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Comparison on Area of Throttle Bore Opening for Butterfly Throttle Body and Dual Plate Slider Throttle Body

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Abstract: Throttle body (TB) is a component that regulates air to the internal combustion engine (ICE). Butterfly valve type TB is commonly used in the application for most ICE vehicle. The aim of this study is to compare the bore opening area of butterfly TB (BTB) and dual plate slider TB (DPSTB). Mathematical analysis was done by validation from TB model created using SolidWorks software. Results shows that DPSTB offers better area of opening in every condition observes in this study with no obstruction to airflow at wide open throttle (WOT). The opening area is increased by 8.3, 3.5, 2.3, 1.7, 1.3, and 1.3 times respectively for valve opening condition 1-6. This finding will help ignite idea for TB designer to explores new package of TB design for future ICE.

Keywords: Throttle Body, Internal Combustion Engine, Automotive

Abstract (Malay): *Badan pendikit (TB) ialah komponen yang mengawal udara ke enjin pembakaran dalaman (ICE). TB jenis injap rama-rama biasanya digunakan dalam aplikasi untuk kebanyakan kenderaan ICE. Matlamat kajian ini adalah untuk membandingkan luas bukaan TB rama-rama (BTB) dan TB gelangsar dwi plat (DPSTB). Analisis matematik dilakukan melalui pengesahan daripada model TB yang dibuat menggunakan perisian SolidWorks. Keputusan menunjukkan bahawa DPSTB menawarkan luas bukaan yang lebih baik dalam setiap keadaan yang diperhatikan dalam kajian ini tanpa halangan kepada aliran udara pada pendikit terbuka sepenuhnya (WOT). Luas bukaan meningkat sebanyak 8.3, 3.5, 2.3, 1.7, 1.3, dan 1.3 kali masing-masing untuk keadaan bukaan injap 1-6. Penemuan ini akan membantu mencetuskan idea untuk pereka TB bagi meneroka pakej baharu reka bentuk TB untuk ICE masa hadapan.*

Kata Kunci: *Badan Pendikit, Enjin Pembajaran Dalaman, Automotif*

1. Introduction

Butterfly and gate valve concept was well known for the usage on throttling service for many mediums such as liquid, gasses and solid grains or soils. Both of the valve type had their advantages and disadvantages depending on their usage highlighted in previous study by Huamei, (2020). Research done by Kirk J. Gomes, (2011) and Oh et al., (2021) in their fields shows the significant of having a study to investigates the situation in various area of valves application and how it effect the system.

In automotive technology, air intake system for Internal combustion engine (ICE) utilizes the used of valve to ensure efficient amount of air supplied to ICE in order to achieve optimum engine performance (Fauzun & Yogiswara, 2021) and reduced vehicle emission (Adam & Wahid, 2021; Dalha, Said, Karim, & Mohammed, 2022). Various investigation approach done by researcher that been summarized in the review articles by Tahiruddin et al., (2022) and Ashok et al., (2017). Majority researcher focused on the study related to butterfly throttle body (BTB) since it was the vastly used throttle body (TB) concept in passenger vehicles. BTB is prominently used in the passenger vehicles due to the simple structure and low manufacturing cost.

Nevertheless, gate valve concept TB also known as slider TB (STB) was introduced for the usage of high-speed vehicles (Saxonparts.com, 2002; Stroes, 2006) and aircraft

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(Alekseenkov, Obolenskiy, Obolenskiy, & Samsonovich, 2021). STB benefits racing vehicles as it was mainly operated at full engine load and STB offers no obstruction at wide open throttle (WOT) resulting in a better airflow supplied for combustion in ICE (Coxon, 2013; Rowswell, 2018). This concept was established to fulfil the idea of having maximum air intake supplied to the ICE to achieve highest combustion power (Ashraf, Khedr, Diab, & Elzaabalawy, 2017).

