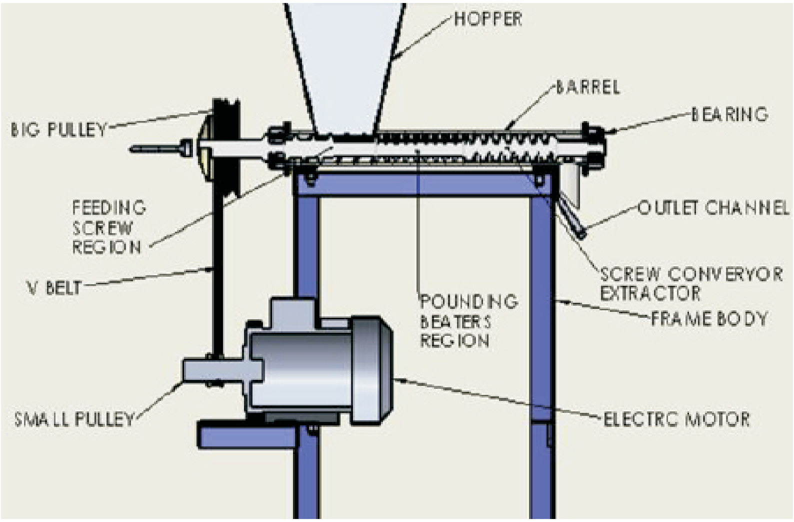


Figure 10: Dual operated single screw- driven yam pounding machine
Source: *Lifi et al., 2018*

Concepts are the means for providing functions. Concepts can be represented as verbal or textual descriptions, sketches, paper models, block diagrams, or any other form that gives an indication of how the function can be achieved. Figure 11 shows all the activities involved in conceptual design.

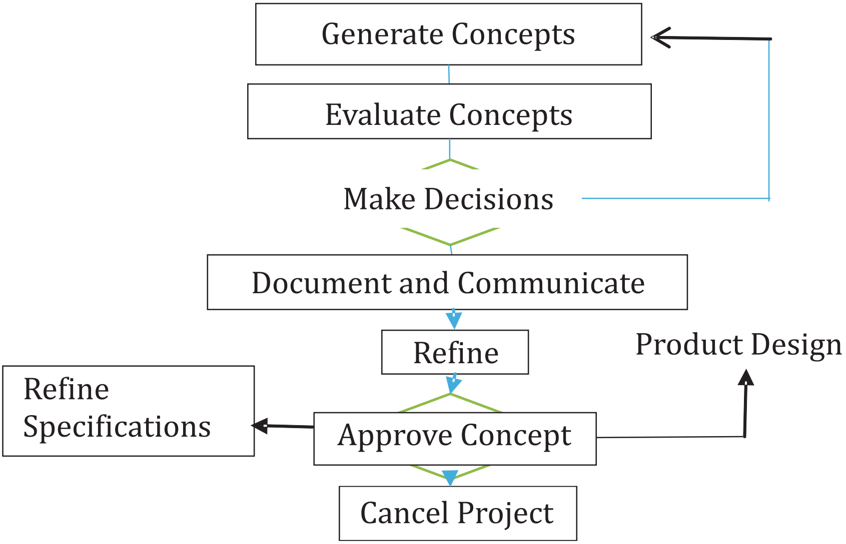


Figure 11: Concept Design Phase in the Design Process

Source: *Ullman, 2010*

Over the years there has been a rapid increase in the number of methods for generating creative concepts. For the purpose of this lecture, it will be sufficient to have a brief discussion on these methods. Without following any particular order they are: (1) Brain storming, (2) Brain writing or 6-3-5, (3) Use of analogies, (4) Finding ideas in reference books, trade journals and on the web, (5) Using experts to find ideas. (6) Patents as a source of ideas, (7) Using contradictions to generate ideas and (8) Theory of inventive machines (TRIZ, "trees").

2.2.3.1 Brain Storming

Brainstorming, was developed as a group-oriented technique but can also be used by an individual designer. Each member of the team suggests ideas freely without initial judgement. The more the numbers of ideas the better. There are simple rules that guide brain storming:

1. Record all the ideas generated. Appoint someone as secretary at the beginning; this person should also be a contributor.

2. Generate as many ideas as possible, and then verbalize these ideas.

3. Think wild. Silly, impossible ideas sometimes lead to useful ideas.

4. Do not allow evaluation of the ideas; just generate them. Ignore any evaluation, judgment, or comments on the value of an idea.

In groups, one member's idea will trigger ideas from the other team members. A brainstorming session should be focused on one specific function and allowed to run through at least three periods during which no ideas are being generated.

2.2.3.2 The 6-3-5 or Brain Writing

A drawback to brainstorming is that it can be dominated by one or a few team members. The 6-3-5 method forces equal participation by all. This method is effectively brainstorming on paper and is called *brain-writing* by some.

2.2.3.3 Use of Analogies

This involves looking around for objects that performs a function similar to the desired function for idea and adaptation. According to Ullman, (2010) the inspiration for the concept of a one-handed bar clamp came from the caulking gun. Analogy in nature can also serve to generate ideas in creative design.

2.2.3.4 Finding Ideas in Reference Books, Trade Journals and on the Web

Many reference books contain analytical information that may guide idea generation. This is particularly true in domains where similar functions have been highly researched over the years. For example, motion in mechanism has been so well developed such that any function relating to motion can be properly guided by enormous reference books in this domain.

2.2.3.5 Using Experts to Help Generate Concepts

When faced with new domain, design engineer has to seek out an expert to learn from or spend time to gain knowledge in the new domain. It is not always easy to find an expert; the domain may even be one that has no experts. A good source of information is manufacturers' catalogs and, even better, manufacturers' representatives. A competent designer should spend a great deal of time on the telephone with these representatives, trying to find sources for specific items or trying to find “another way to do it.”

2.2.3.6 Patents as a Source of Ideas

A patent search reveals how others solve the problem. A creative mind will build on the known to get to the unknown but aim at unique result. A patent search often yield information that can reasonably guide in understanding what others have done in domain of current interest.

2.2.3.7 Using Contradictions to Generate Ideas

A contradiction occurs when improvement in one aspect results in something else getting worse. This means that the ability to fulfill the target for one requirement adversely affects the ability to fulfill another requirement. For example: (a) The product gets stronger (good) but the weight increases (bad). (b) An automobile airbag should deploy very fast, to protect the occupant (good), but the faster it deploys, the more likely it is to injure somebody (bad).

Consider a company's flagship product that was once the market leader but now competition has caught up with it. The company can add more functions, but then the product gets heavier and larger. They need to add functions but can't make the product larger and heavier. To resolve the conflict, the contradiction must be correctly articulated. How can more functions be added without increasing the mass of the product and yet not compromise integrity of the product? To answer this question, the assumptions made in the initial design may have to be examined until a win-win condition is achieved.

2.2.3.8 The Theory of Inventive Machines, TRIZ

TRIZ (pronounced "trees") is the acronym for the Russian phrase "The Theory of Inventive Machines." TRIZ is based on two ideas:

1. Many of the problems that engineers face contain elements that have already been solved, often in a completely different industry, for a totally unrelated situation, that uses an entirely different technology to solve the problem.

2. There are predictable patterns of technological change that can be applied to any situation to determine the most probable successful next steps.

