DESIGN AND DEVELOPMENT OF AUTOMATION SYSTEM FOR PRECISION APPROACH PATH INDICATOR (PAPI) IN AIRFIELD LIGHTING

SHAH RIZAL BIN MOHD SHAHER

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RESEARCH REPORT SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF ENGINEERING (MECHATRONICS)

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DESIGN AND DEVELOPMENT OF AUTOMATION SYSTEM FOR PRECISION APPROACH PATH INDICATOR (PAPI) IN AIRFIELD LIGHTING

Field of Study: **Automation**

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ABSTRACT

Airfield Grounding lighting (AGL) is the aid for the pilot to take off and land, it consists of the structure of lights, power supply, mounting systems and control from the air traffic control tower to substation and to lights. AGL are divided into three main parts, which are power supply, lighting and control system. In this project, we focused only on the lighting part that gives an aid to the pilot for safe landing by using a 3-degree slope of runway. It is called Precision Approach Path Indicator (PAPI) which is the most important light in airfield lighting. PAPI is a valuable visual aid that can provide precision direction for pilots when making a landing. Normally PAPI is a single bar with four units located on the left side of a runway for touch-down aiming point, whilst in some airports PAPI are installed in 2 bars on left and right side. To maintain operational conditions and precision of the system, PAPI must be calibrated once a year and maintenance must be carried out periodically. The calibration is done by using special tools and manually adjust the angle of the PAPI as instructed by the flight calibration team provided by the department of civil aviation authority. While carrying out PAPI calibration, the access to the runway will be blocked and all aircraft will be rescheduled. The inspection on PAPI is made by checking each of PAPI angle as specified in ICAO annex 14 which are 2.50°, 2.83°, 3.17°and 3.50°. This is very time consuming as the calibration needs to be done manually and extra man power is needed to communicate with aircraft calibration. Also, if mis-align then consume time to re align. The more time taken to conduct this exercise the more cost will be incurred to pay to the department of civil aviation authority. In this project, an automated PAPI calibration system is designed by using PAPI system and Leadscrew Stepper Motor on AutoCAD SOLIDWORKS. Then, design ladder Diagram has been constructed to simulate operation of stepper motor combined with PAPI system for automatic movement. Design model of Leadscrew

stepper motor is integrated on PAPI system and helped to move the PAPI up and down (vertically) to adjust elevation angle of PAPI system. This design will allow automatic adjustment of the system and subsequently it would reduce the cost of maintenance on extra man power, special tools, safety and the most important factor is less time consuming.

ABSTRAK

Semua cahaya dalam lampu Airfield Grounding (AGL), dengan sistem bekalan kuasa, sistem pelekap dan sistem kawalan masing-masing yang digunakan untuk "penglihatan" menyokong pendaratan, pergerakan, teksi dan pesawat udara. AGL boleh dibahagikan kepada tiga bahagian, seperti bekalan kuasa, pencahayaan, Sistem Kawalan Pencahayaan Airfield (ALCS & ILCMS). Dalam projek ini, kami menumpukan Precision Approach Path Indicator (PAPI) salah satu cahaya dalam lampu lapangan terbang. PAPI adalah bantuan visual berharga yang dibangunkan untuk memberikan arahan ketepatan untuk juruterbang apabila membuat pendekatan ke landasan kapal terbang. Penyokong sistem PAPI membantu penambah baikan berikut seperti peralihan cepat warna putih / merah yang tepat dari satu warna ke yang lain. Titik merentas satu bar, panduan pelbagai laluan (maklumat tambahan). Untuk mengekalkan keadaan operasi dan ketepatan sistem, penyelenggaraan dijangka dijalankan menggunakan misalnya mesin terbang atau platform kerja mengangkat. Menyekat akses ke landasan, pemeriksaan PAPI dibuat dengan mensimulasikan pendekatan sinusoidal untuk mengesahkan sudut ambang dan memastikan pematuhan dengan peraturan. Oleh itu, lapangan terbang itu semestinya menutup jalan landasan, memakan masa, memaksimumkan logistik rumit dan mengambil risiko dengan menggerakkan pengendali di udara dan landasan. Pada masa ini untuk menyesuaikan sudut ketinggian, memerlukan alat khas dan tenaga manusia tambahan untuk berkomunikasi dengan penentu ukuran pesawat dan menyesuaikan sudut menggunakan alat dan manual. Terdapat lebih banyak masa, memakan kos yang lebih banyak bagi pihak berkuasa penerbangan awam jabatan. Juga, jika salah menyelaraskan kemudian mengambil masa untuk menyelaraskan semula. Dalam projek ini, sistem PAPI dan Leadscrew Stepper

Motor direka pada AutoCAD SOLIDWORKS. Diagram Ladang juga merancang untuk memeriksa Operasi Simulasi motor stepper yang digabungkan dengan sistem PAPI. Model reka bentuk stepper motor Leadscrew bersepadu pada sistem PAPI dan membantu menggerakkan PAPI ke atas dan ke bawah (menegak) untuk menyesuaikan sudut ketinggian sistem PAPI. Reka bentuk ini membantu membuat sistem automatik dan ia dapat mengurangkan kos tenaga manusia tambahan, alat khas, kos dan faktor yang paling penting menjimatkan masa.

ACKNOWLEDGEMENTS

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Next, I am deeply indebted to my parents for their continuous encouragement and support. To my mother I really loves you, always pray for you. For my father whom has passed away in 2016, I really respect you and I am here because all of your guide. May Allah blessed you. His loves and cares has been driving force for this endeavor and no words of gratitude are enough.

Special thanks to my wife, families and sisters for their unconditional love and support. Thanks, are also due to all my friends, relatives, and colleagues for their support.

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LIST OF SYMBOLS AND ABBREVIATIONS

PAPI	:	Precision Approach Path Indicator
ICAO	:	International Civil Aviation Organization
AC	:	Alternating Current
DC	:	Direct Current
PLC	:	Programmable Logic Control
PM	:	Permanent Magnet
I.C	:	Integrated Circuit
PMH	:	Permanent Magnet Hybrid
VR	:	Variable Reluctance
NR	:	Total Number of Rotor Teeth
SPR	:	Number of Steps Per Revolution
SA	:	Step Angle
ILS	:	Instrument Landing System
OCS	:	Obstacle Clearance Surface
WCT	:	Wheel Clearance at Threshold
MWHT	:	Minimum Wheel Height over the Threshold
EWH	:	Eye-to-Wheel Height
TCM	:	Threshold Clearance Margin
EAH	:	Eye-Antenna Height
MEHT	:	Minimum-Eye-Height-Over Threshold
NEMA	:	National Electrical Manufacturers Association
VASI	:	Visual approach slope indicator
BLDC	:	Brushless Direct Current

CHAPTER 1: INTRODUCTION

1.1 Introduction

Airfield lighting consists of set configurations of lights such as Approach, Precision Approach Path Indicator (PAPI), Threshold, Threshold Wingbars, Runway edge, Runway Centreline, Runway end and Touchdown zone for the runway of an airport. And for the taxiways, it consists of Edge, Centreline, Stopbar, Lead On and Guidance Sign. Each light gives different indication to pilot and helps pilots to land, taxiing and park to apron area (Runyon et al., 1996).

One of most important light used in airfield lighting is PAPI. PAPI is a valuable visual aid developed to provide precision direction for pilots when making an approach to land. PAPI was internationally accepted visual aid by the ICAO in 1995 (D. J. W. Walker, 2012). Supporters of PAPI system claimed the following improvements (or advantages ?) of PAPI system as shown in Figure 1.1.

1. A quick sharp white/red transition from one color to the other.
2. Below 200 feet better guidance (or Better guidance for below 200 feet)
3. A single bar touch-down aiming point.
4. Guidance of multiple path (incremental information).

Figure 1. 1 System of PAPI

Bar of four light units in PAPI system (two or three lamps per unit) located mostly on the left side of the runway 300-450 meters from the runway threshold. In PAPI principle, it utilizes red and white lights in several combinations to give a clear signal to the pilot of the approach angle the aircraft is following. Each PAPI unit is set at a little unalike angle (20 minutes apart) and emits a high intensity of light beam, red is shown by lower half and the upper half showing white. The effective visual range of this instrument is up to 20 miles at night and up to 3 miles during the day. To maintain operational conditions and precision of the system, projected maintenance is carried-out using flying machines or elevating work platforms. Blocking off the access to the runway, PAPI's checking is made by simulating sinusoidal approaches to verify threshold angles and ensure compliance with regulations (Castle, 1983).

For the purpose of this research, selection of motor is made from the different types of electrical machines such AC, DC and special purpose motors. The special purpose motors cover wide area of applications in almost every industry and is the most important electrical machine used for specific applications. Stepper motor is one type of special purpose motor used for applications that need a small step angle and it is used in various applications like tools of machine, healthcare industry, controlling of process, business machines and computers industry. There are different types of stepper motor namely variable reluctance, permanent magnet and hybrid stepper motor. Depends on application, each motor has their own advantages and disadvantages (Toliyat et al., 2012),(Slemon, 1992),(Hubert, 1990).

1.2 Problem Statement of Research:

To maintain operational conditions and precision of the system, projected maintenance is carried-out using for instance flying machines or elevating work platforms. With runway is closed for all activities, simulation of sinusoidal approaches is made by the flying machine or elevating work platforms to verify the threshold angles as outlined in the requirement documents set by the regulations. On the down side, this exercise would result in the airport necessarily shuts down the runway, consuming up-time, imposing complicated logistics and taking risks by deploying operators in the air and on the runways.

Currently the method to adjust the elevation angle requires dedicated tools and extra manpower to communicate with the calibration aircraft. The calibration aircraft is a service provided by the department of civil aviation authority and paid by the airport operator for this exercise. The angles are adjusted manually using the tool to get the desired angles as per specified in the regulation documents ICAO Annex 14.

In most of the cases, the operator would take quite some time to adjust and get to the desired angles as the adjustments are done manually. As the time taken gets longer to calibrate accurately, the more cost will be incurred for the flying machines service. Not only that, in case of mis-alignment, the operator needs to do re-alignment which results in longer time consumption.

With these influencing factors on the difficulties adjusting the PAPI for calibration, this research aimed to develop the PAPI with automation to adjust the elevation angle by using hybrid stepper motor and timer as well as to design the PAPI to integrate with the mechanism of stepper motor.

1.3 Objective of Research:

There are three main objectives of this project as follows:

1. To design a PAPI using SOLIDWORKS
2. To develop controller for PAPI by using a programmable Logic Control (PLC).
3. To test and simulate the controller for PAPI by using CX-Programmer

1.4 Scope of Project

Current product in the industry are still using the manual way to adjust the elevation angle using special tools. The scope of this project is to design a hybrid stepper motor and timer. PAPI is design based on specification by using AutoCAD SOLIDWORKS. Design model of hybrid lead screw stepper motor is integrated on PAPI system and move the PAPI system vertically to adjust the elevation angle of the system. Both hybrid stepper motor and PAPI system is designed by using AutoCAD SOLIDWORKS software. In future, this technology could reduce a cost of extra man power, special tools, cost and the most important factor which is less time consumption.

1.5 Thesis Organization

This report consists of 5 chapters and begin with chapter 1 with the introduction of this project and problem statement that concerns. While chapters 2 focuses more on the literature review related to the PAPI design, installation, angle and location of the PAPI in the airfield lighting. Chapter 3 will demonstrate the project's flow chart, design SOLIDWORKS and methodology of the project. Meanwhile chapter 4 will discuss on the mathematical derivations, test and simulate the controller using CX Programmer. Finally, chapter 5 contains discussion on overall chapter, conclusion and recommendation for future work.

CHAPTER 2: LITERATURE REVIEW

2.1 PAPI Study

We have reviewed the journal and papers regarding the PAPI study and there are some relevant to the PAPI in this study.

2.1.1 Improved Optimal Route Evaluation Method for Wireless Sensor Network

It is well known that both a "minimal energy consuming path" and "balanced communication load among the nodes" are necessary criteria for route evaluation. To achieve acceptable performance, these two requirements must be well balanced. To provide this balance, we propose an improved optimal route evaluation method based on the principal component approach for wireless sensor networks. This method ensures a diversified evaluation and prompt dynamic load balance in different network monitoring environments. Further, the weighting factor of each evaluation indicator can be estimated using the principal component approach. This method can avoid the problem of requiring manual selection of weight factors based on experience, which lacks guidance based on scientific theories, is subjective, and may negatively affect evaluation precision. Comparison with other state-of-the-art algorithms confirms that the proposed evaluation function improves the performance of a network significantly (Liu & Wang, 2018).

2.1.2. A vision-based method for supporting autonomous aircraft landing

Purpose This paper aims to present a vision-based method for determination of the position of a fixed-wing aircraft that is approaching a runway. Design methodology / approach the method determines the location of an aircraft based on positions of precision approach path indicator lights and approach light system with sequenced flashing lights in the image captured by an on-board camera. Findings As the relation of the lighting systems to the touchdown area on the considered runway is known in advance, the detected lights, seen as glowing lines or highlighted areas, in the image can be mapped onto the real-world coordinates and then used to estimate the position of the aircraft. Furthermore, the colors of lights are detected and can be used as auxiliary information. Practical implications The presented method can be considered as a potential source of flight data for autonomous approach and for augmentation of manual approach (Oszust et al., 2018).

2.1.3 LED Light sources in the approach slope indicators and their visibility in inhomogeneous atmosphere

The PAPI (Precision Approach Path Indicator) optical system with incandescent light sources (halogen airport lamps) is already an integral part of the airport lighting system (Nagod & Halse), both stationary and mobile airfields of The Czech Air Force. The development unambiguously directs to the replacement of the incandescent light sources in the APAPI (Abbreviated PAPI) an optical unit with LED (Light-Emitting Diodes) light source with the high luminous efficiency. Considerable technological and light differences among the LED light sources and the halogen airport lamps lead to high difficulties of the theoretical design, development and construction of the new LED APAPI optical system assembly. This article illustrates the shape, light efficiency and spectral characteristics, differences among the LED light sources and the halogen airport lamps and a possible way of APAPI optical system design with LED light sources. Every element of the approach slope indicator system must be watched for the minimum specific time to provide information. This time is defined at least 2 or 3 seconds and most importantly depends on the pilot and his abilities. The visibility of the APAPI light is caused by its light on the retina surface in the eye. The basic requirement is the fact that the intensity of the light must be on a higher level than the contrast threshold. The contrast threshold depends on lots of conditions - basically on the color of the light or on the bandwidth of the light spectrum, brightness of the background, a current state of the pilot, etc. If the light source dimension is small enough - ten centimeters watched from hundreds of meters - it is considered as a spot light. Anyway, Allard's law is used for the range determination of the simple APAPI light. The results of these reflections are described and defined in the aerodrome standards and documents, especially in ICAO Annex 14 for a long time. However, these kinds of standards are built only for classical light sources as the halogen bulbs. Thinking about incoming light sources, especially LEDs in demanding airport lightning applications like PAPI, it is necessary to consider not only intensity of the light but also their non-continuous spectral characteristics and to verify the light sources in these aerodrome applications by the mentioned ways (Bloudicek & Luzica, 2015).

2.1.4. Optical design of Precision approach path indicators in a portable runway lighting system

Portable runway lighting systems pose an interesting illumination challenge. They are typically used in harsh environments where generators or batteries are used to provide electricity. As a result, not only do the systems have to satisfy the regulatory requirements which determine the light intensity profile, but they also need to be highly efficient and within a compact design. This paper summarizes the optical design and performance of a PAPI system using LEDs which are coupled into a waveguide to generate the required light distribution at an intermediate plane after the waveguide. The use of waveguides means that a single projection lens is used to generate the final beam and these images the output of the waveguides into the far field (D. J. Walker & Monaghan, 2015).

2.2 Technical Notes on PAPI

The Precision Approach Path Indicator (PAPI) is a valuable visual aid developed to provide precision guidance for pilots when making an approach to land (Kaminski et al., 2008).

In principle it utilizes white and red light in various combinations to give a clear indication to the pilot of the approach angle the aircraft is following. In 1995 the PAPI became the ICAO internationally accepted visual aid. PAPI system claimed of following Improvements are (D. J. W. Walker, 2012):

- A quick, sharp white/red transition from one color to another.
- Below 200feet better guidance.
- Guidance of multiple path
- A touch-aiming point with single bar.

There is bar of four light units (three lamps per unit) in PAPI system facing the approach runway end. Each unit emits a light beam of high intensity, the lower half showing red and upper half showing white and each unit fixed at a marginally different angle (20 minutes apart). Figure 2.18 shows signal sectors side view in the zone of approach. As seen by the approaching pilot, it consists of four quick transition red/white light bar units who's on-glide path signal (generally 3°) is two white and two red lights When the aircraft between 2° 50 minutes and 2° 30 minutes which is marginally below glide path, the signal changes to one white and three red lights. A fly-up of four red lights is seen, when the aircraft is further below glide path (below 2° 30 minutes). On the other hand, red-light units turn to continually white due to deviations above the glide path. The lights can be seen at about 5 miles from the runway threshold (in unlimited visibility) in this configuration and the on-glide path depth of signal progressively decreases to approximately 6 feet at the threshold (Tian & Tian, 2013).