It is commonly known that the concept of regulating air flow across TB was based on the area of valve opening that allowing the air to pass through towards ICE. CFD analysis help researcher to understand airflow characteristic across TB and improvements are proposed in various aspects (Abd Ghapar, 2021; Che Hashim, 2021; Wan Mohd Zakri, 2021). Looking from a different angle of view, mathematical analysis on the area of valve opening can also help researchers to further understand the valve opening characteristic that effect the flow and new design concept of TB can be proposed from the observation.

Therefore, this study will include the following: First, both TB concepts BTB and dual plate slider TB (DPSTB) was modelled using SolidWorks software. Second, area of opening for BTB and DPSTB is observed in six opening condition and analysed using mathematical analysis and comparison was presented in this study.

2. Modeling the BTB

Fig. 1 shows the BTB that consists of throttle bore cavitation with valve plate and shaft located in the middle of the bore. The plate rotation will regulate the amount of air bypassing across the TB to ICE. Area of valve opening was calculated at six different opening angle of 15°, 30°, 45°, 60°, 75°, and 90°. Opening of 15° is known to be the idle opening for TB where it is the condition of minimum opening and fail-safe close condition during operation failure occur either due to DC motor or gear issues (McHarek, Azib, Hammadi, Larouci, & Choley, 2020). Opening angle of 30° to 75° is known to be the partial throttle angle and the maximum airflow occurs on the valve opening of 90° which known as the WOT.

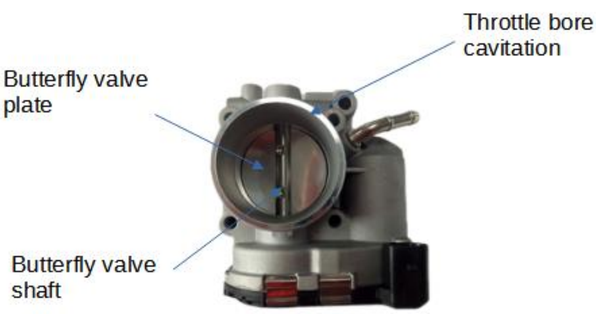

Figure 1: Butterfly based Electronic TB

In this study, BTB with 60 mm bore diameter and valve plate thickness of 2 mm (Bosch Engineering, 2021) was modelled using SolidWorks software with the intention to calculate the area of valve opening using mathematical analysis. The model will be observed from front view angle and only focusing on the valve and the TB bore cavitation. Mathematical calculation approach will be executed to calculate the area of valve opening. The parameter involves in the BTB model is define as shown in Fig. 2.

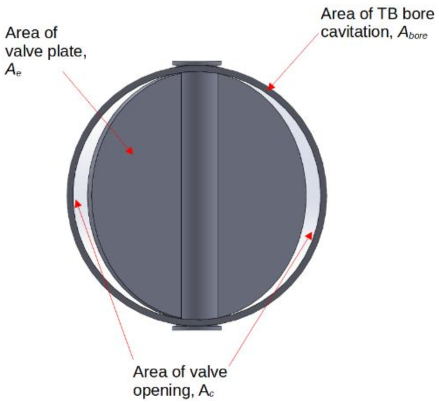

Figure 2: Parameter Observe from Butterfly TB

2.1 Area of Opening for BTB

From Fig.2, area of valve opening (A_c) is given as

$$A_c = A_{bore} - A_e \qquad (1)$$

where,

A_{bore}	=	Area of TB bore cavitation
A_e	=	Area of valve plate

Area of valve plate is equal to the area of ellipse as the butterfly plate formed an ellipse shape at the angle of front view. Ellipse consists of major axis *(a)* and minor axis *(b)* as shown in Fig. 3.

