DEVELOPMENT OF A 6-AXES ROBOT

ANAN KONGYOO

THESIS SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENT FOR THE DEGREE OF
MASTER OF ENGINEERING IN MECHANICAL ENGINEERING
SCHOOL OF GRADUATE STUDIES
KING MONGKUT'S INSTITUTE OF TECHNOLOGY LADKRABANG
2002

ISBN 974-324-614-2

หัวข้อวิทยานิพนธ์ การพัฒนาหุ่นยนต์แบบ 6 แกน
นักศึกษา นายอนันต์ คงอยู่
รหัสประจำตัว 44062028
ปริญญา วิศวกรรมศาสตรมหาบัณฑิต
สาขาวิชา วิศวกรรมเครื่องกล
พ.ศ. 2545
อาจารย์ผู้ควบคุมวิทยานิพนธ์ รศ.ทวี เทศเจริญ

บทคัดย่อ

วิทยานิพนธ์นี้นำเสนอการออกแบบหุ่นยนต์ ชุดควบคุมและโปรแกรมควบคุมการทำงานของหุ่นยนต์ 6 แกน ซึ่งมีมอเตอร์แบบขั้นเป็นตัวขับเคลื่อนในแต่ละข้อต่อของหุ่นยนต์ โปรแกรมและชุดควบคุมถูกออกแบบให้ใช้กับระบบการเคลื่อนที่ของปลายแขนหุ่นยนต์แบบจากจุดหนึ่งไปยังอีกจุดหนึ่งโดยไม่ได้คำนึงถึงเส้นทางในการเดิน โดยโปรแกรมที่พัฒนาขึ้นมานี้ ผู้ที่ควบคุมหุ่นยนต์สามารถที่จะใส่ค่าตำแหน่งที่ต้องการให้ปลายแขนของหุ่นยนต์เคลื่อนที่ตามระบบแกน XYZ ซึ่งในควบคุมการเคลื่อนที่ของหุ่นยนต์จะกระทำโดยผ่านทางไดอะล็อกบ็อกของโปรแกรมและทางแป้นพิมพ์ โปรแกรมนี้จะทำงานตามระบบการควบคุมตำแหน่งที่มีระบบป้อนกลับซึ่งสามารถเลือกความเร็วที่มีการโปรแกรมไว้ในการเคลื่อนที่ของข้อต่อได้ รหัสของโปรแกรมที่เขียนขึ้นทั้งระบบควบคุมและกราฟฟิคที่แสดงบนหน้าจอนี้จะใช้โปรแกรมวิชวลเบสิค ในส่วนของระบบการป้อนกลับจะใช้เอนโค้ดเดอร์เป็นตัวป้อนกลับค่าของมุมที่มอเตอร์หมุนในแต่ละข้อต่อ

ชุดควบคุมที่สร้างขึ้นนี้สามารถนำไปใช้ได้ทั้งการควบคุมแบบจากจุดหนึ่งไปยังอีกจุดหนึ่งและการควบคุมแบบคำนึงถึงเส้นทางการเดิน ซึ่งในชุดควบคุมนี้ประกอบด้วย วงจรในการรับส่งข้อมูลเพื่อติดต่อกับระบบคอมพิวเตอร์ที่ใช้ในการควบคุมการทำงาน วงจรแปลงสัญญาณจากสัญญาณอะนาลอกไปเป็นสัญญาณดิจิตอลเพื่อใช้แปลงสัญญาณที่ป้อนกลับจากเอนโค้ดเดอร์ ลิมิตสวิทช์ หรืออุปกรณ์ภายนอกอื่นๆ วงจรแปลงสัญญาณจากสัญญาณดิจิตอลไปเป็นสัญญาณอะนาลอกเพื่อใช้แปลงสัญญาณที่จะนำไปควบคุมความเร็วของมอเตอร์แบบขั้นและอุปกรณ์ในภาคขับเคลื่อนมอเตอร์

สิ่งที่คาดหมายไว้ในการทำวิทยานิพนธ์นี้คือ สามารถสร้างหุ่นยนต์ ชุดควบคุมและโปรแกรมควบคุมการทำงานของหุ่นยนต์ 6 แกนได้ โดยค่าความผิดพลาดที่เกิดขึ้นจะต้องอยู่ในช่วงที่ยอมรับได้ ซึ่งสามารถประเมินได้ในขั้นตอนของการตรวจสอบระบบการทำงาน

Thesis Title	Development of A 6 axes robot
Student	Mr. Anan Kongyoo
Student ID.	44062028
Degree	Master of Engineering
Programme	Mechanical Engineering
Year	2002
Thesis Advisor	Associate professor Thavee Teschareon

ABSTRACT

This research aims to design and build a 6-axes robot, robot controller and controlled program for 6-axes robot. Stepper motors are used as the power source in each joint. Worm gear set is used for power transmission system in each joint of robot. Controlled program is objected to develop for point-to-point motion (PTP), in which the start and endpoints of the motion are critical while the trajectory between the points are uncertain. User can manually enter required end-effector position values in XYZ coordinate system. Robot's movement can be controlled by dialog box, graphic program and keyboard, which based on the position control by the feedback with feed-forward control system. Visual Basic program is used to be the controlled source code and user interfaced programming. Encoders are selected to be the position feedback equipment for sending the present status signal to the controlled system.