3. Creative innovations use scientific effects outside the field where they were developed (Mindtools.com, 2021).

TRIZ was developed by a Russian mechanical engineer Genrikh Altshuller after the second world-war. The idea came while searching through 400,000 patents. Today the data base of patent is over, 2.5 million (Ullman, 2010). TRIZ is the driving force behind the tremendous increase in creative design in Russia after the death of Stalin. Altshuller found that there are 40 inventive principles underlying all patents. He developed them into 40 inventive principles that help to overcome contradictions in concept generation. They can also be described as "solution pathways" or methods of dealing with or eliminating engineering contradictions between parameters in design.

2.2.3.9 Building a Morphology

The technique involves using the functions identified to foster ideas. It is a very powerful method that can be used formally or informally as part of everyday thinking. There are three steps to this technique. The first step is to list the decomposed functions that must be accomplished. The second step is to find as many concepts as possible that can provide each function identified in the decomposition. The third is to combine these individual concepts into overall concepts that meet all the functional requirements. The design engineer's knowledge and creativity are crucial here, as the ideas generated are the basis for the remainder of the design evolution. This technique is often called the "morphological method," and the resulting table a "morphology," which means "a study of form or structure."

Any of this methods or a combination of them can be used in conceptual design by a design team or by an individual designer. The key to creative design is to diverge before converging. Let the number of concepts be many at the beginning of the process and narrow it down by iterative process to what looks like the optimum by continuous evaluation.

2.3 Concept Evaluation and Selection

Often people generate ideas but have no ability to evaluate them. Evaluation requires comparison between generated ideas and the laws of nature, the capability of available technology, and the requirements of the design problem itself. Comparison, then, necessitates modelling the concept to see how it performs with respect to these measures. The ability to model is usually a function of knowledge in the domain. The engineer must remember always that keeping cost low is number one priority of management while safety is number one priority of the public. He must strike a balance between the two contradictions.

In case of each of my design works referred to so far in this lecture all the preliminary stages of the design process were passed through before concept evaluation. In the case of oil pump, the target sector is the petroleum downstream sector. A quick survey revealed an actual customer demand in this sector to be self-priming pumps (Egbe, 2013). Thus all concepts selected at the preliminary stage were positive displacement types. Holland and Chapman (1966) indicated that spur gear pumps are best suited for low capacity pumps while for capacity above 912 litres per minute, helical and herringbone gears should be used. Following the design axiom of “keep it simple”, the concepts that contain subunits outside the range of recommended capacities were considered to be non-cost effective. The simpler the subunits the lower the overall cost. Available technology, skill and manufacturing processes were some of the factors considered in narrowing down choice candidates for each of my products shown in Figure 4 (Internal gear hydraulic pump), Figure 5 (Metallic plastic mould), Plate I (Ball milling machine), Figure 6 (Wet legume de-huller), Figure 7 (Double roll crushing machine), Figure 8 (Thermoplastic extrusion meter), Figure 9 (Horizontal shaft hammer mill) and Figure 10 (Dual operated single screw yam pounding machine).

3 PRODUCT DESIGN AND EVALUATION

The basic elements of the product design process are shown in

Figure 12, and moving from concept to manufacture-able product requires work on all the elements shown in this Figure.

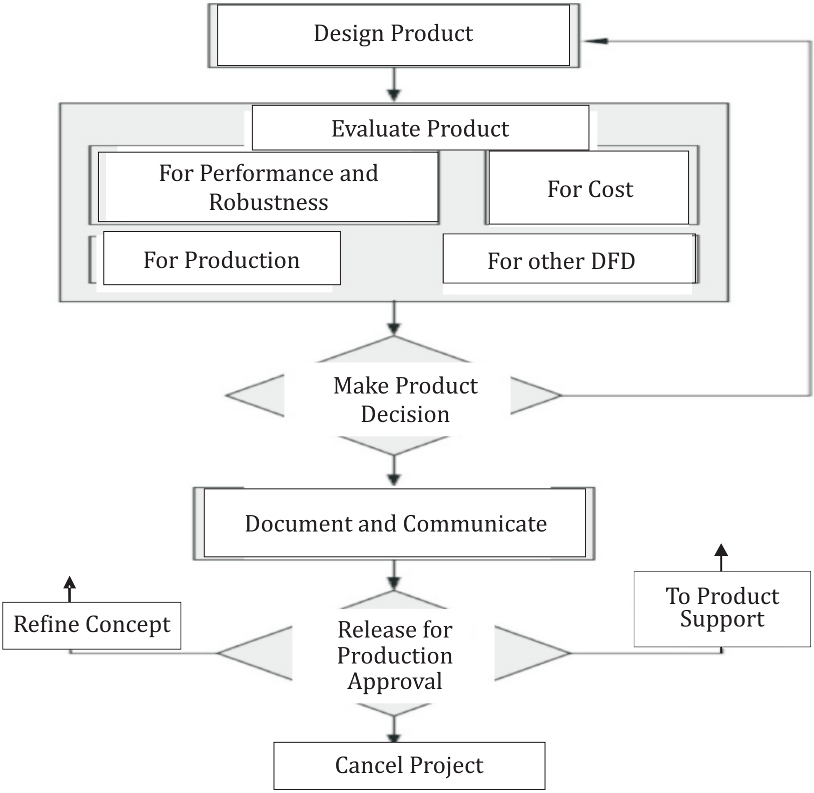


Figure 12: The product design phase of the design process

Source: *Ullman, 2010*

The product design goes iteratively with evaluation to determine how well it satisfies performance target, quality objectives, reliability and cost. Quality is measured by the product's ability to meet the engineering requirements and the ease with which it can be manufactured and assembled. Evaluation results suggest whether to refine concept or release design for production approval or cancel project. Some of my design works shall be used to illustrate the design decisions and analytical processes involved in product design.

3.1 MY CONTRIBUTION TO KNOWLEDGE IN PRODUCT DESIGN AND EVALUATION

3.1.1 Internal gear hydraulic oil pump (Egbe, 2013)

One major requirement of the design problem that must be satisfied by pump concept is specified flow rate of 24.55 l/min. The relevant model equation that ensures satisfaction of this requirement for spur gear concept relates to volume displaced per unit time, denoted by D_p. The volume displaced per revolution is a function of gear face width, the pitch circle diameter and the number of gear teeth.

The model equation on D_p in addition to constraint on face width and available involute cutting teeth guided the design. Mott (1992) had indicated that face width must be greater than 8D/n but less than 16D/n. The upper limit is a critical value that must be avoided in order to prevent failure resulting from dynamic forces due to misalignment and bending of the gear under load. Moreover the noise level increases with face width. Thus application of science aids completion of the geometric design of the gear size and form. The interaction between energy and fluid displacement makes it possible to determine energy requirement. A simple analogy to this is the effect of paddle size on pull obtainable per stroke for a small boat. The lager the paddle the more the pull and effort required to paddle the boat.

The information obtained from this stage of product design was used to carry out stress analysis and materials selection. Stress analysis ensures safety of life and protection of the public. The dimensions of the gears which were obtained on basis of expected discharge were not altered under consideration of stress. Figure 13_a shows the forces acting on the two involute gears while Figure 13_b shows the force resolved into tangential and radial directions. The force exerted by gear one on gear two, denoted by F_{12} is equal but opposite to force exerted by gear two on one, F_{21}. The load responsible for transmission of power from driver to driven gear is the tangential component of F_{12}. The tangential load determines the torque requirement for pumping.

