Project-Based Learning in Product Design Engineering: A Case Study of External Gear Pump Design

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1 Introduction

A gear pump is a pump that uses the meshing of two gears to seal an amount of liquid and transmit it when the gears are moving. There are two types of gear pumps, namely the external gear pump and the internal gear pump. However, the scope of this project is to focus on the external gear pump. As part of the Product Design Engineering (PDE) module.

This project requires research and a survey of the types of gear pump characteristics and functions, such as size, type of gear, etc., that are desirable from a customer standpoint. From there, the design problem can be understood, and multiple concept designs and alternative concept designs were generated. Concepts were weighted using a Pugh matrix, with evaluation criteria such as manufacturability and durability being one of the important ones. A parametric design for the gear pump was performed using an Excel spreadsheet to determine an optimal spur gear configuration. A risk assessment was performed on the pump to reduce the overall potential risk of the pump.

External gear pumps effectively manage solids-free and lubricating fluids and perform well in sectors such as fuel and food industry as lubricant oil pumps and high viscosity fluid pumps, respectively. A gear pump has three cycles: filling, transfer and delivery as presented in Carletti et al. (2016). In the filling stage, the unmeshed gears expand the pump's inlet volume, creating a vacuum that allows the fluid to be pushed in by external pressure. In the transfer stage, the trapped fluid between the gear teeth and the cavity of the wall casing is transferred from the pump inlet to the outlet as the gears rotate. Fluid is forced out under pressure in the delivery stage as the

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Table 1 Component types with their functions

No	Components	Type	Function
1	Seal	Standard parts	To prevent water leak
2	Cover	Special purpose parts	To prevent damage to the internal components
3	Drive Shaft	Special purpose parts	To drive and turn the idler gear
4	Driving Gear	Special purpose parts	To alter the speed and/or direction generated by the motor
5	Inlet	–	For fluid intake
6	Driven Gear	Special purpose parts	To transfer motion from the driving gear
7	Bushing	Standard parts	To reduce vibration and friction between moving parts
8	Casing	Special purpose parts	To prevent damage to the internal components

gears interlock on the outlet side. A helical, spur and herringbone gear is used in an external gear pump. Spur gears can handle high differential pressures, whereas helical gears are silent and reduce trapped fluid. Herringbone gears combine the benefits of helical and spur gears but are more expensive to manufacture and more prone to fluid trapping. According to Carletti et al. (2016), the components of external gear pumps are classified into three categories: standard components, standard assemblies and special-purpose components. The function of each component is presented in Table 1.

2 Methodology

2.1 Design Problem Formulation

An Engineering Design Specification (EDS) was used to define the design requirements of the external gear pump, that is, the requirements of the customer and the team. In order to know the customer requirements, a survey was created and distributed to know if the available external gear pump on the market meets the customer needs and expectations. According to the survey, most of the respondents are students, engineers and practitioners, general assistants and self-employed, and their preferred external gear pumps are the following: medium size, lightweight, medium water displacement, complex build, low noise and low vibration. These functions are quantified in Table 2 and are directly related to the team method to meet these requirements using the House of Quality (HoQ) in Fig. 1. The HoQ shows that the type of gear plays the most crucial factor in achieving the customer's requirements, followed by the cost of production, lifespan and casing thickness.

In this study, five alternative design concepts were proposed in Table 3. These alternative design concepts were then evaluated based on a few criteria such as

Table 2 Product function and engineering characteristic of the external gear pump

Function	Engineering characteristics	Units	Limits
Medium size	Dimension of overall components	Cubic centimetres	The total height, width and depth is at least 9 cm by 13 cm by 24 cm
Lightweight	Weight of all components	Gram	100–300 g
Medium water displacement	Displacement	Cubic centimetres/rev	20 cc/rev
Complex assembly	Components' design		
Regular services	Casing's design		
Low noise	Number of teeth		Have more than 9 teeth

manufacturability, durability, rigidity, functionality, efficiency, lightweight and low cost. A weight is given to quantitatively measure the alternative design concepts as presented in Table 4. The weight is based on the customer survey results and potential user surveys. The alternative design concept with the highest weight is selected as the final concept design.

3 Results and Discussion

3.1 Gear Parametric Design

After the design concept is made, the gear design needs to be considered for the performance. The team decided on the design using a gear calculator in Excel to calculate the gear parameters such as the number of teeth, pitch diameter and gear face width. After careful deliberation, the pitch diameter was set to 5.5 cm, the pressure angle was set to 20° to reduce the undercut, and the number of teeth was set to 18 to pair with the pressure angle. The gear parameters set were set into an Excel file where it calculated the theoretical displacement value of 17.12 cm^3/rev.

