FINAL REPORT

Project Details:

Project No: **03-01-16-SF0172**

Project Title: **Development and characterisation of a flexible valve timing system towards optimised performance of small internal combustion engines.**

Project Leader: **Dr. Mohd Razali Hanipah**

Project Team Members:

Dr. Jafferi bin Jamaludin (UM)

Dr. Mohamad Heerwan Bin Peeie (UMP)

Ir. Dr. Zamri Mohamed (UMP)

Assoc. Prof. Dr. Abdul Adam b. Abdullah (UMP)

Start & End Date: **May 2017 until November 2019**

Performance Against Objective

- **Objectives :**

Objective 1: To produce design specifications of the mechanically-assisted electromagnetic valve system.

Key metrics: Size of the linear motor, valve lift, valve timings, power requirements, key parameters must be identified.

Objective 2: To produce 3D design and analyses on the mechanically-assisted electromagnetic valve system.

Key metrics: 3D printable parts, Manufacturibility for prototyping, Assembly, Key stress and strain behaviour.

Performance Against Objective

- **Objectives :**

Objective 3: To complete rapid prototyping components of the mechanically-assisted electromagnetic valve system.

Key metrics: Test bench operational, data acquisition able to measure key variables for model validation and future improvement, electrical and electronics performance.

Performance Against Objective

Actual:

Objective 1: To produce design specifications of the mechanically-assisted electromagnetic valve system.

M1:Completion of review on camless technology.

M2:Completion of Mechatromagnetic design specifications.

Objective 2: To produce 3D design and analyses on the mechanically-assisted electromagnetic valve system.

M3:Completion of computer aided design and analyses of mechatromagnetic components.

Performance Against Objective

Actual:

Objective 3: To complete rapid prototyping components of the mechanically-assisted electromagnetic valve system.

M4:Completion of test bench, control and data acquisition systems.

M5:Completion of laboratory prototype of the mechatromagnetic valve actuation system.

Project Schedule

Gantt Chart *(planned VS actual)*

Activities	Year 1 (2017)												Year 2 (2018)												Year 3 (2019)											
	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
Review on camless solenoid valve actuator technology.																																				
Specification preparation on the mechatromagnetic system.																																				
Base engine dismantling and geometric measurements.																																				
Computer-aided design, numerical modelling and analyses of mechatromagnetic components and system.																																				
Rapid prototyping, test bench development and control system programming.																																				
System integration of mechatromagnetic laboratory prototype.																																				

Key:	
Plan	
Actual	
Milestone	

Project Schedule

Milestones achievement

No.	Milestones	Achievement (Yes/No)	Deliverables	Date of Achievement	
				Original *(as in agreement)*	Actual / Revised
1.	Completion of review on camless technology.	Yes	A table of comparison of various camless technology.	Aug/2017	Aug/2017
2.	Completion of Mechatromagnetic design specifications.	Yes	Design specifications.	Mar 2018	Mar 2018
3.	Completion of computer aided design and analyses of mechatromagnetic components.	Yes	Simulation model and results.	Aug 2018	Aug 2018
4.	Completion of test bench, control and data acquisition systems.	Yes	Test rig with DAQ.	Jan 2019	Jan 2019
5.	**Completion of laboratory prototype of the mechatromagnetic valve actuation system.**	Yes	A complete system of Mechatromagnetic laboratory prototype	Nov 2019	Nov 2019

Research Progress & Milestones Achievement

- M1 until M5 have been completed.

(will be explained in the subsequent slides)

Research Progress & Milestones Achievement

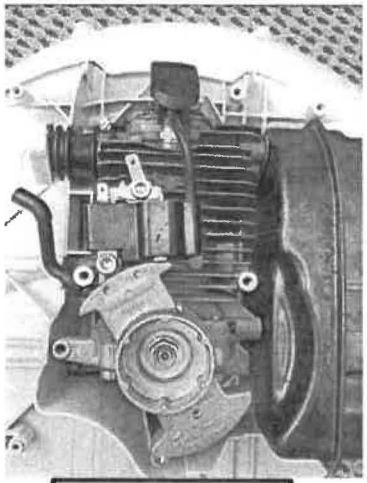
M1: Review on camless technology.

Variable Valve Technology	Variable Valve Timing	Variable Valve Lift	Variable Valve Duration
Honda VTEC	Yes. Limited to 2 camshaft profiles.	Yes. Limited to 2 camshaft profiles.	Yes. Limited to 2 camshaft profiles.
Toyota VVT	Yes. Limited to certain angle.	No.	No.
BMW Vanos	Yes. Limited to certain angle.	No.	No.
BMW Valvetronic	No.	Yes. Fully variable valve lift.	No.
Koenigsegg Freevalve	Yes. Fully variable valve timing.	No. Not fully variable. Lift actuation is fixed.	Yes. Fully variable valve duration.
Proposed Flexible Valve System	Yes. Fully variable valve timing.	Yes. Fully variable valve lift.	Yes. Fully variable valve duration.

Table 1: Summary and comparison of the current variable valve control technologies in the market

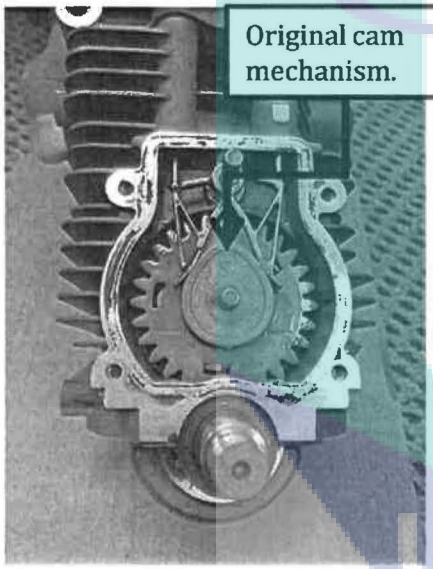
Research Progress & Milestones Achievement

M2: Design specifications.

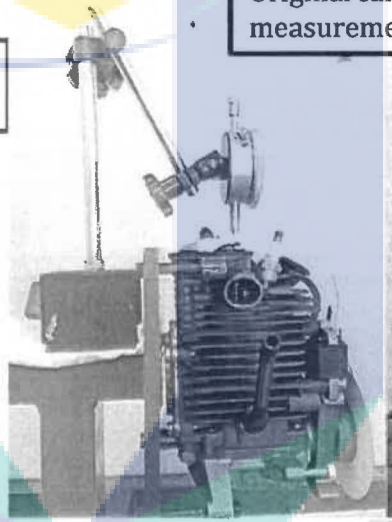


BR600 Stihl 4MIX engine.

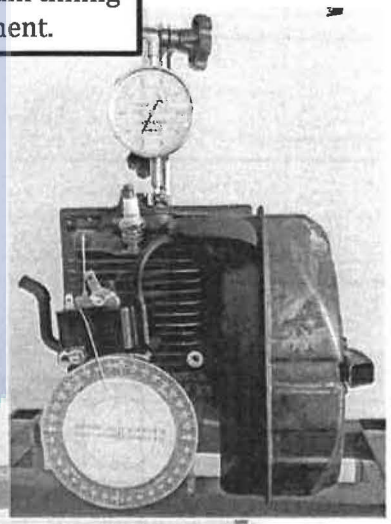
Baseline engine disassembly and measurement.



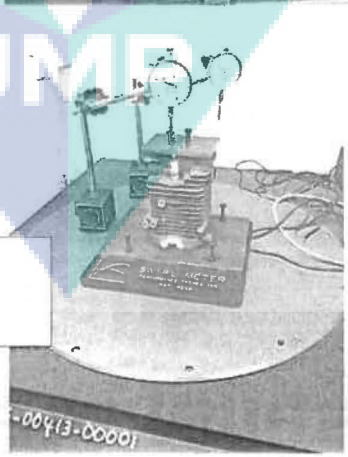
Original cam mechanism.



Original cam timing measurement.



Portflow performance measurement.



Research Progress & Milestones Achievement

M2: Design specifications.

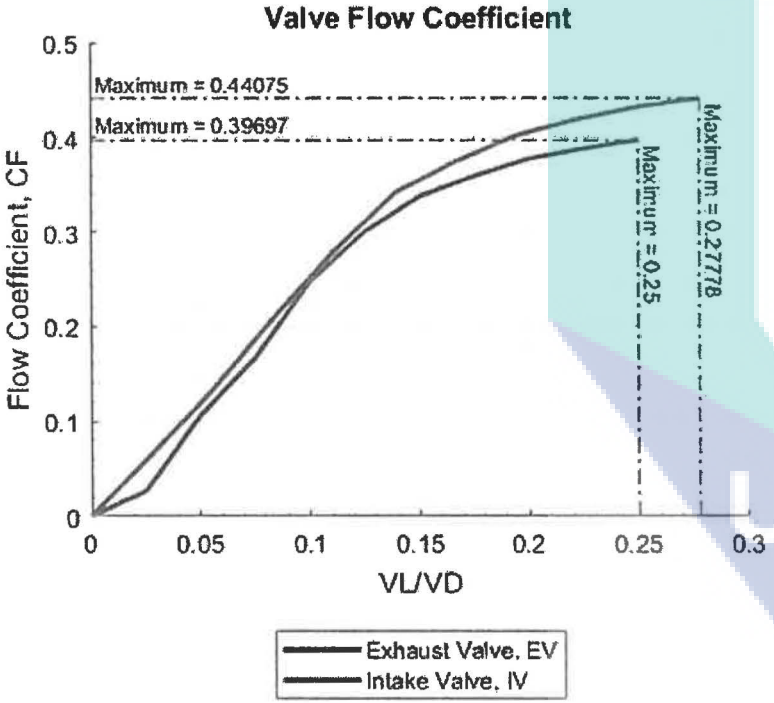


Figure 1 Intake and Exhaust flow coefficient values.

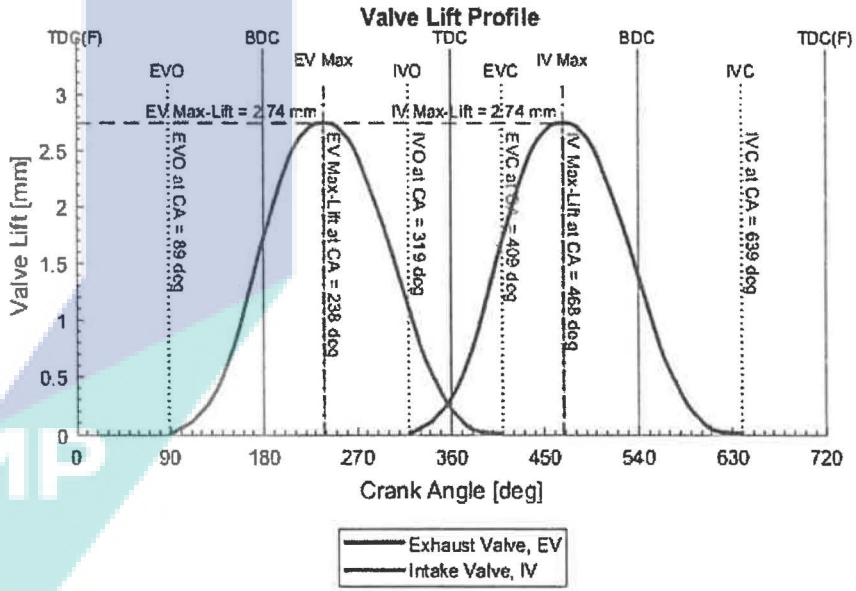


Figure 2 Valve Lift Profile of Baseline Model

Research Progress & Milestones Achievement

M2: Design specifications.

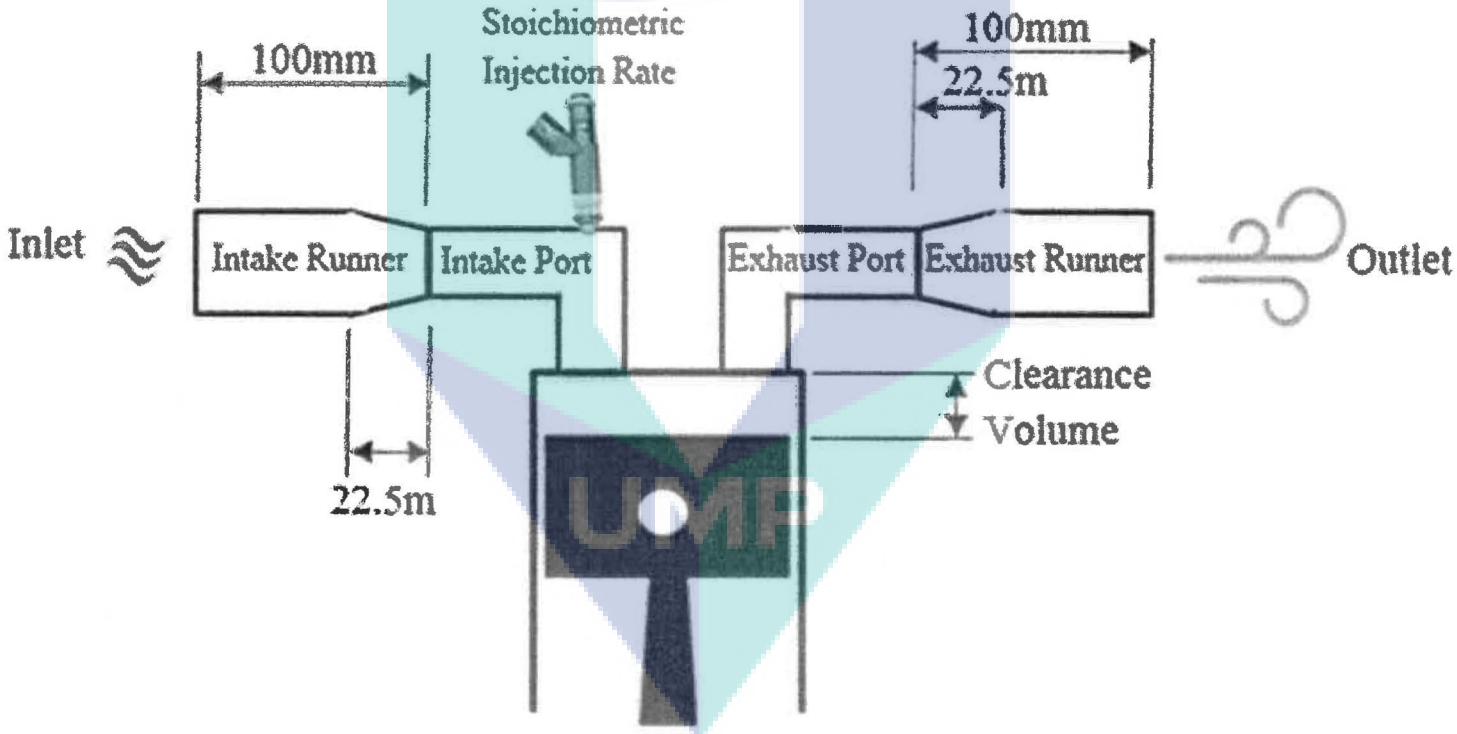


Figure 3 Engine Structure of Baseline Model

Research Progress & Milestones Achievement

M2: Design specifications.