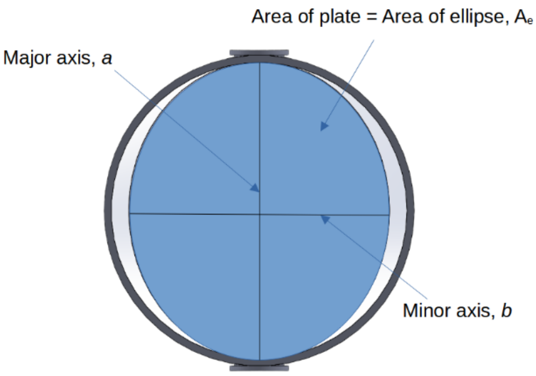

Figure 3: Parameter of Ellipse in BTB

Referring to Fig. 3, Area of ellipse (A_e) is given as

$$A_e = \pi ab \qquad (2)$$

where,

a	=	major axis length
b	=	minor axis length

To calculate the area of opening for BTB, SolidWorks measure tool was utilised to obtain the parameter needed from the model. Fig. 4 shows the measuring process done to BTB model with 15° angle of opening. Ellipse minor axis length of 58.47mm recorded from the model and formula of area for ellipse were adapted to calculate area of valve plate, A_e.

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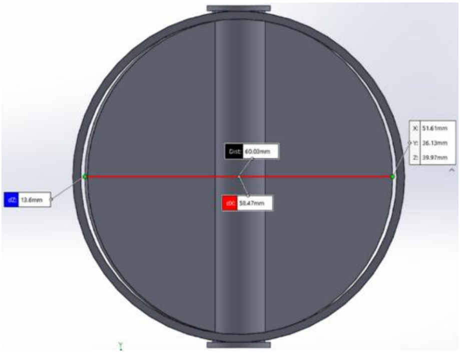

Figure 4: Measuring the Distance of Plate Opening using Tools in SolidWorks

Area of TB bore cavitation A_{bore} is shown in Fig. 5, whereby the area is equal to the area of a full circle.

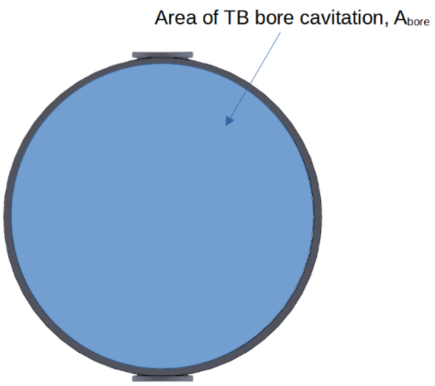

Figure 5: Parameter of Area for TB Bore Cavitation

Referring to Fig. 4, Area of TB bore cavitation (A_{bore}) is given as

$$A_{bore} = \pi r^2 \qquad (3)$$

where,

r = radius of TB bore

Thus, area of valve opening *(A_c)* was calculated by utilizing formula (1), (2), and (3) and this mathematical analysis was repeated to calculate area of plate opening at angle of 30^o, 45^o, 60^o, and 75^o.

As for the valve opening angle of 90^o, the valve is in WOT and from the front view it is observe that the area of the butterfly shaft can be calculated using the formula of trapezium area where it consists of base *(a)*, base *(b)* and height *(h)* as shows in Fig. 6. A very small area of curve at the shaft was assume to be zero as it is too small.

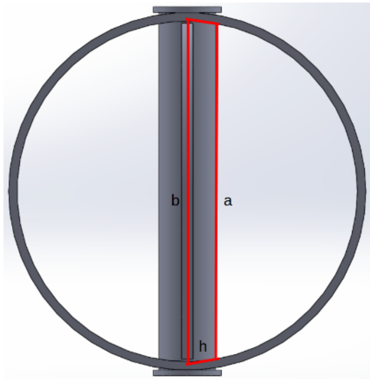

Figure 6: Parameter of Trapezium in BTB

Referring to Fig. 6, Area of trapezium ($A_{trapezium}$) is given as

$$A_{Trapezium} = \frac{1}{2}(a+b)h \qquad (4)$$

where,

a = upper base length
b = lower base length
h = height of trapezium

From the SolidWorks model, butterfly shaft diameter was known to be 10mm in thickness and butterfly shaft area was identified to be approximately similar to the area of two trapezium with the height of 5mm as shown in Fig. 7.