Controller is built for support both point-to-point control and path control. This controller includes data transmission circuit (I^2C to parallel transmission), analog to digital converter (ADC), digital to analog converter (DAC) and stepper motor driving board.

The expectation of this research is ability to build a 6-axes robot, controller and developed program in point to point motion control under the appropriated error acceptance. Thus, to evaluate operation of robot, controller and controlled program, steps of overall system testing are presented in this thesis.

ACKNOWLEDGEMENT

I would like to express my gratitude to all those who gave me the possibility to complete this thesis. I want to thank the Department of mechanical department of KMITL for giving me permission to commence this thesis in the first instance, to do the necessary research work and to use departmental equipment and machines.

I am deeply indebted to my advisor Assoc.Prof. Tavee T. whose help, stimulating suggestions and encouragement helped me in all the time of research and writing of this thesis. My former colleagues from the Department of design in my research work. I want to thank them for all their help, support, interest and valuable hints. Especially I am obliged to Assoc.Prof.Dr. Mongkol M., Asst.Prof.Dr. Unnut P., Dr. Chinaruk T. and Asst.Prof.Chamlong P. I also want to thank my younger brother Mr. K. Nutthapong was of great help in difficult times. My friend, Ms. Ch. Sermsiri looked closely at the final version of the thesis for English style and grammar, correcting both and offering suggestions for improvement.

Especially, I would like to give my special thanks to my family whose patient love enabled me to complete this work.

CONTENTS

CONTENTS

PAGE

CONTENTS

PAGE

CONTENTS

LIST OF TABLES

TABLE **PAGE**

LIST OF FIGURES

LIST OF FIGURES

FIGURE **PAGE**

LIST OF FIGURES

LIST OF FIGURES

LIST OF SYMBOLS

a	ADDENDUM
b	DISPLACEMENT
b_G	DEDENDUM
c	CENTER DISTANCE
d	OFFSET DIMENSION
d_w	PITCH DIAMETER
F	TANGENTIAL FORCE
F_G	FACE WIDTH
I	CURRENT
K_p	PROPOSIONAL CONSTANT
K_f	FEEDFORWARD GAIN
L	LEAD
N	GEAR RATIO
N_G	TEETH NUMBERS
P	POWER
p_e	SPECIFIED POSITION
p_t	CIRCULAR PITCH
p_x	AXIAL PITCH
q_x	TOOL POSITION ON X-DIRECTION
q_y	TOOL POSITION ON Y-DIRECTION
q_z	TOOL POSITION ON Z-DIRECTION
R	RADIUS
T	TORQUE
u_x	ROLL ORIENTATION ON X-DIRECTION
u_y	ROLL ORIENTATION ON Y-DIRECTION
u_z	ROLL ORIENTATION ON Z-DIRECTION
v_x	PITCH ORIENTATION ON X-DIRECTION
v_y	PITCH ORIENTATION ON Y-DIRECTION

LIST OF SYMBOLS

v_z	PITCH ORIENTATION ON Z-DIRECTION
V	VOLTAGE
V_G	PITCH LINE VELOCITY OF THE GEAR
V_S	SLIDING VELOCITY
V_W	PITCH LINE VELOCITY OF THE WORM
w_x	YAW ORIENTATION ON X-DIRECTION
w_y	YAW ORIENTATION ON Y-DIRECTION
w_z	YAW ORIENTATION ON Z-DIRECTION
W	FORCE
W_f	FRICTIONAL FORCE
W_G	FORCE AGAINST THE WORM
W_W	FORCE AGAINST THE GEAR
W^x	ORTHOGONAL COMPONENT ON X-AXIS
W^y	ORTHOGONAL COMPONENT ON Y-AXIS
W^z	ORTHOGONAL COMPONENT ON Z-AXIS
α	TWIST ANGLE
ω	ANGULAR VELOCITY
ϕ	ROLL ANGLE
ϕ_n	PRESSURE ANGLE
η	EFFICIENCY
λ	LEAD ANGLE
μ	FRICTION COEFFICIENT
θ	ROTATION ANGLE
ϑ	PITCH ANGLE
ψ	YAW ANGLE
ψ_G	HELIX ANGLE

CHAPTER 1

INTRODUCTION

1.1 Introduction

In the present, many kinds of industries object to increase efficiency, productivity and decrease the loss in process and processing time. Thus, for obtain these objectives, automation system and other methods are let to be the tools to improve them. A way to support in the present is taking robot system into these processes. So, this research is happened for learning the robot system

This chapter describes statement and significance of the present problem, objectives, scope of research, process of the research, assumption and motivation in this research. Furthermore, the outlines in each chapter are presented in the last of this chapter.

1.2 Statement and significance of the problem

Recently, industrials trend to be the flexible manufacturing and automated industries because they want to improve quality and increase productivity. One way to support that is the robot and automation system. In Thailand, most of robots are imported from abroad, which increase the production cost. This research is occurred from the way that can reduce cost and develop our industrial and educational efficiency.

1.3 Objectives

1. To study, investigate and learning the robot system.
2. To design and build a 6-axes robot, controller and controlled program for using to be prototype and educational robot system.
3. To reduce cost of imported robot system from aboard.