Table 2 Valve Lift Event of Baseline Model

Valve Lift Event	Crank Angle Degree (deg)
Exhaust Valve Opening (EVO)	At 89
Exhaust Valve Closing (EVC)	At 409
Exhaust Valve Max. Lift	At 238
Exhaust Valve Duration	320
Intake Valve Opening (IVO)	At 319
Intake Valve Closing (IVC)	At 639
Intake Valve Max. Lift	At 468
Intake Valve Duration	320
Valve Overlap	90

Research Progress & Milestones Achievement

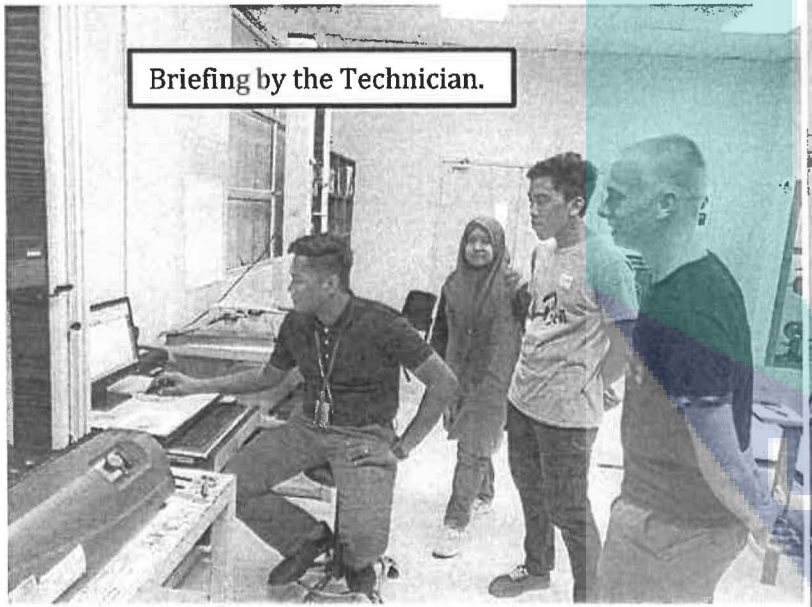
M2: Design specifications.
Flexible Valve Timing Strategies (8 Strategies)

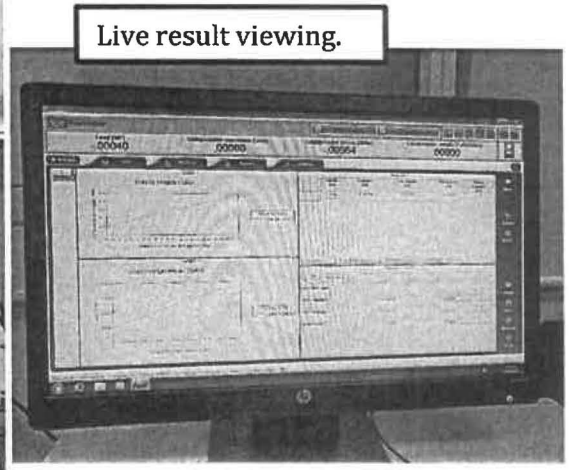
1. Late Intake Valve Closing (LIVC)
2. Early Intake Valve Closing (EIVC)
3. Late Intake Valve Opening (LIVO)
4. Early Intake Valve Opening (EIVO)
5. Late Exhaust Valve Closing (LEVC)
6. Early Exhaust Valve Closing (EEVC)
7. Late Exhaust Valve Opening (LEVO)
8. Early Exhaust Valve Opening (EIVO)

Source: Hong, H., G. Parvate-Patil, and B. Gordon, *Review and analysis of variable valve timing strategies—eight ways to approach.* Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering, 2004. **218**(10): p. 1179-1200.

Research Progress & Milestones Achievement

M2: Design specifications.



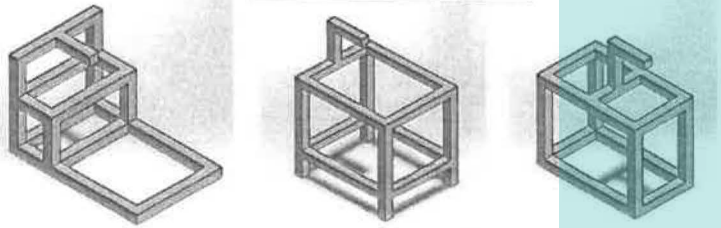


In order to determine the motor size suitable for the actuation, the spring constant must be determined from experiment.

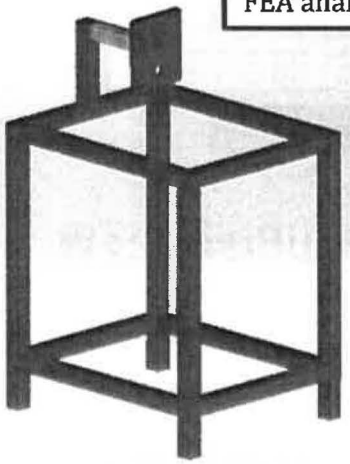
Research Progress & Milestones Achievement

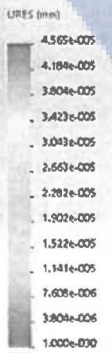
M3: Computer aided design and analyses.

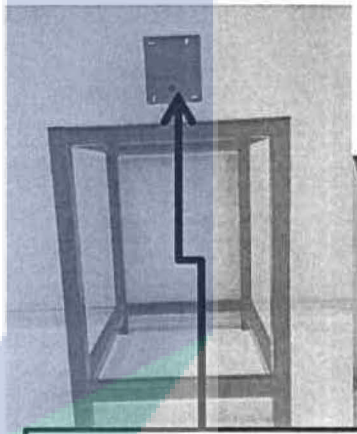
Design 1, 2 and 3



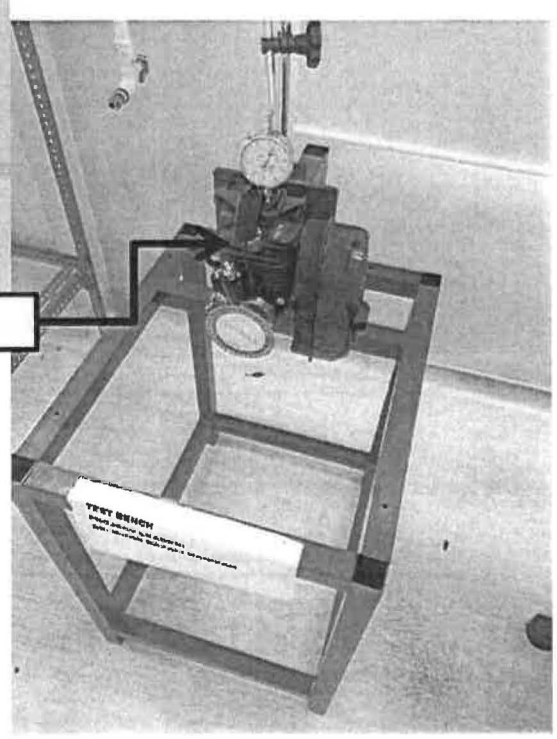
Test rig final design FEA analyses.







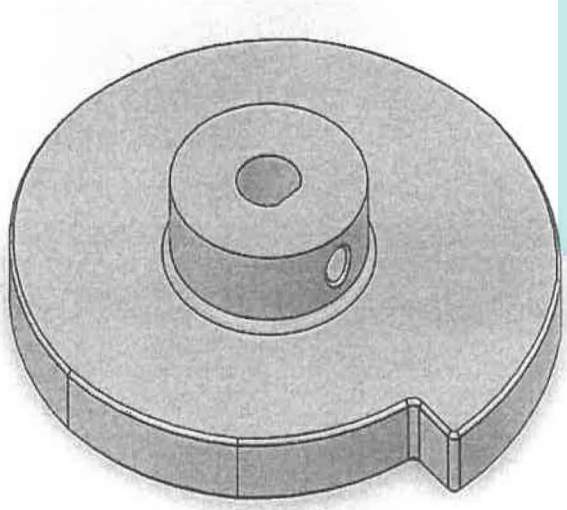
Engine mounting plate.



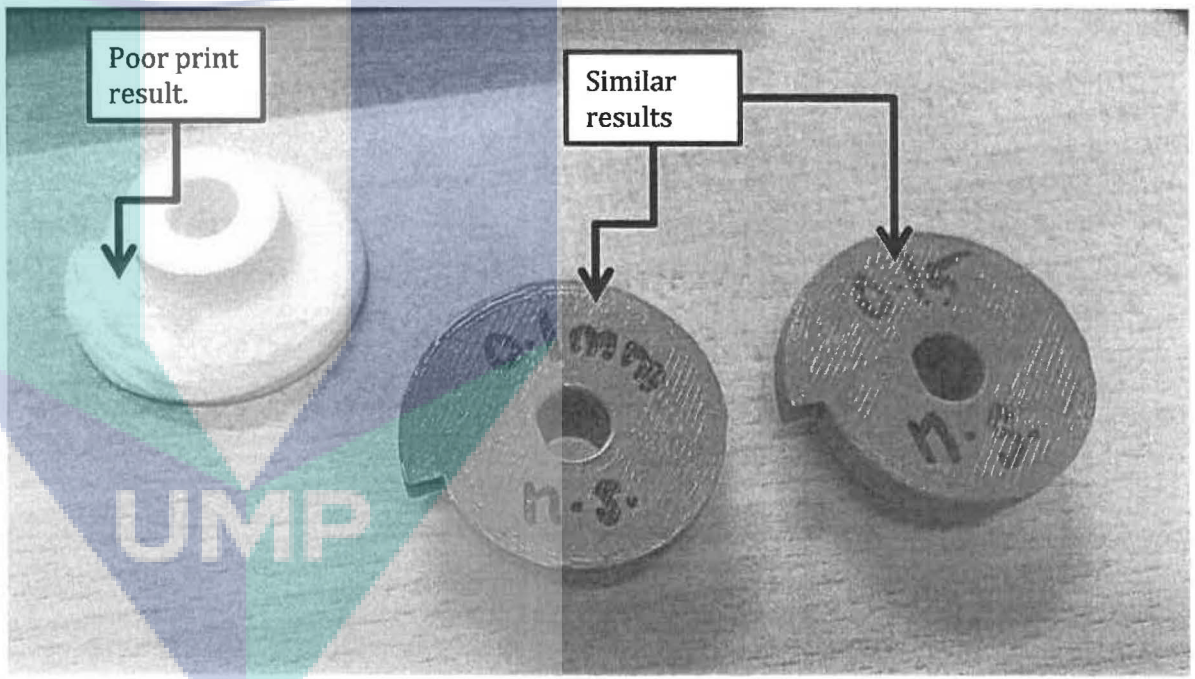
Research Progress & Milestones Achievement

M3: Computer aided design and analyses.

CAD-Key Components Design



CAD drawing Snail Cam

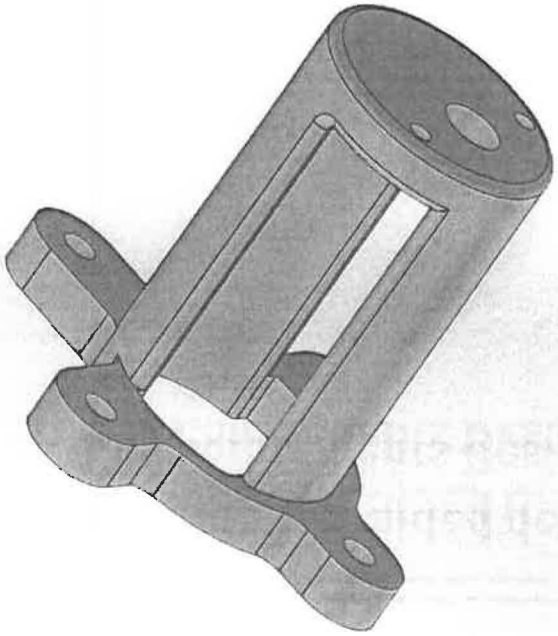


The snail cam concept is proposed for the flexible actuation system using rotary stepper motor. 3D print of snail cam at different resolution.

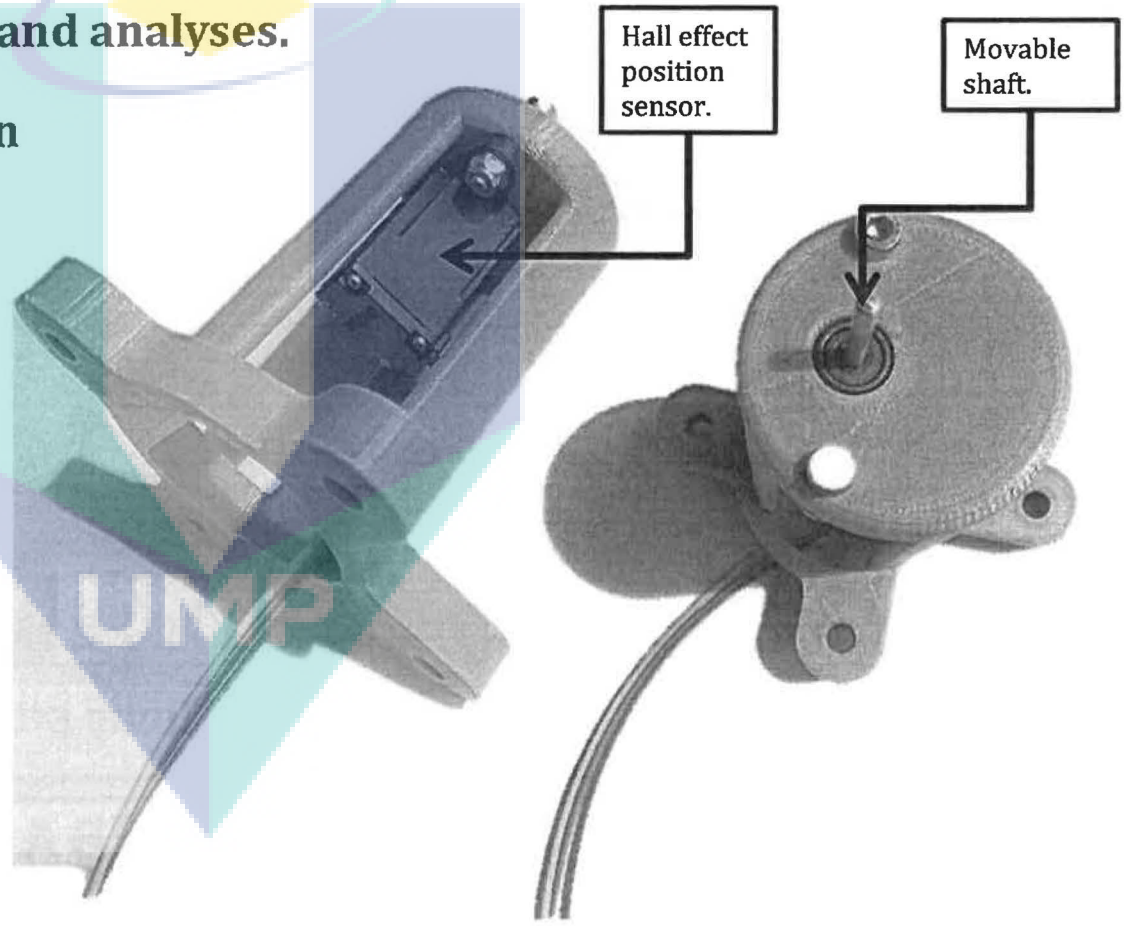
Research Progress & Milestones Achievement

M3: Computer aided design and analyses.