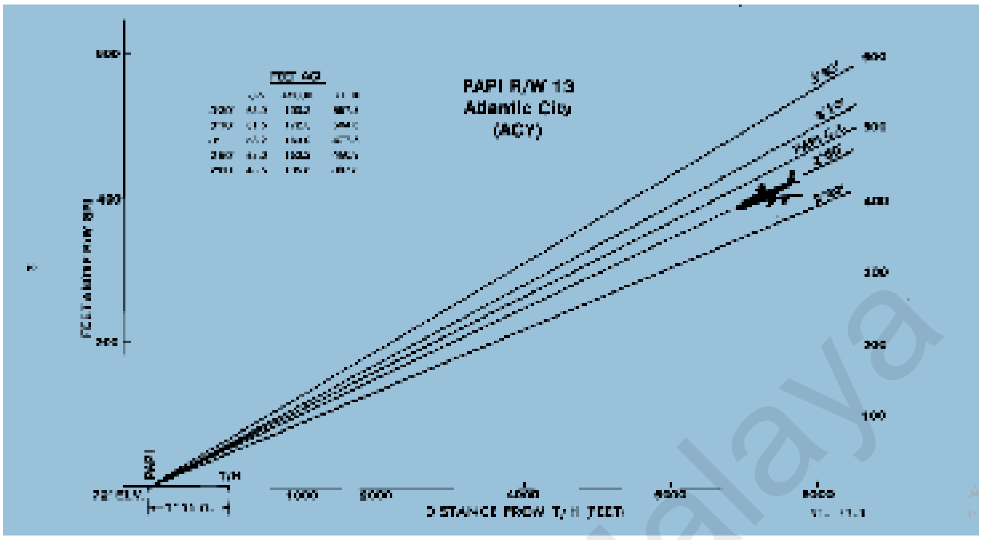


Figure 2. 1 PAPI approach path (side view)

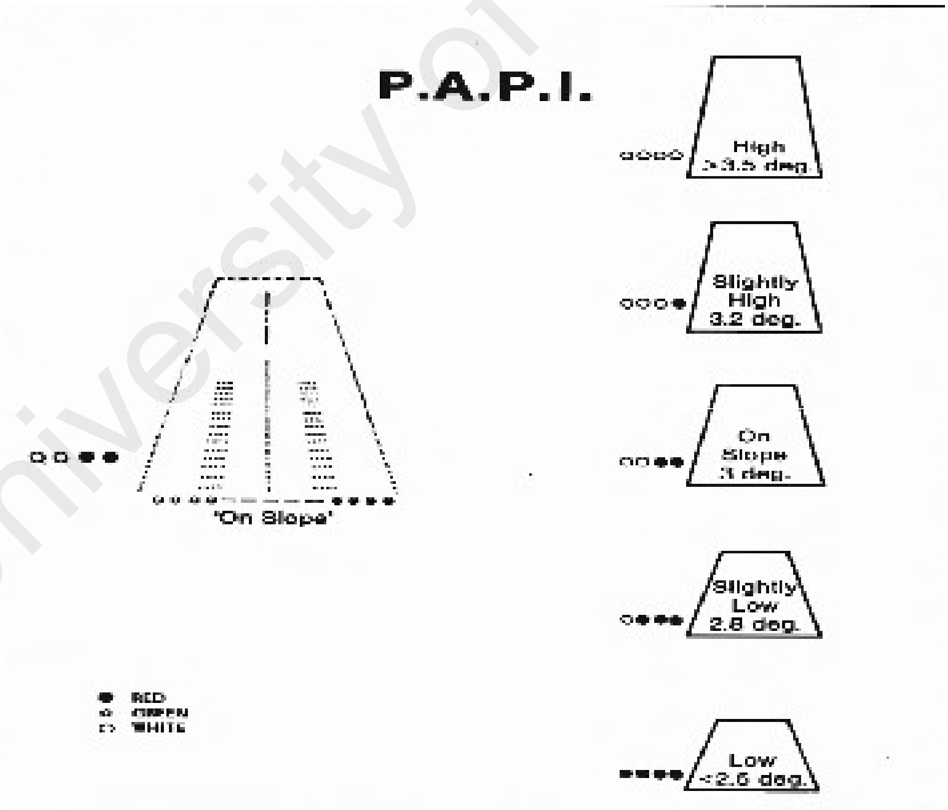


Figure 2. 2 Approach Path Illustration

The Precision Approach Path Indicator (PAPI) is a 4 light units block located beside landing runways, that provides visual guidance information to pilots for acquiring and maintaining a safe and accurate glide slope on final approach. Placed perpendicular to the runway approach path, generally on the left side, each PAPI unit fits a row of lights emitting red light below a certain angle, and white light over. This instrument can have an effective visual range up to 3 miles during the day and up to 20 miles at night.

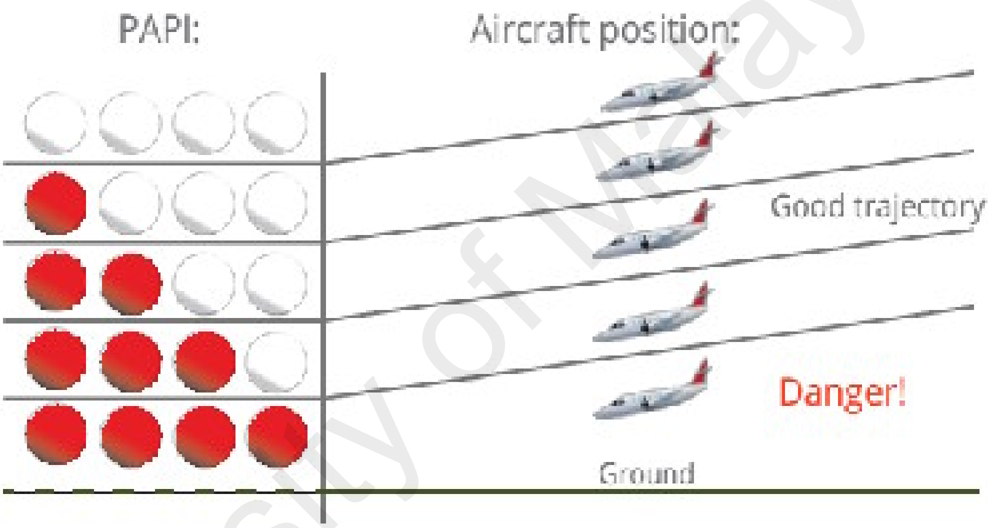


Figure 2. 3 PAPI light units block visual guidance

While landing, pilots can determine if their approach is too high, too low or on the correct slope, thanks to the red and white indicators. For a correct approach, the pilot must observe 2 red and 2 white lights as follow. From 3 white lights and more, it indicates that the aircraft is too high. On the other hand, 3 red lights and more indicates that the aircraft approach is dangerously too low. To maintain operational conditions and precision of the system, projected maintenance is carried-on using for instance flying machines or elevating work platforms. Blocking off the access to the runway, PAPIs checking is made by simulating sinusoidal approaches to verify threshold angles and ensure compliance with regulations. On the down side, the airport necessarily shuts down the runway, consuming up-time, imposing complicated logistics and taking risks by deploying operators in the air and on the runways (Castle, 1983).

2.3 Back ground of PAPI

Since precision landings have been required, there have been several devices used to assist pilots when making an approach to land. They ranged from single light units that incorporated a motor to drive a disc housing colored filters, to the more commonly used 2 Bar and 3 Bar VASI or AVASI. There are other systems still in use (e.g. Australia) such as the T-VASIS and ATVASIS. To improve approach slope guidance, developers and designers of visual aids increased the numbers of light units dramatically. The result was to add a greater element of confusion in to the equation. The old systems where constructed around, SIMPLICITY INCREASES RELIABILITY, so developing a system that basically only uses 4 light units was a change for the better (Castle, 1983).

2.4 The Requirement

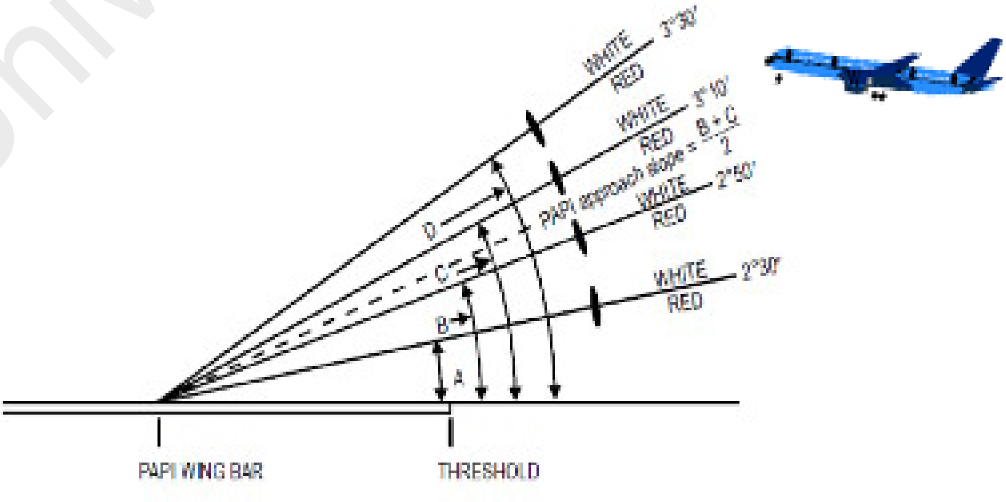
The PAPI system is normally a single wing bar consisting of 4 light units situated on the left side of the runway. However, it is acceptable to locate the PAPI on the right side if local conditions prevent it being located on the port side. In addition, many airports adopt to have two PAPI Wing-Bars. This configuration is referred to as bi-lateral and consists of port and starboard wing bars that employ a total of 8 light units for each runway touchdown zone. A full bi-lateral system would generally be employed on the larger airports providing the runway/taxiway layout places no restrictions on its use (Smith & Johnson, 1976).

Figure 2. 4 Typical unit of PAPI

2.5 Settings angles

1. The typical settings angles for a 3° glide slope are 2°30' (unit A); 2°50' (unit B); 3°10 ' (unit C) and 3°30': it means a sector of 20' difference between each unit.
2. The on-course sector of 20' can vary according the presence of an instrument landing system (ILS) (2°25'; 2°45'; 3°15' & 3°35')
3. If double wing : symmetric transition at the same moment
4. A-PAPI: setting angles of 2°45 and 3°15'
5. If double wing: symmetric transition at the same moment

a



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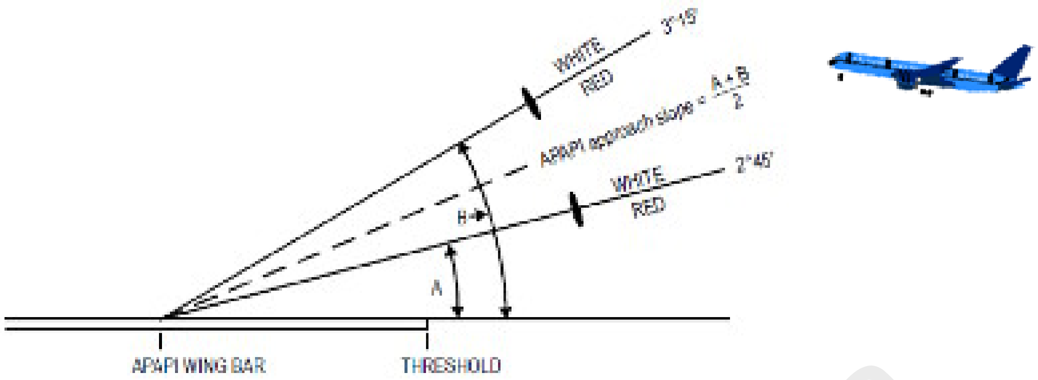


Figure 2. 5 Setting (a) Angles of PAPI and (b) A-PAPI

2.6 Obstacle Clearance Surface

- To guarantee the obstacle clearance for an aircraft approaching the runway guided by a PAPI system, the OCS is established and measure it is clear up to 15 kilometers.
- This OCS is an inclined plane surface starting from the runway before the PAPI unit. The slope of the OCS surface is 0.57° lower than the setting angle of the lowest PAPI
- Its horizontal projection is also defined
- The angle of elevation settings of the light units in a PAPI wing bar shall be such that, during approach, the pilot of an aero plane observing a signal of one white and three reds will clear all objects in the approach area by a safe margin.
- If the units show red in color, the pilot knows he is dangerously below the glide slope and possibly even below the obstacle clearance surface (OCS) (Millar, 1984).

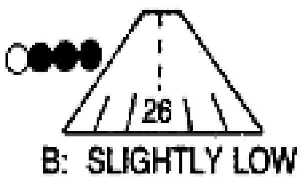


Figure 2. 6 Shows Pilot Approach Slightly Low

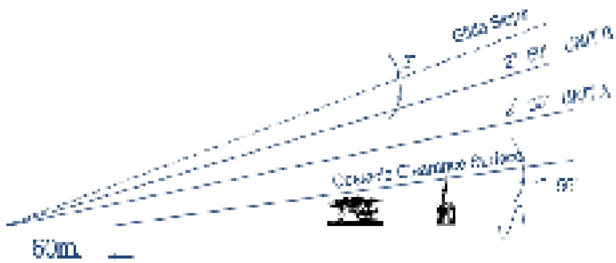


Figure 2. 7 View of obstacle clearance surface

2.7 Design of the PAPI unit

Each PAPI unit divides the light output into two main sectors. The area that divides the white and red light is known as the Transition Sector. In this area, pink light is produced as a result of white and red light overlapping which create pink in between.

Manufacturers have design limits that do not exceed ICAO Annex 14 recommendations, namely:

- A maximum of 3 minutes of arc are all that are allowed for the transition sector.

The modern method for those companies using credible design and good lens optics, is to have a double lens configuration to reduce the pink zone.

Many pilots today complain that the PAPI units are pink looking after a period. Unfortunately, when this is the case it is either:

- The deterioration in the quality of the lens
- Or the unit is constructed using one lens assembly only.

Whilst these units under aircrew complaint are compliant at manufacture and installation, deterioration soon occurs resulting in the pink complaint from the aircrew. When this is the situation, we can only assume that the airport has purchased units from less reputable suppliers

2.8 Transition Sector

- **PAPI unit:** light signal**,** lower half: red, upper half: white.
- The transition from one color to another one in a vertical plane have to be virtually instantaneous => impossible

- The color transition from red to white in the vertical plane shall be such as to appear to an observer, at a distance of at least 300m, to occur within a vertical angle of not more than 3’,
- Transition sector lower than 3’ arc in depth and 8° horizontally on both sides of the beam’s center, with a maximum expansion of 5’ arc in depth and 8° horizontally on both edges of the beam.

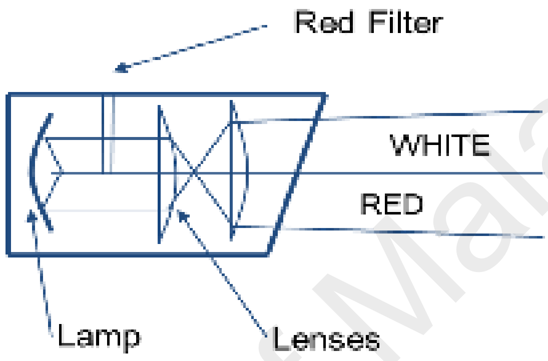


Figure 2. 8 Internal view of PAPI Unit

- Thanks to the use of the two lenses in tandem, the producer reaches a transition sector which does not exceed 3’ arc through the whole horizontal width of the beam.
- Only one lens: big distortion of the projected image.

The following diagram shows the light output from a reputable supplier:

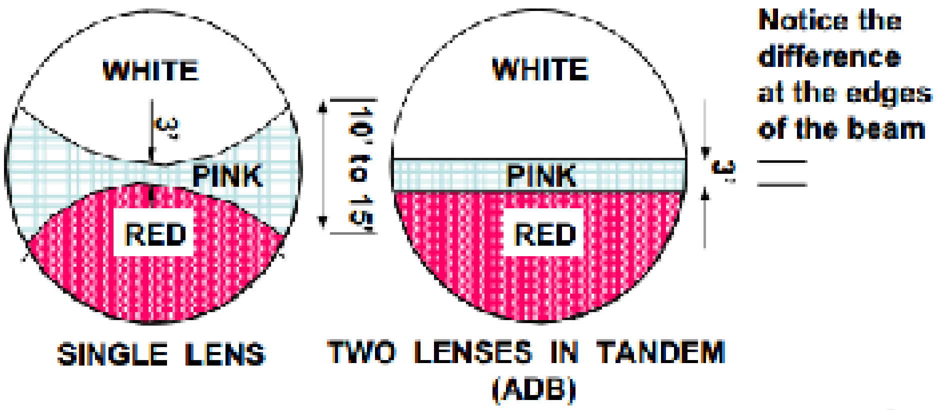


Figure 2. 9 Characteristics of the light unit's Transition Sector Sharpness

- The transition sector is essential and must be as small as possible.
- Example: only one lens: transition sector of 10' on the beam's edges (optical distortion) => operational area: only 10' => very difficult for the pilot.

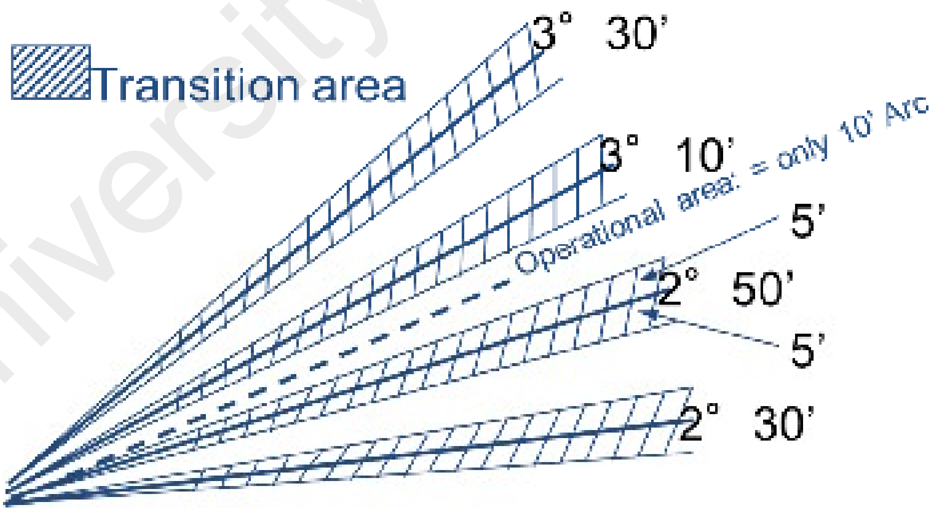


Figure 2. 10 Shows Transition Area

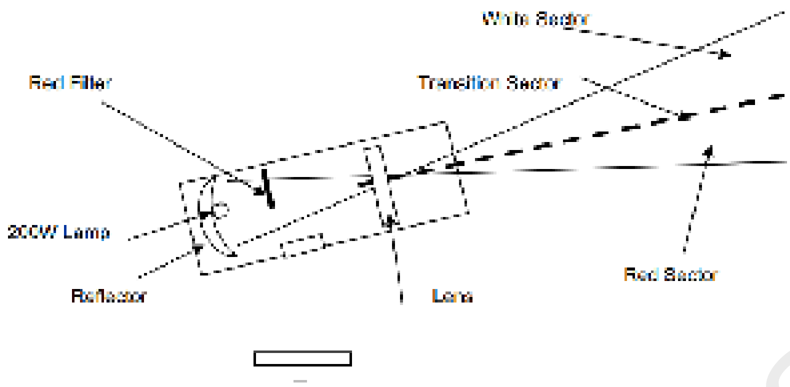


Figure 2. 11 Typical PAPI Component Layout

2.9 Typical PAPI Construction

Different components of a typical PAPI used in the construction PAPI unit are listed below as shown in figure 2.29.