1.4 Scope of the research

1. In each joint of 6-axes robot is activated by stepper motor only.

2. The controller system is position control, which base on point to point control with basis on kinematics control only.
3. The program can accept for the entering and recording of required points from user.
4. The robot movement can control from dialog box, graphic program and keyboard.
5. The robot can move by joints and Cartesian coordinate control at selectable speed.
6. The program can display recorded positions and their present coordinates.
7. The system without regard to the forces/moments that cause the motion is considered.
8. The inertia from dynamic of robot and disturbance are neglected in consideration.

1.5 Process of the research

1. Study the robot systems and their controlled system.
2. Visit factory and exhibition that concern with this research.
3. Study the characteristic of stepper motor and controlled methods.
4. Study the required controlled systems and their circuits.
5. Design and search the circuits for use to be parts in the controller.
6. Build PCB and assembly the controller.
7. Write and debug program by Visual Basic programming version 6.
8. Test Controller and program with the robot.
9. Edit and improve both controller and program.
10. Test the efficiency of robot by operation in actual situations.

1.6 Assumption

1. A 6-axes robot can be developed for use as the prototype in the study of automation and robot control system.

2. The controller and program can be used for controlling 6-axes robot with point to point control in the acceptance error.

1.7 Motivation

As the author interested in the automation control and robotics system for a long period and working in this field. Furthermore, the main studied course trends to the designed and controlled system. For these motivations, the 6-axes robot is purposed to study the possibility of robotic controlled system.

1.8 Research outline

Chapter 2 presents the literature review and basis of robot, formulation for robotic kinematics, stepper characteristics with their control and the kinematics of worm gear.

Chapter 3 is involved for the robot kinematics and the specification of the 6-axes robot, including the robot structure, forward and inverse kinematics. Furthermore, the kinematics control is presented in the last section of this chapter.

Chapter 4 describes the control system for the 6-axes robot, which base on position control with the position feedback. The methodologies for stepper motor control and data transmission are highlighted here. Concept of programming is presented.

Chapter 5 presents the experimentation and testing of overall system, which includes capability, repeatability, accuracy, joint interaction and joint response testing.

Chapter 6 explains the conclusion of robot's structure, controller and program testing. Furthermore the ways to improve in the future are suggested in this chapter.

1.9 Robotic terms and definitions [1]

Accuracy The ability of a manipulator, upon receiving a controller command, to position the end effector at a specified, but not pretaught, point in Cartesian space.

Actuator An electric, hydraulic, or pneumatic motor or other automatic device, that is used to produce link motion.

Arm An anthropomorphic manipulator usually characterized by a series of links connected by revolute joints.

Articulated Characterized by one or more joints.

Cartesian space Generally a two or three dimensional rectangular space defined by mutually perpendicular Cartesian axes, normally denoted as x and y or x,y and z. In robotics, a Cartesian space vector may also include appropriate orientation information.

Closed loop control see Unity feedback system.

Configuration The position and orientation of a particular part of a manipulator, such as the tool or end effector.

Base Coordinate A reference system (frame), usually Cartesian, with origin fixed to some nonmoving portion of the manipulator's base. Note: Base coordinates are generally used to specify the components of a three dimensional position vector from the origin of the base to the origin of the tool frame. Furthermore, projections of the tool coordinate axes onto the base axes are often used to specify the orientation of the end effector.

Link (Joint) Coordinates A reference system, fixed to each link, that is used to describe the configuration of a given manipulator in terms of link (joint) displacement.

Tool coordinate A reference system, usually Cartesian, with origin attached to a moving object at the end of the manipulator, such as a tool carried by the end effector or gripper. The direction from which the gripper would approach an object defines the approach vector, a. The direction that specify the orientation of the gripper, from fingertip to fingertip, defines the sliding vector, s. The final vector, known as the normal vector, n, completes a right-handed set of vectors, so that a x n = s.

World (Task, Station, or Universe) Coordinates A reference system, usually Cartesian, with origin fixed to some reference point in the vicinity of one or more robots. Note: World coordinates are used when a robot is employed with other devices whose configuration must be determined relative to one another, such as in a manufacturing cell.

Degrees of freedom The number of parameters used to specify the configuration of any element in a kinematic chain with respect to any other. Note: A rigid body that is free to move in a three-dimensional space has six degrees of freedom, three that specify position and three that specify orientation. Furthermore, a robot with separate drive motors for each link is sometimes said to have as many degrees of freedom as the number of motor-driven, articulated links.

Displacement vector A vector generally defined between the (disjoint) origins of difference Cartesian coordinate systems (frames).

End effector A particular gripper or "hand" attached to the end of a manipulator which is generally used to transport a tool or any other project.

Geometric (Kinematic) configuration The number and types of joints and links that comprise a manipulator, and their positioning relative to one another. For a general purpose manipulator, the geometric configuration is called Cartesian if the first three joints are prismatic. Cylindrical if the first joint is revolute and the next to are prismatic, and revolute if all of the first three joints are revolute.

Robot (Robot association of America) A reprogrammable, multifunctional manipulator designed to move material, parts, tools, or special devices through various programmed motions for the performance of diverse tasks.