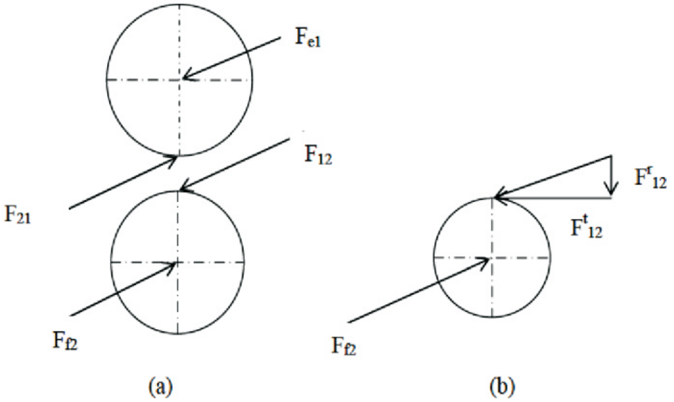


Figure 13: Forces acting on the gears and component of forces

Source: *Egbe, 2013*

A modified Lewis stress model gives a relevant relationship between stress and load transmission capacity for a gear of known face width and material (Mott, 2004; Khurmi and Gupta, 2007). The torque obtained from this model was modified to account for dynamic nature of gear drives. The gears are safe if the dynamic load is reasonably lower than the load bearing capacity for any available material calculated by application of modified Lewis model equation.

The shafts are the simplest components while gears and housing are more and most complex components. By reason of order of complexity, the shaft was sacrificially designed to fail relative to the housing. This is an innovative consideration that can be used in complex designs. This was achieved by application of higher safety factor for housing than for shaft. The housing is essentially a thin walled pressure vessel. Thus the model equation for circumferential stress was used with safety factor of 1.5 to get a wall thickness of 5mm. All the components of the pump were machined, assembled before coupling to the prime mover.

The performance test results showed a volumetric efficiency of 81.47 per cent and a gradual drop in flow rate with height as shown in Figure 14.

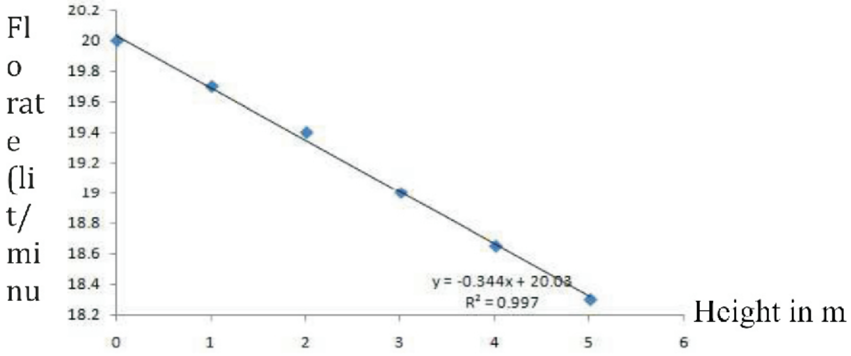


Figure 14: Variation in discharge rate with increase in height

Source: *Egbe, 2013*

3.1.2 Metallic Thermoplastic Mould (Egbe, 2016)

I shall only consider design decisions which are peculiar to this product. A mould designer has to take decisions on (a) the number of cavities in the mould, (b) the parting line of the piece, (c) the type and location of gate, (d) the runner system, (e) sprue, (f) the ejection system, (g) the temperature control system and (h) the venting system (Rosato *et al.,* 2000). The quality of each of these decisions determines the performance of the mould (Rubin, 1979). The major factors that determine the number of cavities in the mould are, (a) the capacity of the injection moulding machine, (b) the size of the product and the clamp rating of the machine. The capacity of the machine refers to the volume of the plastic melt that can be injected per shot. The choice of number of cavities must ensure that the volume of plastic injected is enough to fill all the cavities, runners, gates and sprue. This volume depends on the size of the product. The size of the mould must be tailored to fit the clamp space of the machine (Goff, 2012).

The design of cavity dimensions must take the fact of shrinkage into consideration. Levy and Duboise (1984) suggested a model equation for the dimensions of cavities at the initial design stage. The mould must be constructed so that changing dimension to correct for shrinkage can be done by removing metal from the cavity. The design decisions for key subunits are presented in this lecture.

3.1.2.1 Cavities

The dimensions of moulded pieces are part of specifications for this problem. However design decisions have to be made on the cavities. The shrinkage range for po1yethlene (both low and high density polyethylene) is given as 0.02 to 0.05 mm/mm (Levy and Duboise, 1984). A shrinkage value of 0.02 mm/mm was used for first design and 0.05 for the second design. The variation in dimension was obtained by finding the difference between the maximum and minimum dimensions. The tolerance is less by or greater by variation. Thus expected thickness of the tensile piece is 2 ± 0.064 mm. All the dimensions on tensile test piece cavities were obtained in the same way and presented in Table 1.

Table 1: Dimensions of tensile test piece cavity

Piece dimension (D_p)	Cavity dim. (D_{c1})	Cavity (D_{c2})	Tolerance
2 mm	2.041 mm	2.104 mm	± 0.064
50 mm	51.02 mm	52.625 mm	± 1.6
12 mm	12.245 mm	12.63 mm	± 0.39
20 mm	20.41 mm	21.05 mm	± 0.64

Source: *Egbe, 2016*

A similar application of the model equation to the dimensions of the compression and flexural test pieces produced the dimensions of the cavities presented in Table 2 and Table 3 respectively.

Table 2: Dimensions of compression test piece cavity

Piece dimension (D_p)	Cavity dim. (D_{c1})	Cavity (D_{c2})	Tolerance
20mm	20.41mm	21.05 mm	± 0.64
10mm	10.2mm	10.525mm	± 0.32
12mm	12.245mm	12.63mm	± 0.39

Source: *Egbe, 2016*

Table 3: Dimensions of flexural test piece cavity

Piece dimension (D_p)	Cavity dim. (D_{c1})	Cavity (D_{c2})	Tolerance
120 mm	122.45 mm	126.3 mm	± 3.85 mm
12mm	12.245mm	12.63mm	± 0.39
3 mm	3.061 mm	3.158 mm	± 0.096

Source: *Egbe, 2016*

3.1.2.4 The Sprue Design

The injection nozzle of the moulding machine is 3.5 mm. According to Levy and Duboise, (1984) the runner should be 1.8x nozzle diameter in order to correctly insert the nozzle into the sprue. That constraint led to a sprue diameter of 6.3 mm. A standard orifice of 6 mm diameter was chosen as initial design. The length of the sprue was chosen on the basis of geometrical considerations since it must extend to the centre of the runner. The length of the longer cavity is 144.9 mm. Let the cavity be located 20 mm from the edge of mould plate (Figure 16). Adding 20 mm to half the length of the longer cavity and accounting for the size of constricted gate the length of the sprue was found to be

94.2 mm (as shown in Fig. 15). A runoff of 3mm was added to accept and retain the first surge of material. Applying the law of continuity, the flow into the two cavities was found to be 1.1432×10^{-6} m^3/s. Substitution into relevant model equation resulted in a pressure drop of 3.96MPa in the sprue.