1. Cover

2. Front glass

3. Front glass gasket

4. Outer lens + clamping ring

5. Inner lens + clamping ring

6. Red filter

7. Filter retainer

8. a. Refocus cold mirror halogen lamp (3)

8. b. Fixing holding spring

9. Terminal block with cut-out

10. Heat resistant wire

11. Cover gasket

12. Lockable latch

13. Aluminum alloy housing

14. Compression bushing)

15. 2-core cable with 2-pole plug

16. Upper flange

17. Levelling plate

18. Lower flange

19. Mounting leg with frangible groove

20. Ground mounting flange

21. Anchor bolts (6) (optional)

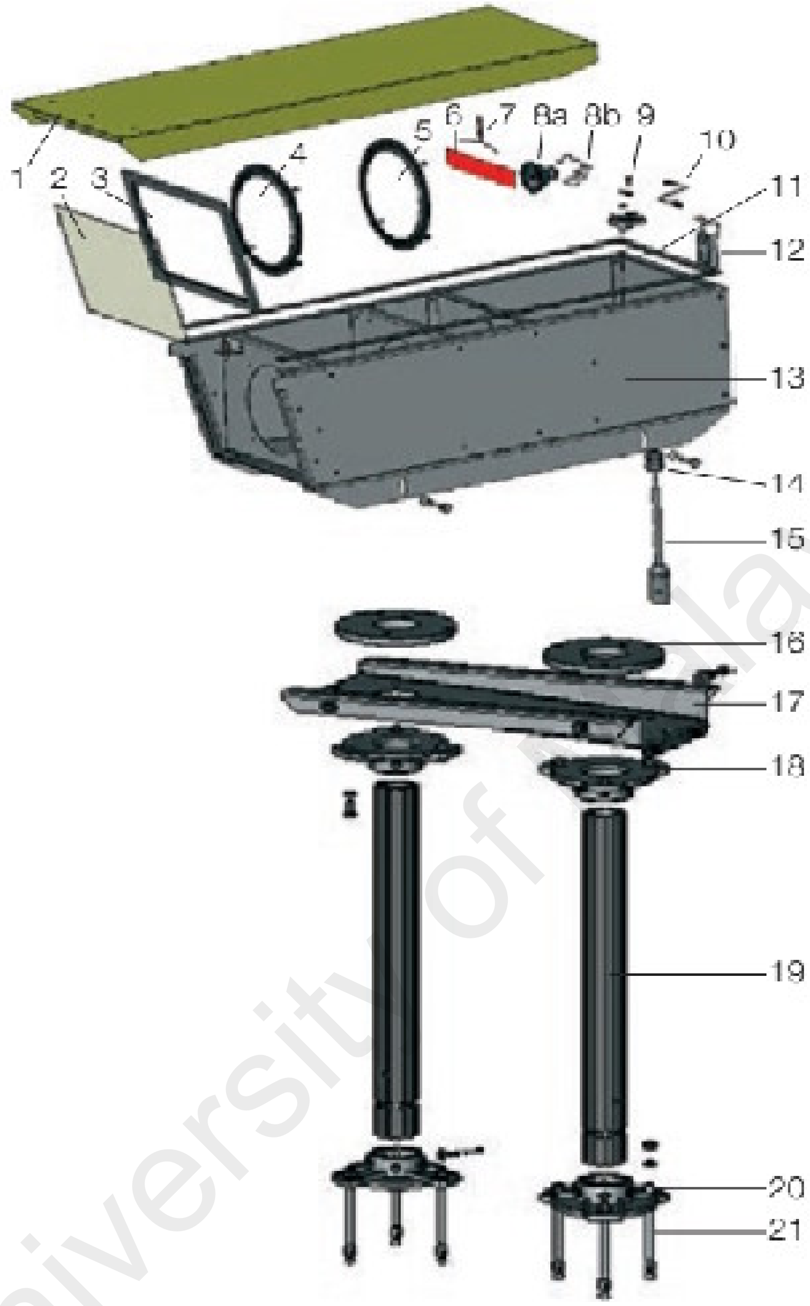


Figure 2. 12 Exploded view of PAPI

2.10 Light beams and angle of elevation setting of PAPI

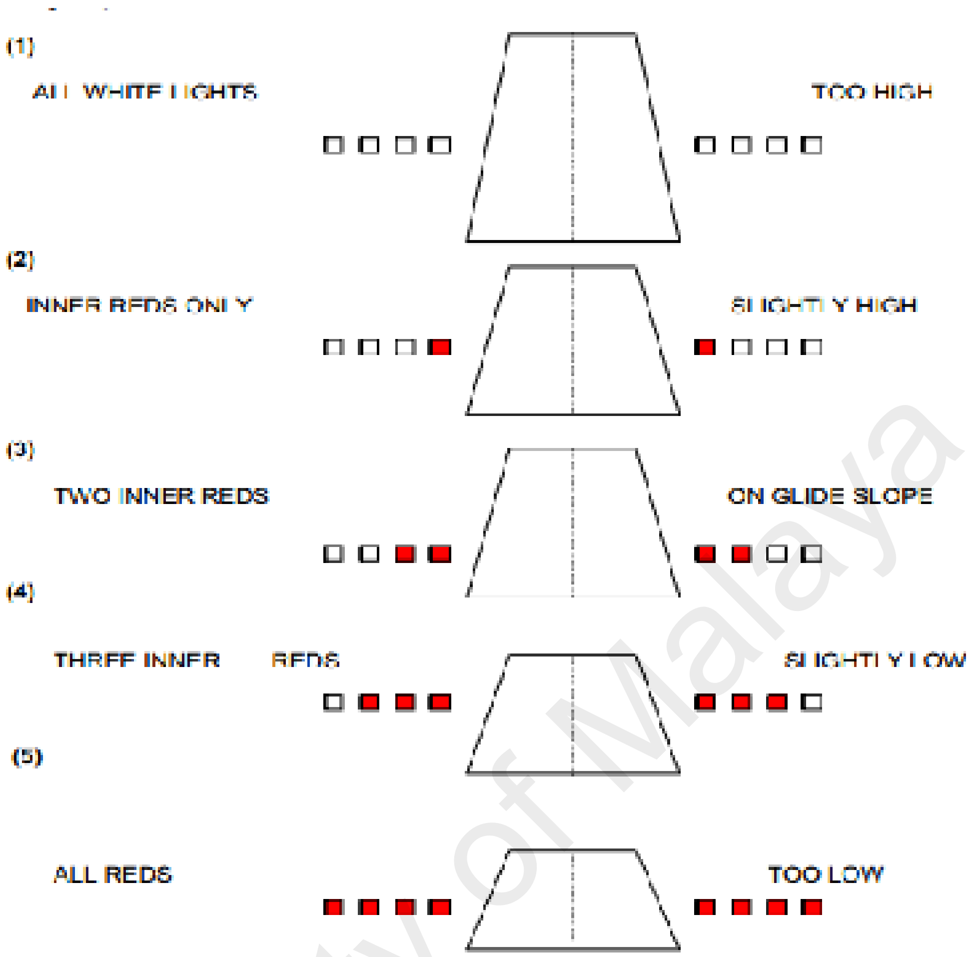


Figure 2. 13 Pilots View of PAPI Installation Depending on Approach Slope

2.11 Installation of PAPI unit

The position of the PAPI system will depend on:

- The type of airplane operating on the airfield
- The angle of the glide slope
- The OCS – Obstacle Clearance Surface
- The MWHT – Minimum Wheels Height over the Threshold
- The existence of non-visual aids giving a similar information (ILS, MLS, etc.).
- The clearance of the threshold: with a sufficient margin in height and speed.
- The WCT (Wheel clearance at threshold) depends on the EWH (eye-to-wheel height) which characterizes each plane.

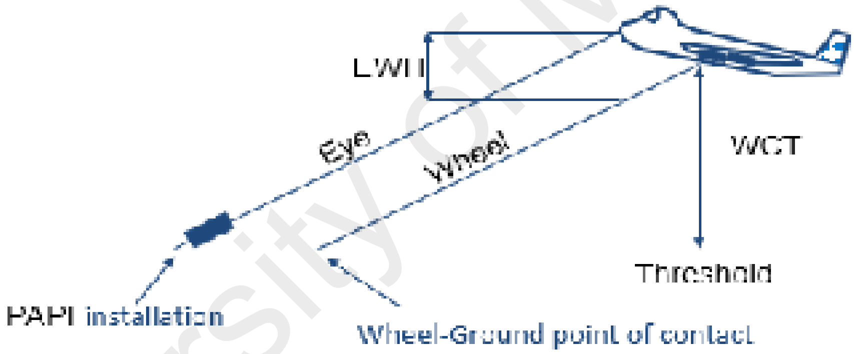


Figure 2. 14 PAPI Position

- Always consider the most constrained airplane with the biggest eye-wheel height to calculate the PAPI location

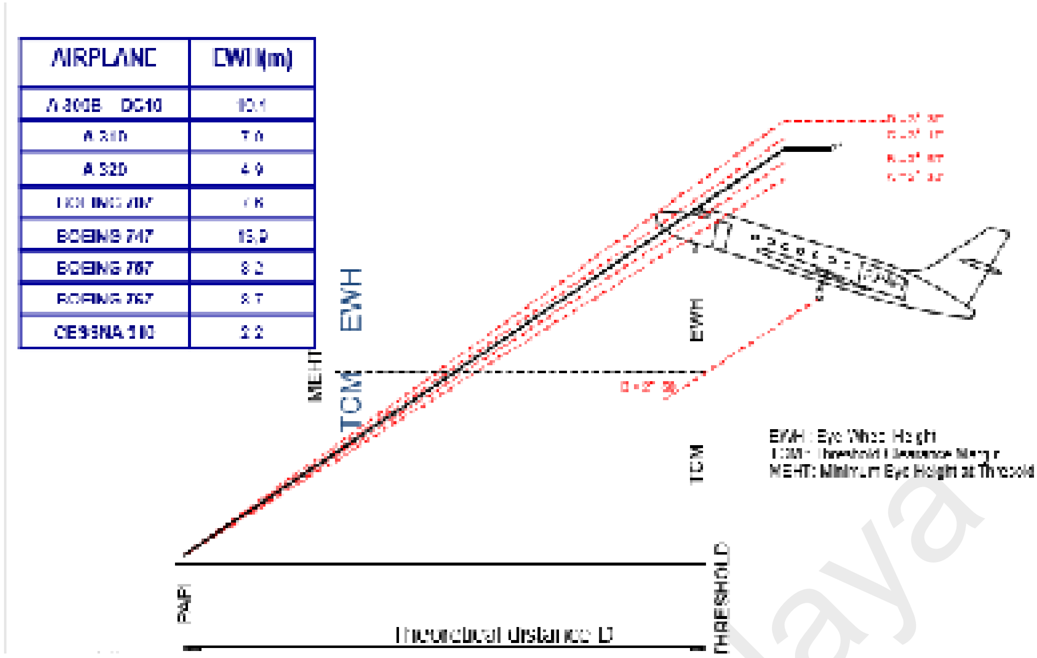


Figure 2. 15 Calculation of PAPI Location with Biggest Eye-Wheel Height

To determine the installation in relation to the threshold we first have to know the reference plane. This choice determines the EWH (Eye-Wheel Height) parameter and consequently the TCM (Threshold Clearance Margin) characteristic given below in the following table:

Table 2. 1 Characteristics of EWH and TCM

EHW	**Desire TCM**	**Minimal TCM**
< 3m	6m	3m (1)
≥3m et < 5m	9m	4m
≥5m et < 8m	9m	5m
≥8m et < 14m	9m	6m

- In exceptional cases this margin can be reduced to 1.5m if the runway is only used by light planes other than turbojet planes.
- The PAPI installation will not be done on the same location depending on whether the airfield is equipped with an ILS (Instrumental Landing System) or not.

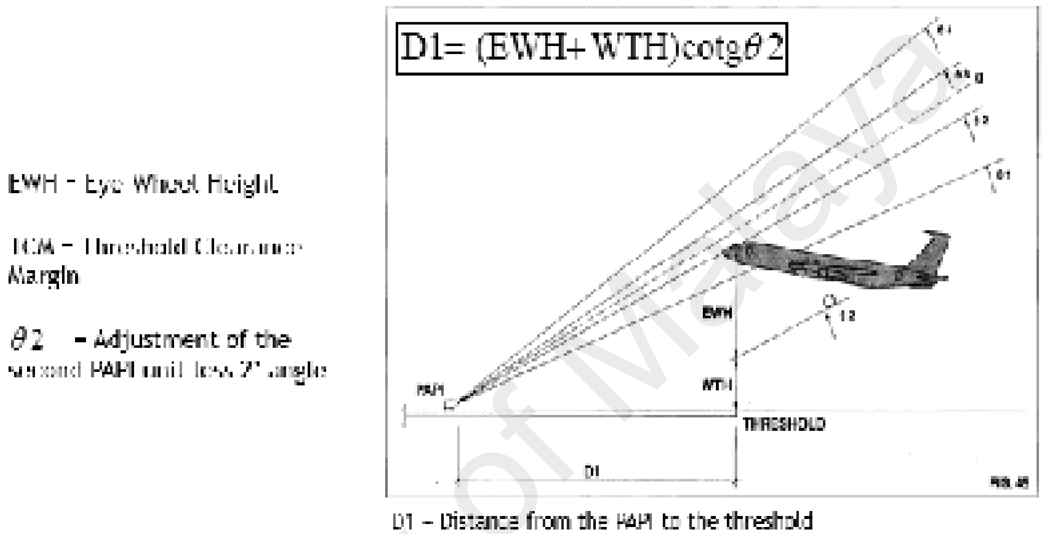


Figure 2. 16 Theoretical Positioning of the PAPI to Assure an Appropriate Threshold Clearance Margin

2.11.1 Verification of the interferences with Obstacle Clearance Surface (OCS)

- Lower edge: at 60 m of the threshold, width depends on the number code of the runway
- OCS = θ1 - 0.57°

θ1: adjustment of the PAPI-A unit

If the approach slope is of 3°

The OCS slope will be: = 2° 30’ - 0.57°= 1°56

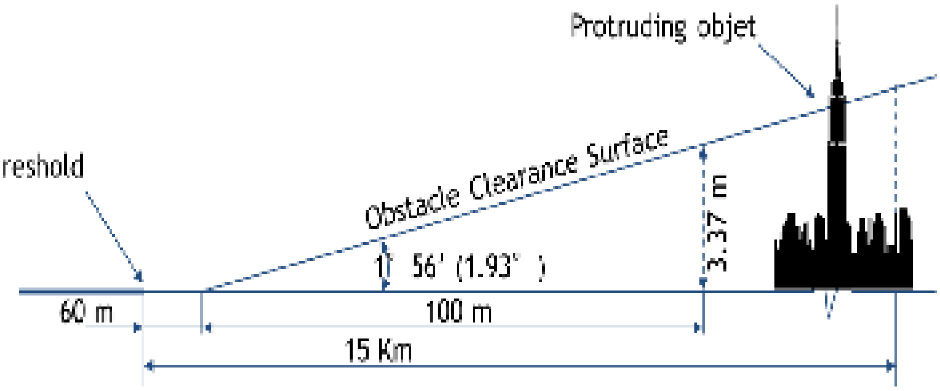


Figure 2. 17 Verification of the interferences with Obstacle Clearance Surface

If an obstacle interferes with the OCS, it will be necessary:

A) To displace or to remove the obstacle (if it is feasible)

B) To displace the threshold

C) To displace the PAPI in such a way the threshold clearance margin is increased by a height equal to the interference height of the obstacle

D) As a last resort, the approach slope shall be increased until the obstacle is no more in the OCS.

The calculation of PAPI's position is done based on the hypothesis that the units are at the same level as the runway axis adjacent to their position, which would be the same as the one of the threshold. If it is not the case, some additional calculations shall be done in order to iron out the topographical differences.

2.11.2 Installation of a PAPI with an ILS: Harmonization between the PAPI and ILS

- There is one point since where the pilot is out of the PAPI's approach way but still in the one of the ILS
- This point depends on the Eye-Antenna height (EAH)
- The influence of the ILS might extend the run
- until 30' for some kinds of devices (>< 20' normally).