CAD-Key Components Design



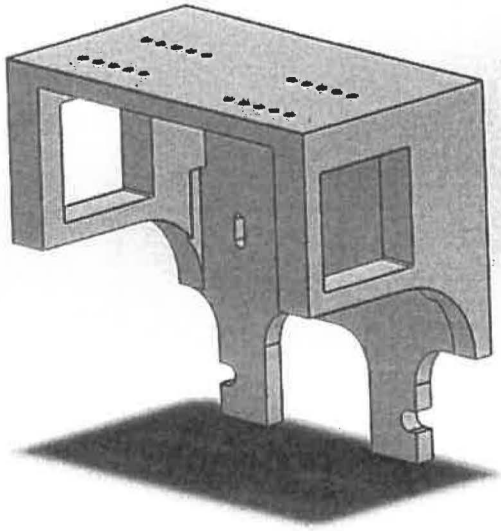
Valve Position Sensor mounting



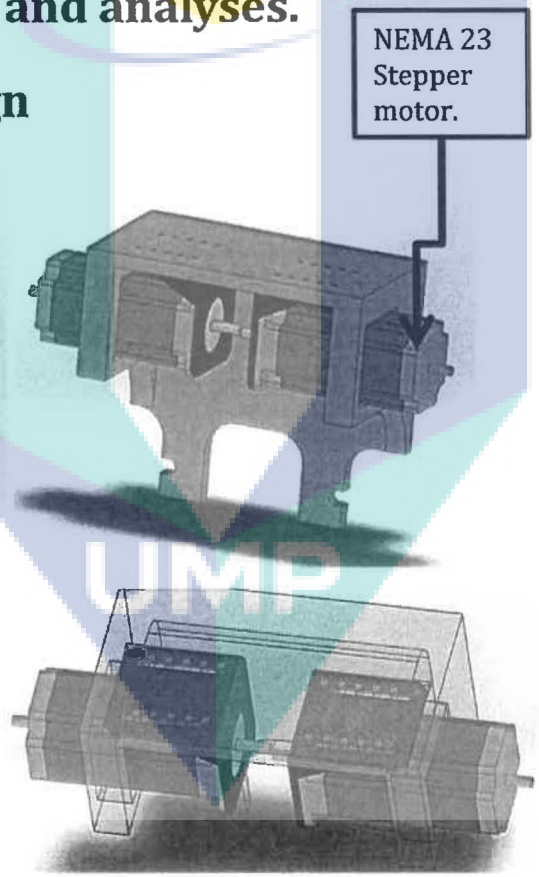
Research Progress & Milestones Achievement

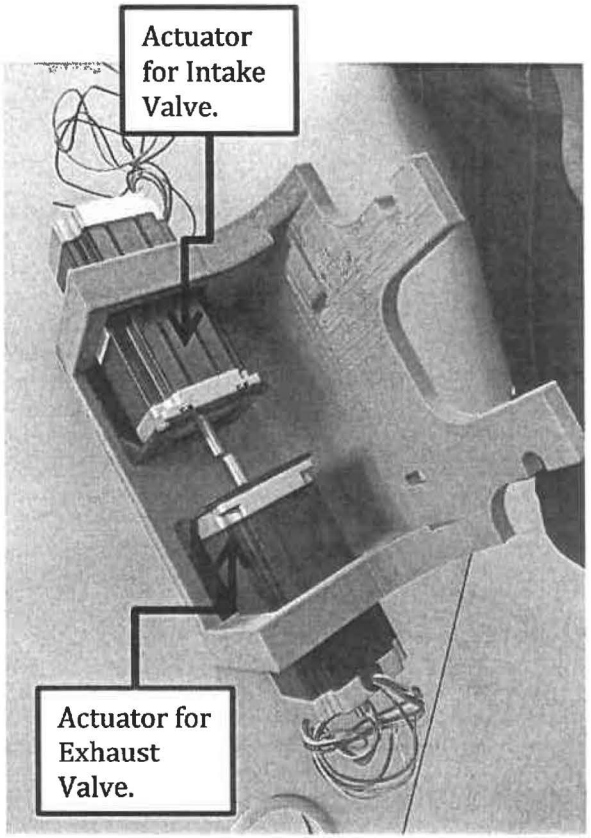
M3: Computer aided design and analyses.

CAD-Key Components Design



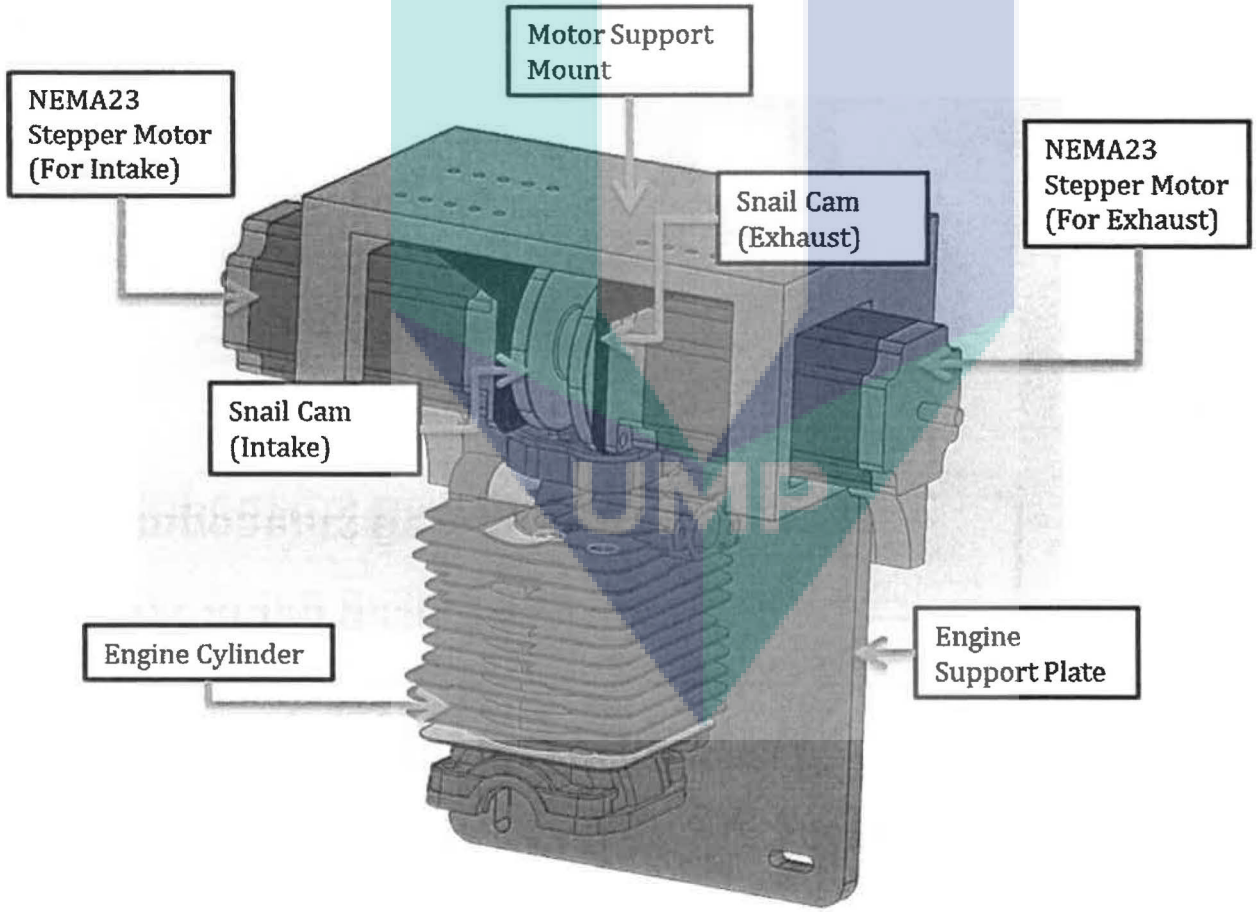
The mounting for the stepper motors





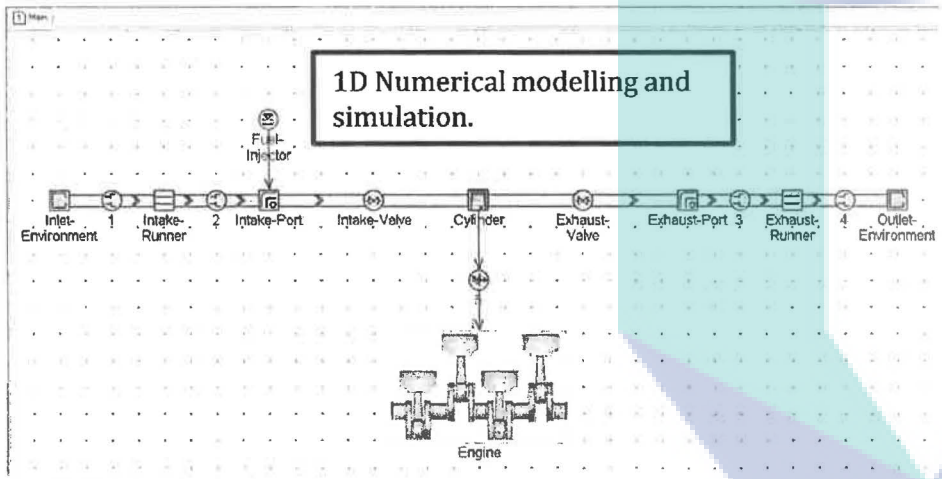
Research Progress & Milestones Achievement

M3: Computer aided design and analyses.

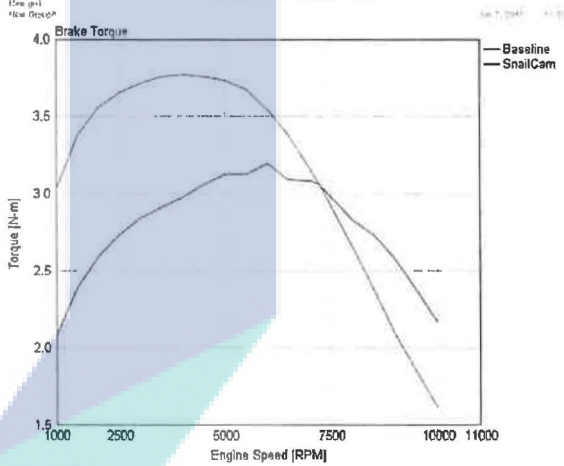


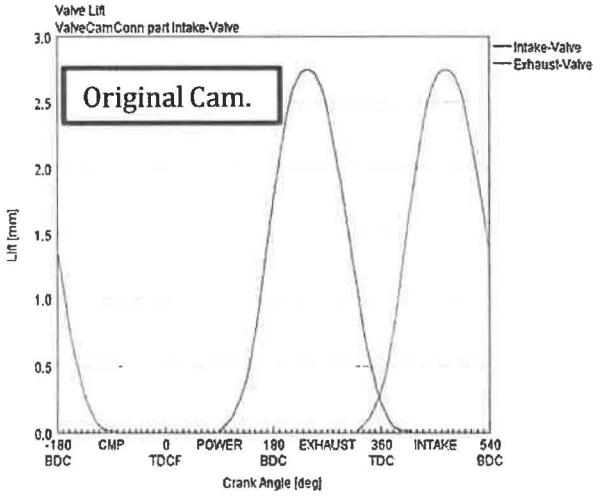
Research Progress & Milestones Achievement

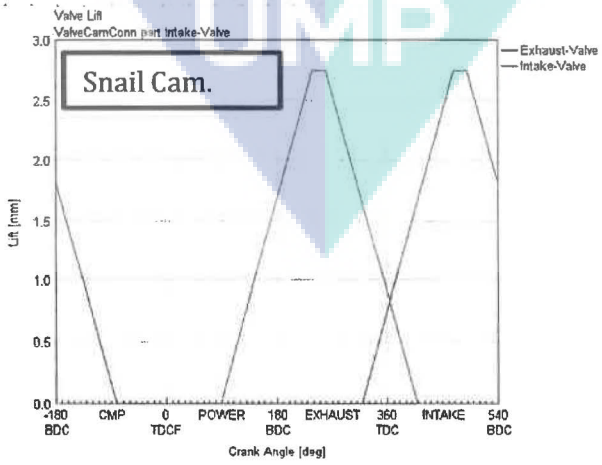
M3: Computer aided design and analyses.

