VERTICAL LIFTER DESIGN OF EXPERIMENT IN IMPROVING MOLD EFFICIENCY

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***Abstract*-- This study was conducted on an injection plastic mold at a motorcycle manufacturing company in Indonesia. Along with consumer demands, the company is required to always develop the latest models. As models continue to change, the company is faced with demands to improve mold efficiency. This research aims to improve mold efficiency by shrinking mold dimensions in terms of lifter component usage using an innovative vertical lifter design. The method used in this research is Design of Experiment by using the vertical lifter design in designated mold. The experiment focused on changing the lifter mechanism from an angled rod to release the undercut to a perpendicular rod with an angled groove on the head. Simulation of the vertical lifter design showed a reduction in the dimensions of the test mold base so that the material cost of the test mold base could be reduced by 30%. The research conducted contributes to efforts to improve mold efficiency.**
***Keywords*: Design of experiment, internal undercut lifter, mold base, plastic undercut.**

Abstrak--Penelitian ini dilakukan pada cetakan plastik injeksi di sebuah perusahaan manufaktur sepeda motor di Indonesia. Seiring dengan tuntutan konsumen, perusahaan dituntut untuk selalu mengembangkan model-model terbaru. Seiring dengan model yang terus berubah, perusahaan dihadapkan pada tuntutan untuk meningkatkan efisiensi cetakan. Penelitian ini bertujuan untuk meningkatkan efisiensi cetakan dengan cara mengecilkan dimensi cetakan dari segi penggunaan komponen lifter dengan menggunakan desain lifter vertikal yang inovatif. Metode yang digunakan dalam penelitian ini adalah Design of Experiment dengan menggunakan desain vertical lifter pada cetakan yang telah ditentukan. Eksperimen difokuskan pada perubahan mekanisme lifter dari batang bersudut untuk melepaskan undercut menjadi batang tegak lurus dengan alur bersudut pada bagian kepala. Simulasi desain lifter vertikal menunjukkan adanya pengurangan dimensi cetakan uji sehingga biaya material alas cetakan uji dapat ditekan hingga 30%. Penelitian yang dilakukan memberikan kontribusi dalam upaya peningkatan efisiensi cetakan.
***Kata kunci*: Desain eksperimen, pengangkat *undercut* internal, dasar cetakan, *undercut* plastik.**

I. INTRODUCTION

According to a data statistic released by Central Statistics Agency (BPS) [1], motorcycles are the mode of transport with the highest number of users in Indonesia. Users buy motorbikes based on several reasons, one of which is due to the affordable price. Diverse and always new models are also a demand for manufacturing companies to remain in demand by customers.

Ongoing model changes present challenges in terms of mold utilisation. The short lifetime of molds requires the company to make efficiency improvements to remain competitive. Improving mold efficiency can be seen from three cost factors [11, 12] such as material costs, manufacturing costs and maintenance costs. These three cost factors play an important role in the total cost of molds for motorcycles.

Plastic molds consist of various components with their respective functions [17, 18], one of these mold components is the internal undercut lifter or lifter. The lifter component functions to form and release the internal undercut on the product [2]. The lifter construction consists of a lifter rod mounted at an angle on a movable support. The fulcrum is placed on the lifter shoe which serves as the housing and base of the fulcrum, and there is a lifter guide to keep the lifter on its axis. Such construction requires a large space to place a set of lifters so that it affects the dimensions of the mold which will also enlarge.

Based on the description that has been presented, a problem can be taken, which is the large space requirement for the lifter component which has an impact on increasing the dimensions of the mold. Innovation in the lifter component is needed so that the space required can be reduced to reduce the dimensions of the mold so as to reduce the material costs used.

Research Aim

The aim of the research conducted is to increase the efficiency of the mold by shrinking the dimensions of the mold in terms of the usage of lifter components so that material costs can be reduced.

II. RESEARCH METHODOLOGY

The research method used in this paper is Design of Experiment [19]. By using design of experiment methodology used for planning and conducting experiments as well as analyzing and interpreting data obtained from the experiments [3]. Referenced from a company named CUMSA which sold parts used in plastic injection mold, one of them is a part which name is dog lifter [4]. By taking reference designs available on existing websites, the movement mechanism of the design was analysed and parts were designed for design trials. The design was then tested by applying it directly to the test mould and testing using a simple loading simulation to test whether perpendicularly mounted rods have more load resistance than angularly mounted rods.