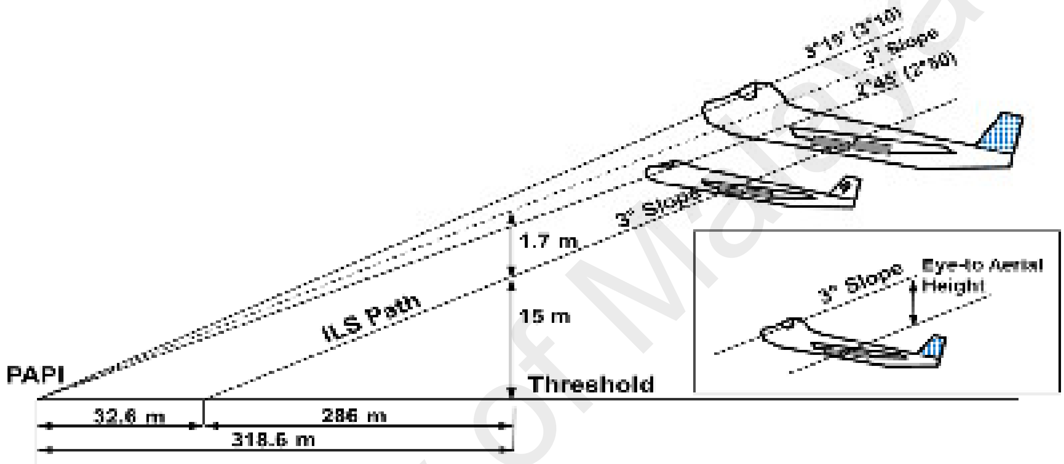


Figure 2. 18 Installation of a PAPI with an ILS

2.11.3 Calculation for the Positioning of a PAPI on a Runway Equipped with an ILS

2.11.4 Verification of wheel clearance height

A) EWH B737: 5.18m

	TCM Minimum TCM	(Threshold clearance margin)
B737	9m	6m

If MEHT of 15m, 15-5,18= 9.82m > 9m => OK.

2.11.5 Correction of the PAPI Position Depending on the Topographical Variation

- The critical data during the modification of PAPI's position is the METH.
- For a difference of threshold level of -3.14m, it is necessary to move the position of the PAPI of 3.14 x cotg 2°43' = 66.33 m towards the threshold
- PAPI's amended position is of 252.27 m from the threshold.
- If at this place the ground level is not the same as the originally calculated position of 318.6m, we must recalculate again the new topographical data.

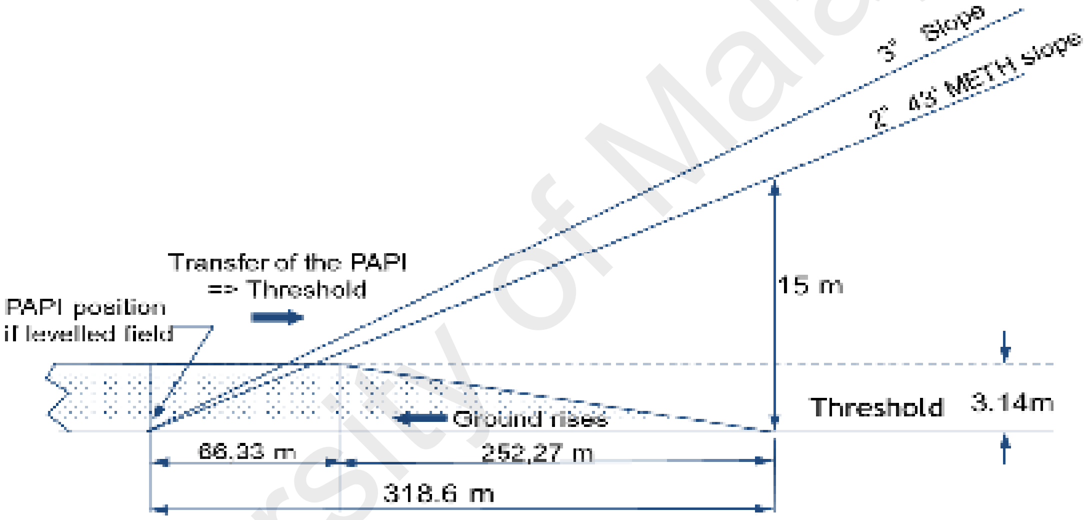


Figure 2. 19 Correction of the PAPI position depending on the topographical variation

2.11.6 Verification of the Ground Level:

- Ground height at 318.6 m: 63.79 m
- Ground height at 252.27 m: 63.08 m
- Difference: - 0.71m

  ⇨ PAPI has to be moved of 0.71 x cotg 2°43' = 14.96m away from the threshold

- New position for the PAPI: 252.27 + 14.96 = 267.3 m
- Double-checking of the ground height in the new position:
- Ground height at 267.23 m: 63.31 m
- Ground height at 252.27 m: 63.08 m
- Difference: 0.23m
- Difference lower than 0.3m => no more iteration needed

2.11.7 Correction of the PAPI Position Depending on the Lens Height

Let us say that the lens center is 30 cm high from the ground:

=> Move the PAPI closer of the threshold: 0.3 x cotg 2°43' = 6.32 m

=> Final position of the PAPI: 267.27 - 6.32 = 260.91 m or <u>261m</u>

. Double-checking of the MEHT against coarse errors

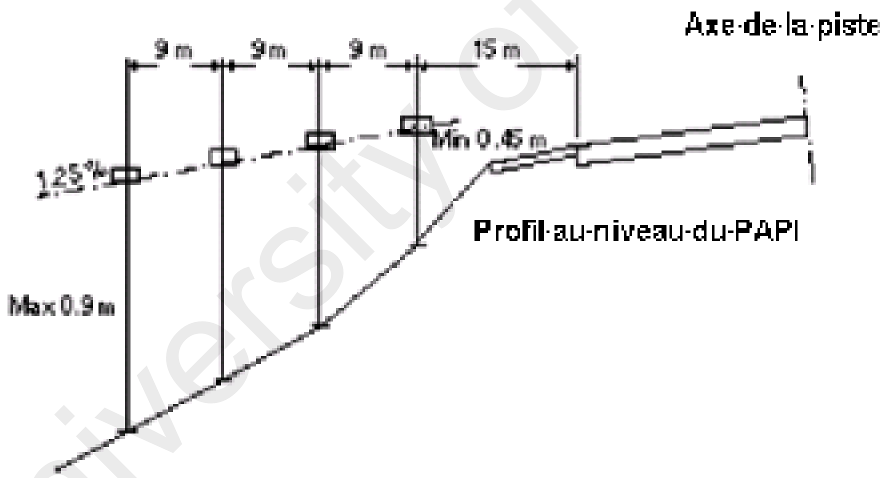
MEHT: 261 x tan 2°43' + (63.21 - 60.65) + 0.3

12.37 + 2.56 + 0.3 = 15.23 m

This value is > 15m => OK

2.11.8 Compensation of the Transversal Slope of the Runway

- The transversal slopes exist on all the runways and have to be taking into account in the positioning calculation of the PAPI's. All the levels have to make reference to one datum: the height of the runway axis.
- A topographical study has to be carried out from one side to the other side of the runway at the place where the PAPI's have to be installed.
- Sometimes when the transversal slope of the runway is important, it is necessary to align the PAPI's on a leaning axis perpendicular to the runway, so that it corresponds to the limit height of the bases of the four aligned units.
- According to the field, the whole group of PAPI units might not be placed on a straight line, perpendicular to the runway (Smith & Johnson, 1976).



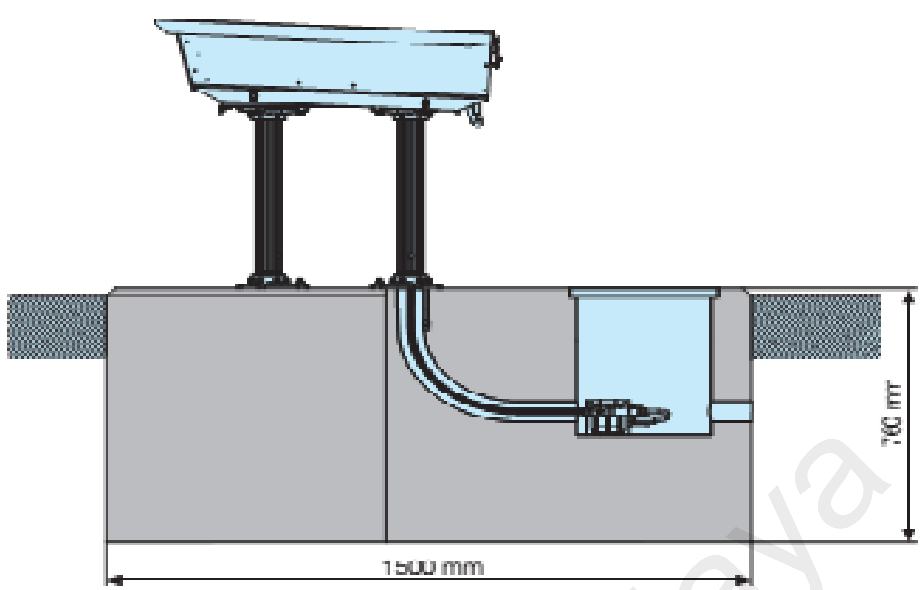


Figure 2. 20 Connection of PAPI Unit

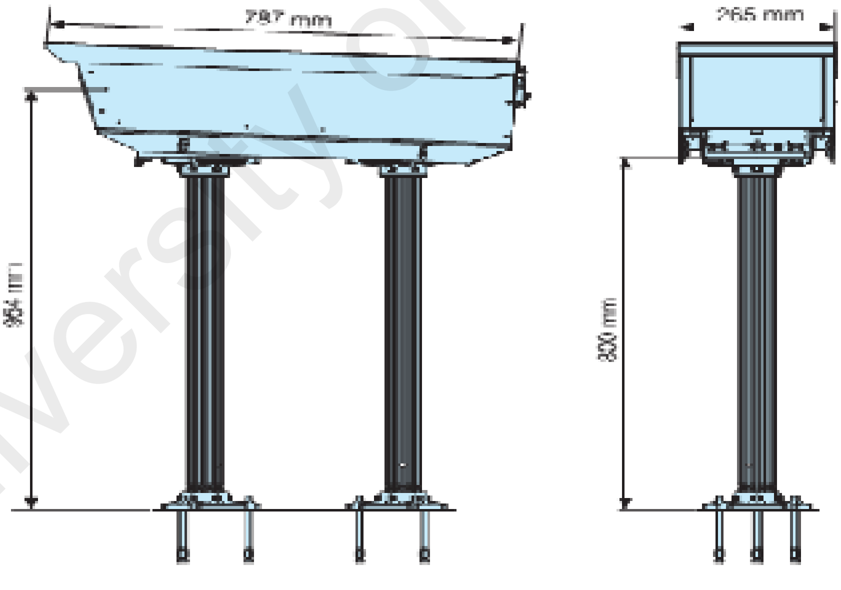


Figure 2. 21 Dimensions of the Typical PAPI

CHAPTER 3: METHODOLOGY

3.1 Introduction

In this chapter, methodology on designing and simulating the PAPI is discussed. This chapter start with explanation on the flow diagram of this research. Next, parameters of stepper motor are defined. Then, analysis the performance of stepper motor. Lastly, showing the simulation result using AutoCAD SOLIDWORKS.

3.2 The Flow Diagram of Study

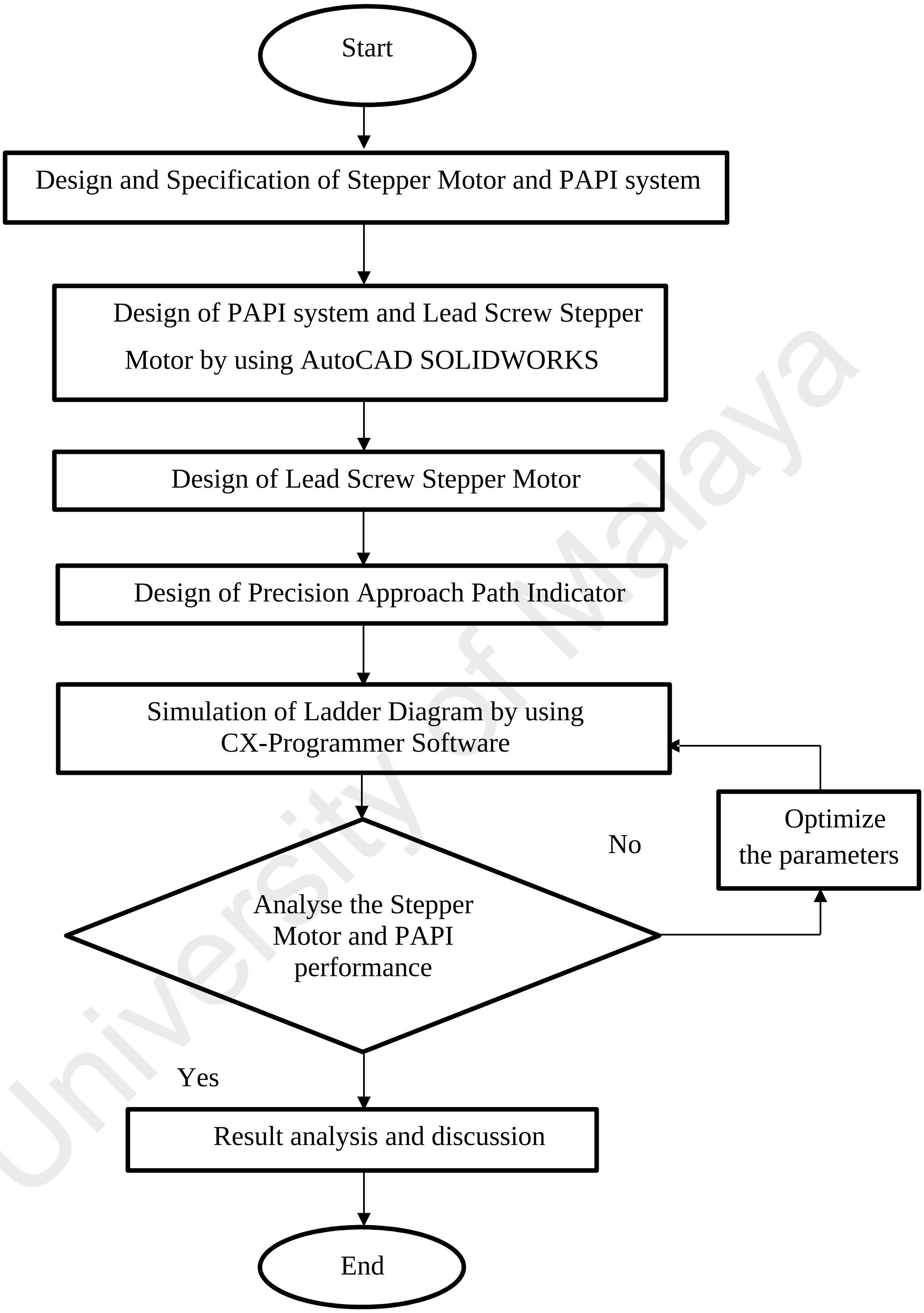


Figure 3. 1 Flow chart for stepper motors for application of PAPI

This research begins with reading all the literature material on electrical machines, special purpose motors, stepper motors, types of stepper motor, working principle of each stepper motor, advantages and disadvantages of stepper motor and applications of stepper motor in industry peripherals, solar array tracking system, motion control and robotics, business machine, which are included in machine tool and process control applications. In addition, the type of PAPI, the siting locations and angle information are all gathered. Going through literature review process will give brief ideas on 'how' and 'what' this project will be doing. All the related theory and useful formula for stepper motor such as step angle is collected during the literature review.

From all the information gathered in literature review stage, PAPI and stepper motor design specification are determined. Stepper motor will be installed underneath the PAPI front area for the control of the angle of the PAPI lights. The PLC will be installed inside the PAPI to control the elevation angle and the push button to control up and down will be installed on the side out of PAPI. Then from the design specs, PAPI with stepper motor is modelled using AutoCAD SOLIDWORKS software. Based on flow chart shown in figure. Important steps to simulate the model in SOLIDWORKs are begin with building the PAPI with the integration of the stepper motor

To analyze the stepper motor behavior and performance, a design of stepper motor is simulated. Results from the simulation is obtained and proceed with the analysis stage. Next discussion is made based on the result obtained. Finally, a conclusion is made referring to the project outcome and research project recommendation or future improvement is proposed.

3.3 Design and Specification of Stepper Motor and PAPI System

In this project, we are going to use Nema 42 stepper motor for controlling of PAPI system in airfield ground lighting. Design of stepper motor is shown in Figure 3.1 and a following specification of stepper motor is given in following Table 3.1 below.

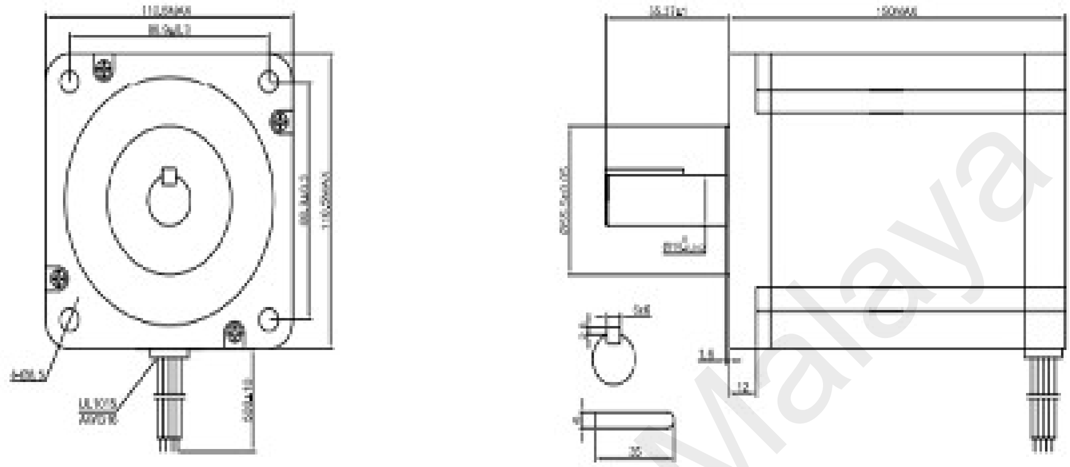


Figure 3. 2 Design of Nema 42 Stepper motor

Table 3. 1 Physical Specification of Nema 42 Stepper Motor

specifications	**value**
Model	42HS59-6004S
Body length	150mm
Shaft diameter	Φ19mm
Key way length	35mm
Shaft length	55.37mm
Number of leads	4
Lead length	500mm
Weight	10.9kg
Frame size	110 * 110mm

Above Table 3.2 shows physical specification of stepper motor such model of motor is 42HS59-6004S, body length of 150mm, weight of motor 10.9kg, number of leads is 4 and some more. Physical specification shows that stepper motor suitable to handle the load of PAPI system and perform a operation nicely.