The gear parameter value was tested with different slip coefficient values and different pressure values which in turn affect the volumetric efficiency, actual flow and the time it takes to fill a 5-L tank. From the simulated values, with increasing pressure and a higher value of slip flow coefficient, the lower the flow value, and thus the time spent to fill a 5-L tank increases.

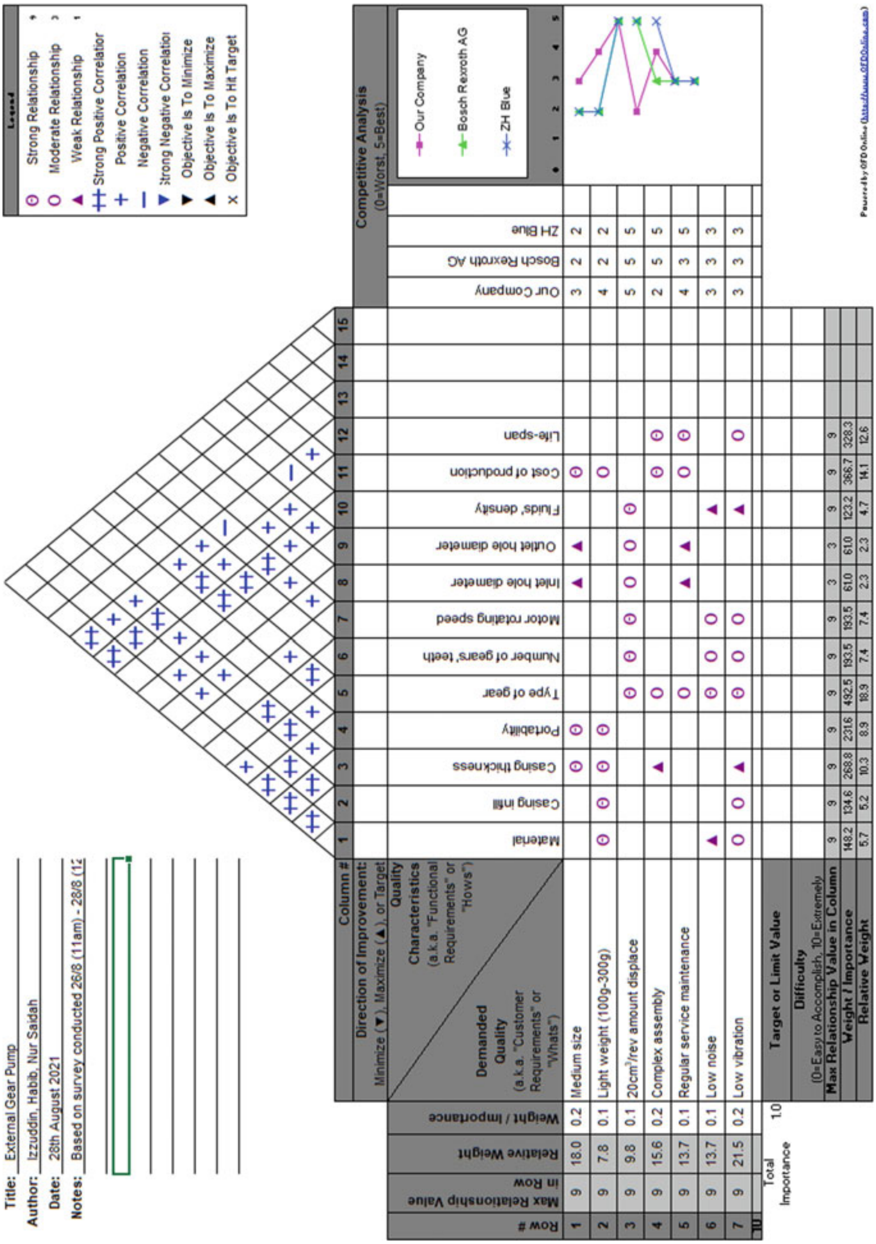

Fig. 1 HoQ for the team's external gear pump

Table 3 Alternative design concepts

Design	Standard	Concepts
1	Physical principle Material Geometry	Spur gear PLA Box shaped with rounded edges
2	Physical principle Material Geometry	Spur gear PETG Box shaped
3	Physical principle Material Geometry	Spur gear PLA with transparent acrylic cover Box shaped
4	Physical principle Material Geometry	Herringbone gear PLA Box shaped
5	Physical principle Material Geometry	Herringbone gear PETG Pill shaped

3.2 *Final Concept Design*

Figure 2 illustrates the final concept design based on the evaluation of Concept #3 and the parametric design selected. The design was created using SOLIDWORKS 2020 and Gear DXF.