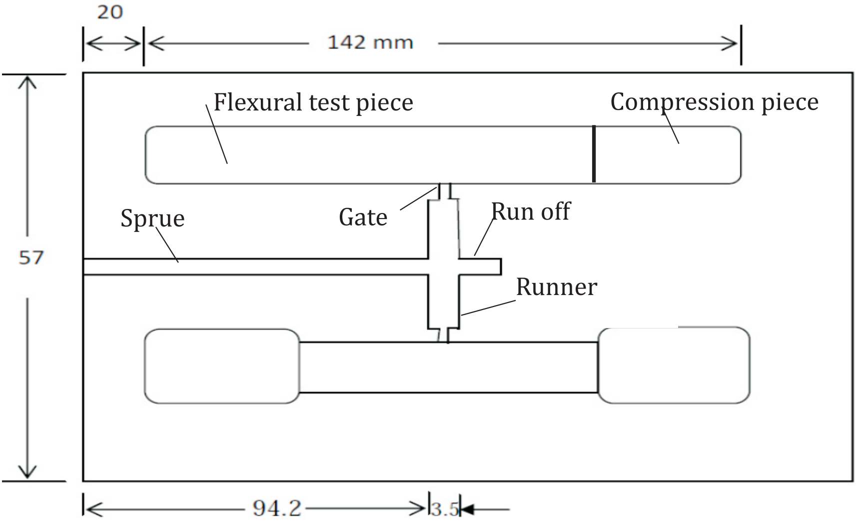


Figure 15: The plan view of cavity plate

Source: *Egbe, 2016*

The product served the purpose for which it was made very well. The performance of this product was evaluated in terms of dimensional accuracy. The dimensional accuracy varied between 87 % and 95 % which was very satisfactory. My thirteen years' sojourn in the industry revealed a gap in mould design for the plastic industry in Nigeria. The few who put themselves forward as mould makers engage in trial and error with challenge of poor performance associated with it. This work established model equations and engineering principles for plastic mould design.

3.1.3 Ball Milling Machine (Egbe *et al.*, 2016)

It will be sufficient for the purpose of this lecture to highlight peculiar aspects of design decisions that were made in generating this product (shown in Figure 16).

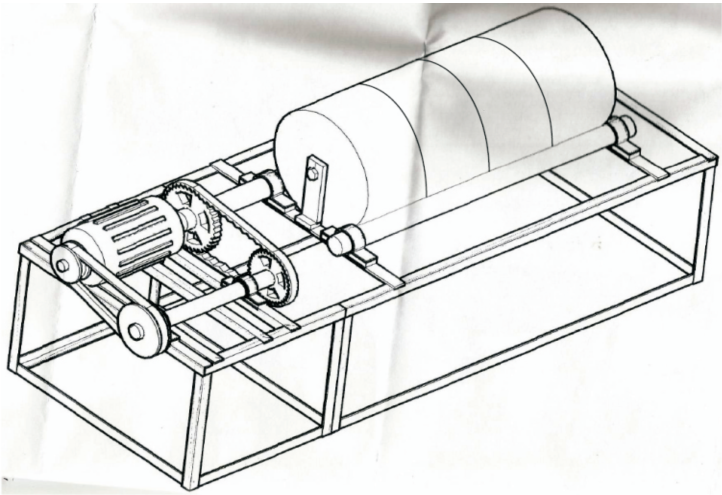


Figure 16: Ball milling machine
Source: *Egbe et al., 2016*

The mechanism by which the mill is rotated is contact friction between cylindrical tank (milling jar) of radius R and the two shafts of radius r (Fig. 17).

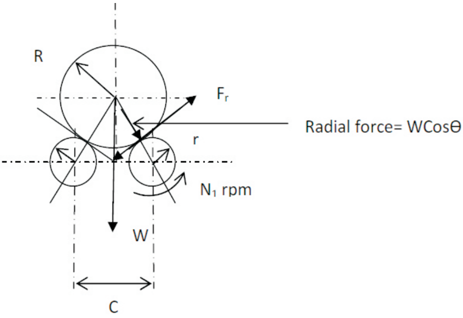


Figure 17: Schematic layout of the milling machine
Source: *Egbe et al., 2016*

In the configuration shown the driving shaft rotates anti-clockwise, hence friction force act upwards as shown in Figure 17. The load W, exerted by the mill is shared equally by the two shafts with the radial and tangential components of this load being 0.5WCos? and 0.5WSin? respectively. Angle ? is the inclination of the radial component of force to the vertical. The driving torque supplied by input shaft is a function of contact friction, F_r and shaft radius, r.

Khurmi and Gupta (2005) indicates that the frictional force is proportional to the normal reaction through the coefficient of friction. Similar consideration was applied to determine the actual milling torque.

Geometrical considerations of Figure 17 indicate that angle ? is a function of centre distance and the radii of the two rolls and the milling jar. In light of available milling jar for testing the machine and available grinding media size, the critical milling speed was found to be 131 rpm. However, optimum grinding takes place at a mill speed of $0.7V_c$ (Gupta and Yan, 2006; Wills and Napier-Munn, 2006). Thus mill speed is limited to 91.7rpm. With a roller diameter of 40mm and milling jar diameter of 140mm the speed ratio at this stage is 3.5:1. Thus optimum grinding requires that the rollers run at a speed of 321rpm.

3.1.4 Wet Legume De-huller (Egbe & Roland, 2016)
It is sufficient to highlight peculiar aspects of design decisions that were made in generating this product (shown in Figure 6). The stripping torque had to be determined from knowledge of abrasive strength of cultivars. Two cultivars of cowpea were considered for the design, Sampea 7 and Tvx3236. The de-hulling/striping torque required is a product of abrasive force and geometric mean diameter of cultivars

The approximate abrasive forces required to de-hull cowpea Tvx

3236 and sampea 7, at a feed rate of 20 seeds per minute was given as 92.56N and 64.55N, by Chukwu and Sumonu, (2010). The average abrasive force for feed rate of 500 seeds per second was deduced to be 1571.1N for Tvx3236 and sampea 7. The geometric mean diameter of seeds was found to be 6.245mm and de-hulling torque was found to be 12.2644Nm for a specified feed rate of 500 seeds per second.

3.1.4.1 Determination of the Power Required from the Motor

Reichert *et al.*, (1979) recommended an optimum de-hulling speed of 45.87rad/s. However low speed motors run at a speed of 146.6 rad/s. Thus speed reduction was inevitable. Application of engineering science gave a motor power of 562.57Watts. Accounting for efficiency of motor resulted in selection of 760 Watts motor.

3.1.4.2 Determination of Forces on the Shaft

The actual power delivered to the shaft at point A (Figure 18) is 760 W and the shaft torque at this point is 16.57 Nm. The net driving force on pulley was found to be 207.13 N. Figure 18 show the horizontal forces and their reactions.

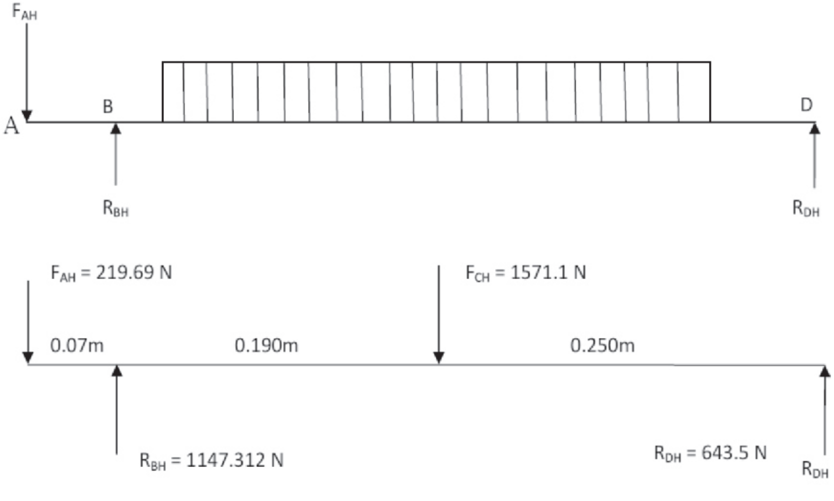


Figure 18: *Horizontal Forces and Reactions*

Source: *Egbe & Roland, 2016*

3.1.4.3 Determination of Shaft Diameters

The shaft is subjected to torsion at point A, combined bending and torsion at B and C and only shear force at D. The forces and bending moments were obtained and relevant diameters were found by application of engineering science. The diameter at A was found to be 12.6 mm, at B 20.5 mm, at C 40 mm and at D 10 mm. The machine was fabricated and the test results shown in Table 4 had a maximum de-hulling efficiency of 95.2 % at a through put of 540 kg per hour.