Table 3. 2 Electrical Specification of Nema 42 Stepper Motor

Specification \ **Connection**	**Bipolar**
VOLTAGE (VOC)	4.80
AMPS/PHASE	6.00
RESISTANCE/PHASE (Ohms) at 25°C	0.80 ± 10%
INDUCTANCE/PHASE (mH) at 1 KHz	14.00 ± 20%
HOLDING TORQUE (Priya & Inman)(lb – ln)	22.00 (194.72)
STEP ANGLE	1.80°
STEP ACCURACY (NON-ACCUM)	±5.00%
ROTOR INERTIA (g- cm^2)	13000.00
Motor type	Bipolar stepper

Above Table 3.2 shows an electrical specification of Nema 42 stepper motor that type of motor is Bipolar type can operate in both directions and having a step angle of 1.8°. Therefore, some of specification of stepper motor not mentioned in above Table 3.2, such as stepper motor Temperature Rise: Max 80°C (Motor standstill; for 2 phase energized), Ambient Temperature -10°C-50°C (14°F-122°F), Insulation Resistance under normal temperature and humidity is 100Mohm, insulation class B 130°C

(266°F), between the motor coils and the motor case the Dielectric strength of motor for 1min is 500VAC and Ambient humidity Max 85% (no consideration). Figure 3.2 is given below, shows the external connection type of stepper motor.

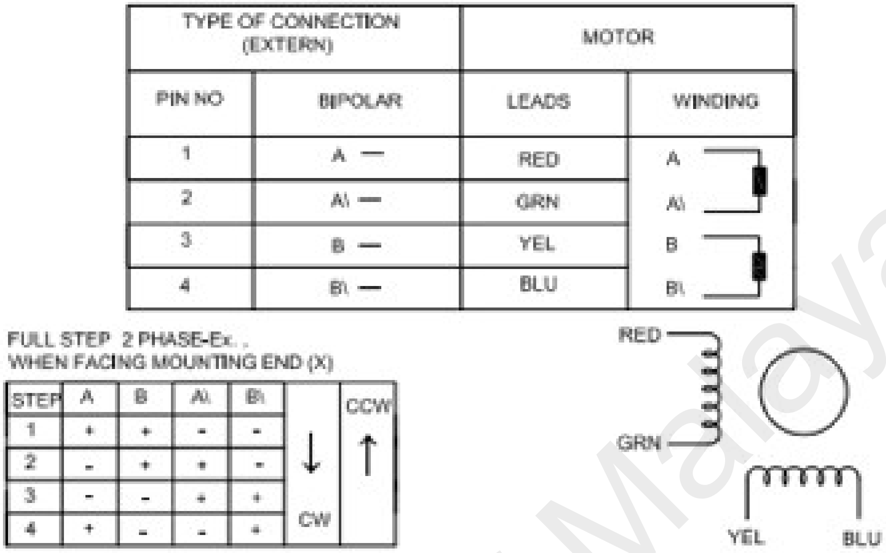


Figure 3. 3 Shows a Stepper motor external connection type

3.4 Design of PAPI system and Lead Screw Stepper Motor by using AutoCAD SOLIDWORKS

Based on project, Design of PAPI system stepper motor with Lead Screw is design on SOLIDWORKS software. Following Figure given below shown a design of PAPI system and Lead Screw stepper motor.

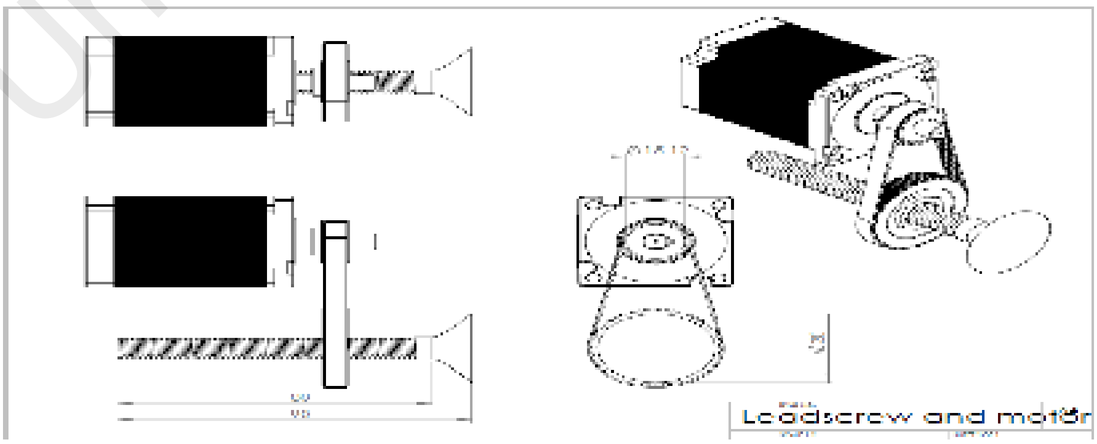


Figure 3. 4 Lead Screw Stepper Motor

Above figure 3.3 shows a lead screw stepper motor design on SOLIDWORKS software. Lead screw stepper motor consist of small gear, big gear and screw. Rotation of stepper motor small gear helps to rotate the big gear of stepper motor relatively screw will also move up and down. Lead screw movement results the up and down movement of PAPI system. Stepper motor attached on front pole of PAPI system because back end of PAPI system is fixed and front end is movable. Specification of stepper Motor is shown in Table 3.3 below.

Table 3. 3 Specification of Lead screw of Stepper Motor

Items	Specifications
Screw pitch	0.5mm
Diameter of screw	10mm
Length of screw	90mm
Ratio big to small gear	1:2

From the above Table 3.2 we know that weight of complete PAPI System is 10Kg. Based on PAPI system we design a stepper motor in SOLIDWORKS software with lead screw with a diameter of screw is 10mm and length of screw 100mm which is suitable to carry the load of PAPI system and easily handle the rise and down movement of PAPI system and pitch of screw is 0.5mm. we assume the ratio between the big gear of motor to the small gear of motor is 1:2 means 2 revolution of small gear equal to one revolution of big gear. Big gear is used to support a screw up and down movement.

In addition, we selected 90 mm of length which is sufficient to cope for the maximum angle of the PAPI system.

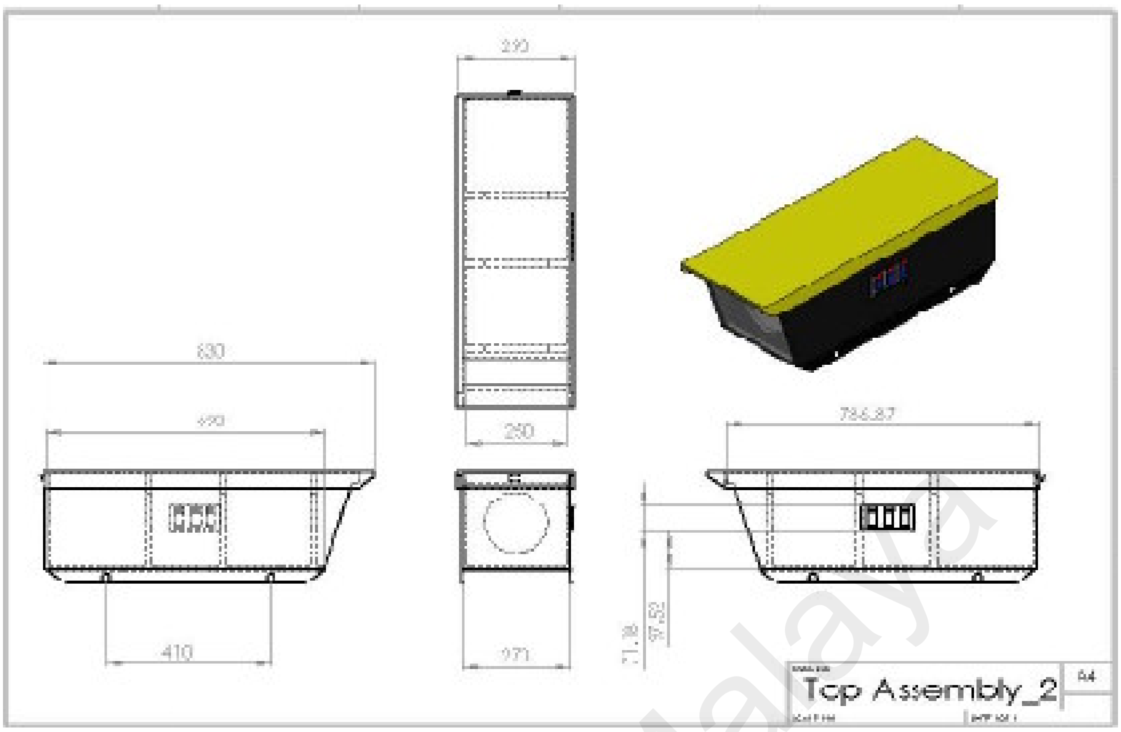


Figure 3. 5 Top assembly of PAPI System with push button and indicator to control raise and lower the elevation

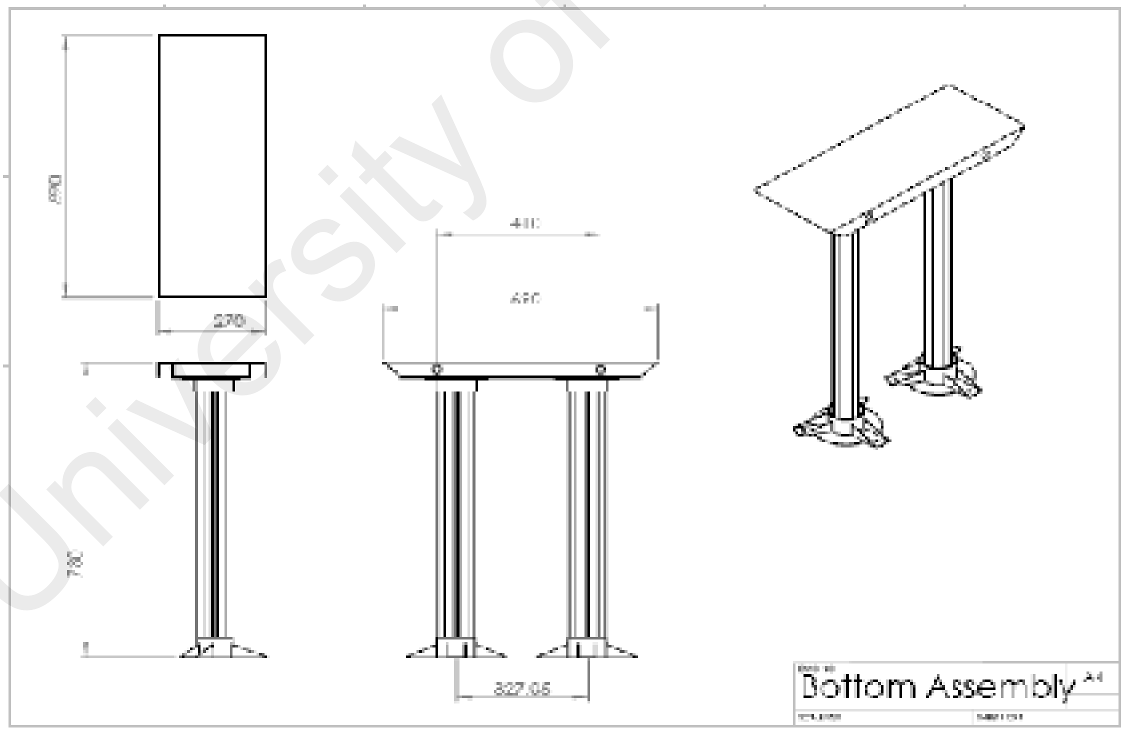


Figure 3. 6 Bottom assembly of PAPI leg to mount on site

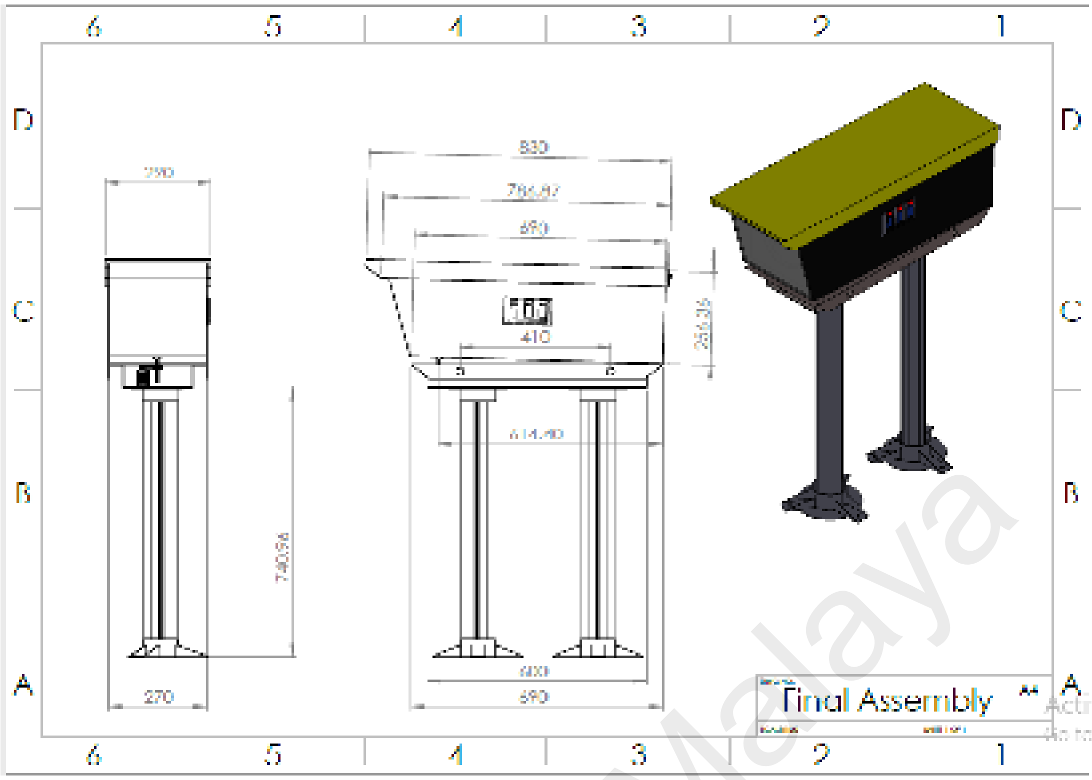


Figure 3. 7 Final assembly of PAPI with two legs

Above figure 3.7 is the picture of complete assembly of PAPI with stepper motor. The stepper motor is installed underneath of the top assemble PAPI front side in the middle. With the hinge mount at the back between top and bottom assemble to permanently fix the PAPI. By fix at the back of the PAPI thus the angle of the light beam can be created when the stepper motor raise or lower on the front PAPI. We designed also the push button and the indicator for the maintenance team to press and select of 4 setting angles require. The left button is for raise, second button for the lower and third button reserve for future use. The maintenance team also can see the display of the digital inclinometer to confirm the angle is correct.

PAPI A	2.50°@ 2°30'
PAPI B	2.83°@ 2°50'
PAPI C	3.17°@ 3°10'
PAPI D	3.50°@ 3°30'

3.5 Design of Leadscrew Stepper Motor

First design of Leadscrew stepper motor which would be integrated on PAPI system and design begins by defining the parameters of leadscrew stepper motor.