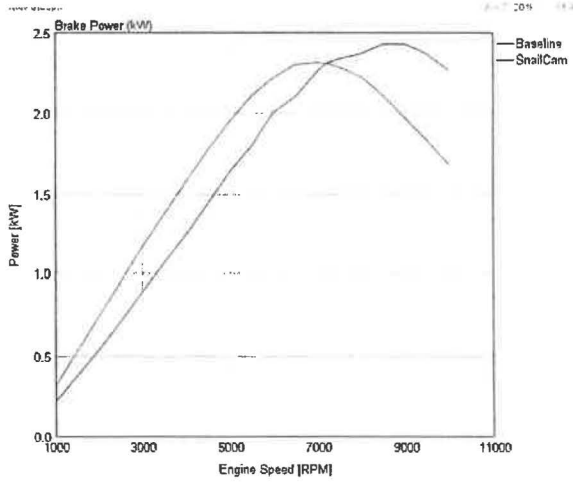


Engine Performance Results





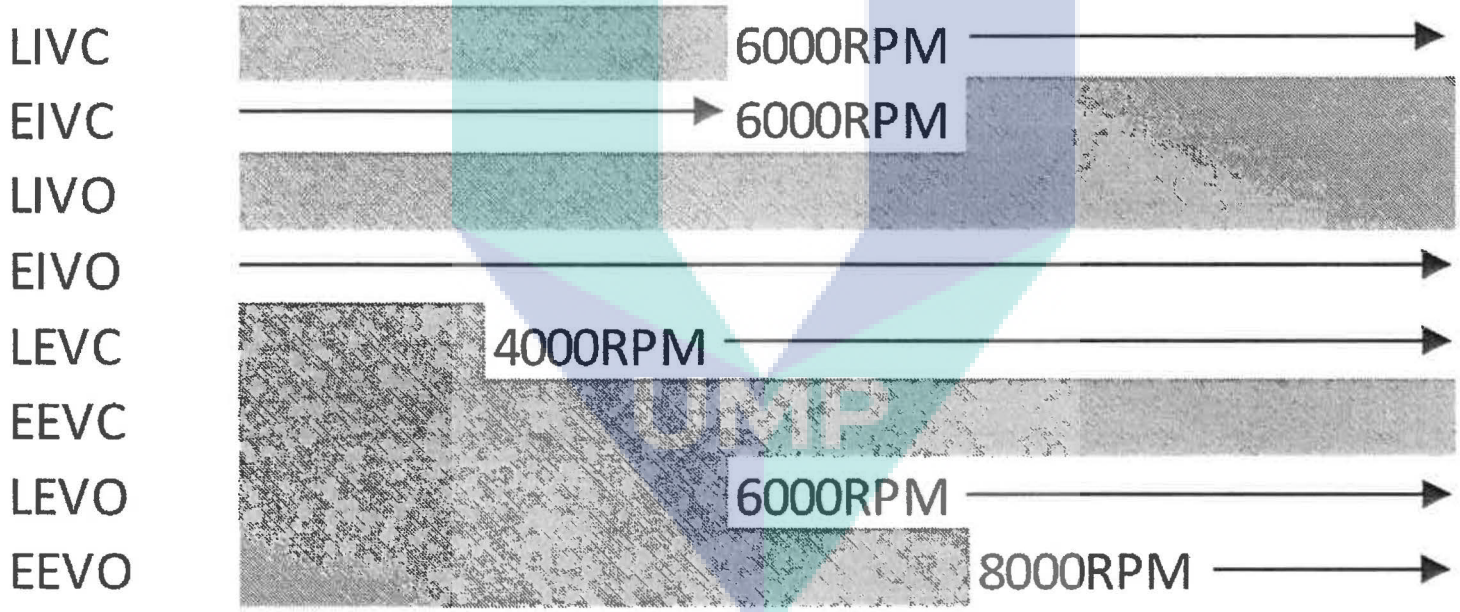




Research Progress & Milestones Achievement

M3: Computer aided design and analyses.

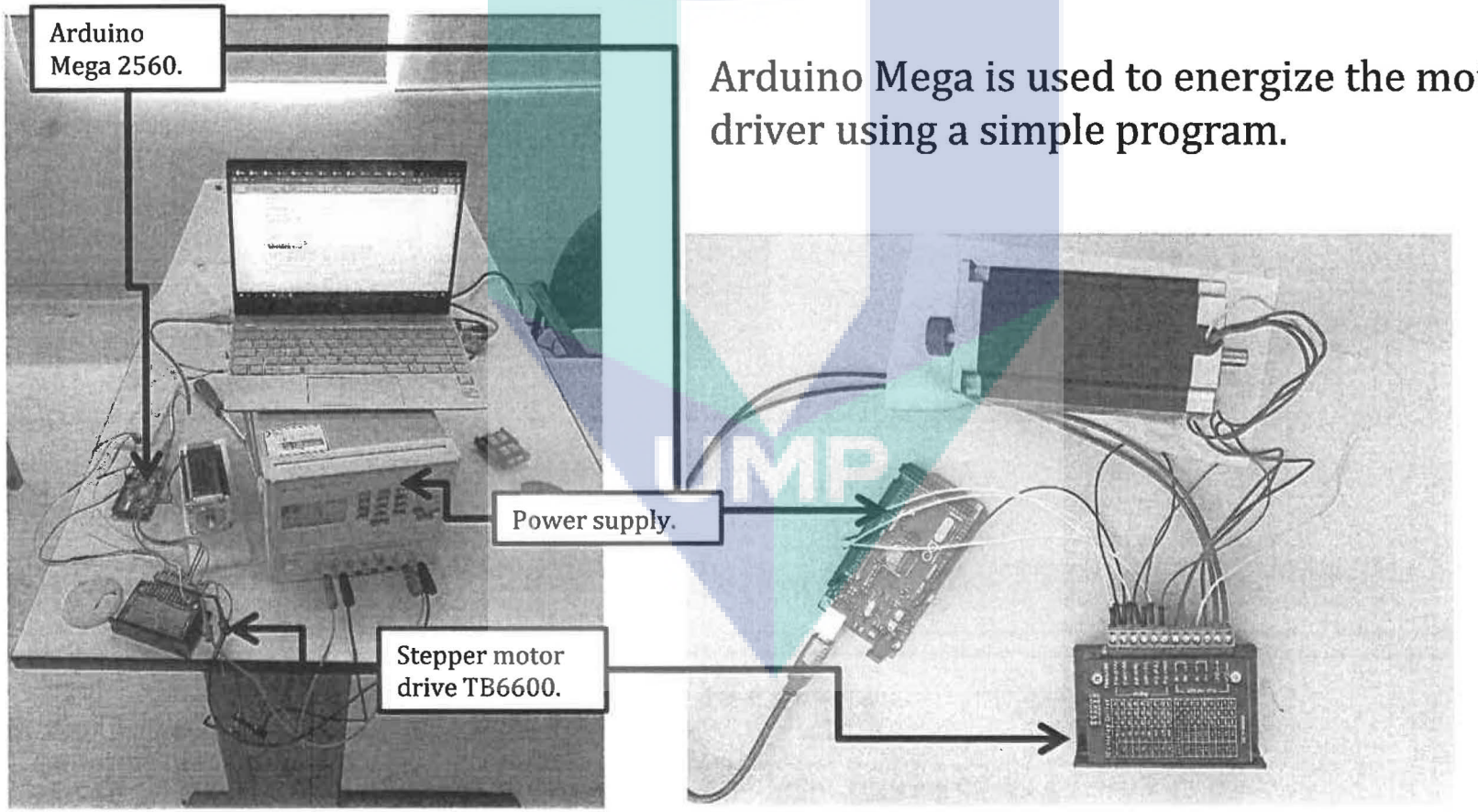
Simulation Results: 8 Strategies of flexible timing.



Summary of Positive Impact of Flexible Valve Timing on Engine Performance.

Research Progress & Milestones Achievement

M4: Development of test bench, control and data acquisition systems.

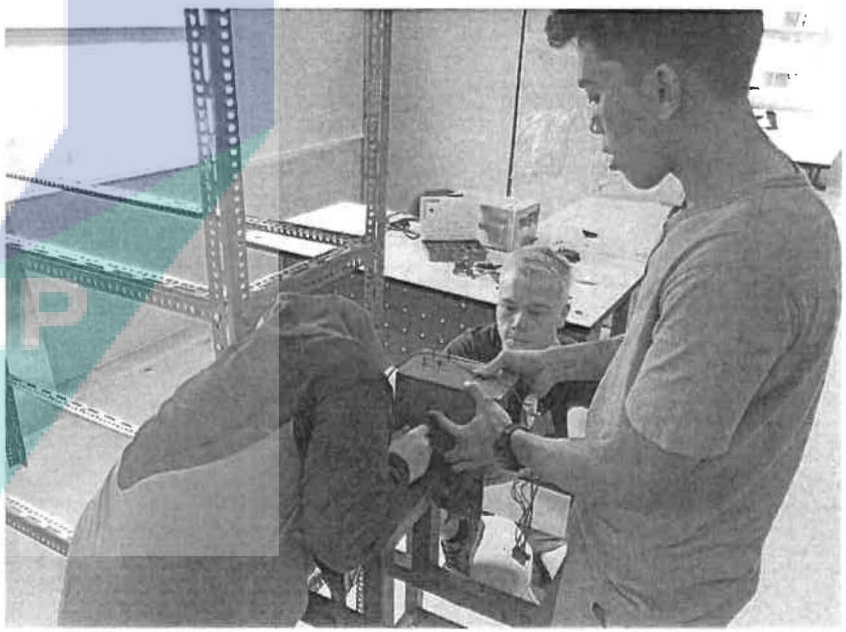


Arduino Mega is used to energize the motor driver using a simple program.

Research Progress & Milestones Achievement

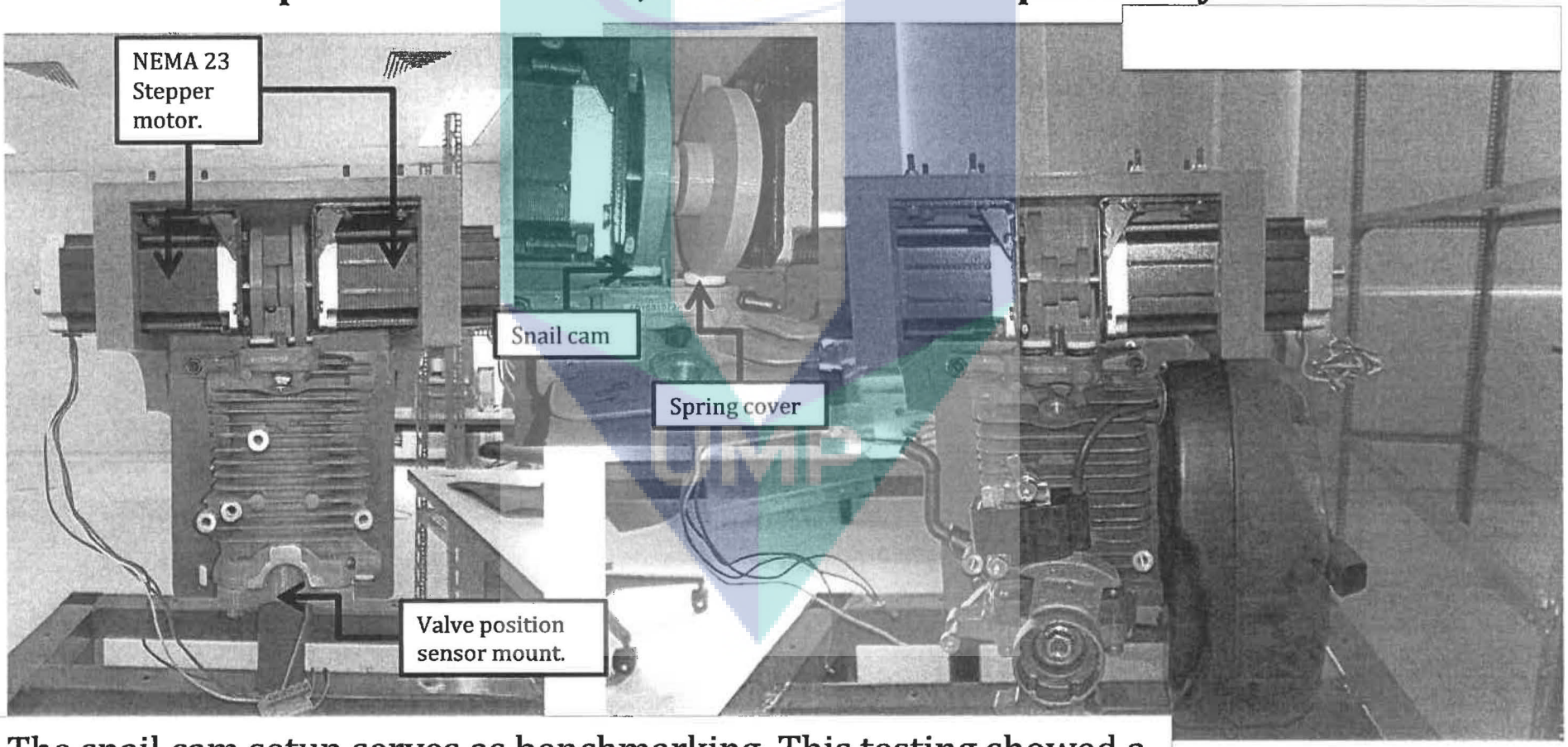
M4: Development of test bench, control and data acquisition systems.

Pre-assembly and parts fitting.



Research Progress & Milestones Achievement

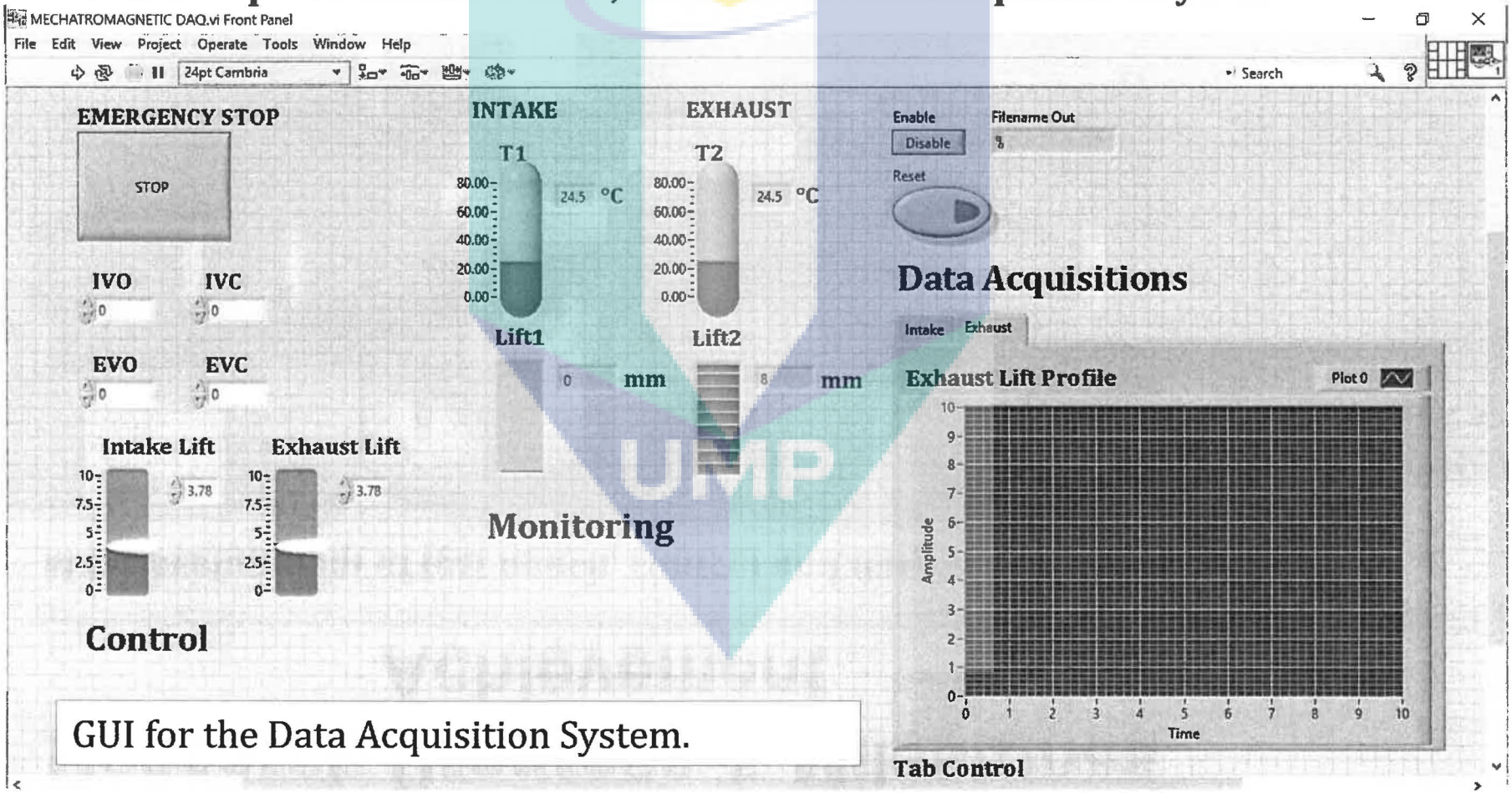
M4: Development of test bench, control and data acquisition systems.