Kinematic chain A series of rigid bodies (links) connected by joints. If every link is connected to at least two other links, the kinematic chain is said to be closed. If certain links are connected to only one other link, the kinematics chain is said to be open, and such mechanisms are called manipulators.

Kinematic configuration see Geometric Configuration.

Kinematics That part of dynamics involving the study of the geometry and the time-dependent motion of kinematic chains, without consideration of the forces and/or moments that may have caused the motion. Forward kinematics generally is the process of solving for the Cartesian configurations, velocities, and accelerations of a given manipulator in terms of its articulated link displacements, velocities, and accelerations, whereas inverse kinematics pertains to the converse process.

Kinetics That part of dynamics involving the study of the relations between the forces acting on manipulators, the masses of the various links that comprise a manipulator, and the link motions. Kinetics is used to predict the motion caused by given forces or to determine the forces required to produce a given motion.

Link A rigid body in as kinematic chain.

Link (Joint) space An n-dimensional space defined by the various displacements of and n-link manipulator.

Mainpulator The articulated portion of a robot, teleoperator, or telechir, which normally consists of a series of connected links, including the end effector, i.e. an open kinematic chain, as well as any associated actuators and/or sensors.

Orientation The location of a particular axis system (frame), fixed to some link on a manipulator, such as the end effector, relative to a base coordinate system. Often specified by either three Euler angles or the perpendicular projections of the approach, sliding, and normal vectors.

Path The positional information associated with a time-dependent trajectory.

Point To Point A nonservo control technique that enables a robot to stop at numerous distinct points, often specified by an initial lead-through operation, but does not allow any controlled motion between the points. This form of control is often used in so-called pick-and-place type operations, where the manipulator is programmed to pick up an object at one location, and place it at another.

Position The location of a particular point on a manipulator, such as the tool or wrist origin, usually relative to a base (world) Cartesian coordinate system, which is defined by three mutually orthogonal axes, such as x, y, and z.

Precision The accuracy, repeatability, and resolution associated with a manipulator.

Repeatability The ability of the manipulator to position the end effector at the same point during repeated trials.

Resolution The smallest displacement that a manipulator can be commanded to move.

Revolute Joint(Link) A connection between a pair of links that allows only relative rotation about a single axis (the link that rotates about the specified axis).

Sensor A transducer whose input is due to a physical phenomenon and whose output is a measure of that physical phenomenon. Note: A sensor mounted on the manipulator and designed to measure a physical quantity associated with the manipulator itself, e.g., an angular position or velocity, is called an internal sensor. A sensor designed to measure a physical relationship between a manipulator and its environment, e.g., the force exerted by a gripper on an external on an external object, is called an external sensor.

Stable A "well-behaved" dynamical system whose output remains bounded in response to bounded external input.

Steady-State Error A performance measure that reflects the difference between the output of the a stable, closed loop system and the external input (which the system output is to track) after the transient response has converged to zero.

Task Level (Programming) A desired, but as yet experimental, form of programming robots using explicit command statements that specify desired functional goals, rather than the implicit interim positional moves required to achieve the goal.

Teach Pendant (Box) A physical device (usually hand-held) that is used to move a robot to visually determined configurations, where the link displacements can be committed to memory or "taught" for subsequent replay during task execution.

Trajectory A special position/time curve that usually represents a desired manipulator motion in either link or Cartesian space. A path along with appropriate velocity and/or acceleration information.

Trajectory Planner A special computer program that generally produces a time-varying signal representing the desired path or trajectory that a robot is to follow in either Cartesian or link space.

Transient Response In the case of a stable system, the short-term response of the controlled system that the normally converges to zero in some finite time.

Working Envelope The boundary of the working range (volume).

Working Range (Volume or Space) The set of all points that can be reached by any part of a manipulator when articulated through all possible configurations.

Wrist (Links) A set of links (usually the last three) located between the main body of a manipulator and its end effector, which is primarily used to orient the end effector. Note: If all three of the axes of a wrist intersect at a common point (the wrist origin), the wrist is called spherical.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Before beginning to describe the robot kinematics, control and its structure that will be presented in the next chapter. This chapter contains the history in robot development, basic of robot control. It includes Devit hartenberg formulation, stepper motors and their basic control, power transmission and kinematics motion control. After this chapter, the next chapter will apply these basis to the 6-axes robot.

2.2 Background and historical development of the robot

With the pressing need for increased productivity and the delivery of end products of uniform quality, industry is turning more and more toward computer-based automation. At the present time, most automated manufacturing tasks are carried out by special purpose machines designed to perform predetermined functions in a manufacturing process. The flexibility and generally high cost of these machines, often called hard automation systems, have led to a broad-based interest in the use of robots capable of performing a variety of manufacturing functions in a more flexible working environment and at lower production costs.

The word robot originated from the Czech word robota, meaning work. Webster's dictionary defined robot as "an automatic device that performs functions ordinarily ascribed to human beings." A definition used by the Robot Institute of America gives a more precise description of robot: " A robot is a reprogrammable multi functional manipulator designed to move materials, parts, tools, or specialized devices, through variable programmed motions for the performance of a variety of tasks." In short, a robot is a reprogrammable general-purpose manipulator with external sensors that can perform various assembly tasks. With this definition, a robot must possess intelligence, which is normally due to computer algorithms associated with its control and sensing systems [2].