Table 3. 4 Parameters of Lead Screw Stepper Motor

Parameter	**Value**	**Unit**
Body Length	150	mm
Shaft Diameter	Φ19	mm
Key Way Length	35	mm
Shaft Length	55.37	mm
Lead Length	500	mm
Frame Size	110 * 110	mm
Screw Pitch	0.5	mm
Diameter of Screw	10	mm
Length of Screw	90	mm
Big gear and small gear diameter	30/15.12	mm

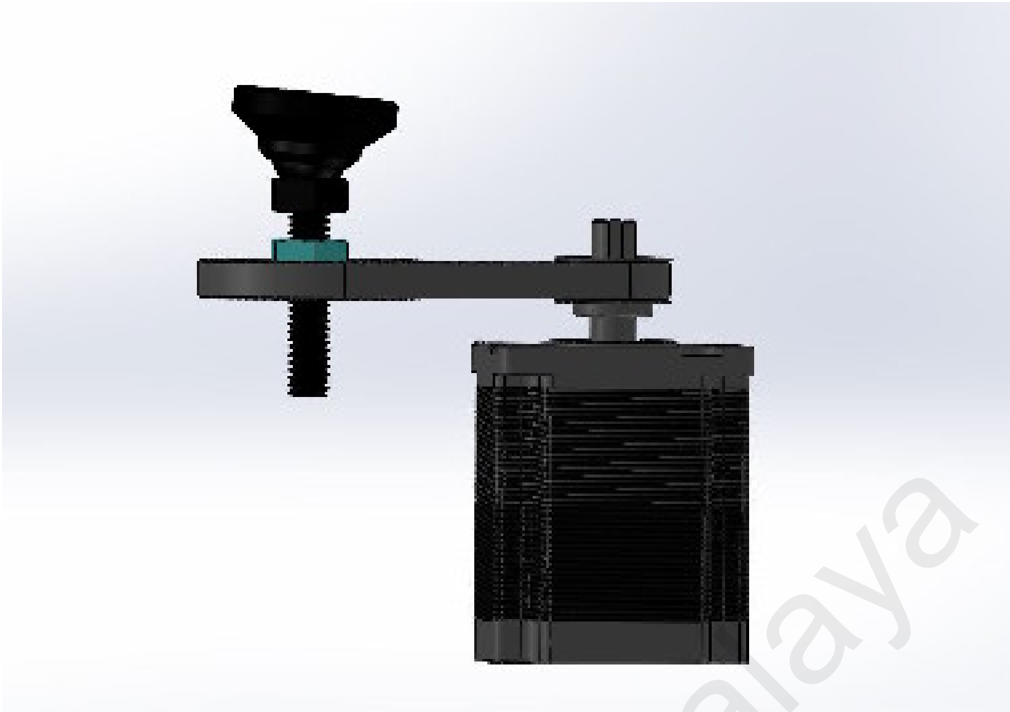


Figure 3. 8 Design of Leadscrew Stepper Motor

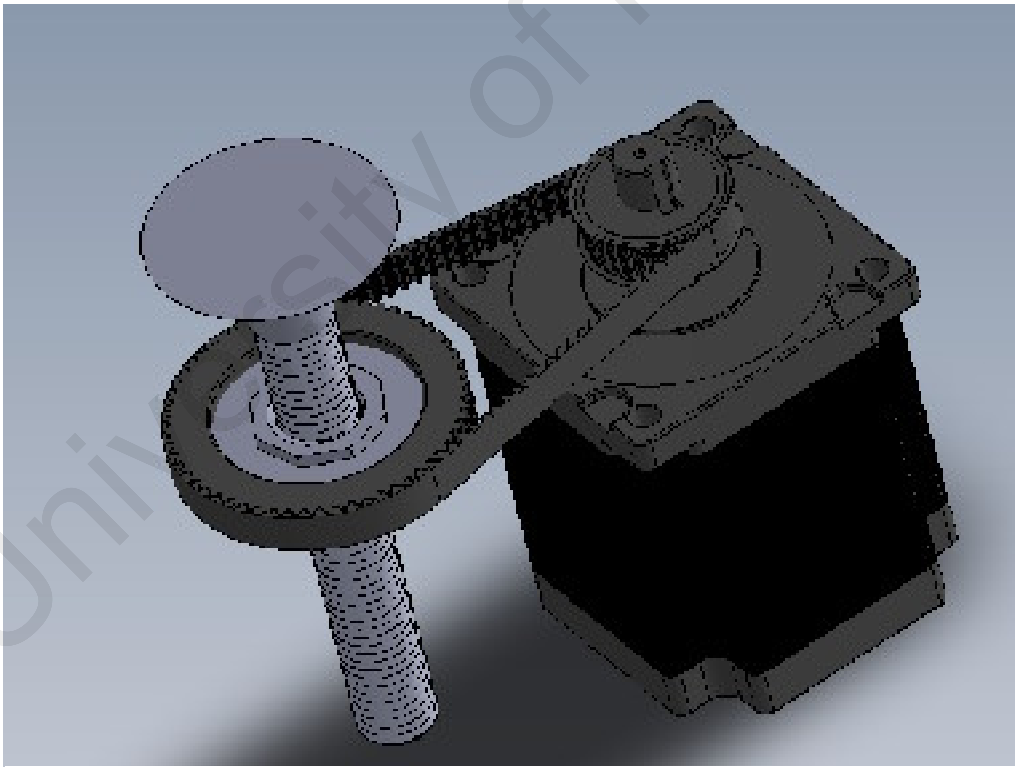


Figure 3. 9 Top-View of Leadscrew Stepper Motor

Figure 3.8 shows the Leadscrew stepper motor which is designed by using AutoCAD SOLIDWORKS software. The motor design with leadscrew because leadscrew support and help in up and down movement of PAPI system. Diameter of screw is 10mm suitable to hold the weight of PAPI and screw pitch is 0.5mm. when big gear complete one revolution screw moves 0.5mm up or down depends on adjustment of elevation angle of PAPI. Length of screw 90mm which is suitable to cover the desired the angle of PAPI. Figure 3.9 shows top part of view which helps in vertical movement of PAPI system. Big is used to support the lead screw and ratio between big gear to small gear is 1:2 means that one revolution of big gear is equal to two revolutions of small gear also can be consider two revolution of stepper motor moves the 0.5mm vertically. Frame is size of motor is 110 * 110mm. Later, motor should be integrated on suitable position underneath of PAPI. Other parameters which is used in designing of PAPI is mentioned in above Table 3.4.

3.6 Design of Precision Approach Path Indicator

In second case, design of Precision Approach Path Indicator system begins by defining the parameters of PAPI system.

Table 3. 5 Parameters of PAPI System

Parameter	Value	unit
Weight of PAPI top assembly	10.2	kg
PAPI top assembly length	830	mm
PAPI top assembly hinges to stepper motor	614.4	mm
PAPI top assembly width	290	mm
Height top assembly	256.36	mm
PAPI bottom assembly length	690	mm
PAPI bottom assembly width	290	mm

Figure 3. 10 Design of Bottom Assembly of PAPI System

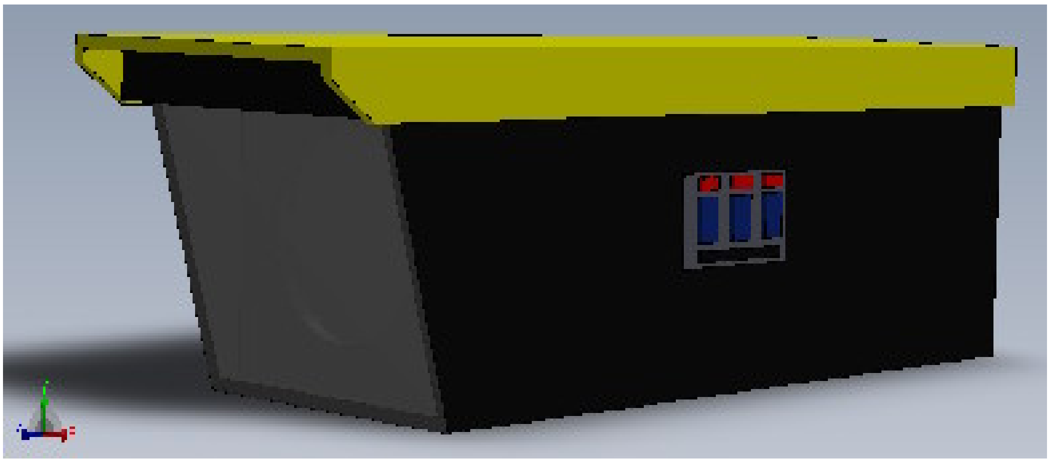


Figure 3. 11 Design of Top Assembly of PAPI System

Figure 3. 12 Complete Assembly Design of PAPI System with Leadscrew Stepper Motor

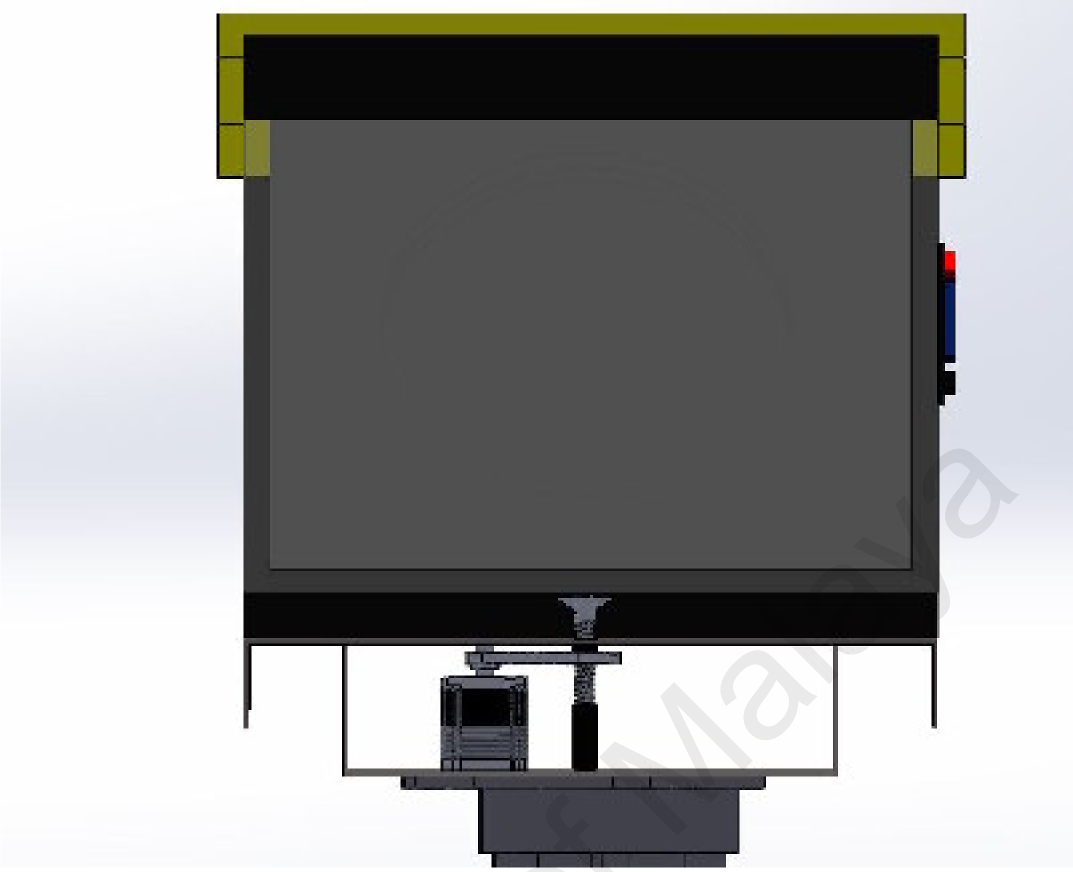


Figure 3. 13 Back – View of PAPI System

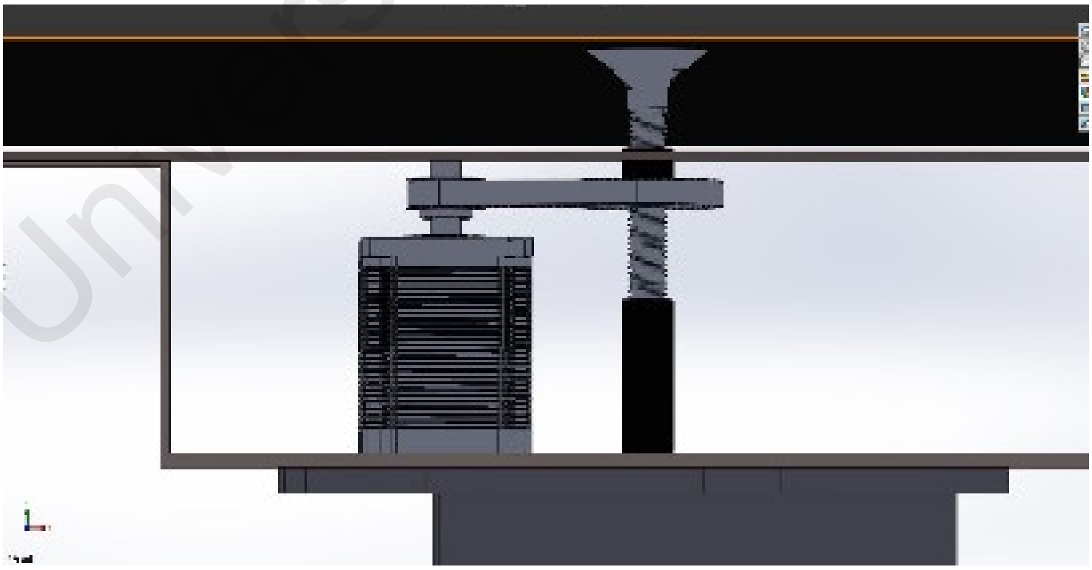


Figure 3. 14 Lead Screw Stepper Motor with Support thread

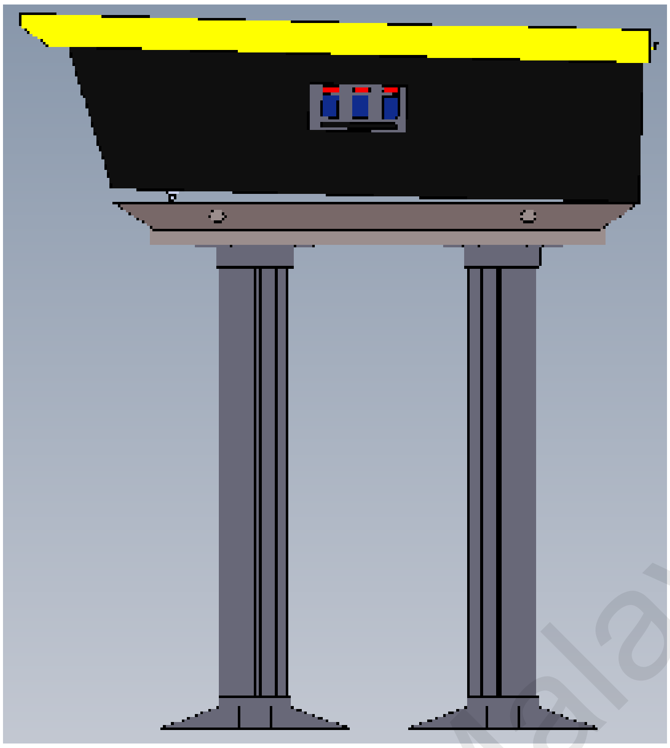


Figure 3. 15 Side-View of PAPI System

Figure 3.10 shows the bottom assembly of PAPI system. Bottom assembly of PAPI fixed at ground and can say supporting legs for top assembly of PAPI. However please note that the bottom assembly height can cut during installation to set the same height at the center of the light to the Threshold light height. So here the distance“x” will be the similar height and the setting angle of PAPI is 3 degree. Thus, the consultant or design Engineer is able to determine the plane type during design the airport. Top assembly of PAPI system is shown in Figure 3.11. Red and blue button on top assembly indicates the push button and digital meter of PAPI system. Figure 3.12 shows the complete assembly of PAPI system with leadscrew stepper motor which is integrated underneath of top assembly of PAPI. Leadscrew stepper motor at front below the top assembly which is movable of part of PAPI and another end of PAPI is fixed. Complete PAPI assembly is designed by using the software AutoCAD SOLIDWORKS software. PAPI bottom assembly length is 690mm and PAPI bottom assembly width is 290mm and other parameters of top and bottom assembly is mentioned above in Table 3.5. Therefore Figure 3.14 shows the support leadscrew stepper motor integrated beneath the top assembly and shows the support thread which is used to support the movement of leadscrew and make the movement of screw smoothly. Figure 3.13 and 3.15 shows the back and side view of PAPI system. Figure 4.8 clearly shows that leadscrew stepper motor help to move the top assembly of PAPI system vertically by help of leadscrew one revolution moves the screw vertically 0.5mm and with the help of leadscrew stepper motor can adjust the elevation angle of PAPI automatically. And the stepper motor is fixed with the thread on the bottom assembly at below and top thus it will fix the leadscrew in one position to ensure the smooth of raise or lower of the PAPI. In addition, it will hold and maintain the position of the stepper motor, small and big gear.

3.7 Simulation of Ladder Diagram by Using CX− Programmer Software

Simulation of ladder diagram of PAPI system with timer is performed by using a CX programmer software and shown below.

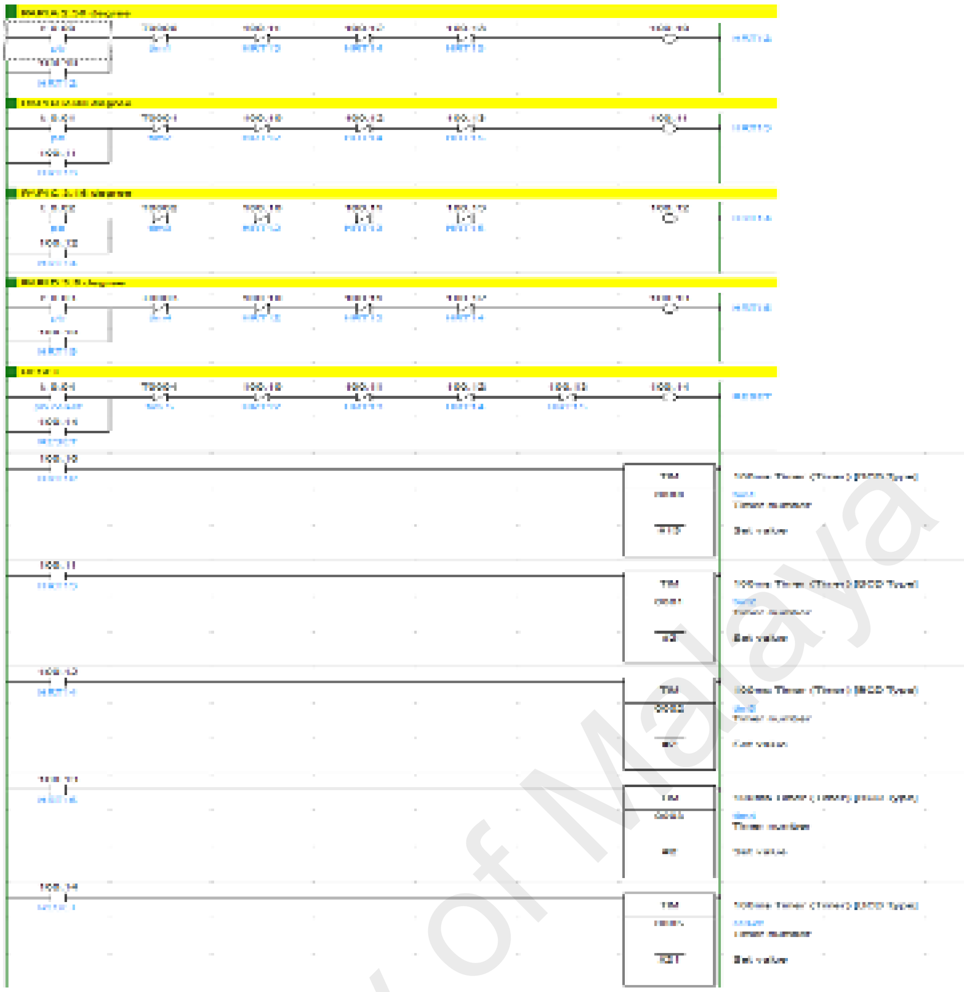


Figure 3. 16 Ladder Diagram of PAPI system

Figure 3.16 shows the ladder diagram of PAPI system by using CX - Programmer. There are four units of PAPI with different elevation angle. PAPI A with elevation angle of 2.50°, PAPI B is 2.83°, PAPI C elevation angle is 3.16° and PAPI D with elevation angle of 3.50°. There is also reset switch for resetting of operation and turn back the PAPI leadscrew to 0°original position. All PAPI's connected separately with their respective timer. Function of timer is that to run motor specific period then OFF, and it will maintain to that position. When any of PAPI is not at proper elevation angle then need to adjust the elevation angle of PAPI by pressing the push button which results in turn on stepper motor with leadscrew for specific period until elevation angle is covered then OFF a motor. for example, to adjust the elevation angle of PAPI A motor should be ON for 1.5s.