Traditional lifter designs typically use angled rods that require considerable space within the mold structure. This results in increased mold base dimensions and consequently higher material and manufacturing costs. Previous research has concentrated on optimizing lifter movement and release stroke through geometric modeling. Zhang et al. (2002) introduced automated lifter generation for injection molds using CAD systems, demonstrating improvements in design speed and accuracy [9]. Meanwhile, Yang et al. (2021) utilized CAE analysis to improve the structural integrity of lifters in large hot-runner molds [10]. However, these studies continue to rely on conventional angled lifter configurations.

In practice, the lifter shoe and guide remain integral in these traditional designs to maintain alignment and support movement. However, these components contribute to increased mold thickness and complexity. Innovations in lifter design that minimize spatial requirements while maintaining performance are needed. This work addresses a critical gap in mold component design by shifting from angle-based motion to perpendicular movement, providing a more compact and robust lifter mechanism. The approach contributes to the field by integrating simulation, cost analysis, and practical testing in a retired mold setting ensuring not only theoretical validity but industrial applicability.

III. DESIGN AND TEST RESULTS

The design of the vertical lifter design is based on the CUMSA reference design and user's needs for the existing problems. Interviews with users are a method used to explore user needs for solutions to the problems faced. The results of the interview with the user can be seen in Table 1 below.

Table 1. User Interview Results

5W + H	Questions	Answers
Who	Who is the target of this design research?	The demand targeted from User.
What	What products should be designed?	The product to be designed is a lifter system with a perpendicularly mounted rod construction.
When	When will the product design be implemented?	The product design will be applied to a new mold when the design has been tested on a retired mold.
Where	Where will the product design be implemented?	The design product will later be applied to the mold of the latest project.
Why	Why should the product be designed?	The product had to be designed because the current lifter takes up a lot of space especially in the thickness of the mold.
How	How will the product design be implemented?	The product design that has been made will be tested first on the previous mold before being used on the new mold.

Based on table 1 a lifter system design that has a vertically mounted rod construction is desired by the user. This desire is based on the large space requirements in the current lifter construction, especially in the dimensions of the mold thickness. The large space requirement causes the enlargement of the material used so that the price of the material required increases. The design made will be tested on a past mold that is no longer in operation to ensure that the design can work properly.

The mechanism of the internal undercut lifter, which is currently widely used, is as follows rod construction mounted at an angle [9] and is referred to as a conventional lifter as shown in Figure 1 on the construction of a conventional lifter.

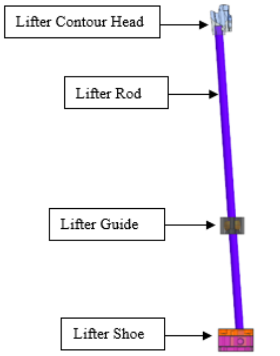

Figure 1. Conventional Lifter Construction

A conventional lifter consists of several components, which are:

1. Lifter contour head

The contour head functions as a printer of the undercut formation on the product and is located at the very top of the lifter which is in direct contact with the product.

2. Lifter rod

The lifter rod serves as the lifter drive and is attached to the lifter shoe at the angle required to remove the undercut during the ejection process.

3. Lifter guide

The lifter guide serves to keep the lifter on its axis while moving.

4. Lifter shoe

The lifter shoe consists of 2 components, namely a moving component that functions as a support for a rod that can move and an immovable component that functions as a housing and groove for the moving component [20].

The movement of a conventional lifter consists of 3 main factors [8, 10] which are:

1. The ejection stroke distance of a mold,
2. The angle at which the lifter rod engages,
3. The resulting release stroke distance.

The three conventional lifter movement factors can be described as a lifter movement triangle as shown in Figure 2 on the following lifter movement triangle.

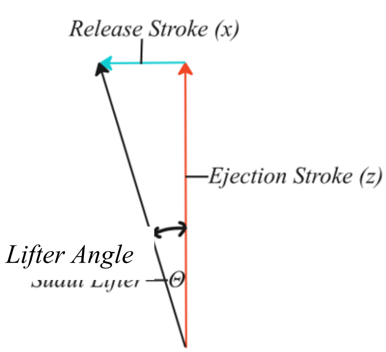

Figure 2. Lifter Movement Triangle

The release motion produced by a lifter serves to release the molded undercut. The distance of the release movement is referred to as the release stroke. The size of the release stroke of the lifter is obtained using trigonometric calculations using the tangent function [5]. The release stroke formula required by a lifter is as follows:

$$\tan\theta = \frac{x}{z} \quad (1)$$

Description:
$\tan\theta$ = tangen lifter angle
x = release stroke (mm)
z = ejection stroke (mm)

Based on the existing conventional lifter construction, the development of conventional lifter construction into a vertical lifter is carried out. The design of the vertical lifter itself focuses on the construction of rods that are installed perpendicularly. The construction of perpendicularly mounted rods will certainly eliminate some of the components used in conventional lifters. The conventional lifter components that are replaced in the vertical lifter are the lifter shoe and lifter guide. Both components are not used in the vertical lifter but the working principle of the two components is adopted in the vertical lifter.