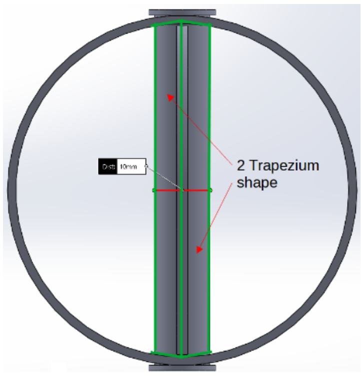

Figure 7: Two Trapezium is the Area of the Butterfly Shaft

Table 1 shows the findings on area calculated for each degree of throttle rotation observed in this study. At the angle of 15^o, BTB was in the idle condition with area of opening 72.10mm^2. It is obvious that area of throttle plate decreases with respect to the angle rotation resulting in bigger area of opening on throttle bore, allowing more air to pass through the TB. Maximum airflow through TB was recorded at 90^o angle with 2231.63mm^2 area of opening.

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Table 1: Area Opening on Each Degree Rotation.

Area of Throttle Bore, A ∏r2 (mm^2)	Angle of rotation (degree)	Area of throttle plate, B (mm^2)	Area of opening, C (mm^2)
	15	2755.33	72.10
	30	2495.68	331.75
2827.43	45	2065.91	761.52
	60	1495.24	1329.64
	75	822.78	1982.71
	90	595.80	2231.63

3. Modeling the DPSTB

As for the DPSTB, Fig. 8 shows the DPSTB concept proposed in this study. The valve plates will slide in a opposite direction to each other creating a centre opening at the throttle bore cavitation allowing air to flow into ICE.

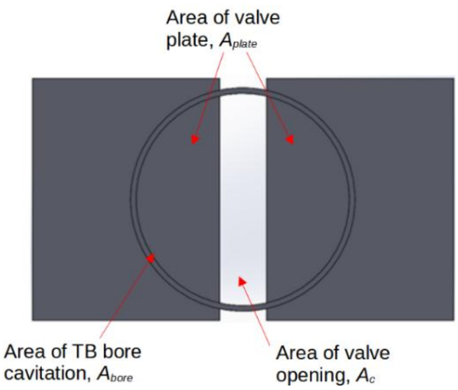

Figure 8: Cross Section of DPSTB Opening

Using SolidWorks software, plate travel was assigned to six different opening distance of 5mm, 10mm, 15mm, 20mm, 25mm, and 30mm. Maximum plate travel of 30mm was the WOT condition on the DPSTB which is also equal to the radius of throttle bore cavitation. Fig. 9 shows the parameter involve to obtain DPSTB area of valve opening.

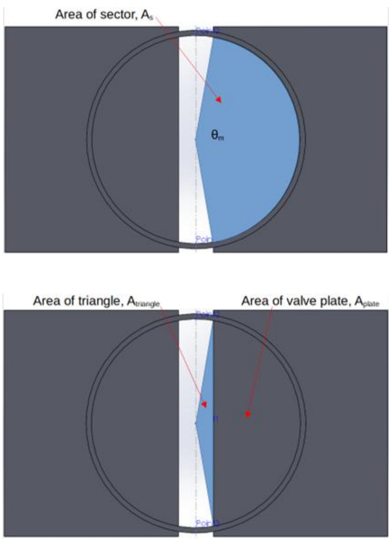

Figure 9: Parameter Observe in DPSTB

3.1 Area of Opening for DPSTB

Referring to Fig. 9, mathematical analysis was done to calculate both side of right and left throttle plates. Due to the symmetrical shape, calculating one side of throttle plate and multiply by two will manage to get both the plates area. Area of one valve plate (A_{plate}) is given as

$$A_{plate} = A_{sector} - A_{triangle} \qquad (5)$$

where,

A_{sector} = Area of sector at angle θ
$A_{triangle}$ = Area of valve opening in triangle shape

To identify the Area of sector *(A_{sector})*, manipulated angle θ_m and manipulated distance *(a)* was obtain from SolidWorks model and radius of throttle bore, *(R_{eff})* was known to be 30mm. Fig. 10 shows the parameter involves in findings the area of opening for DPSTB.