3.3 *Failure Mode Analysis*

Failure cannot be permanently eliminated in the manufacturing industry. However, it can be reduced using an analysis called failure mode and effects analysis, FMEA, by calculating the Risk Priority Number (RPN). This RPN is based on three factors: severity (S), occurrence (O), and detection (D) (Bhattacharjee et al. 2020). Each factor has a rating of 10, 1 is the least and 10 is the maximum. Equation (1) is the formula to find the RPN value. Hence, the range value for the RPN value is between 1 and 1000.

$$\text{RPN} = S \times O \times D. \tag{1}$$

A thorough discussion was conducted among the team members to identify the possibility of failure modes that can happen to the external gear pump. The RPN rating of the external gear pump is presented in Table 5. A descriptive of the RPN rating for the following failure mode: (1) External gear pump leaked, (2) External gear pump severe pressure fluctuation and (3) External gear pump power loss.

To reduce the failure mode, the following is the recommended action for each failure mode:

Table 4 Final evaluation of alternative design concepts

Evaluation criteria	Importance Weight (%)	Concepts									
		Concept #1		Concept #2		Concept #3		Concept #4		Concept #5	
		Rating	Weighted rating	Rating	Weighted rating	Rating	Weighted rating	Rating	Weighted rating	Rating	Weighted rating
Manufacturability	15	3	0.45	3	0.45	2	0.3	2	0.3	2	0.3
Durability	10	2	0.2	3	0.3	3	0.3	2	0.2	3	0.3
Rigidity	15	2	0.3	3	0.45	4	0.6	2	0.3	3	0.45
Functionality	15	3	0.45	3	0.45	3	0.45	3	0.45	3	0.45
Efficiency	20	3	0.6	3	0.6	4	0.8	4	0.8	4	0.8
Lightweight	10	4	0.4	2	0.2	2	0.2	3	0.3	2	0.2
Low cost	15	3	0.45	2	0.3	2	0.3	2	0.3	2	0.3
Total percentage	100		2.85		2.75		2.95		2.65		2.8

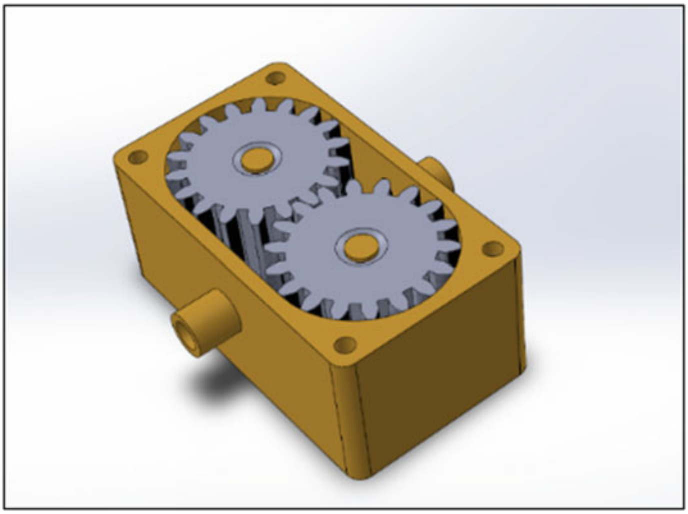

Fig. 2 Final concept design

Table 5 RPN rating

Failure mode	Severity (S)		Occurrence (O)		Detection (D)		RPN
	Effects	S rating	Causes	O rating	Control tests	D rating	
External gear pump leaked	Improper fluid transfer and spills	3	Improper seal inside the external gear pump Cracks	6	Very easy	1	18
External gear pump severe pressure fluctuation	Fluid transfers fluctuate	5	Cavitation	7	Likely	4	140
External gear pump power loss	Improper shaft RPM	3	Motor speed fluctuation	1	None	5	15

1. External gear pump leaked
   a. Proper installation of the gasket
2. External gear pump severe pressure fluctuation
   a. Install pressure gauge
3. External gear pump loss of power
   a. Automatic tapping gearbox
   b. RPM meter on the shaft.

4 Conclusions

To conclude the project, proper and strategical planning from the lab practical helps team members solve the problems encountered during planning and studying, especially with assistance from the instructor. From the class lecture, combined with the multiple labs practical, the team member was able to identify the possible problem that can occur in the manufacturing process. The team also developed another skill, creating the possible survey question using Google Forms services elicited from developing an external gear pump. With the second wave of the pandemic affecting Brunei, various limitations arise, one of which is that the campus is not accessible to students, making the fabrication of the project difficult. Moreover, the limited supply of material, such as PLA puts a constraint on team members.

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