The snail cam setup serves as benchmarking. This testing showed a need for direct actuation through linear motor and different spring setup.

Research Progress & Milestones Achievement

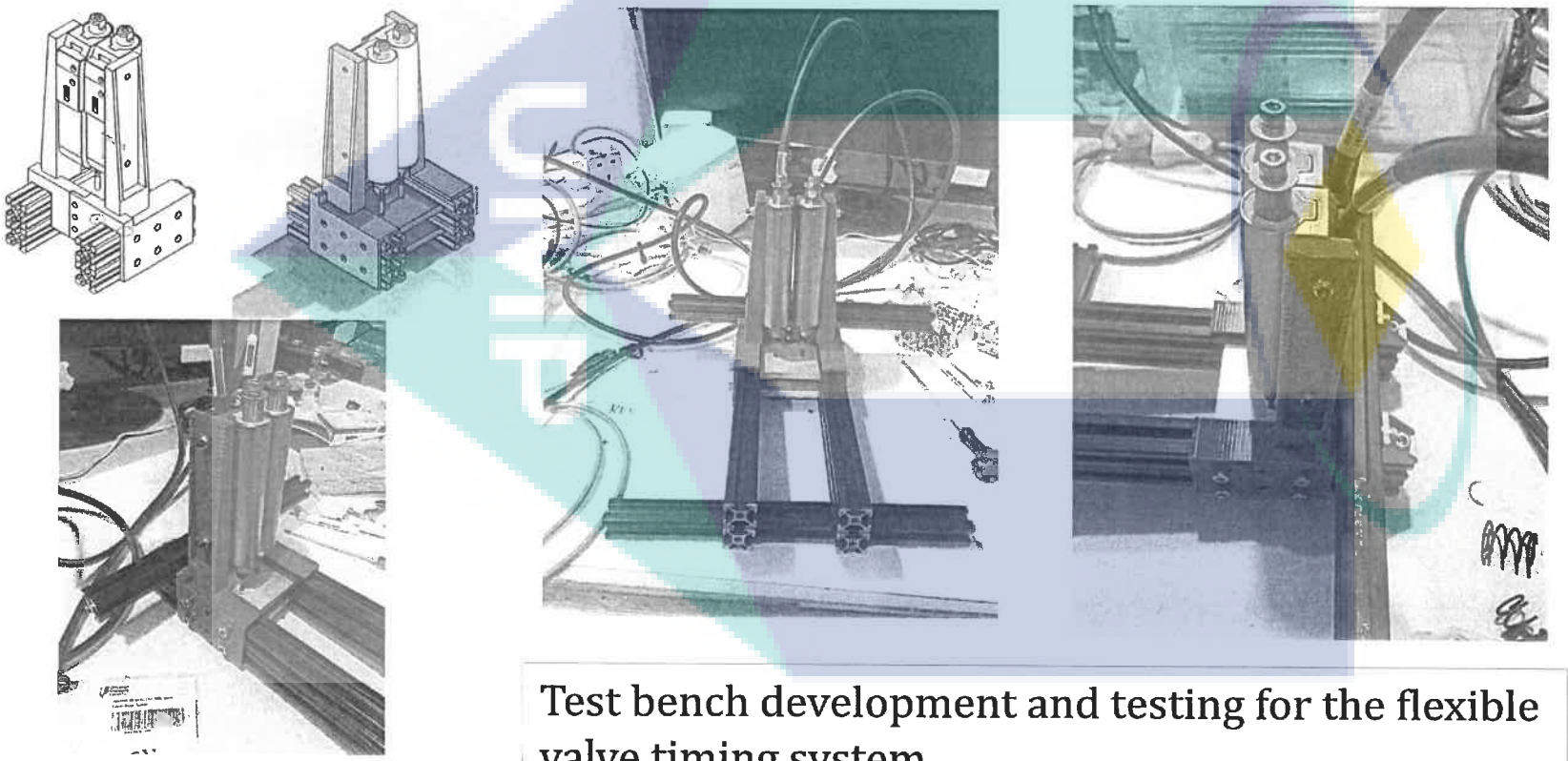
M4: Development of test bench, control and data acquisition systems.



GUI for the Data Acquisition System.

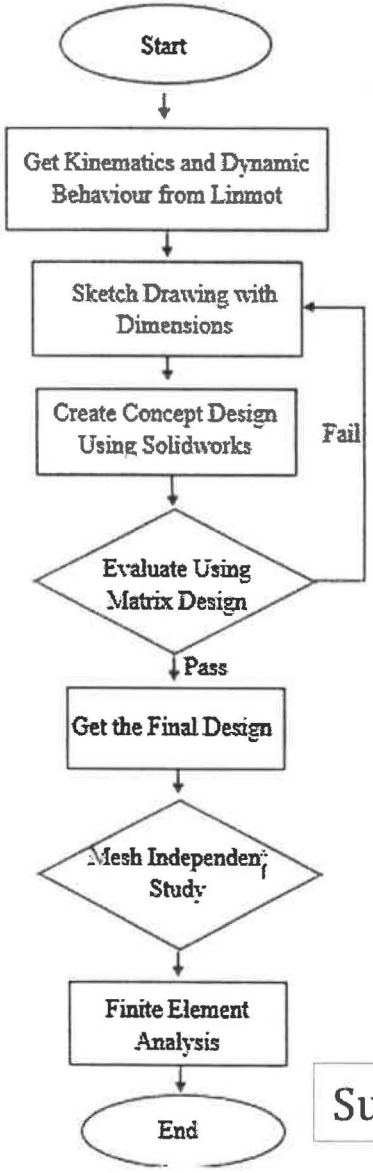
Research Progress & Milestones Achievement

M4: Development of test bench, control and data acquisition systems.



Test bench development and testing for the flexible valve timing system.

Research Progress & Milestones Achievement



Sub-project flowchart

M5: Completion of laboratory prototype of the mechatromagnetic valve actuation system.

SUB-PROJECT: Design and Finite Element Analysis for Linear Motor Mounting

i. To design the mounting using the computer-aided design tool.

ii. To conduct finite element analysis on the model.

Motor Setup	
Motor Type	P02-23Sx80F/0x60-HP
Motor Variant	High Performance (HP)
Stator Type	PS02-23Sx80F-HP
Slider Type	PL01-12x130/90-HP
Guide Type	N/A
Slider Mounting	Regular
Moving Part	Slider (fixed cable)
No. of Motors	1
Drive Type	E11x0-XC / B1100-XC
Supply Voltage	DC Link 72 V
Braking Method	None
Cable Type	None
Cable Length	0 m
Ambient Temperature	25 C
Cooling Method	Flange

Linear motor specifications

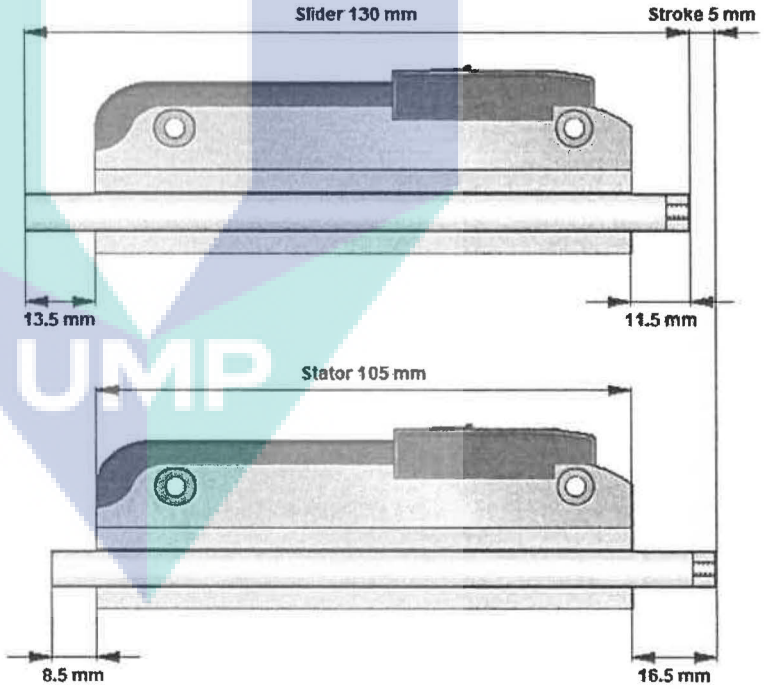
Research Progress & Milestones Achievement

M5: Completion of laboratory prototype of the mechatromagnetic valve actuation system.

SUB-PROJECT: Design and Finite Element Analysis for Linear Motor Mounting

P02-23Sx80F/0x60-HP

Linear motor layout

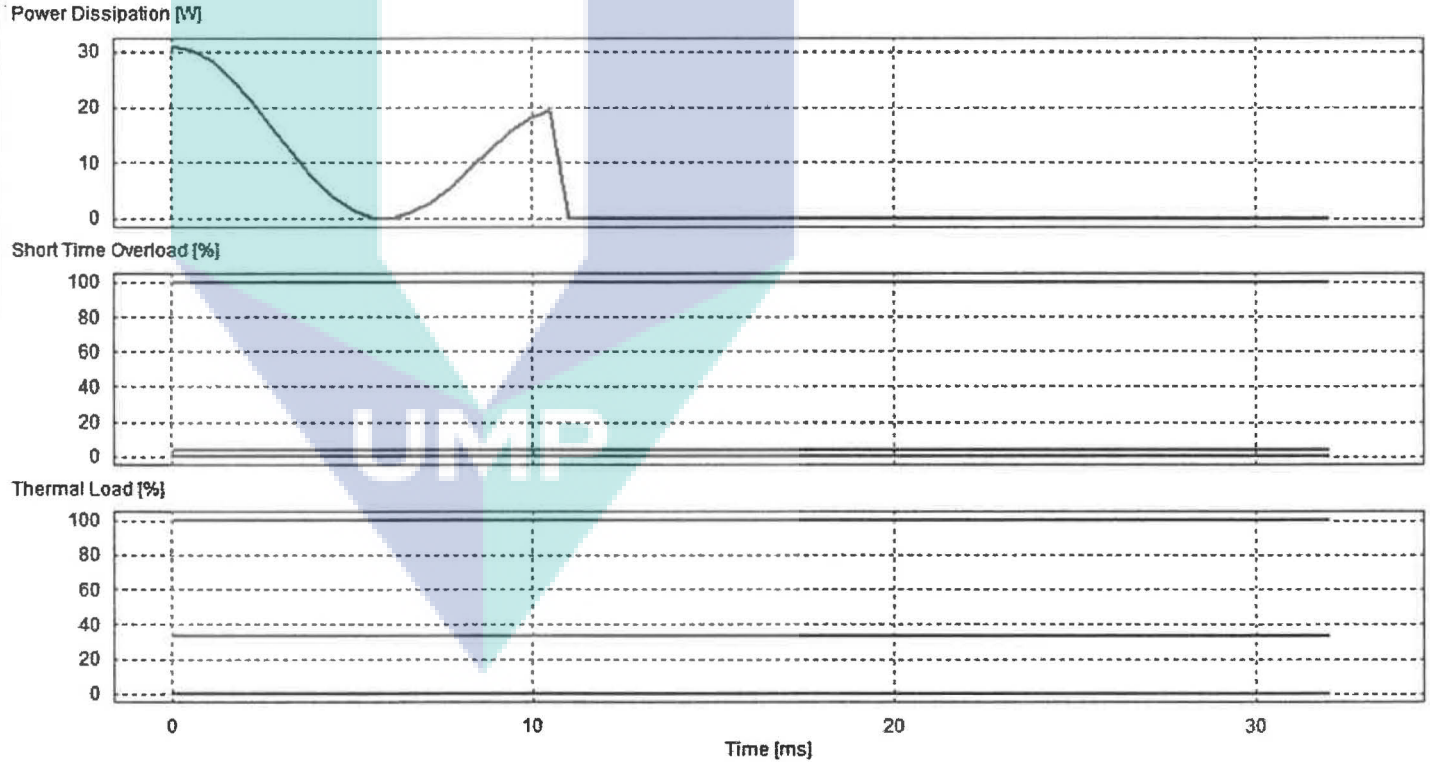


Research Progress & Milestones Achievement

M5: Completion of laboratory prototype of the mechatromagnetic valve actuation system.

SUB-PROJECT: Design and Finite Element Analysis for Linear Motor Mounting

Power consumption and loading predictions (at 2500RPM ,11ms per stroke of 5mm).