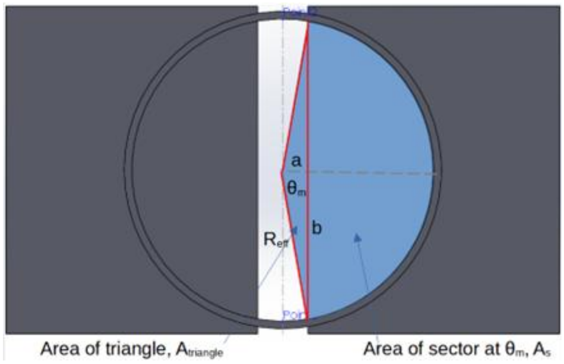

Figure 10: Parameter Involves in Calculation of Area for DPSTB

Referring to Fig. 10, area of sector (A_{sector}) is given as

$$A_{sector} = \frac{\theta_m}{360}\pi r^2 \qquad (6)$$

where,

θ_m = Manipulated angle
r = Radius of TB bore, R_{eff}

To define the manipulated angle (θ_m), the formula is given as

$$\theta_m = \cos^{-1}\frac{a}{R_{eff}} \qquad (7)$$

where,

a = Manipulated distance
R_{eff} = Radius of TB bore

Area of triangle ($A_{triangle}$) was determined by obtaining the height of triangle that also known as manipulated distance *(a)* and length of triangle side *(b)*, as shown in Fig. 11.

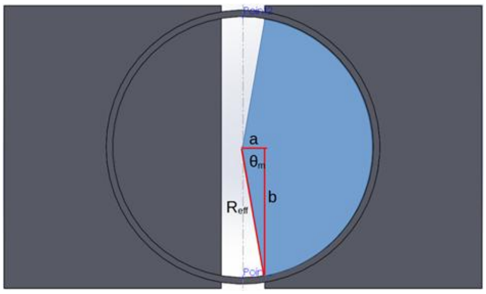

Figure 11: Parameter of Triangle in Area of DPSTB

Referring to Fig. 11, area of triangle ($A_{triangle}$) is given as

$$A_{triangle} = \frac{1}{2}ab \qquad (8)$$

where,
a = Height of triangle / manipulated distance
b = Length of side triangle

and for the length of side triangle b, is calculated by using the Theorem Pythagoras formula as given

$$b = \sqrt{\left(R_{eff}\right)^2 - (a)^2} \qquad (9)$$

where,
R_{eff} = Radius of TB bore
a = Height of triangle / manipulated distance

SolidWorks measure was utilised to ensure the plate opening according to desired distance. Fig. 12 shows 5mm distance opening of the DPSTB set using SolidWorks.

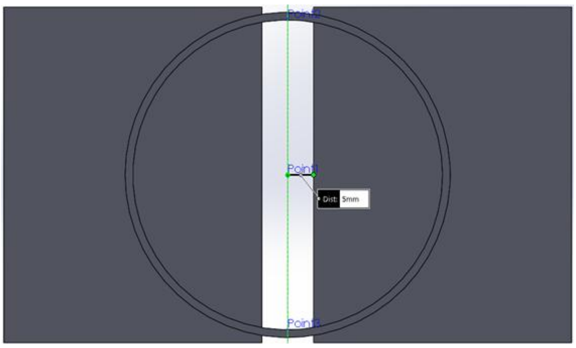

Figure 12: Measuring Process of 5mm Opening Distance for DPSTB

The calculation was done to obtain area of bore opening at plate travel distance of 5mm, 10mm, 15mm, 20mm, 25mm and 30mm. Table 2 shows the findings on each distance opening observed in this study. It is shown that maximum opening at WOT was calculated to be similar with the area of DPSTB bore which is 2827.43mm^2.

Table 2: Area of Opening for DPSTB.