Table 4: Results for cowpea

Soaking time, min	Weight of Soaked seed(kg)	Dehulled beans (kg)	Undehulled beans (kg)	Efficiency ?(%)
2 min	1.25	1.129	0.121	90.3
4 min	1.25	1.171	.079	93.7
6 min	1.25	1.19	0.06	95.2
8 min	1.25	1.189	0.061	95.1
10 min	1.25	1.188	0.063	95

Source: *Egbe & Roland, 2016*

3.1.5 Thermoplastic Extrusion Meter (Teran & Egbe, 2018)

It is only the peculiar design decisions that have not been covered under the products discussed so far that shall be dealt with here. It may be mentioned that safety and cost are common factors relevant to the success of most products. This product (shown in Figure 8) is one out of my masters' students' projects.

The essential function of this product is to provide a standard measure of mass flow rate (MFR) of thermoplastic melt under specified pressure, temperature and die size, since these operating conditions affect the mechanical properties (Egbe and Onyepke, 1992; ISO.BS EN1133, 2005; ASTM D1238, 2013).

The extrusion pressure depends on the specified mass for test thermoplastic. The maximum specified mass is 21.6 kg which is for high density polyethylene (PE) (ISO. BS EN 1133, 2005).

The pressure in the heating barrel was found to be 2.989MPa. The location of the temperature monitoring hole was determined by applying thin walled pressure vessel principles to the design. The required distance from internal wall of barrel to the hole is equivalent to the thickness, t, of a thin walled pressure vessel.

The fact that a drilled hole has rough finished surface which makes presence of stress concentrations inevitable and high temperature condition made it necessary to keep safety factor at high value of 3. Using the yield strength for ANSI 1018 cold rolled mild steel in relevant model equation gave a thickness of 0.12mm. This is the minimum but the actual hole was given a clearance of 2mm from the barrel wall to account for drilling error.

The test results indicated that MFR for virgin HDPE was 9.96g/10 minutes which fell within the range of 2.2 to 22g/10mins provided by the manufacturer while MFR for recycled HDPE was 10.88g/10 minutes. The result of the first time recycling indicates, it is healthy for reuse since the MFR fall within acceptable limits. On the other hand higher value than virgin material suggests that some degrading has taken place, which established the need for this product for continuous monitoring of thermoplastic recycling in Nigeria.

3.1.6 Double Roll Crusher (Egbe & Olugboji, 2016)

This lecture will highlight design decisions that are peculiar to this product. The double roll crusher was designed for low hardness rocks and ores such as kaolin and lime stone. The second important design decision is to agree on the maximum feed size of ores to be crushed and the maximum product size. The feed size is a function of the roll diameter and roll gap while maximum product size is a design decision and is equal to the roll gap. The desired maximum product particle size was 5mm, rolls of 120mm were available and output capacity of 0.356tonne/hour was the target. Considering submission by Gupta and Yan (2006); Wills and Napier-Munn (2006) that the actual capacity of roll crushers are only 25 % of the theoretical values due to voids between particles and loss of speed in gripping feed particles, the theoretical capacity was calculated to be 1.43t/hr.

3.1.6.1 Maximum size of the particle that can be fed into the roll crusher

Figure 19 shows a geometry of double roll crusher. The particle is assumed to be spherical and of size x_1.

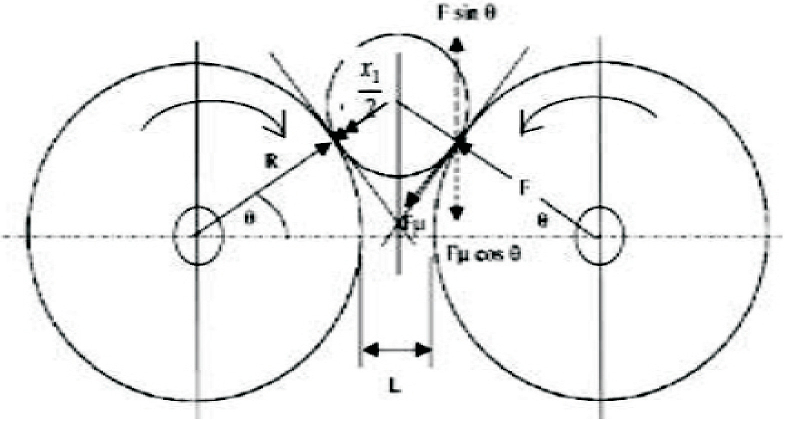


Figure 19: Double roll crusher geometry
Source: *Egbe & Olugboji, 2016)*

In the Figure shown, a spherical particle is about to enter the crushing zone and is about to be nipped. For rolls that have equal radii and length, tangents drawn at the point of contact of the particle and the two rolls meet to form the nip angle 2θ. A consideration of geometry revealed that the nip angle, 2θ, is a function of roll radius R, the size of the particle to be crushed i.e. size of the feed (x_1), the distance between the two rolls (roll gap) L and the coefficient of friction μ between the roll surface and the particle surface. Average coefficient of friction μ of low hardness rocks (hardness number 1 to 4 on the Moh's hardness scale) in contact with steel is between 0.2 and 0.3. Adopting, the lower limit, and substituting into relevant model equation gave the nip angle as 22.62 degrees. For a specified roll diameter of 120 mm and roll gap of 5 mm, the maximum feed size, x_1, was found to be 7.5 mm.

3.1.6.2 Crushing Power

The power required for crushing depends on capacity, reduction ratio and the hardness of the ore. The hardness of ore is measured in terms of Bond's work index which defines the energy required to grind one tonne of ore from infinite size to 80 % passing 100 micro metre. In this work Q = 0.356 t/hr and x_1 was found to be 7.5mm. A roll gap of 5mm had already been specified and x_2 is less than or equal to this value. Maximum power is drawn for x_2 = 5mm. Thus Maximum power requirement for limestone, with w_i of 7 kWh/t becomes, P = .356 x 1.5x 7 = 3.74kW or 5hp. Thus motor power of 5hp was used. The product was fabricated from locally available materials and the test results showed a satisfactory performance. The work provides relevant model equations and data for the development of the solid mineral sector in Nigeria.

3.1.7 Horizontal Shaft Hammer Mill (Source: Sulaiman *et al.*, 2017)

This lecture will cover design decisions that are peculiar to this product. This hammer mill was designed to reduce the size of granite from 50 mm to 10 mm at a throughput of 400 kg per hour as my M.ENG student's project.

3.1.7.1 Determination of the Energy Requirement

The feed size and product size specifications for this work are 50 mm and 10 mm respectively and granite is the material to be used for performance evaluation. Gupta and Yan (2005) gave the average work index of granite as 16.6 kWh/t and Mingqing (2015) gave its compressive strength as 200 MN/m^2. For a feed rate of 400kg/h or 0.4 t/h aimed at in the work, the energy required to crush coarse particles, given by modified Kick's model (Backhurst, *et al.,* 2002) was adopted for the design. This gives $P = 1.72$kW, and the energy required for crushing is 4300 J. However to obtain the design power a service factor of 2 was adopted to get a design power of 3.44kW (Kachalla, 2011). In selecting an electric motor, the efficiency is put into consideration. Lartey (2016) gave efficiency of 0.84 for electric motors in the power range of 1 to 4 hp. Thus, a motor power of 4.1kW was used.