There are two vertical lifter designs that were created. Design 1 is called VLS (Vertical Lifter System) with an additional limiter component LLS (Lifter Limiter System). Design 2 is a further development of design 1 which has several additional modifications, but the most emphasized aspect of the modification is the flexibility aspect. The design of the two designs is as shown in figure 3, figure 4 and figure 5.

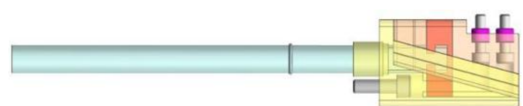

Figure 3. Vertical Lifter Design 1

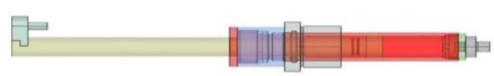

Figure 4. Limiter Design 1

Figure 5. Vertical Lifter Design 2

The prototype in this research was made using the virtual prototyping method. The prototyping process carried out is a simulation of the loading on the rod and the calculation of the manufacturing cost of each vertical lifter design made.

Simulation of Rod Loading

Conventional lifter construction used today has several problems that often occur, one of these problems is broken lifter rods. Broken rods are caused because the rod receives a load exceeding its capacity until it finally bends and breaks. The hypothesis that can be drawn from this phenomenon is that rods that are installed at an angle are more at risk of bending and breaking than rods that are installed perpendicularly. Based on this hypothesis, a test was conducted using a loading simulation on the rod using software [6, 16]. The results of the loading simulation on the rod can be seen in figure 6 and figure 7.

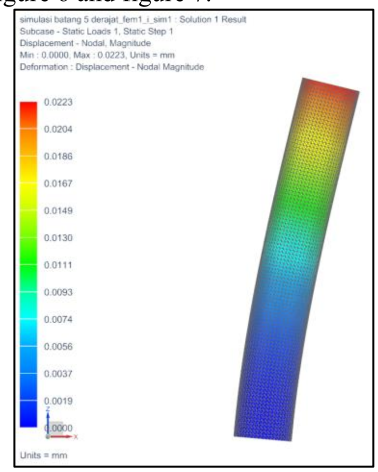

Figure 6. Simulation Results on Angled Bars

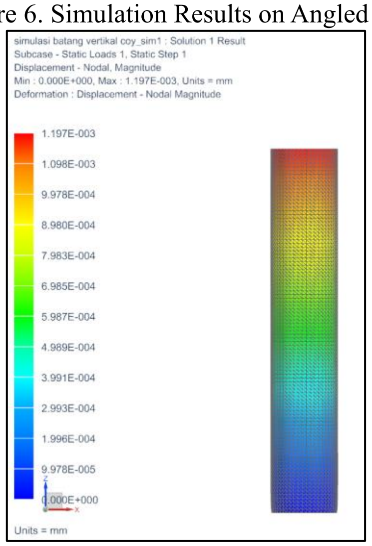

Figure 7. Simulation results on perpendicular rods

The color range in the simulation results shows the deformed part, the red color means the highly deformed area and the dark blue color means no deformation. The obliquely mounted specimen rod shows a deformation of 0.0223 mm at the rod tip and the rod looks curved. The perpendicularly mounted specimen rod still deformed by 1.197E-003 which is not visible to the eye. FEA simulation testing on both specimen rods can answer the hypothesis that angled mounted rods are more at risk of warping and fracture compared to perpendicular mounted rods [7].

Manufacturing Cost Calculation

Based on the design design that has been made, the estimated cost of making a vertical lifter can be calculated. The calculation of the estimated cost of making a vertical lifter uses the following rules:

1. The cost calculation will only calculate the cost of one vertical lifter. The calculation does not include mass production costs.
2. Raw material costs are rounded to the nearest kilo per component.
3. Material prices and machine hour prices will use market price data in Indonesia.

The material price uses the unit price per kilogram, so to calculate the mass of each component will use the measure bodies feature of the Siemens NX 10 software [15]. The calculation of the estimated material cost for each design can be seen in Table 2 and Table 3.