3.8 Summary

This chapter discussed on the methodology approach for this research project. Beginning of this chapter explained the flow chart of the methodology that has been used. Followed by defining the design and structure parameters of stepper motor and PAPI system based on project requirements. Next, the stepper motor design parameter and the varied parameter is chosen for PAPI application. All the design is realized using AutoCAD SOLIDWORKS software. Finally, Simulation of Ladder Diagram by using CX-Programmer Software.

CHAPTER 4: RESULT AND DISCUSSION

4.1 Calculation of PAPI System and Lead Screw Stepper Motor for PLC

Following formula given below is used to calculate the Steps per revolution

$$\text{Steps per Revolution} = 360\square \;/\; \text{Step Angle} \qquad 4.1$$

Revolution per Second can be calculating by using equation given below.

$$\text{Revolution per Second} = V/(L*2*Imax)/(steps/rev) \qquad 4.2$$

Vertical movement of PAPI system can be calculate by using equation given below.

$$\text{Tangent } \theta = Y/X \qquad 4.3$$

Calculated values of PAPI system given below in Table 4.1

PAPI System	Elevation Angle	Screw Pitch	Steps per Revolution	Vertical Movement of PAPI	Revolution per Second Calculate	PLC Timer in sec	Percentage %
PAPI A	2.5^o	0.5mm	200	26.825mm	1.53	1.50	1.98
PAPI B	2.83^o	0.5mm	200	30.371mm	1.73	1.70	1.74
PAPI C	3.16^o	0.5mm	200	33.92mm	1.94	1.90	2.00
PAPI D	3.5^o	0.5mm	200	37.57mm	2.14	2.10	1.88

Table 4. 1 Calculated value of PAPI and leadscrew stepper motor

Based on table 4.1, We know 1 revolution of the big gear will result in 1 rotation of the screw and vertical movement of 0.5 mm This is equal to 2 rev of the small gear (since N = 2), and hence 2 rev of the motor So, 1 rev of the motor will cause the screw to move only half pitch, i.e. 0.25mm since 1 rev is equals to 200 steps, 1 step will give 0.25mm/200 = 0.0125 mm vertical movement and make it easy to determine the number of steps required for different vertical movements of the screws. Therefore, when we get know the vertical movement of screw then in result can calculate the revolution per second of leadscrew stepper for each PAPI unit to cover the desired elevation angle.

4.2 Simulation of the PLC Automation for PAPI A at 2.5°

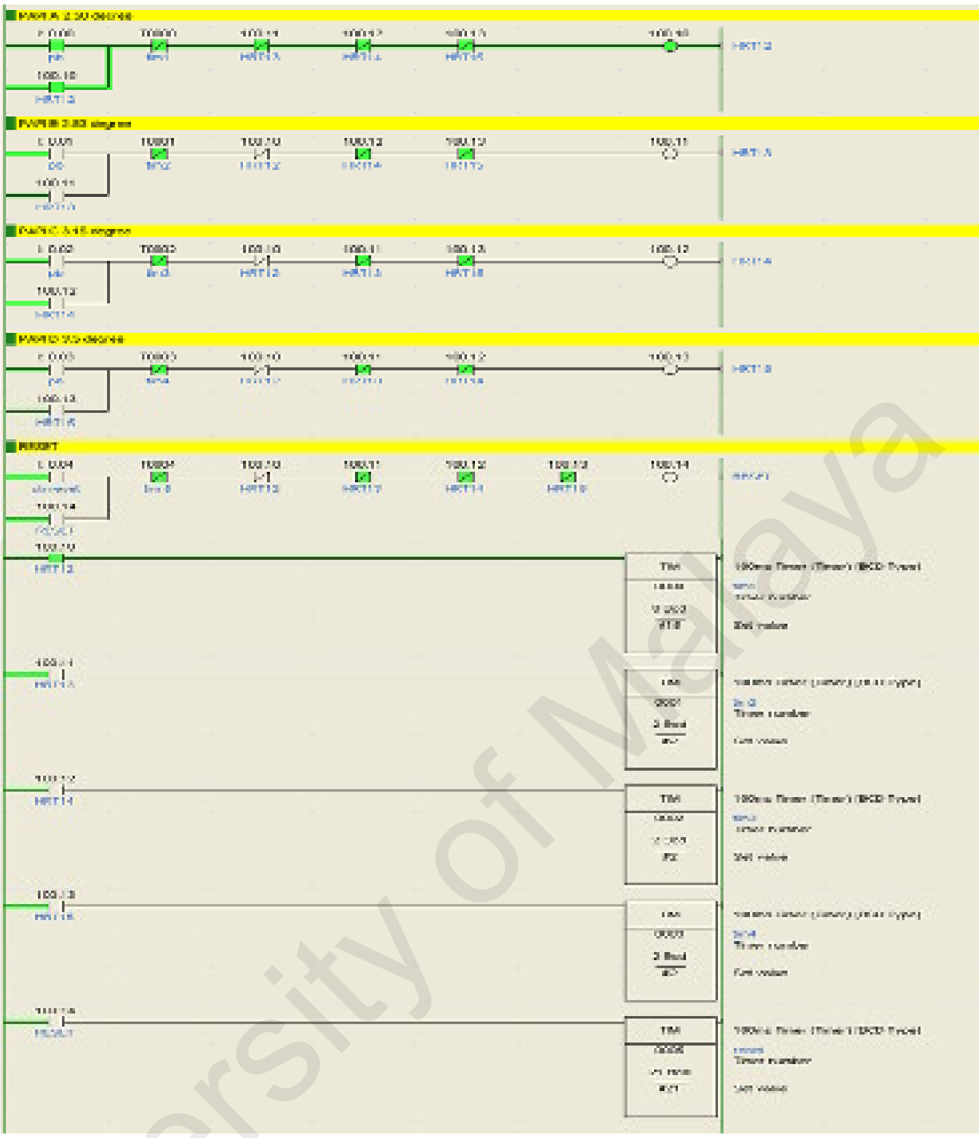


Figure 4. 1 PAPI A at 2.5°

Above Figure 4.1 shows the simulation of ladder diagram for PAPI A. During installation of the PAPI, the installer just pressed one-time push button and the elevation angle of PAPI A will be set. The timer and motor will be turn ON at same time. Motor will run for 1.5 seconds to cover the angle of 2.50° then it will be OFF. First rung of ladder diagram shows the simulation of PAPI A and rung 6 represent the function of timer and green line at both one and six rung represents a timer and motor is performing a function to adjust the angle of PAPI A. Figure 4.2 shows that a timing diagram of PAPI A.

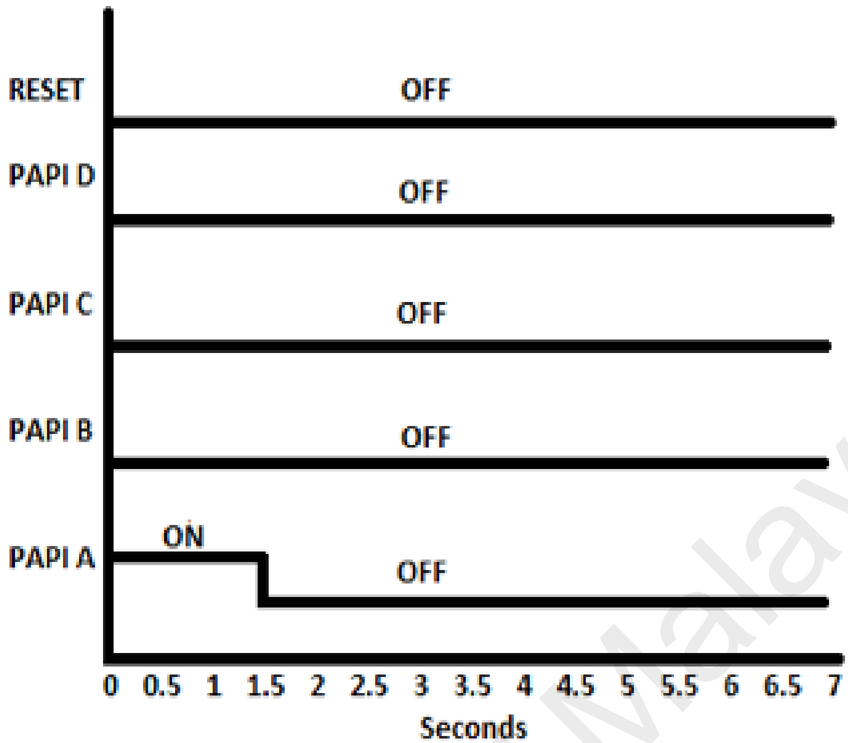


Figure 4. 2 Timing Diagram of PAPI A

4.3 Simulation of the PLC Automation for PAPI B at 2.83°

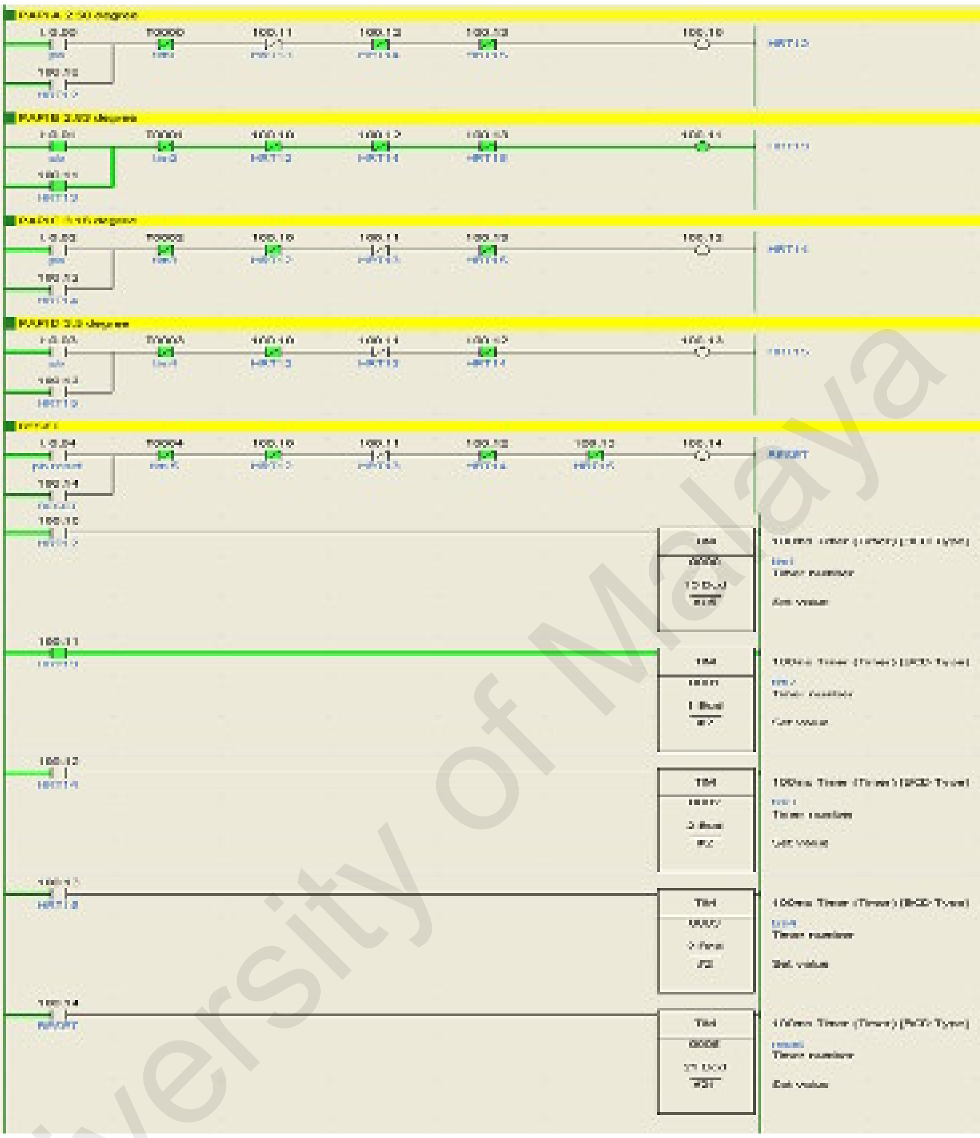


Figure 4. 3 PAPI B at 2.83°

Simulation for PAPI B is shown in Figure 4.3. During installation of PAPI B, press the push button for the first time, and when it will stop at 2.50°, and press again the push button for the second time and the second timer will add on another 0.2 seconds which will cover PAPI B position which is 2.83°. It will automatically align the position of PAPI B by help of leadscrew stepper motor. Figure 4.3 shows that rung 2 green line in ladder diagram shows the function of motor and rung 7 green line represent the timer function and for alignment of elevation angle of PAPI motor will run approximately 1.7 seconds because motor will cover 2.83° in 1.7 seconds.

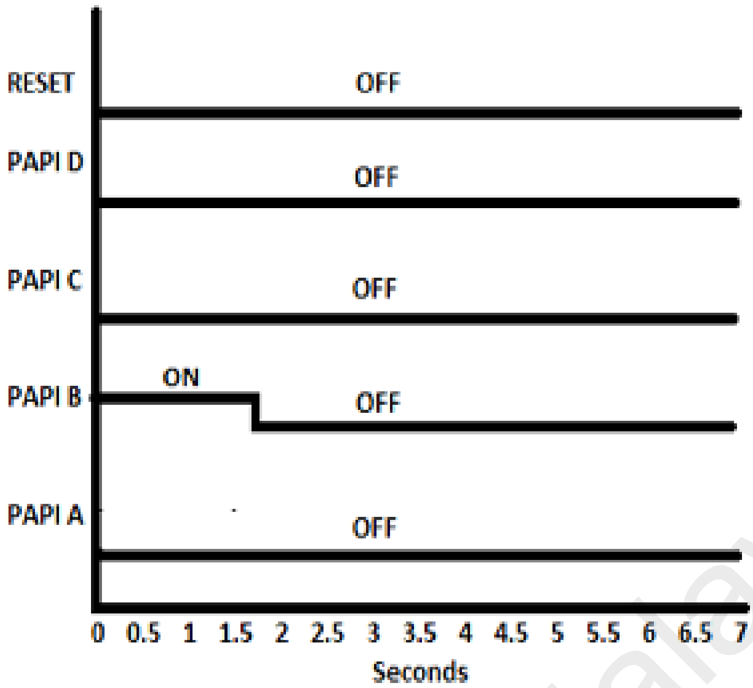


Figure 4. 4 Timing Diagram of PAPI B

Figure 4.4 shows the timing diagram of PAPI B and it indicates that lead screw stepper motor is ON for 1.7 seconds to align back the elevation angle of PAPI B. All other PAPI's OFF while aligned the PAPI B.

4.4 Simulation of the PLC Automation for PAPI C at 3.16°

Above Figure 4.3 shows the simulation result of PAPI C. Accurate elevation angle of PAPI C is 3.16°. To set PAPI C, we will need to press the push button for 3 times. Means 1.5 second plus 0.2 seconds and plus another 0.2 seconds will be in total 1.9 seconds to cover 3.16°. Figure 4.3 shows that rung 3 and rung 8 with green line marked shows the simulation result of PAPI C.

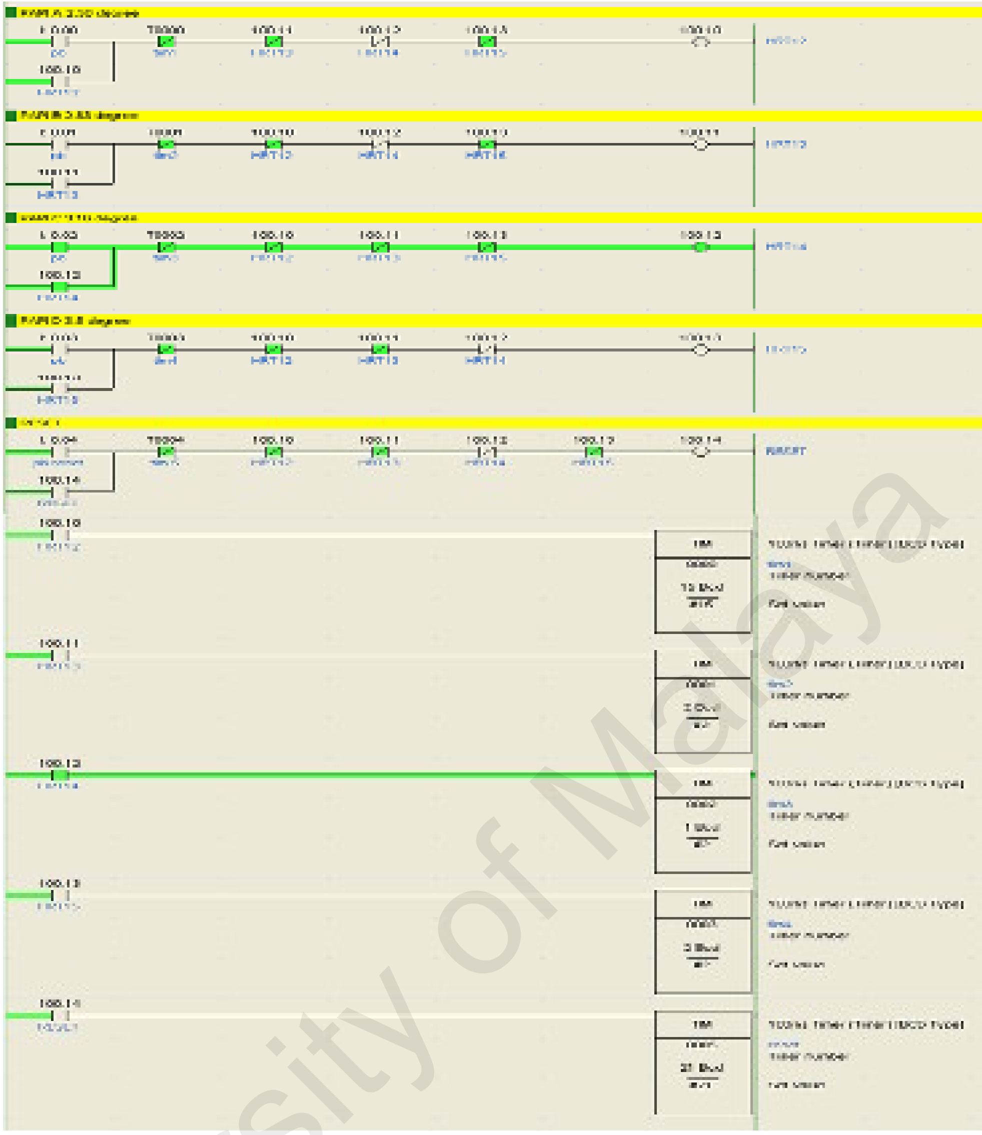


Figure 4. 5 PAPI C at 3.16°

Timing diagram of PAPI C is shown below in Figure 4.6. Timing diagram indicated to adjust the elevation angle of PAPI back to 3.16° lead screw motor need to turn ON for a time of 1.9s. After 1.9s PAPI C aligned back to its original position.