3.1.7.2 Determination of Hammer Plate Dimensions

The compressive strength of granite has been given above as 200 MN/m^2. Applying maximum shear stress theory of failure (Khurmi & Gupta, 2005) the maximum shear stress required to crush granite will be half its compressive strength, (that is 100MPa). The maximum area resisting crushing of a 50 mm diameter stone is its cross sectional area, πr^2. Thus the force resisting crushing, F_1 was found to be 196.35kN. The machine showed a theoretical through-put efficiency of 75.4 per cent. The products from crushing were found to be well graded. In addition, the work provides relevant data and technical guide for future development of both aggregate production sector and the mineral industry.

3.1.8 Auto Controlled/Totalizing Gas Filling System

In a constantly changing world, mechanical engineering design remains relevant as it moves from purely mechanical systems to complex systems that combines mechanical system with electrical, electronic and computer processing unit. The first time I went to refill gas in Lagos I was completely dissatisfied with the manual filling in operation on account of environmental pollution involved. Two auto-filling concepts occurred to me then: volume flow rate control and mass flow rate control, but there was no design then since there was no determination to solve the problem. I took another look at the two concepts about four years ago and decided to work on it. The volume controlled system was already in use at the time but at exorbitant price. Evaluation of the two concepts revealed that the volume conversion to mass is temperature dependent in addition to the high cost. Thus the product design was based on auto-mass control. The product shown in Figure 20 is made up of eleven subunits. Namely pump, bypass valve, control valve, pressure gauge, solenoid valve, discharge unit, pipe network, load cell, cantilever mounting, micro-processing unit and frame.

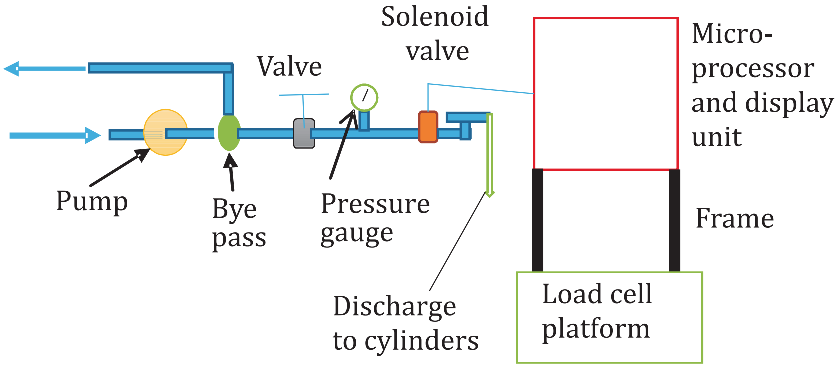


Figure 20: Layout of auto-controlled/totalizing gas filling system
Source: *By Permission of PF P. Ltd*

A brief discussion of the functions of notable subunits will be sufficient for this lecture.

3.1.8.1 Pump

The positive displacement pump was selected to meet specification of discharge capacity, pressure and properties of the fluid (LPG).

3.1.8.2 By-Pass Valve

The function of by-pass valve is to prevent a build-up of excessive pressure in the pump and on the discharge line by releasing some of the fluid back to the tank. It also makes it possible to keep the pressure reaching the solenoid valve below specified limit.

3.1.8.3 Control valve and pressure gauge

The control valve regulates the pressure reaching the solenoid valve and by extension the filling pressure while the gauge measures the pressure.

3.1.8.4 Solenoid valve

The function of the solenoid valve is to auto-release gas until a predetermined mass of LPG is dispensed and then auto-shuts off supply.

3.1.8.5 Weighing Unit

This unit is made up of a cantilever load cell mounted on a cantilever platform that is fixed to a frame. The initial concept for this subunit was a column load cell, but a prototype revealed that the load must be located at the centre of the column. Such a limitation was not considered cost effective nor fool-proof for a product of this type. The interaction between this subunit, the solenoid and the micro-processing unit determine the mass and price of gas dispensed. The weighing unit was designed to carry a load of 2943 N.

3.1.8.6 Micro-processing unit

This unit is the control room of the product. It sends signal to open the solenoid valve and keeps it so until feedback from the weighing unit demands it to close the solenoid valve. The initial and upgraded micro-processing/display units are shown in Figure 21 (a) and (b).

(a) (b)

Plate II: Initial (a) and Final (b) micro-processing units
Source: *By Permission of PF P. Ltd*

The product is unique and the overall performance has been satisfactory. Upgrading to a bigger display unit became necessary because some customers wanted to see the display from a longer distance than was designed for.

The changes of the 20th and 21st centuries have also impacted material development either by making possible what was previously impossible or by challenge to demand for improved materials for design. As noted by Egbe, *et al*., (2013) what was previously lean gold ore has become valuable resource by reason of technological innovation and coming of computer into testing and analysis of results. The creative mechanical engineer remains the need of a changing world to transform our rich/lean resources into viable products for a sustainable economy.

Concluding Remarks and Recommendations

Vere (2009) expressed dissatisfaction over creativity content in engineering curricular in most universities. Many academics

and professionals have called for a change from a narrow focus on engineering science as such practice produce engineers who are competent technically but not capable of innovation (Beder, 1997; Dym, 1999; Pappas, 2002; Akay, 2003). Beder (1997) and Pappas (2002) called for cultural change through which students will “develop innovation and creativity”. Akay (2003) advocates the need for a 'renaissance' engineer who is a creative thinker.
In a rapidly changing world, with increasing complexity in manufacturing processes and growing competition, engineering schools cannot be training engineers for technological task completion. The 21st century industry wants engineers who are creative thinkers. The industries all over the world are looking for creative engineers who will solve their problems. The companies in U.S. usually make their staff sign an undertaken at the beginning that every invention shall be the property of the company, which is an expression that creativity is key to success of an engineer. The purpose of engineering education is to graduate engineers who can design.

When I joined FUT in 2005, my first mechanical engineering design course for 500 Level students in 2005/2006 session, was an elective, with only three students out of a class of over 200 students. I felt sad over that situation because it was difficult for me to reconcile the expectation of the industrial sector (where I was for 13 years) with a graduate engineer without design. I complained about it and those of us in design option kept on talking until recently when 500 level design course was made compulsory. While appreciating this improvement, I will, like Oliver Twist ask for more. Creativity cannot be effectively impacted via a two unit credit lecture in the final year. I have expressed it severally that mechanical engineering design II should not be less than a minimum of 3 hours per week.

The challenges of educating the generation to who we shall entrust the future cannot be achieved with outmoded engineering curricula. The future requires engineers who are thoroughly prepared for the challenges that face global communities; water shortages, global warming, environmental degradation, energy and materials consumption, sanitation, carbon emissions and demographic and cultural shifts. In a rapidly changing world, creative solutions are required.

To correctly reposition engineering students for the future, they must be trained to be creative and this cannot wait till the final year. Every engineer can be creative if properly guided. We must imbue the new generation of engineers with the appropriate skills to deal with a rapidly changing world that is in desperate need of creative and innovative engineering. A total shift from engineering science fixated culture of engineering education to a creative design based education without compromising science integrity is required in the 21st century. Robust creative design projects should run throughout the training of engineering students and not just in final year. This calls for concerted efforts on the part of government and our education planners. The core responsibility of the engineer is to solve problems in our immediate communities through creative thinking. There is always a better way to solve problems confronting our ever changing world today and the solutions are within our reach.