Area of Throttle Bore, A $\prod r^2$ (mm^2)	Throttle plate travel distance (mm)	Bore opening distance (mm)	Area of opening, C (mm^2)
2827.43	5	10	597.23
	10	20	1177.27
	15	30	1721.87
	20	40	2207.89
	25	50	2602.27
	30	60	2827.43

4. Comparison on Area of Opening for BTB and DPSTB

Table 3 shows the comparison of bore opening area for BTB and DPSTB concept examine in this study. Cross section for the valves opening was shown in detail for each condition. BTB opening at WOT was only 2231.63mm^2 which was 595.8mm^2 less, compared to total area of bore opening which is 2827.43mm^2. This was due to the butterfly shaft existence at the centre of the TB bore.

Table 3: Comparison on Valves Area of Opening.

	Butterfly TB			Dual plate Slider TB		
Condition	Opening angle	Cross section	Area Opening (mm^2)	Plate opening (mm)	Cross section	opening area (mm^2)
1	15		72.10	10		597.23
2	30		331.75	20		1177.27
3	45		761.52	30		1721.87
4	60		1329.64	40		2207.89
5	75		1982.71	50		2602.27
6	90		2231.63	60		2827.43

For the DPSTB concept, solid amount of 2827.43mm^2 area opening was obtained at WOT. No obstruction at WOT as the throttle plate slide to side of the throttle bore. Each throttle plates will travel at the half distance of bore diameter to achieve this condition creating a centre throttle opening that will result in maximum air flow travel at the highest speed into the ICE as shown in Fig. 13. Velocity of the flow was at maximum speed on the centre of the cross section (Pijush K. Kundu, Ira M. Cohen, 2016)(Cashco, 2011). Thus, DPSTB

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concept will benefit the ICE intake system as the airflow entering combustion chamber without any obstruction and at the maximum velocity.

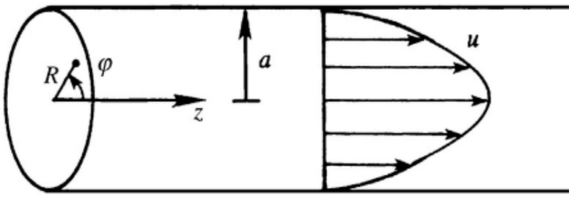

Figure 13: Theory of Flow in Round Pipe (Pijush K. Kundu, Ira M. Cohen, 2016)

Fig. 14 shows the result of the comparison on area of opening for BTB and DPSTB. DPSTB offers better opening area compared to BTB which is 8.3, 3.5, 2.3, 1.7, 1.3, and 1.3 times more opening area respectively for condition 1-6 observes in this study.

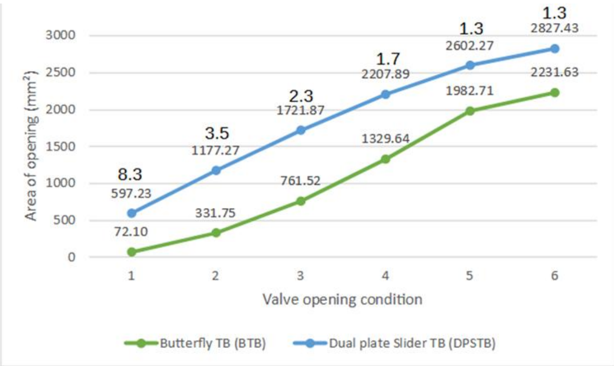

Figure 14: Graph Area of Opening vs Valve Opening Condition

5. Conclusion

Results shown that DPSTB offers bigger area of opening compared to BTB at each valve opening condition. Butterfly shaft existence at the centre of BTB bore was recognised as the reason of this findings. The originality of DPSTB was adapting centre flow opening concept to TB operation which was significant as various researchers explores the idea of centre opening TB concept (Banis, 2020; Isbester Thomas, 1976; John, 2004; Waits C, 2014). For future study, further effort on development of DPSTB prototype is suggested to allow observation on the operation and characteristics of the DPSTB concept.

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