A robot is a general purpose, computer controlled manipulator consisting of several rigid links connected in series by revolute or prismatic joints. One end of the chain is attached to a support base, while the other end is free and equipped with a tool to manipulate objects or perform assembly tasks. The motion of the joints results in relative motion of the links.

Mechanically, a robot is composed of an arm (or mainframe) and a wrist subassembly plus a tool. It is designed to reach a work-piece located within its work volume. The work volume is the sphere of influence of a robot whose arm can deliver the wrist subassembly unit or any point within the sphere. The arm subassembly generally can move with three degrees of freedom. The combination of the movements positions the wrist unit at the work-piece. The wrist subassembly unit usually consists of three rotary motions. The combination of these motions orients the tool according to the configuration of the object for ease in pickup. These last three motions are often called pitch, yaw and roll. Hence, for a six-jointed robot, the arm subassembly is the positioning mechanism, while the wrist subassembly is the orientation mechanism.

Most of today's robot, though controlled by mini and microcomputer, are basically simple positional machines. They execute a given task by playing back prerecorded or preprogrammed sequences of motions that have been previously guided or taught by user with a hand held control teach box. Moreover, these robots are equipped with little or no external sensors for obtaining the information vital to its working environment. As a result, robot are used mainly improving the overall performance of the manipulator systems are presented in this research.

The below table describes some highlights in the developed history of robotics.

Table 2.1 Some highlights in the history of robotics [2].

Year	Highlights descriptions
2000 B.C.	- An Egyptian toy dog with a lever-controlled jaw is fabricated.
1400s	- The first android clocks are developed in Germany and Switzerland.
1770	- Piere and Henri Jacquest-Droz construct lifelike automata that can write, draw and play musical instruments and are controlled by cams and driven by springs.
1818	- Eli Whitney invents a milling machine.
1830s	- Charles Babbage devises his analytical engine, the forerunner of the modern digital computer.
1870s	- Herman Hollerith perfects the first automatic calculator.
1921	- Karel Capek's play Rossum's Universal Robots introduces the term robot, derived from the Czech word robota, which means, "forced labor".
1930s	- The first spray painting machines with recorded paths are developed.

Table 2.1 Some highlights in the history of robotics (continue)

Year	Highlights descriptions
1940s	- Isaac Asimov and John Campbell devise the concept of the intelligent robot that follows introduces, and together they write numerous science fiction stories about robots. Asimov coins the phase robotics to denote the study of robots.
1942	- The first automatic sequence controller is developed at Harvard University.
1944	- R. Goertz introduces the first master-slave (teleoperator) manipulator.
1946	- George Devol develops the magnetic controller playback devices.
1948	- J.P. Eckert and John Mauchley complete construction of the ENIAC computer at the University of Pennsylvania.
1949	- EDSAC, the first computer with a stored program, is developed at Cambridge University
1952	- The first numerically controlled machine tool is built at MIT.
1954	- Georgr Devol designs the first programmable robot.
1955	- Denavit and Hartenberg develop their method for determining and specifying the configuration of the various links in a manipulator.
1956	- Joseph Engelberger, a Columbia University physics student, buys the rights to Devol's robot and soon after starts the Unimation Company.
1961	- The first Unimate robot is installed in Trenton, New Jersey, plant of General motors (to tend a die-casting machine).
1965	- John McCarthy initiates a major program in robotics at the Stanford University Artificial Intelligence Laboratory (SAIL).
1968	- Kawasaki Heavy Industries in Japan obtains a licensing agreement from Unimation.
1970	- The Stanford manipulator, which uses electrical drive motors, is employed to automatically stack colored blocks at Stanford University.
1974	- Cincinnati Milacorn introduces the T3, the first robot to employ a completely revolute configuration.
1975	-Unimation Inc. registers its first financial profit.
1978	- The first PUMA (whose design is based on Victor Sheinman's Stanford manipulator) is shipped to GM by Unimation.

2.3 Devit hartenberg (D-H) formulation [3]

2.3.1 D-H (Denavit-Hartenberge) Coordinate Transformation for 6-axes articulate vertical robot

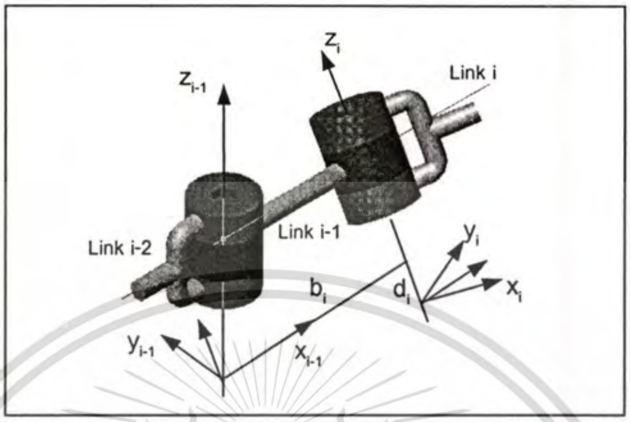


Figure 2.1 Basic three connected links for D-H coordinate transformation

Consider the situation depicted above, Let Z_{i-1} and Z_i represent fixed axes at either end (joint) to link $i-1$, about which or along which links $i-1$ and i move, respectively.