ACKNOWLEDGEMENTS

To the LORD God Almighty be all the glory, honour and praise. It is of His mercy that I was not consumed. My father told me how disappointed and dissatisfied he felt, with a seeming disability, on account of which, he could not accept that a son had been born to him. He told me a voice whispered in his ear asking him to leave the boy alone and that could have only been the voice of Him who knew me before He formed me in the womb, took away the disability, and guided me through the journey of life. My soul rejoices in the LORD GOD Almighty who was and is and is to come. The way was long and rough but God has always been there to bring me to this place wherein I stand.

I greatly appreciate my amiable wife, Mrs. Edith Olufunmlayo Egbe for her love, care, support and understanding. Today could not have happened if it were not for your support. Thank you so much. I thank my young adults (our children) Builder Oghenefejiro Foloruso and her husband Engr. Isaac Folorunso, Eseoghene Egbe, Ogheneruno Egbe and Emuogheneruru Egbe for their love support and understanding.

I deeply appreciate my late father Chief Edward Egbe Ikpapor and my late mother Mrs. Hanah Oreruejerien Egbe who jointly insisted on my education against all odds. My father physically ordered me to come down from the top of a palm tree and warned me never to try it again. I could not understand and felt very embarrassed. However at 200 Level he told me he stopped me on the basis of the voice that ordered him to leave me alone. He was consistent and insisted that a day like this would come.

I deeply appreciate my late maternal uncle Elder Gabriel

Owhodede Igharha and his wife Mrs. Alice Ebiyemi Igharha who without request from my parents asked me to pick a secondary school form. They virtually became my new parents who saw me through school. They were the great hand of help that God sent to prepare me for today.

I appreciate the contributions of my brother in-law and his wife, Dr. and Dr. (Mrs.) Sunday Olatunji Oyegbile, for their love and counsel. Thank you.

I appreciate the Vice Chancellor and the university administration both present and past for their support and for creating an enabling environment for me to develop and grow. I did my PhD in F.U.T. with your support and good understanding. I deeply appreciate you all. Thank you and thank you.

I appreciate the contribution of my teachers who taught me from primary school to post graduate level. I particularly appreciate my supervisors, Dr. E. Mudiare, Prof. O. K. Abubakre, late Prof. M. I. Ogunbajo (PhD), Prof. B. O. Onyekpe (M.Eng) and Prof. S. Salami (B.Eng) for their counsel/guidance and encouragement. I appreciate my engineering family for your support, advice and encouragement. I appreciate my mechanical engineering family both past and present for your great contributions to my life and academic progress. I thank you all.

I thank my spiritual fathers/mentors, Engr. Hope Ovwah, Engr. Kola Adegoke, Prof. Fred Adegoke, Pastor (Barr.) Caleb Atolagbe, Pastor (Dr.) O. A. Boyo, Brother Shola Ajayi, Bishop (Dr.) Michael Onimole, Bishop Eli Alhasan, Bishop E. C. Nnaji and Bishop O. M. Afolabi.

Finally, I appreciate my siblings, relatives, family, friends and all who are present today to grace this occasion. I thank you all.

REFERENCES

Akay, A., (2003). The renaissance engineer: Educating engineers in a post-9/11 world. *European Journal of Engineering Education*, 28(2), 145-150.

ASTM D1238 (2013). Standard test method for melt flow rates of thermoplastics by extrusion plastomer. www,astm.org/standards/D1238

Backhurst, J. R., Harker, J. H., Richardson, J. F., Coulson, J. M. & Richardson, J. F. (2002). *Solutions to the problems in chemical engineering, Volume 2 (5th Edition) and Volume 3 (3rd Edition)*, Oxford, UK: Butterworth-Heinemann

Beder, S. (1997). *The social role of the new engineer.* Melbourne: Macmillan.

Bridy, A. (2012). Coding creativity: Copyright and the artificially intelligent author. *Stanford Technology Law Review, 5*, 1–28.

Chukwu, O., & Sunmonu, M. O. (2010). Determination of selected engineering properties of Cowpea (*vigna unguiculata*) related to design of processing machines. *Pakistan Journal of Agriculture, Agricultural Engineering and Veterinary Sciences*, 26 (2), 70-79.

Dym, C. A. (1999). Learning engineering: Design, languages and experiences. *Journal of Engineering Education*, 88(2), 145-148.

Egbe, E. A. P. (2013). Design analysis and testing of a gear pump. *International Journal of Engineering and Science*, 3(2), 1-7. http://www.researchinventy.com/archive.html

Egbe, E. A. P. (2016). Development and testing of a metallic mould for thermoplastic products. *Advances in Multidisciplinary Research Journal*, 2(1), 117-126.

Egbe, E. A. P., Mudiare, E., Abubakre, O. K., & Ogunbajo M. I. (2013). Characterization study of Baban Tsauni (Nigeria) Lead-Gold Ore. *International Journal of Management, IT and Engineering*, 3(7), 669-686. http://www.ijmra.us.

Egbe, E. A. P., Mudiare, E., Sadiq, T. K., Fatona, S. V., & Damisa, L., (2016). Design, production and testing of a Ball Milling Machine. *Nigerian Journal of Tropical Engineering,* 9(1&2), 54-60.

Egbe, E. A. P., & Olugboji, O. A. (2016). Design, fabrication and testing of a Double Roll Crusher. *International Journal of Engineering Trends and Technology,* 35(11), 511-515. http://www.ijettjournal.org.

Egbe, E. A., & Onyekpe, E. O. (1992). The Effects of mould temperature and clamping pressure on mechanical properties of injection moulded thermoplastic products. *The Nigerian Engineer, Journal of Nigerian Society of Engineers,* 27(4), 64 - 67.

Egbe E. A. P. & Roland B. O. (2016). Design, fabrication and testing of a Wet Legume De-hulling Machine. *American Journal of Mechanical Engineering*, 4(3), 108-111. http://pubs.sciepub.com/ajme/4/3/4.

Elizondo, L. A., Yang, M., Kisselburgh, L. G., Herleman, E. D., Cipra, R.J., Ramani, K. & Carleton, T. (2010). Understanding innovation in student design projects. *ASME 2010 International Design in Engineering Technical Conferences, Montreal, Quebec, Canada*.

Gaut, B. (2012). Creativity and rationality. *The Journal of Aesthetics and Art Criticism, 70*, 259– 270.

Goff, J. (2012). Understanding Clamping Forces, Moulding Masterclass/Processing Feature, Injection World. www.injectionworld.com, (Retrieved 29th December 2015).

Gupta, A., & Yan, D.S. (2006). *Mineral processing design and operation - An introduction.* Amsterdam: Elsevier.

Holland, F.A., & Chapman F.S. (1966). *Pumping of liquids.* New York: Reinhold Publishing Corporation.

Horn, D., & Salvendy, G. (2006). Consumer-based assessment of product creativity: A review and reappraisal. *Human Factors and Ergonomics in Manufacturing* 16(2), 155-175.

ISO. BS EN 1133 (2005). Determination of the Melt Mass Flow Rate (Mfr) and Melt Volume-Flow Rate (Mvr) of Thermoplastics, www.18-17.net/upload/file/20151202

Kachalla, J. B. (2011). Design and Fabrication of a Hammer Mill, M.Eng thesis, Mechanical Engineering Department, Federal University of Technology, Minna, Niger State, Nigeria.

Khurmi, R. S., & Gupta, J. K. (2005). *A Text book of machine design.* New Delhi: Eurasia Publishing House (PVT) Ltd.

Kronfeldner, M. E. (2009). Creativity naturalized. *The Philosophical Quarterly, 59*, 577–592.