Table 2. Calculation ff Design Material Cost Estimate 1

Design 1		
Material Type	Number of components	Total Price (Rp)
1.2738	4	252.000
1.2311	-	-
S50C	10	400.000
Standard Part	5	19.022
Total		
Rp671.022		

Table 3. Calculation of Design Material Cost Estimate 2

Design 2		
Material Type	Number of components	Total Price (Rp)
1.2738	3	189.000
1.2311	-	-
S50C	7	280.000
Standard Part	3	4.023
Total		
Rp473.023		

The next calculation is the calculation of the manufacturing process cost of each component of the vertical lifter. The components in the design are assumed to go through the existing process. The process of working on each component is assumed to take less than 1 hour or exactly 1 hour. The calculation of the manufacturing process cost of a vertical lifter can be calculated by adding up the total manufacturing costs per component in each design. The results of the manufacturing process cost calculation can be seen in table 4.

Table 4. Calculation of Manufacturing Cost Estimate

	Design 1	Design 2
Process Cost	Rp6.950.000	Rp3.800.000

The calculation results from table 2, table 3 and table 4 can be calculated for the total cost of making a vertical lifter for each design. The total cost of making a vertical lifter is the result of the sum of the estimated price of the material with the estimated price of the process. The results of the calculation of the total estimated cost of making a vertical lifter can be seen in table 5.

Table 5. Calculation of The Estimated Cost of Manufacturing A Vertical Lifter

Design	Total
Design 1	Rp7.621.022
Design 2	Rp4.273.023

The vertical lifter design is simulated on the test mold to see if the design can be applied to the mold. The cavity on the right side of the test mold was used as a cavity to simulate the application of the vertical lifter. The simulation is related to the placement of the vertical lifter layout on the mold and the vertical lifter movement mechanism.

The shape of the undercut found in the product is used as the contour head profile of each undercut. The location, shape and direction of the release stroke of the undercut are used as the basis for the placement of the vertical lifter with the existing contour head. The results of the vertical lifter application on the test mold can be seen in Figure 8 and Figure 9.

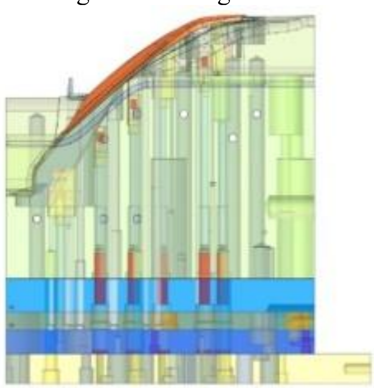

Figure 8. Simulation Results of Design 1

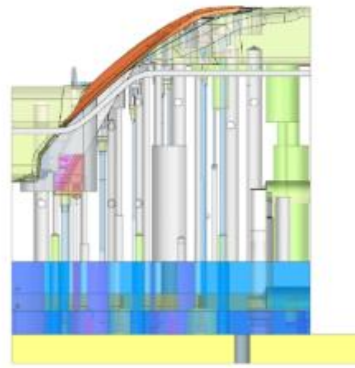

Figure 1. Simulation Results of Design 2

The thickness comparison between the initial mold and the modified mold can be seen in figure 10. The use of vertical lifters can make the mold thinner than before. The initial mold thickness of 869 mm can be reduced to 794.5 mm, which means it can reduce the overall mold thickness by 8.5%. The thickness reduction occurs due to the difference in ejection stroke required, the ejection stroke required by the vertical lifter is only 45 mm compared to the conventional lifter ejection stroke of 120 mm.

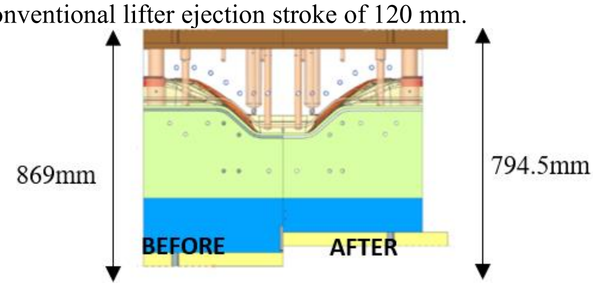

Figure 10. Reduction of Mold Thickness

Simulations on the test mold also show that there is a difference in free space that can be used to reduce the length of the mold base material as shown in figure 11. The conventional lifter distance measurement from the outermost side of the core to the outermost side of the lifter shoe has a free space of 78.63 mm. The vertical lifter layout when measured from the outermost side of the core to the outermost side of the vertical lifter has a free space of 146.5 mm or 46% greater.