1. Let X_{i-1} be defined from Z_{i-1} to Z_i and perpendicular to both.
2. Let O_{i-1} denote the point of intersection of axes Z_{i-1} and X_{i-1}
3. Let Y_{i-1} represent the unique axis that together with X_{i-1} and Z_{i-1} completes a right hand Cartesian coordinate system.
4. Let Z_i represent a vector from O_{i-1} parallel to Z_i
5. Let X_{i-1} represent a vector from O_i parallel to X_{i-1}

The following four ordered operations completely specify the configuration of the frame i coordinate system relative to the frame $i-1$ coordinate system:

1. A constant *twist* of α_i degree about axis X_{i-1} of Z_{i-1} into Z_i
2. A constant *displacement* of b_i unit along X_{i-1} from Z_{i-1} to Z_i
3. A *rotation* of θ_i degrees about Z_i of X_{i-1} into x_I
4. An *offset* of d_i units along Z_i from X_{i-1}, Z_i intersection to O_i

The overall D-H coordinate transformation matrix is then given by

$$T_{i-1}^{i}=\begin{vmatrix} \cos\theta_i & -\sin\theta_i & 0 & b_i \\ \cos\alpha_i\sin\theta_i & \cos\alpha_i\cos\theta_i & -\sin\alpha_i & -d_i\sin\alpha_i \\ \sin\alpha_i\sin\theta_i & \sin\alpha_i\cos\theta_i & \cos\alpha_i & d_i\cos\alpha_i \\ 0 & 0 & 0 & 1 \end{vmatrix} \tag{2.1}$$

2.4 Stepper motor characteristics and control [4]

Stepper motors are being widely used in simple position control system in the open loop and closed loop modes. A digital computer or microprocessor can directly drive a stepper motor using binary numbers. The stepper motor exhibits the characteristics of a synchronous motor. It produces a steady torque at a given speed.

2.4.1 Constructional features

A stepper motor could be either of the reluctance type or of the permanent magnet type (PM) stepper motor has salient magnetic poles and a reluctance stepper motor has unmagnetized salient poles. The basic two-phase stepper motor consists of two pairs of stator poles. Each of the four poles has its own winding. The excitation of any one winding generates a north pole(N) and a south pole (S') gets induced at the diametrically opposite side.

The four poles structure is continuous with the statorframe and the magnetic field passes through the cylindrical stator annular ring as figure 2.2. The rotor magnetic system has two end faces. The left face is permanently magnetized as 'south pole' and the right face as 'north pole'. The south pole structure may have three of five pole faces and the north pole structure possesses similar pole faces. The north pole structure is twisted w.r.t. the south pole structure so that a south pole comes precisely between two north poles as figure 2.3.