Lartey, D. (2016). Energy Efficiency in Electrical Drive Systems:

Technical Potentials, Barriers and Policy Approaches for Small and Medium Industries in Ghana, Master's thesis, University of Technology, Faculty of Technology Electrical Engineering, Lappeenranta, Ghana. https://core.ac.uk/download/pdf/3998 2547.pdf.

Lifi, I.A., **Egbe, E. A. P.,** Alkali B., & Mohammed, M. M. (2018). Development of dual operated single screw-driven yam pounding machine. *Proceedings of the 3rd National Conference of the Institution of Mechanical Engineers*, Minna Chapter, 83-93.

Miller, A. (1996). *Insights of genius: Imagery and creativity in science and art.* New York: Copernicus.

Mind Tools (2021). What is TRIZ?, www.mindtools.com [Retrieved 30/01/2021]

Mingqing, Y. (2015). Strength criterion for rocks under compressive-tensile stresses and its application. *Journal of Rock Mechanics and Geotechnical Engineering,* 7(4), 434–439.

Mott, R. L., (1992). *Machine elements in mechanical design.* New York: Macmillan Publishing Company.

Myer, K. (2014). *Mechanical Engineer's Handbook (Fourth Edition): Design, Instrumentation and Control.* New Jersey: John Wiley and Sons.

Newell, A., Shaw, C., & Simon, H. (1962). *The process of creative thinking*. In Gruber, H., Terrel G. & Wertheimer M., *Contemporary approaches to creative thinking,* New York: Atherton Press.

Pappas, E., (2002). Creative problem solving in engineering design. *ASEE Southeast Section Conference*

Pluhar, W. S. (1987). *Critique of judgment, by Immanuel Kant*. Indianapolis: Hackett Publishing Company.

Reichert, R. D., Lorer, E. C., & Young, C. G. (1979). Village scale mechanical de-hulling of cowpea. *Cereal Chemistry*, 56, 181-184.

Rosato, D. V., Rosato, M. G., & Rosato, D. V. (2000). *Concise encyclopedia of plastics.* Kluwer: Springer Academic Publishers.

Rubin, I. I. (1979). *Injection moulding, theory and practice.* New York: John Wiley and Sons.

Sawyer, R. K. (2012). *Explaining creativity: The science of human innovation*. New York: Oxford University Press.

Simon, H. (1985). What we know about the creative process, *Frontiers in creative and innovative management.* Cambridge: Ballinger.

Smith, R. J. (2021). *Engineering as a Career,* Emeritus Professor of Electrical Engineering, Stanford University, California. https://www.britannica.com//technology/engineering/additional.info. [Retrieved on 01/02/2021]

Sternberg, R. (1999). *Handbook of creativity*. Cambridge: Cambridge University Press.

Stokes, D., & Paul, E. S. (2016). *Naturalistic approaches to creativity*, In Systma, J. & Buckwalter W., *The Blackwell companion to experimental philosophy.* Oxford: Blackwell.

Sulaiman, I., **Egbe, E. A. P.,** Alkali, B., Kolo, I. B., & Enoch, O. I. (2017). Development of a Horizontal Shaft Hammer Mill, *Second International Engineering Conference, School of Engineering and Engineering Technology, Minna, Nigeria, 2, 365-369*.

Teran, G. M., & **Egbe, E. A. P.** (2018). Development of a thermoplastic extrusion meter, *Proceedings of the 3rd National Conference of the Institution of Mechanical Engineers, Minna Chapter,* 103-109.

Ullman, D. (2010). *The mechanical design process*. New York: McGraw-Hill Higher Education.

Vere, I. (2009). Developing Creative Engineers: A Design Approach to Engineering Education, *International Conference on Engineering and Product Design Education, University of Brighton, UK,* 1-8.

Weisberg, R. (1993). *Creativity: Beyond the myth of genius*. New York: W. H. Freeman.

Wills, B. A., & Napier-Munn, T. (2006). *Wills' mineral processing technology - An introduction to the practical aspects of ore treatment and mineral recovery, Seventh Edition.* Amsterdam: Elsevier Science and Technology Books.

Yousef, H., & Tamer, S. (2011), *Engineering design process.* USA: Cengage Learning Global Engineering.

BRIEF PROFILE OF THE LECTURER

Engr. Professor Evudiovo Unuojefiapha Peter Egbe was born to a humble family of late Chief Edward Egbe Ikpapor and late Mrs. Hannah Oreruejerien Egbe from Orhoakpor community in Ethiope East Local Government Area of Delta State, Nigeria. He was born on 29th May 1953 in a small settlement in Ayila, Ijebu Water Side LGA, Ogun State, where his parents sojourned for several decades.

He had his elementary school education at St. Joseph Catholic School, Ayila from 1962 to 1967. He proceeded to St. James Anglican Modern School, Ayila at a financial cost on his mother because his father could not afford to keep two sons in secondary school at the same time. Professor Peter Egbe was unbeatable throughout his time in the modern school. It was while here that his maternal uncle Elder Gabriel Owhodede Igharha requested his father to ask him to collect a secondary school form. His initial reaction was objection based on the idea that his mates were already ahead of him in secondary school. It sounded embarrassing to become junior to those he had been beating in class. However, his father gave him only two options, pick a form or drop the father's name. Of course, he swallowed the empty pride and collected just one form and he was given admission.

Professor E. A. P. Egbe had his secondary school education at Manuwa Memorial Grammar School, Iju Odo, Okitipupa LGA, Ondo State (one of the IONIA group of schools). He finished WAEC in 1976, with first Division but beating to the sixth position in the graduating class of 93 students. He proceeded to Federal Government College, Ilorin for his GCE Advanced level.

Professor E. A. P. Egbe went to University of Benin, Benin City, for his undergraduate studies in Mechanical Engineering and finished with second class lower division in June 1983. While in Uniben he got a merit award at the end of part one (now 200 Level). He did Youth Service at Benue State Polytechnic, Makurdi Campus, where he started his teaching career. He took up a permanent job as a lecturer with the Polytechnic in May 1985 and taught several mechanical engineering courses till July 1992 when he moved to the industry. He acquired his second degree in Mechanical Engineering (Design and Manufacturing option) from University of Benin in November 1990 and was appointed Head of Department upon submission of his M. Eng. result.

Professor Egbe worked with several private companies in Lagos between July 1992 and July 2005 before returning to academics on 2nd August 2005 when he assumed duty in the Department of Mechanical Engineering, Federal University of Technology, Minna. While working he started a part time PhD programme in the Department of Mechanical Engineering, Federal University Technology, Minna, under the supervision of Dr. E. Mudiare, Prof. O. K. Abubakre and late Prof. M. I. Ogunbajo, and graduated in 2013.

Engr. Prof. E. A. P. Egbe has served the University community in different capacities: as SWEP Officer for the Department, PGD Coordinator, SIWES Officer for the school, PG Coordinator of the Department, Final year project Coordinator, Turn-it-in Officer of the Department, and Member School Examination Malpractice Committee.

Professor E. A. P. Egbe has published many journal papers and attended many conferences both national and international. He had supervised many Masters of Engineering students and PhD students and currently supervising Masters and PhD students in addition to Undergraduate students.

Professor E. A. P. Egbe is married to one amiable wife, Mrs. Edith Olufunmilayo Egbe. They have four children, Builder Oghenefejifo Temitope Folorunso, Eseoghene Opeyemi Egbe (a Micro-Biologist), Ogheneruno Egbe (a Bio-chemist), Emuogheneruru Peter Egbe and one son in law, Engr. Isaac Temitope Folorunso.