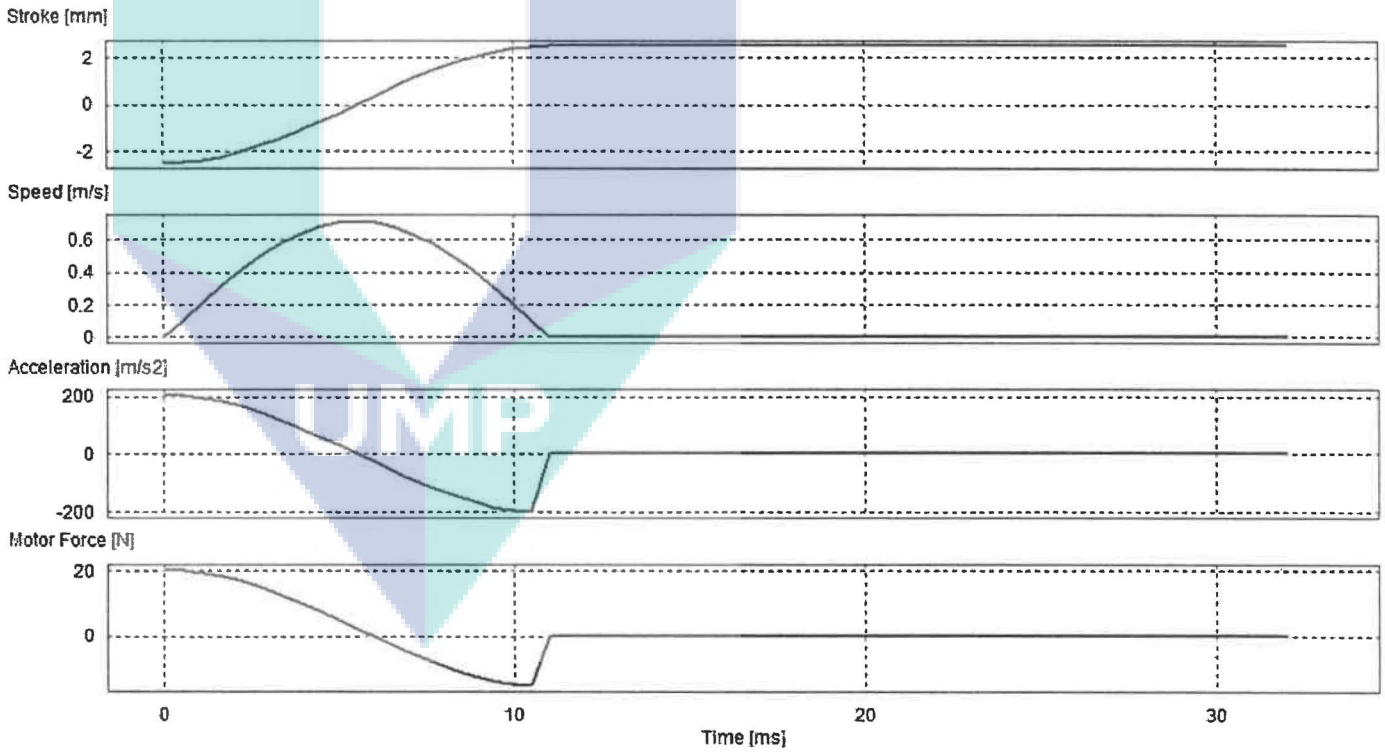


Research Progress & Milestones Achievement

M5: Completion of laboratory prototype of the mechatromagnetic valve actuation system.

SUB-PROJECT: Design and Finite Element Analysis for Linear Motor Mounting

Kinematics performance predictions (at 2500RPM ,11ms per stroke of 5mm).



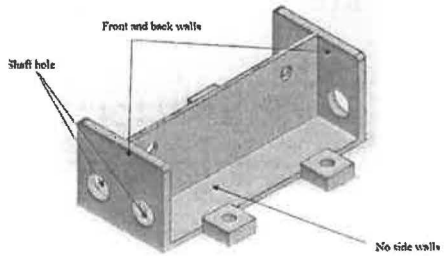
Research Progress & Milestones Achievement

M5: Completion of laboratory prototype of the mechatromagnetic valve actuation system.

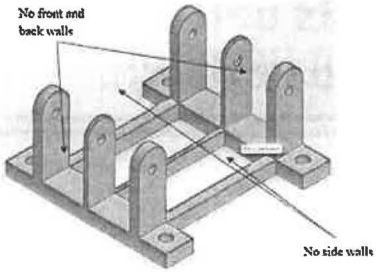
SUB-PROJECT: Design and Finite Element Analysis for Linear Motor Mounting

Motor mounting conceptual designs

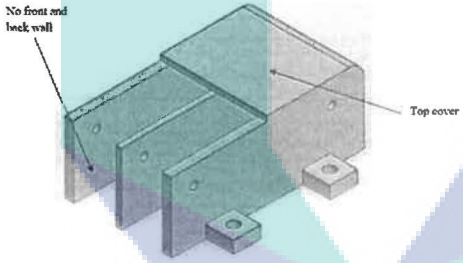
CONCEPT DESIGN NO.1



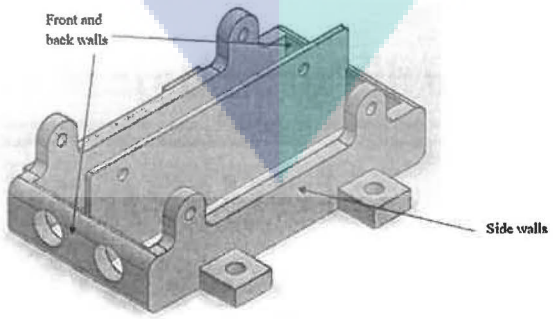
CONCEPT DESIGN NO.2



CONCEPT DESIGN NO.3



CONCEPT DESIGN NO.4



CONCEPT DESIGN NO.5

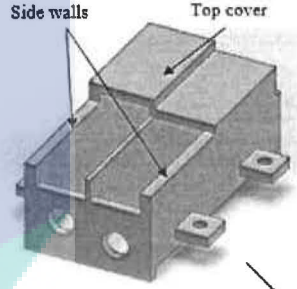


Figure 3-14

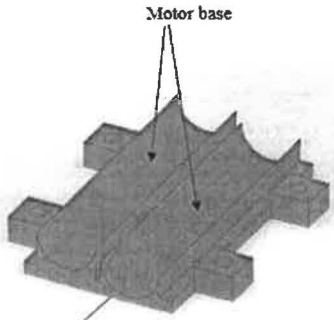
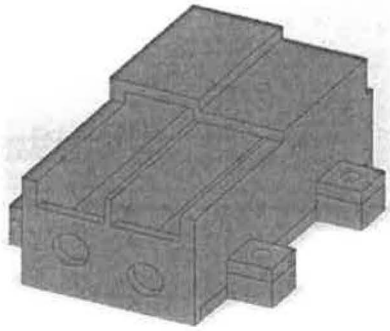


Figure 3-15

Combined

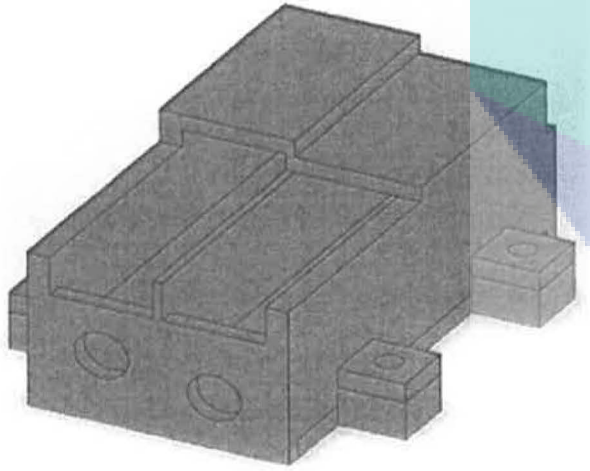


Research Progress & Milestones Achievement

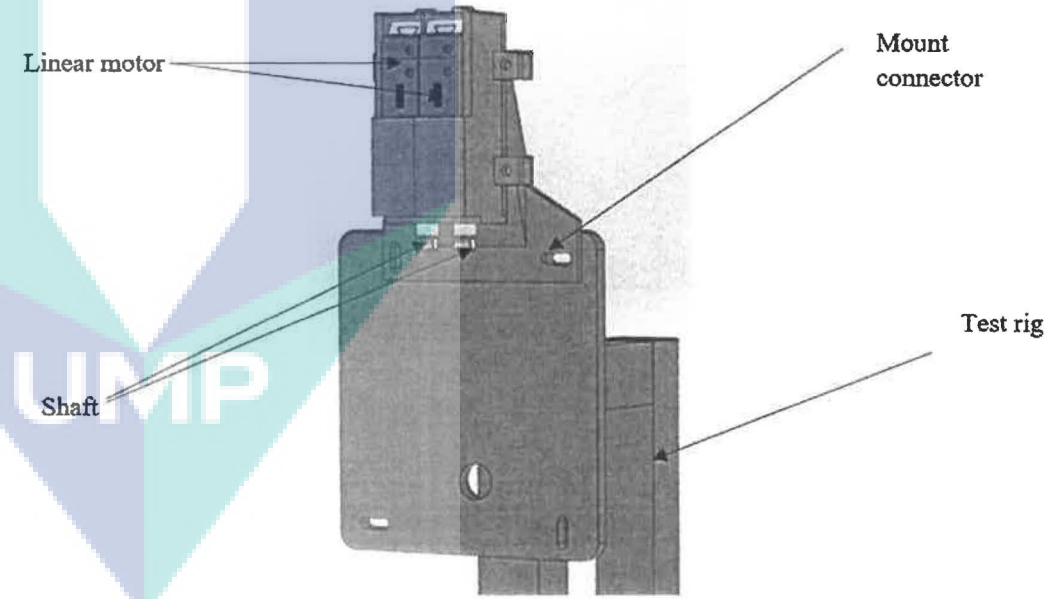
M5: Completion of laboratory prototype of the mechatromagnetic valve actuation system.

SUB-PROJECT: Design and Finite Element Analysis for Linear Motor Mounting

Motor mounting final design.



Propose final design of motor mounting



Assembly of the mounting, linear motors, connector and the rig

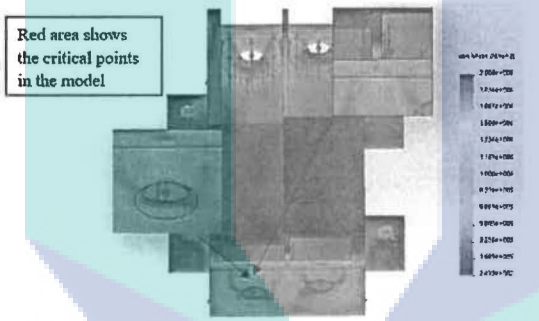
Research Progress & Milestones Achievement

M5: Completion of laboratory prototype of the mechatromagnetic valve actuation system.

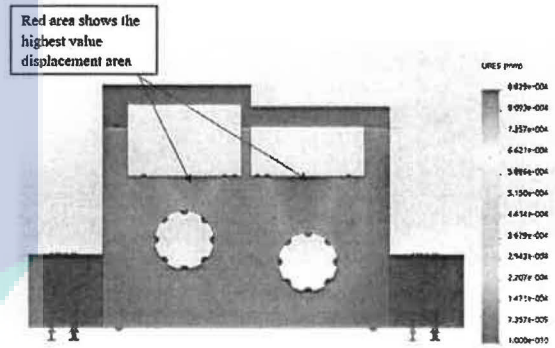
SUB-PROJECT: Design and Finite Element Analysis for Linear Motor Mounting

Motor mounting final design FEA analyses:

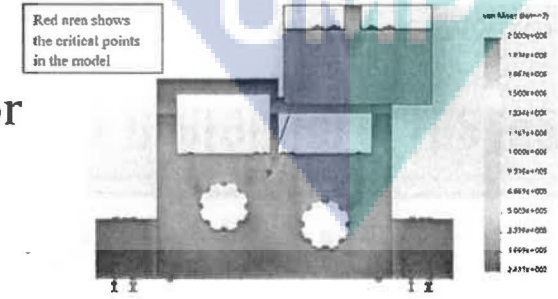
- The stress and displacement values are within safe limits of the design.
- The values of designed Safety Factor is 6.



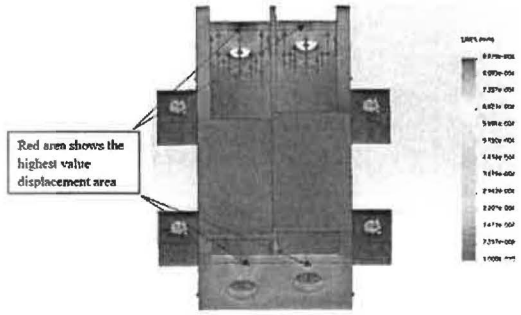
Result for stress (alternate view)



Result for displacement (front view)



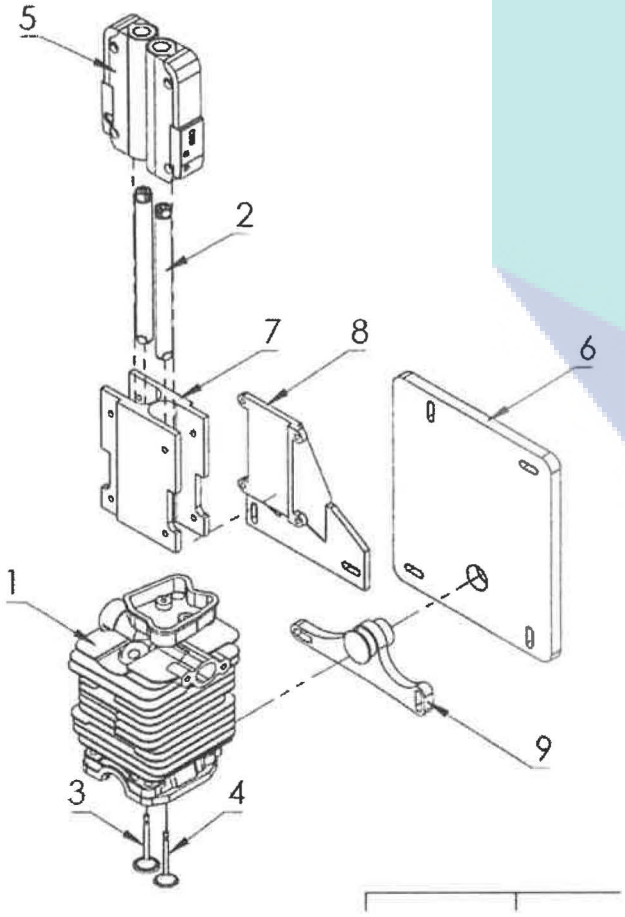
Result for stress (front view)



Result for displacement (alternate view)

Research Progress & Milestones Achievement

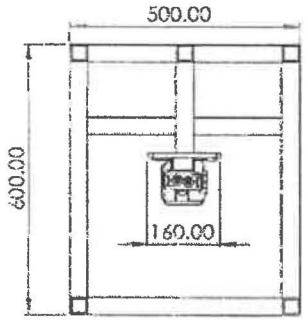
M5: Completion of laboratory prototype of the mechatromagnetic valve actuation system.