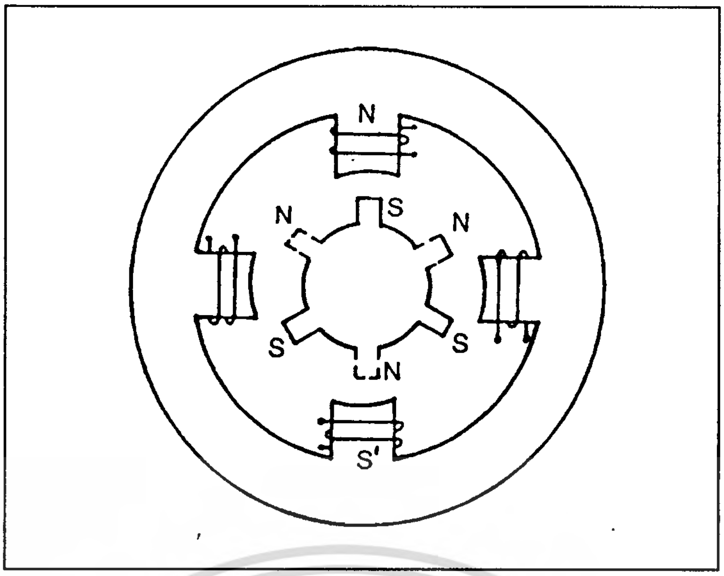


Figure 2.2 Stepper motor cross-sectional view

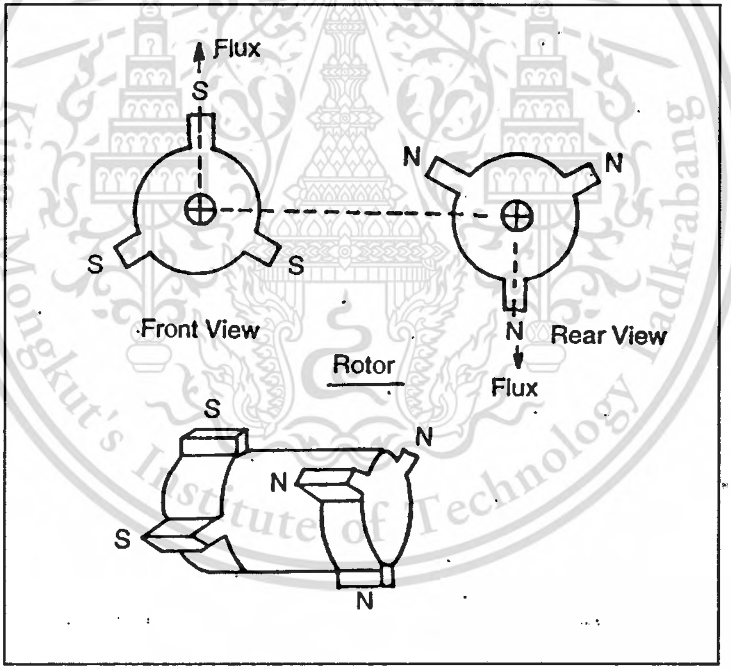


Figure 2.3 Typical stepper motor rotor

2.4.2 Parameters of stepper motors

Certain parameters of stepper motors are defined as following

1. Step angle: This refers to the angle through which the motor moves for one step.

2. Stepping rate: The number of steps executed per second is known as the stepping rate. If the stepping pulses are given at a rate greater than the maximum allowable rate, then the motor would miss many steps.

3. Holding torque: This is equal to the external torque which must be applied to break away from its equilibrium position, when a stator winding remains excited.

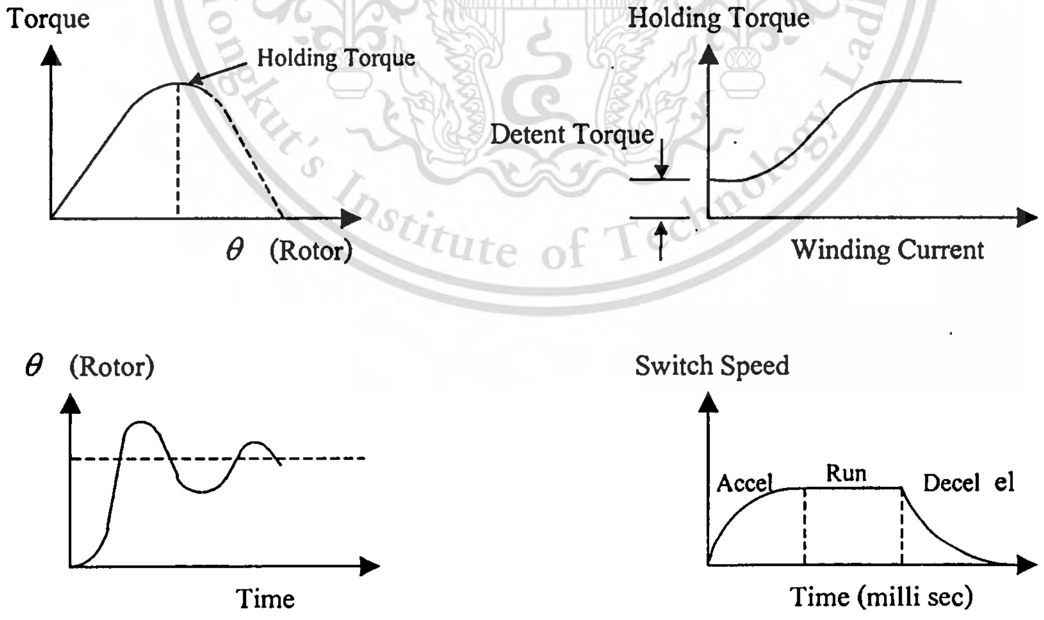
4. Dynamic torque: The torque produced by the stepper motor under a constant stepping rate is known as the dynamic torque.

5. Detent torque: This is the torque required to overcome the residual magnetism and reluctance torque under the unexcited condition. This torque enables the motor to hold a load even when the stator windings are de-energized.

6. Holding torque/inertia ratio: High performance motors have a large holding torque/inertia ratio. Such motor have a length greater than the diameter.

7. Step response: When a single step is executed by the motor, the rotor exhibits a decaying oscillatory response. Mechanical (viscous dampers) may be employed to reduce the setting time.

Some of above parameters are illustrated in below figure.



Transient Response

Ramping

Figure 2.4 Characteristics of stepper motor

8. Resonance: The inertia of the motor together with the magnetic stiffness from an oscillatory system. At certain stepping rates, this phenomenon causes the rotor to oscillate and lose the step integrity. Addition of inertia and viscous damping would improve the stability. Special inertia cum viscous dampers called Lanchester dampers are commonly employed.

9. Ramping: The process of controlling the switching frequency or stepping rate to accelerate a motor from zero to full speed as well as to decelerate it from maximum speed to zero without losing steps is called ramping. For handling large inertia loads, the ramping characteristics must be carefully specified.

10. Step size: The north pole structure is offset with respect to the south pole structure by one pole pitch as explained. In an arrangement where there are four stator poles and three pairs of rotor poles, there exist 12 possible stable positions in which a south pole of the rotor can lock with a north pole of the stator (and the corresponding north pole of the rotor locks with south pole of the stator). It is clear that the step size is $(360°/12) = 30°$ (mechanical). These stable positions can be attained by simply energizing the windings on any one of the stator poles with a direct current.