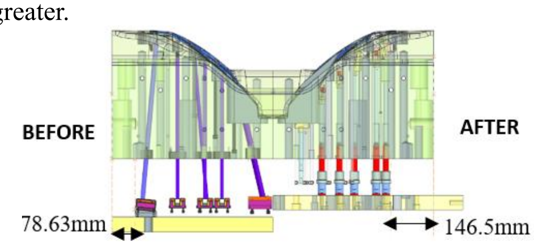

Figure 11. Mold Length Reduction

The application of the vertical lifter also has an impact on the free space of the wide side of the mold as seen in figure 12. The conventional lifter layout when measured from the outermost side of the core to the outermost side of the lifter shoe has a free space of 137 mm. The vertical lifter layout when measured from the outermost side of the core to the outermost side of the vertical lifter there is a free space of 165 mm or 17% greater.

The design simulation that has been carried out shows a reduction in mold dimensions after the vertical lifter is applied. The reduction in mold dimensions will have an impact on the reduction in material costs required. The results of the calculation of the estimated cost reduction of the mold base can be seen in table 6.

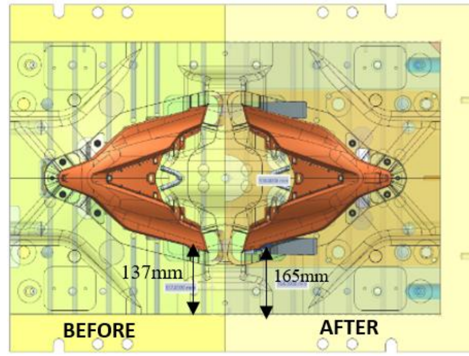

Figure 122. Reduction of Mold Width

Table 6. Reduction of Mold Base Cost

Initial Mold			Modified Mold		
Components	Weight (Kg)	Material	Components	Weight (Kg)	Material
Cavity Plate	2943	1.2738	*Cavity Plate*	2374	1.2738
Core Plate	3123	S50C	*Core Plate*	1590	S50C
Top Clamping plate	590	S50C	*Top Clamping plate*	491	S50C
Spacer 1	206	S50C	*Spacer 1*	88	S50C
Spacer 2	206	S50C	*Spacer 2*	88	S50C
Upper Ejector Plate	116	S50C	*Upper Ejector Plate*	102	S50C
Lower Ejector Plate	155	S50C	*Lower Ejector Plate*	136	S50C
Bottom Clamping Plate	422	S50C	*Bottom Clamping Plate*	351	S50C
Total			Total		
Rp378.129.000			Rp263.402.000		

Other improvements that can be provided through the use of this vertical lifter, when viewed from the QCDSME side, include:

1. Quality
   The manufacturing process in making vertical lifter holes can maintain the quality of the drilling results because it is done perpendicularly so that angular errors can be suppressed.
2. Cost
   The use of vertical lifters on the mold can reduce production costs by 30% and can reduce the risk of broken rods, thereby reducing maintenance costs.
3. Delivery
   Faster manufacturing process due to less risk of hole angle error.
4. Safety
   Assembly operators can work lighter so they don't get tired, which reduces the risk of human error.
5. Morale
   Assembly that more easily maintains operator moral stability.
6. Environment
   It is only necessary to replace the contour lifter head, so that the waste generated are reduced. [13, 14]

IV. CONCLUSION

Based on the results of research that has been carried out through design, simulation and analysis of the design of the vertical lifter design on the test mold with the aim of reducing the dimensions of the mold in terms of the use of lifter components, conclusions can be drawn, such as:

1. Vertical lifters can shrink the dimensions of the test mold base in the length dimension by 13% with an initial length of 1100 mm to 963 mm, the width dimension by 7% with an initial width of 700 mm to 645 mm and the core thickness dimension by 37% with an initial thickness of 520 mm to 328 mm.
2. Rod construction in vertical lifters mounted perpendicularly provides better rod durability than rod construction in conventional lifters mounted at an angle.
3. The use of vertical lifters can reduce the material cost of the test mold base by 30% with the initial price of the mold base material of Rp378,129,000 to Rp263,402,000.
4. This research contributes to technological development in the plastic injection mold industry by offering an alternative solution of using vertical lifters to optimize mold design. With a significant reduction in dimensions and material costs, this approach opens up opportunities for improved production efficiency, cost savings, and more compact mold design without sacrificing functionality. This innovation may encourage manufacturers to consider compact and efficient design as the new standard in industrial mold development.

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