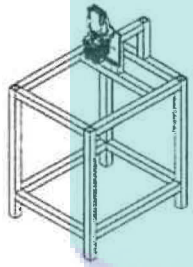


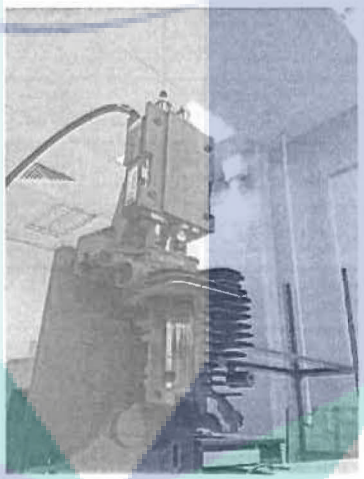
ITEM NO.	PART NUMBER	QTY.
1	Stihl 4MIX 65cc Engine Block	1
2	Motor Shaft	2
3	Intake Valve	1
4	Exhaust Valve	1
5	Motor	2
6	Plate with Oblong hole	1
7	Motor Mount	1
8	Connector	1
9	Crank Point Support	1

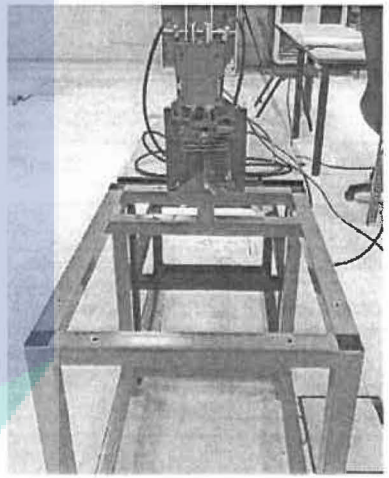
Research Progress & Milestones Achievement

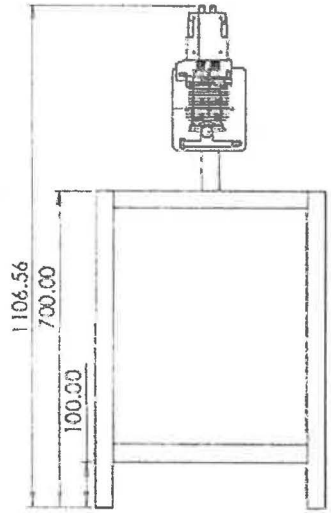
M5: Completion of laboratory prototype of the mechatromagnetic valve actuation system.

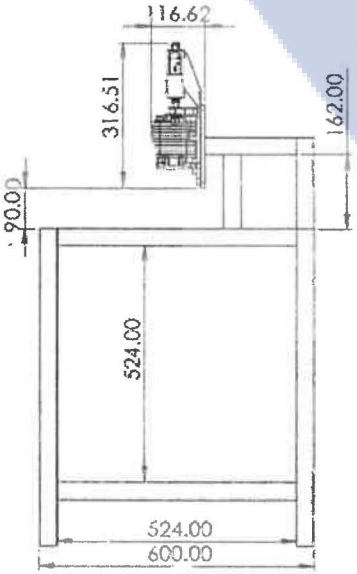


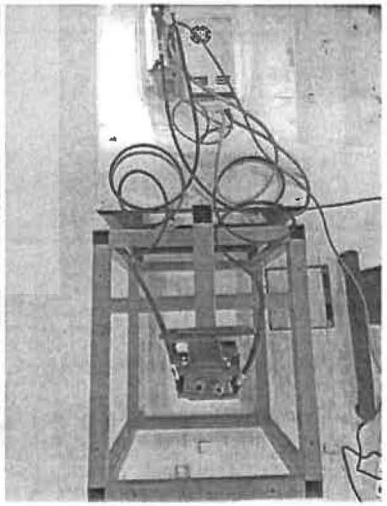






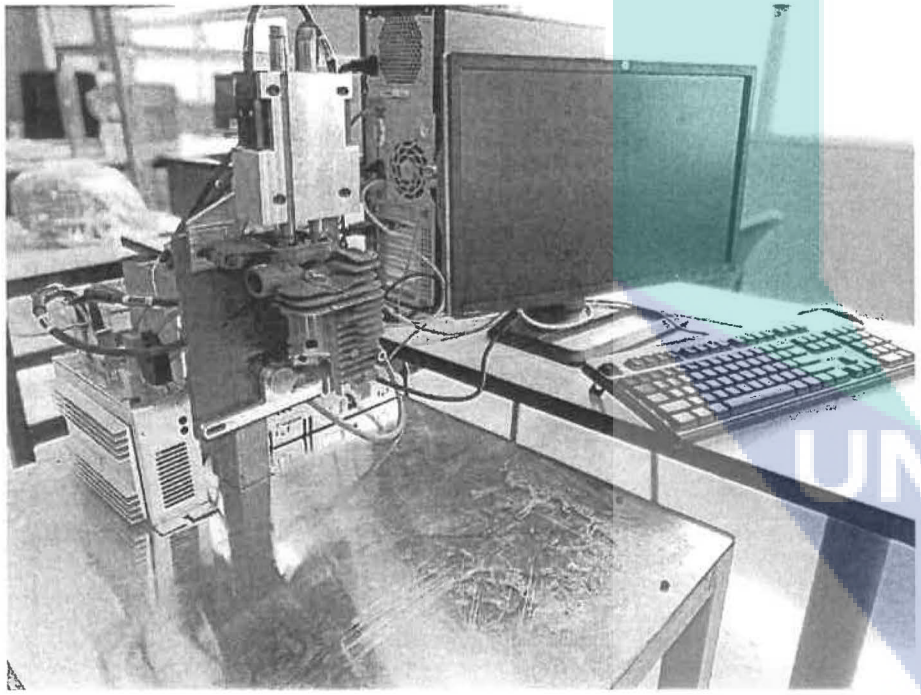


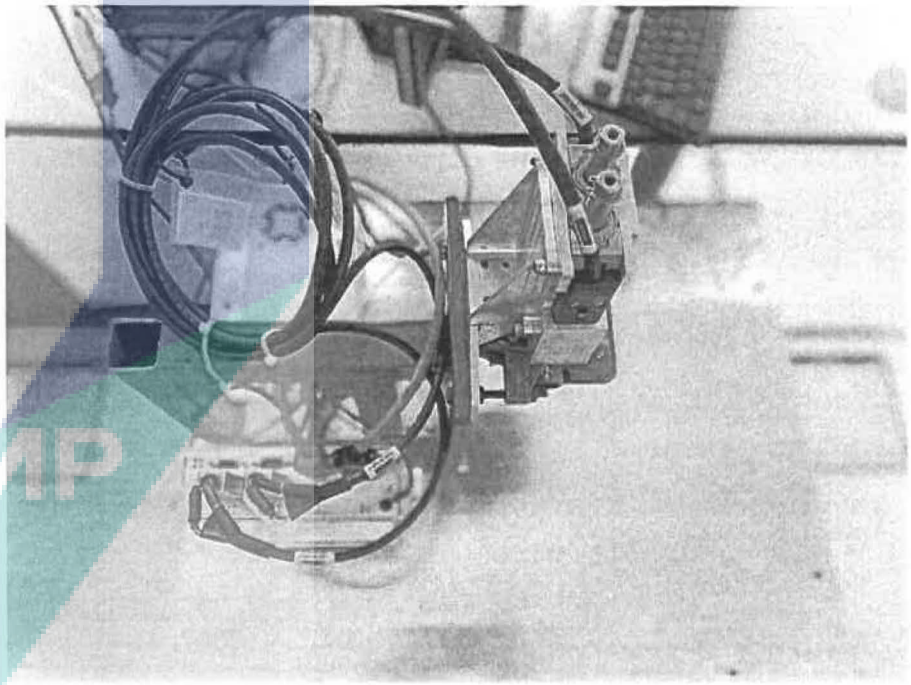




Research Progress & Milestones Achievement

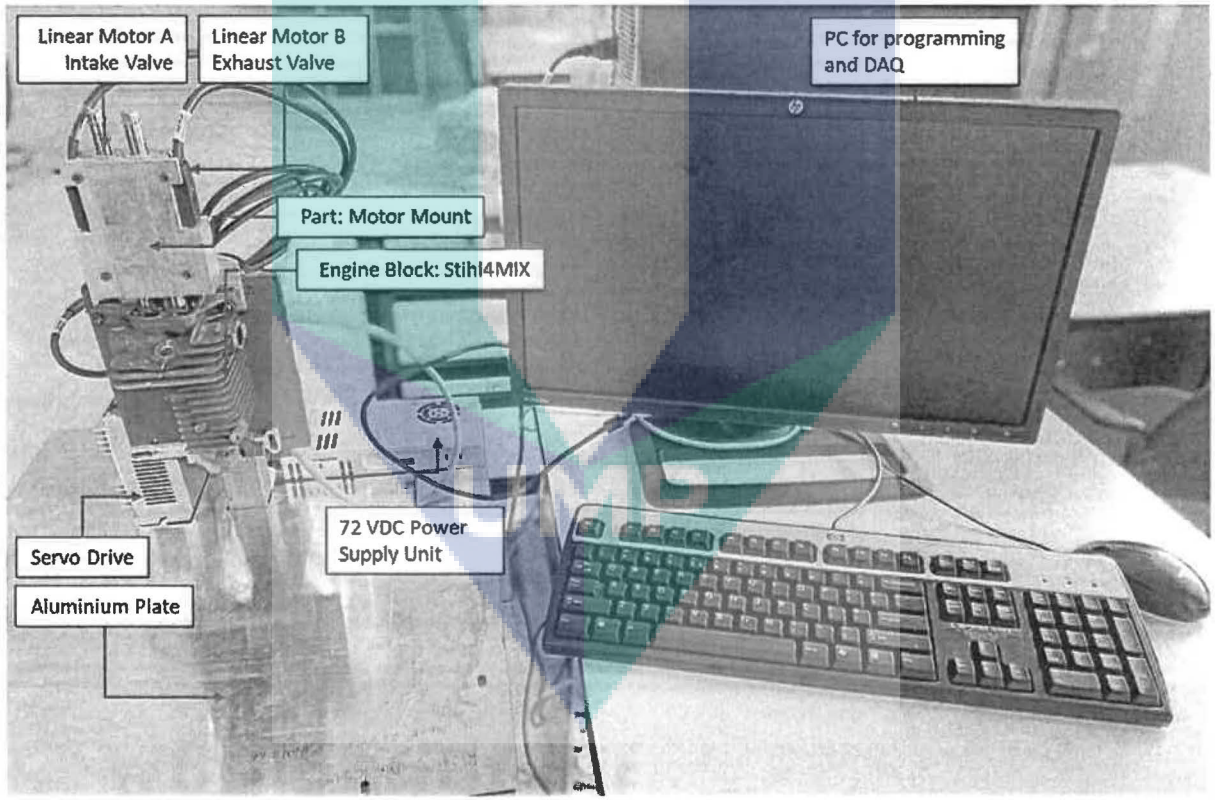
M5: Completion of laboratory prototype of the mechatromagnetic valve actuation system.





Research Progress & Milestones Achievement

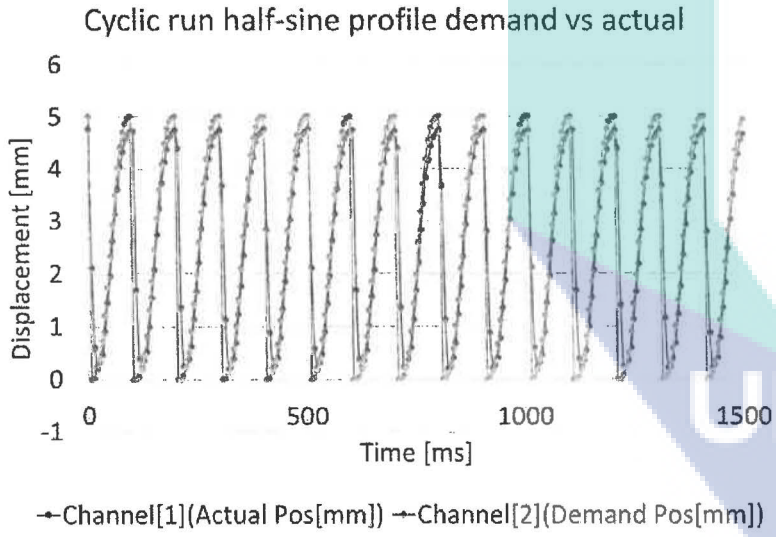
M5: Completion of laboratory prototype of the mechatromagnetic valve actuation system.

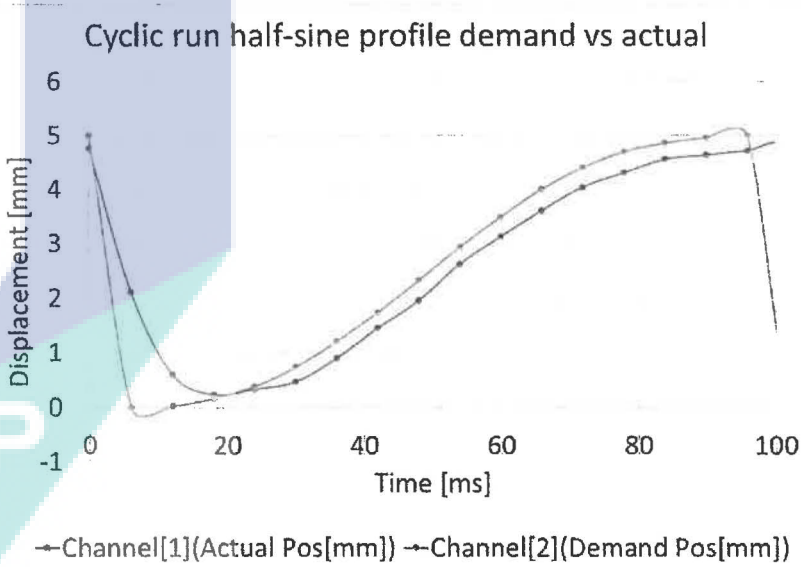


Research Progress & Milestones Achievement

M5: Completion of laboratory prototype of the mechatromagnetic valve actuation system.

Programming and testing of the mechatromagnetic system.





Preliminary testing of the motion control shows:

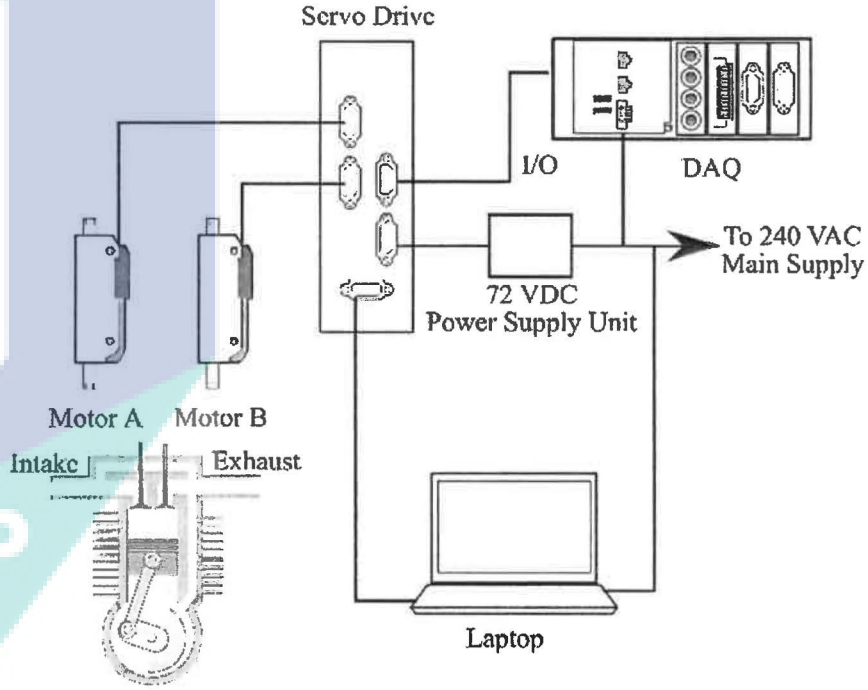
- Small deviation between actual and demand displacement values.
- This can be resolved with further tuning of the linear motor driver configurations.