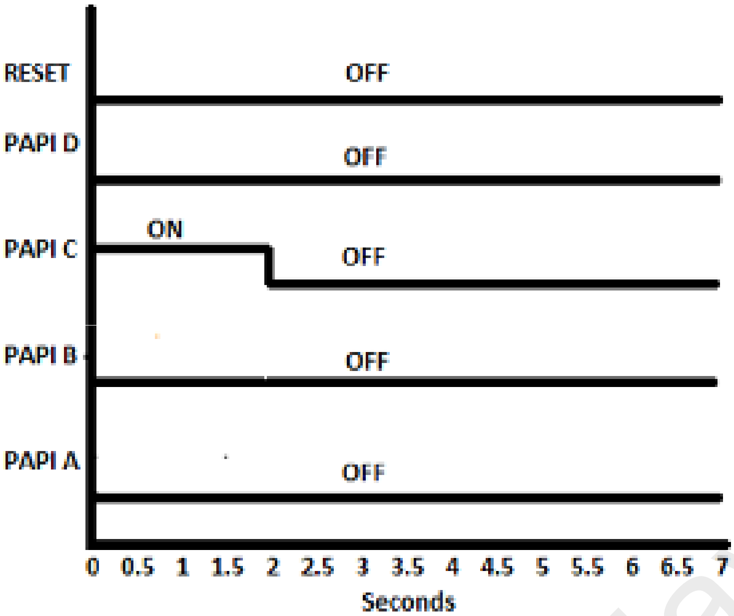


Figure 4. 6 Timing Diagram of PAPI C

4.5 Simulation of the PLC Automation for PAPI D at 3.5°

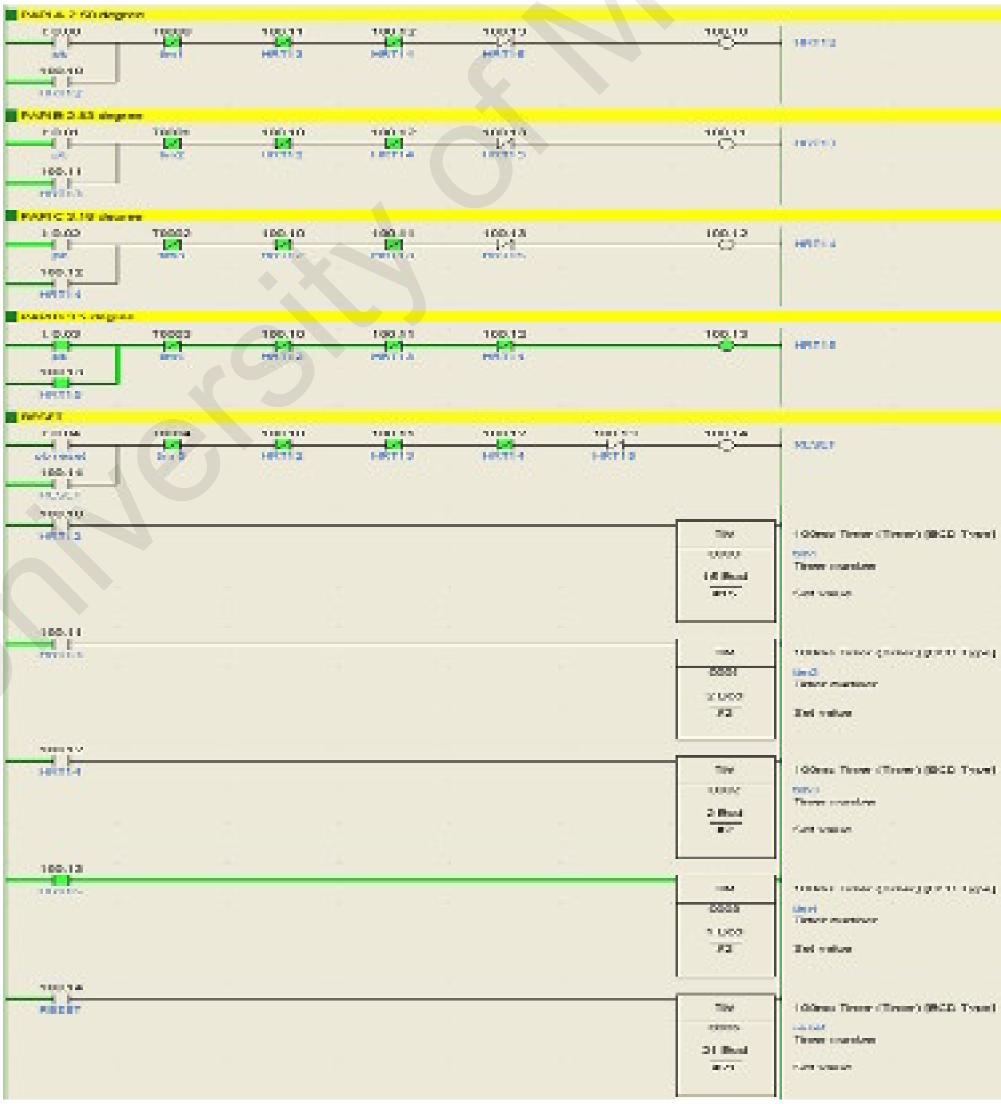


Figure 4. 7 PAPI D at 3.5°

Simulation result of PAPI is shown in Figure 4.7. Green line marked on rung 4 and rung 9 shows the simulation result of PAPI D and timer. In this position, we need to push the button four times means 1.5s plus 0.2s plus 0.2s plus 0.2s which in total 2.1s. To adjust the elevation angle of PAPI D motor need run for 2.1 seconds and motor will cover elevation angle of 3.5 in this period.

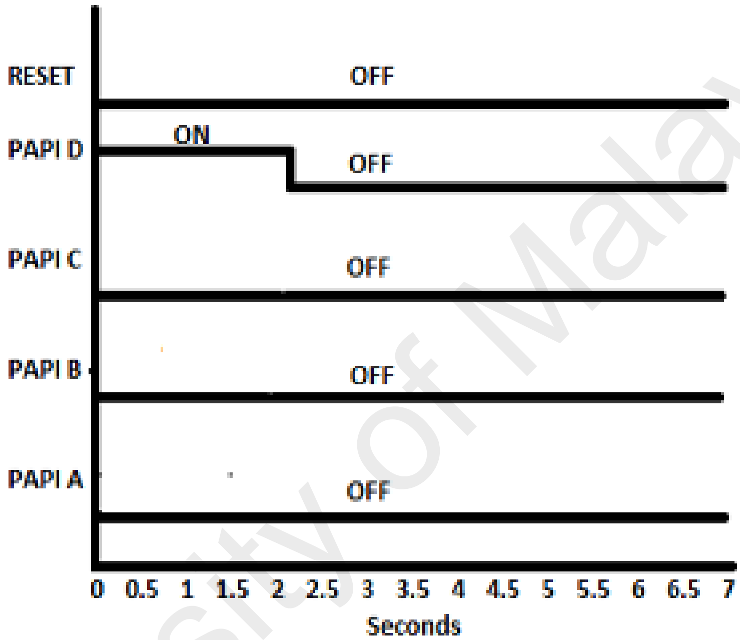


Figure 4. 8 Timing Diagram of PAPI D

Timing diagram of PAPI D is shown below in Figure 4.8. Timing diagram indicated to adjust the elevation angle of PAPI back to 3.5° lead screw motor need to turn ON for a time of 2.1s. After 2.1s PAPI D aligned back to its original position.

4.6 Simulation of the PLC Automation for PAPI System Reset

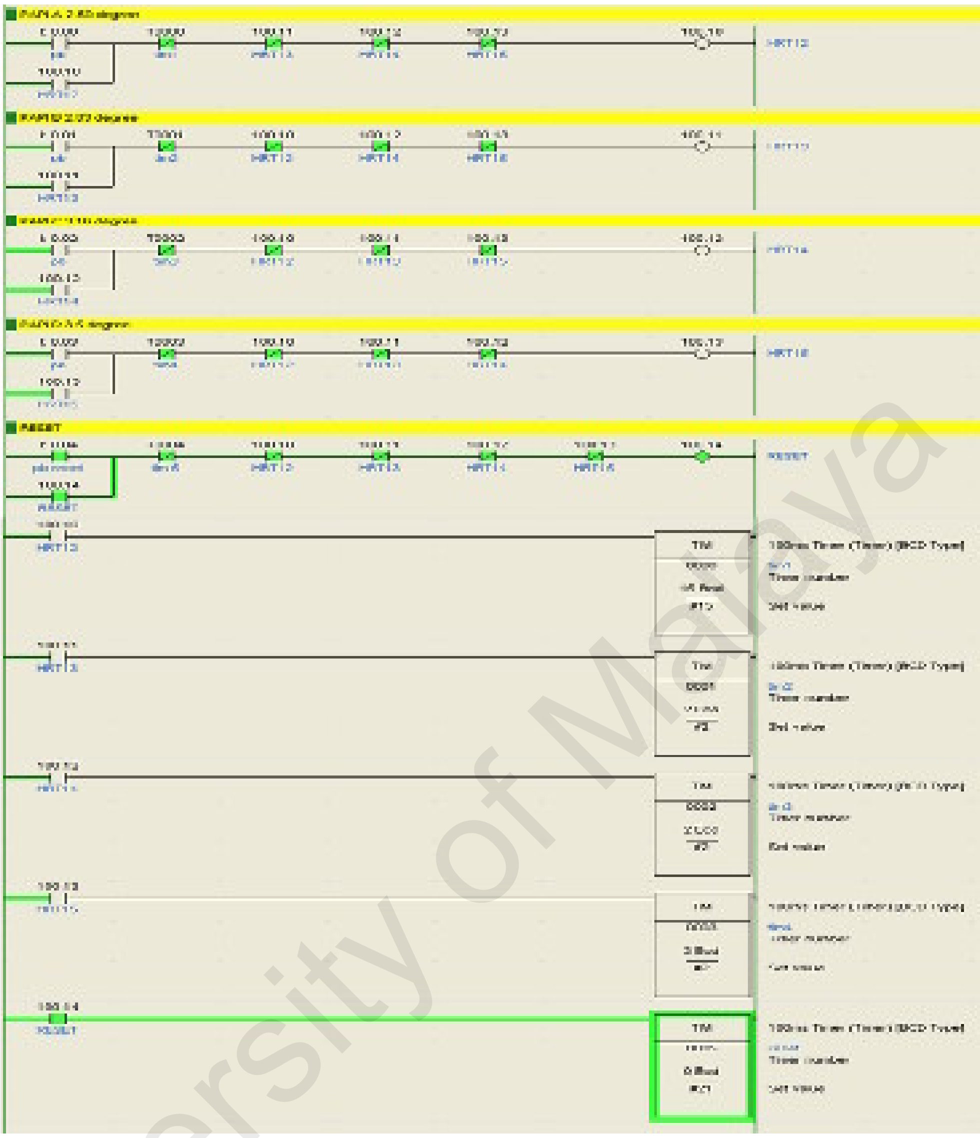


Figure 4. 9 PAPI System Reset

Figure 4.9 shows the simulation result of resetting of PAPI system. Green line marked on rung 5 and rung 10 shows resetting of PAPI system. To reset the PAPI back to original position. Press additional one-time push button after PAPI D. Means 5 times to press the push button. Figure 4.10 shows that a timing diagram for reset of PAPI system. Timing diagram indicated that Reset of system take time of 2.1s after PAPI D is aligned.

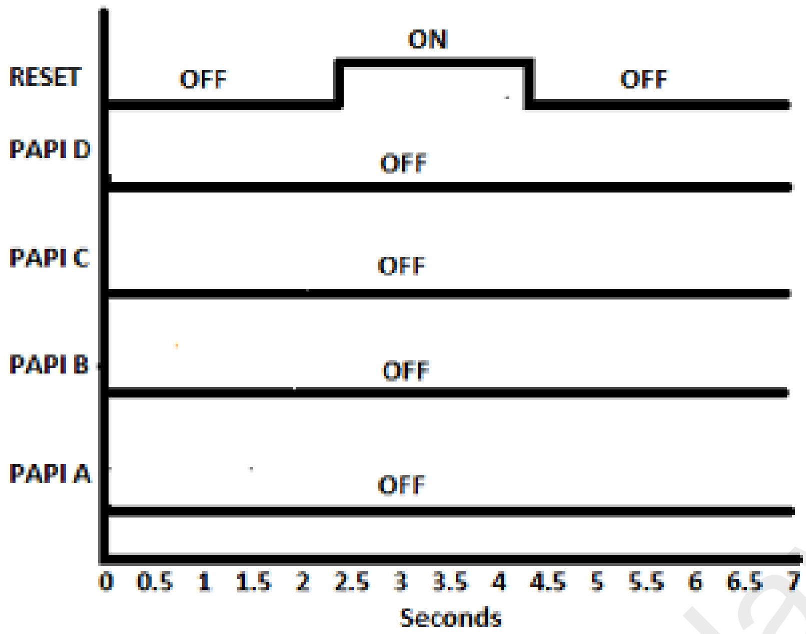


Figure 4. 10 Timing Diagram for Reset of PAPI System

CHAPTER 5: CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Based on this project, first we successfully designed the PAPI and Leadscrew stepper by using the AutoCAD SOLIDWORKS software. Leadscrew stepper motor integrated on PAPI unit. Stepper motor beneath the top assembly of PAPI unit at front side which is a movable part of PAPI. Leadscrew is used in stepper motor and position of leadscrew below the movable part of PAPI and move the PAPI unit vertically up and down for adjustment of elevation angle. Secondly, we performed the simulation of each PAPI unit and leadscrew stepper by using the CX programmer software. timer is used in simulation which helps to run a motor for a specific until a desired angle is covered. From the results obtained, it shows that by integrated stepper motor and timer on PAPI helps in automatically adjustment of elevation angle of each PAPI unit and reduce time consuming, cost reduction, no need of special tools and extra manpower to communicate with aircraft calibration and to adjust the angle using tool and manual.

However, due to the timer in CX Programmer only can set at 0.1 sec the smallest unit, therefore it resulted a small tolerance if compare to the calculation angle. Following table is showed the tolerance which reflect to the calculation angle due to the timer that used.

PAPI System	Elevation Angle	Vertical Movement Calculation	Revolution per Second Calculation	PLC timer in sec	Elevation angle result	Tolerance
PAPI A	2.5°	26.82mm	1.53	1.50	2.46°	0.04°
PAPI B	2.83°	30.37mm	1.73	1.70	2.78°	0.05°
PAPI C	3.16°	33.92mm	1.94	1.90	3.11°	0.05°
PAPI D	3.5°	37.57mm	2.14	2.10	3.43°	0.07°

Table 4. 2 Calculated value of PAPI and leadscrew stepper motor

The maximum tolerance effect on PAPI D which is 0.07°@4'. From the table, found the tolerance is very small compare to between PAPI with 0.33°@20'.

5.2 Recommendation

This research has successfully designed and simulated, however, use of microcontroller instead of PLC is more accurate operation as it can control the number of steps which covers 0.0125 mm height each steps. While with timer it only can cover 0.1 sec the smallest settings. In addition with microcontroller we can design a closed loop system with feedback digital indicator to confirm the angle.

In this project only, vertical movement of PAPI unit controlled. In future research horizontal movement of PAPI unit can be considered for the idea to level the PAPI. In addition, the Leadscrew stepper motor is designed by using AutoCAD SOLIDWORKS software and simulation performed on CX programmer. In future, this designed can be make practically and check PLC programming for the real operation of leadscrew stepper for adjustment of elevation angle of PAPI system.

Table 5. 1 Calculated value of PAPI and lead screw stepper motor

Vertical movement of PAPI	Number of steps required for vertical movement
26.82mm	2146
30.37mm	2429
33.92mm	2713
37.57mm	3005

Above Table 5.1 indicated the calculated value of PAPI and leadscrew stepper motor. Vertical movement of PAPI is 26.825mm to adjust the elevation angle of PAPI A and for that vertical movement the lead screw stepper motor required to move 2146 steps to cover the 26.825mm. PAPI B required vertical movement of 30.371mm to back to its correct position and number of steps required for that vertical movement is 2429 steps. Number of steps required is 2713 steps to cover the vertical movement of PAPI C is 33.92mm. For adjustment of elevation angle of PAPI C the PAPI required vertical movement of 37.57mm for that vertical movement lead screw stepper motor required 3005 steps.

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