Research Progress & Milestones Achievement

M5: Completion of laboratory prototype of the mechatromagnetic valve actuation system.

Testing of the mechatromagnetic system.

The figure shows the flexible valve timing (FVT) laboratory setup consist of computer programmable linear motor A and B (P02-23Sx80F, LinMot, Inc., Zurich, Switzerland) each driving the intake and exhaust valves respectively.



The flexible valve timing (FVT) laboratory setup.

Research Progress & Milestones Achievement

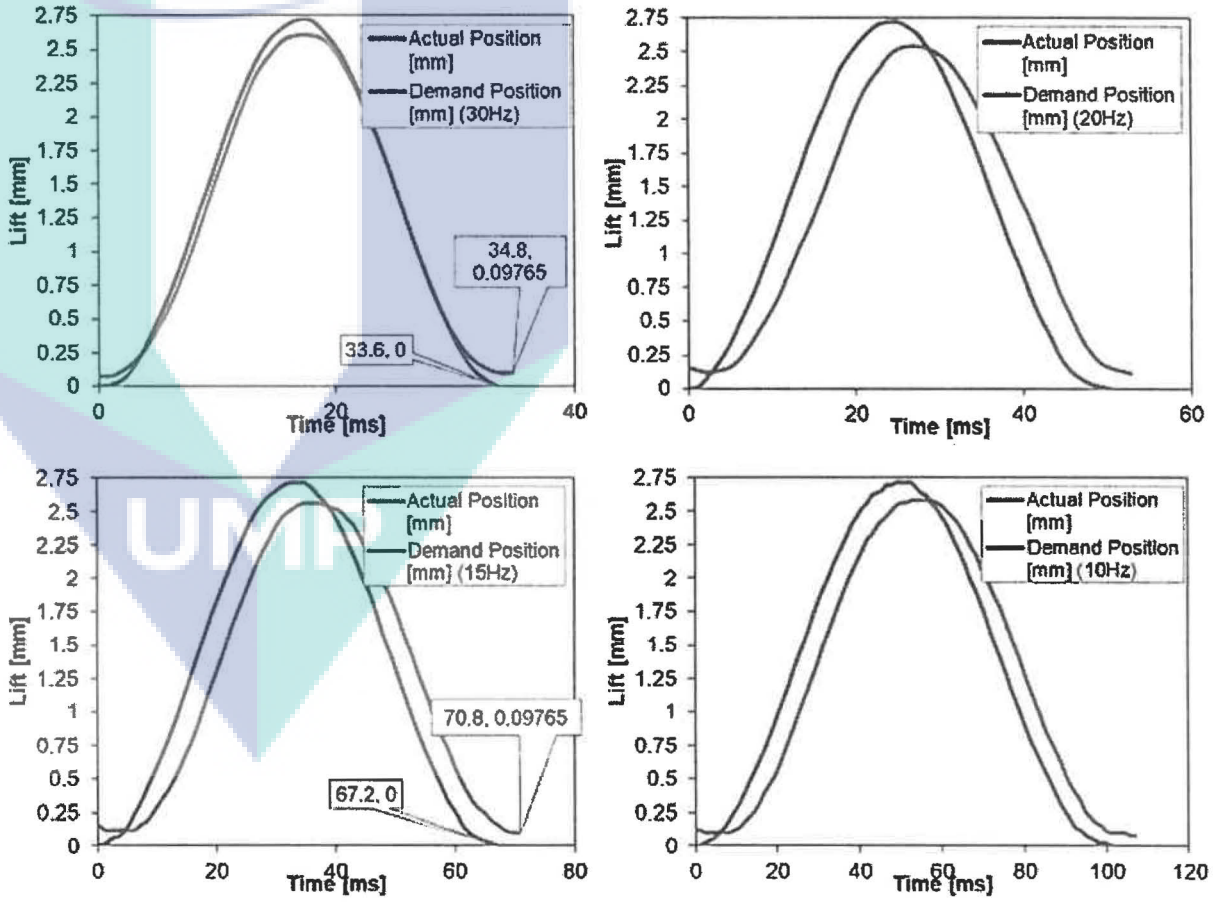
M5: Completion of laboratory prototype of the mechatromagnetic valve actuation system.

FVT motion control results

Figure shows the results from the motion control testing. the demand position is the intended motion profiled which was programmed into the servo drive. The actual position is the sensor reading acquired during the motion testing. The linear motors were driven at four different frequency namely 10 Hz, 15 Hz, 20 Hz and 30 Hz.

The results show a variation exist between demand and actual position, especially at lower frequency. This is because the high-performance linear motor works well close to its designed loading, in this case lower frequency imposed lower load.

In addition, the maximum and minimum positions of the shaft varied by 4 to 11% which must be improved further to ensure precise closing and opening of the valves.

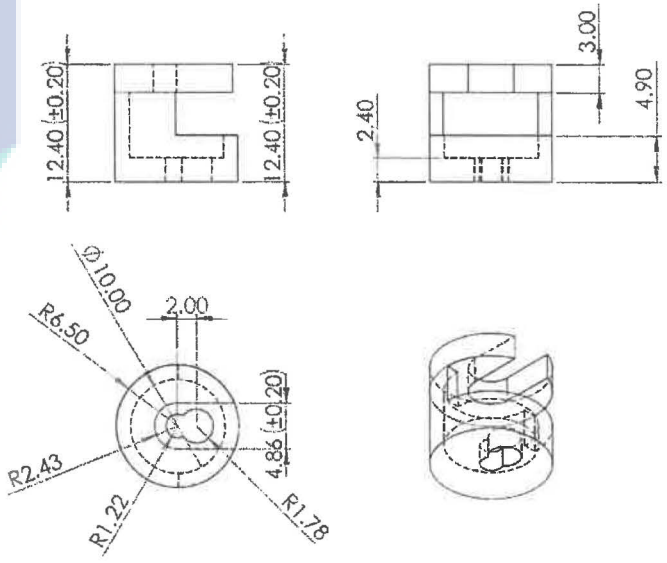


Financial Expenditure

V SERIES	TOTAL ALLOCATION APPROVED (RM) : A	ALOCATION RECEIVED (RM) : B	CUMULATIVE EXPENDITURE (RM) : C	UNSPENT ALLOCATION (B-C)	COMMITED EXPENDITURE (RM) : D
V11000	**48,700.00**	**48,700.00**	**48,700.00**	**0.00**	**0.00**
V21000	**12,000.00**	**12,000.00**	**9,006.96**	**2,993.04**	**0.00**
V24000	**17,000.00**	**17,000.00**	**17,000.00**	**0.00**	**0.00**
V26000	**49,771.00**	**49,771.00**	**49,771.00**	**0.00**	**0.00**
V28000	**3,500.00**	**3,500.00**	**3,500.00**	**0.00**	**0.00**
V29000	**10,400.00**	**10,400.00**	**7,050.00**	**3,350.00**	**0.00**
V35000	**73,427.00**	**73,427.00**	**73,427.00**	**0.00**	**0.00**
	214,798.00	214,798.00	208,454.96	6,343.04	0.00

Challenges / Constraints/ Issues

- Deliverables & Time– All planned activities are on achieved and on track.
- All essential works have been completed
- An issue with the valve link component. This is the only remaining which cannot be machined since it is very small.
- Thus, only 3D printed version is used at the moment.



List of Equipment

No.	List of Equipment Approved by MOSTI (as in agreement)	List of Equipment Bought	Proof of Purchase (Receipts Number / Delivery Order) * Hardcopy to be submitted to MOSTI before/during the presentation
1.	Programmable motor controller	E200-at, motor drive-analog trigger servo controller.	PB205(R)-1711-0005
2.	Linear actuators	Linmot Motor System (Model PS02-23Sx80F)x 2 sets.	PB205(R)-1711-0006
3.	Makerbot 3D printer	Ultimaker 3 3D Printer	PB205(R)-1712-0010
4	Linear actuators	Nitto Kohki Linear Motor	PB105(R)-1808-0010
5	Data Acquisition System	NI C-series modules and accessories for CompactRIO.	PB105(R)-1810-0002

Project Achievements

No.	Achievements	How many?
1.	**Direct Outputs:** -Algorithm/Numerical, Method/Technique, Structure/Design, Prototype, Data -Others	One prototype has been built.
2.	**Intellectual Property (IP):** -Copyright/Trade Secret/Trademarks/Patent	N/A
3.	**Publications:** -Articles/Papers/Books/Others	**Two papers published in Scopus-indexed journal.** **https://doi.org/10.15282/jmes.13.1.2019.25.0395**
4.	**Researcher, Scientist, Engineer (RSE) created:** -PhD/MSc/BSc/Research Staff -Local/International -Specialization Area	3 Master students (Writing-up) 4 FYP Bachelor-COMPLETED 1 FYP Bachelor Thesis (Dwi-Ijazah)-COMPLETED
5.	**Participation in conferences/seminars:** -Local/International	**Two conference papers presented.**
6.	**Award(s)** -Local/International	**Silver Medal CITREX 2019.**

Human Capital Development

No.	Name (MSc/PhD)	Thesis Title	Status (Ongoing/Writing up/Completed)
1.	Muhammad Kamili Bin Zahidi (MSc) MMM16013.	Port Flow Performance Investigations of a Flexible Valve Timing baseline engine.	Waiting for pre-viva.
2.	Mohammad Shahin Bin Mansor (MSc) MMA17005.	Design and performance of flexure bearing for camless engine Flexible Valve Timing system.	On-going.
3.	Muhammad Haziq Adham Bin Rosli (MSc) (MMA18002)	Design and performance of flexure bearing for camless engine Flexible Valve Timing system.	Write-up.
4.	Muhamad Arif Ashraf Bin Abd Satar (FYP-Bachelor Degree) MH13041.	Design and development of a flexure bearing for linear actuator application.	Completed.
5.	Abdul Mu`Iz Bin Ismail (FYP-Bachelor Degree) MH13024.	Design and development of valve actuator test rig.	Completed.
6.	Muhammad Haziq Adham Bin Rosli (Bachelor Thesis (ID: HB13021))	Numerical Investigation Of A Four Stroke Flexible Valve Timings	Completed.
7.	Muhammad Arif Bin Mohamad Juhari (FYP-Bachelor Degree) MH 15026.	Performance Investigation of Various Flexure Bearing Designs.	Completed.

Potential for Commercialization

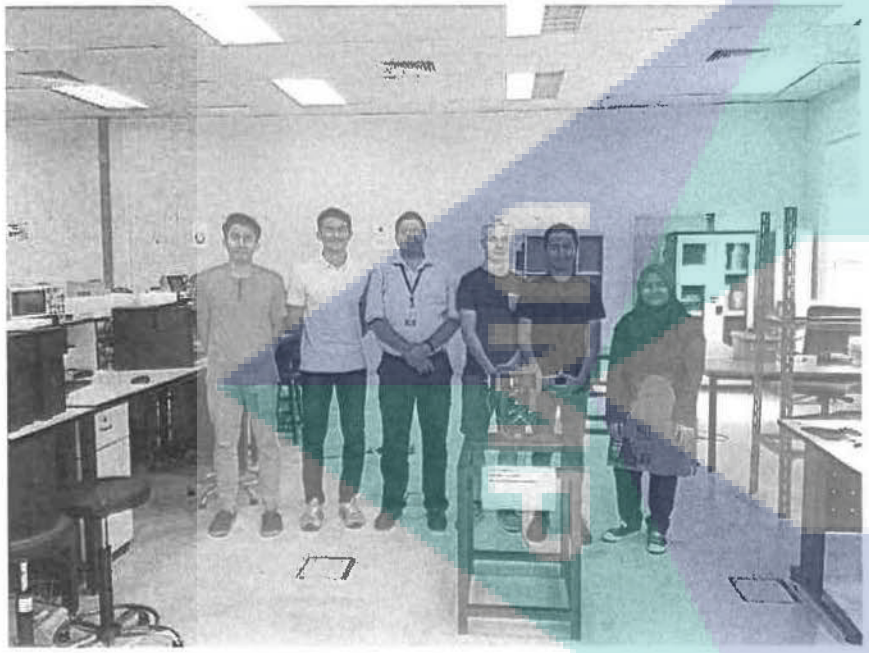
- There are several high potential components/system for commercialisations:

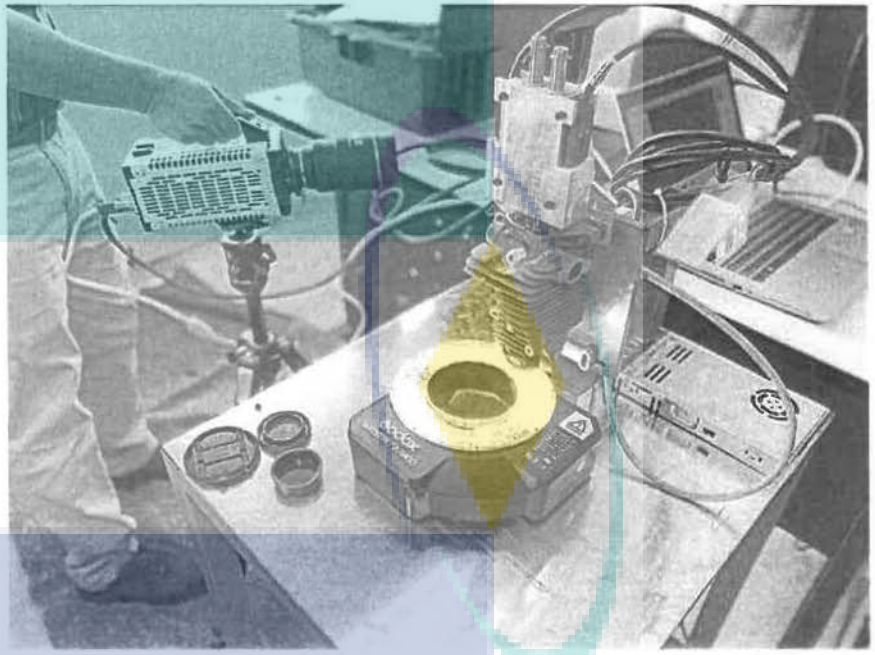
1. The use of linear motor for direct actuation mechanism.
2. The use of flexure bearing as the spring to replace conventional mechanical coil spring.
3. The motion control of the direct actuation system for flexible valve timing (FVT)- which can vary the intake and exhaust valve timings and lifts.

Future Plan

- Apply flagship (internal) fund:
  1. For further improvement of the laboratory prototype preparation into TRL4.
  2. Combustion testing of the prototype to obtain performance curves and thermal impact on the FVT system performance.

End of presentation





Thank you for listening...

UMP