There are at least three different schemes available for "stepping" a stepper motor. These are:

(a) wave scheme

(b) 2-phase scheme and

(c) half stepping or mixed scheme.

These three schemes are described in detail in the following sections

2.4.3 Wave scheme (unipolar operation)

The stepper motor windings A1, B1, A2, B2 can be cyclically excited with a dc current to run the motor in the clockwise direction. By reversing the phase sequence as A1, B2, A2, B1, we can obtain anticlockwise stepping. The excitation signals for the wave scheme appear as shown in figure 2.5.

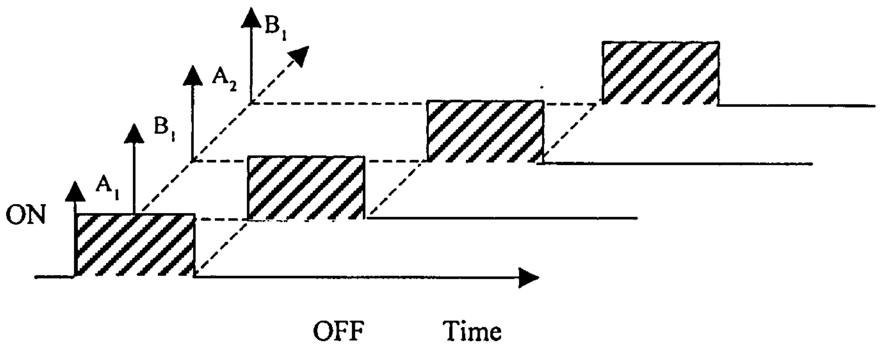


Figure 2.5 Wave scheme

2.4.4 Stepping diagram

The four possible rotor positions and the corresponding stator excitations illustrated in figure 2.6. In step (a) it is seen that the rotor pole S1 locks with the stator pole A1 (N) and the rotor pole N1 locks with the stator pole A2(S'). Under these conditions, it is obvious that the winding A1 must have been energized. A2(S') is an induced south pole.

Next, A1 is de-energized and B1 is turned on. The nearest rotor pole S2 locks with B1(N) and the corresponding rotor pole N2 locks with the induced pole B2(S'). This is illustrated in step (b) of figure 2.6.

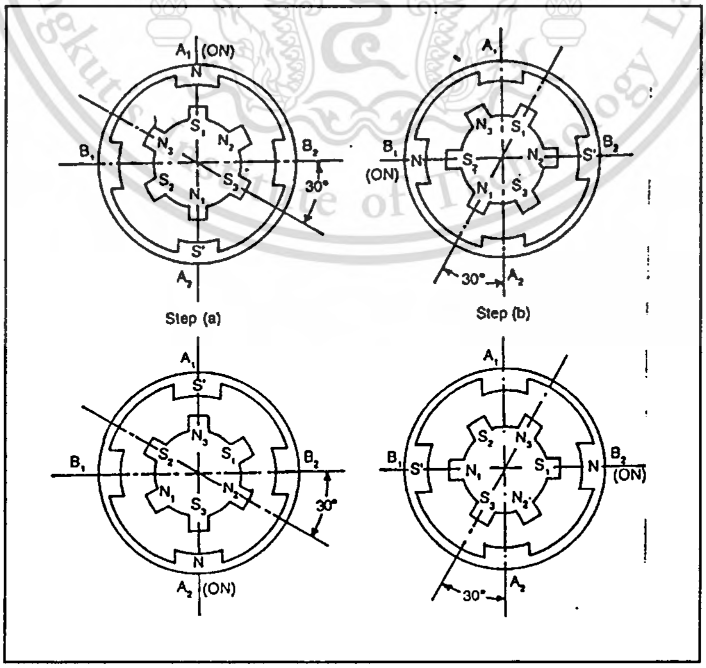


Figure 2.6 Simple wave scheme for stepper motor

When A2 alone is energized next, the nearest rotor pole S3 locks with A2(N) (step (c) of figure 2.8).

B2 alone is energized next and the nearest rotor pole S1 locks with B2(N). Totally 12 such steps cause a displacement of 360 degrees. The step angle is 30 degree (mechanical).

The switching sequence for the wave mode excitation is given in table 2.2.

Table 2.2 Wave switching scheme

Anticlockwise					Clockwise				
Step	A1	A2	B1	B2	Step	A1	A2	B1	B2
1	1	0	0	0	1	1	0	0	0
2	0	0	0	1	2	0	0	1	0
3	0	1	0	0	3	0	1	0	0
4	0	0	1	0	4	0	0	0	1

2.4.5 2-phase schemes

In this scheme, any two adjacent stator windings are energized. There are two magnetic fields active in quadrature and none of the rotor pole faces can be in direct alignment with the stator poles. A partial but symmetric alignment of the rotor poles is of course possible.

Typical equilibrium conditions of the rotor when the windings on two successive stator poles are excited are illustrated in figure 2.7. In step (a), A1 and B1 are energized. The pole-face S1 tries to align itself with the axis of A1(N) and the pole face S2 with B1(N). The north pole N3 of the rotor finds itself in the neutral zone between A1(N) and B1(N). S1 and S2 of the rotor, position themselves symmetrically w.r.t. two stator north poles.

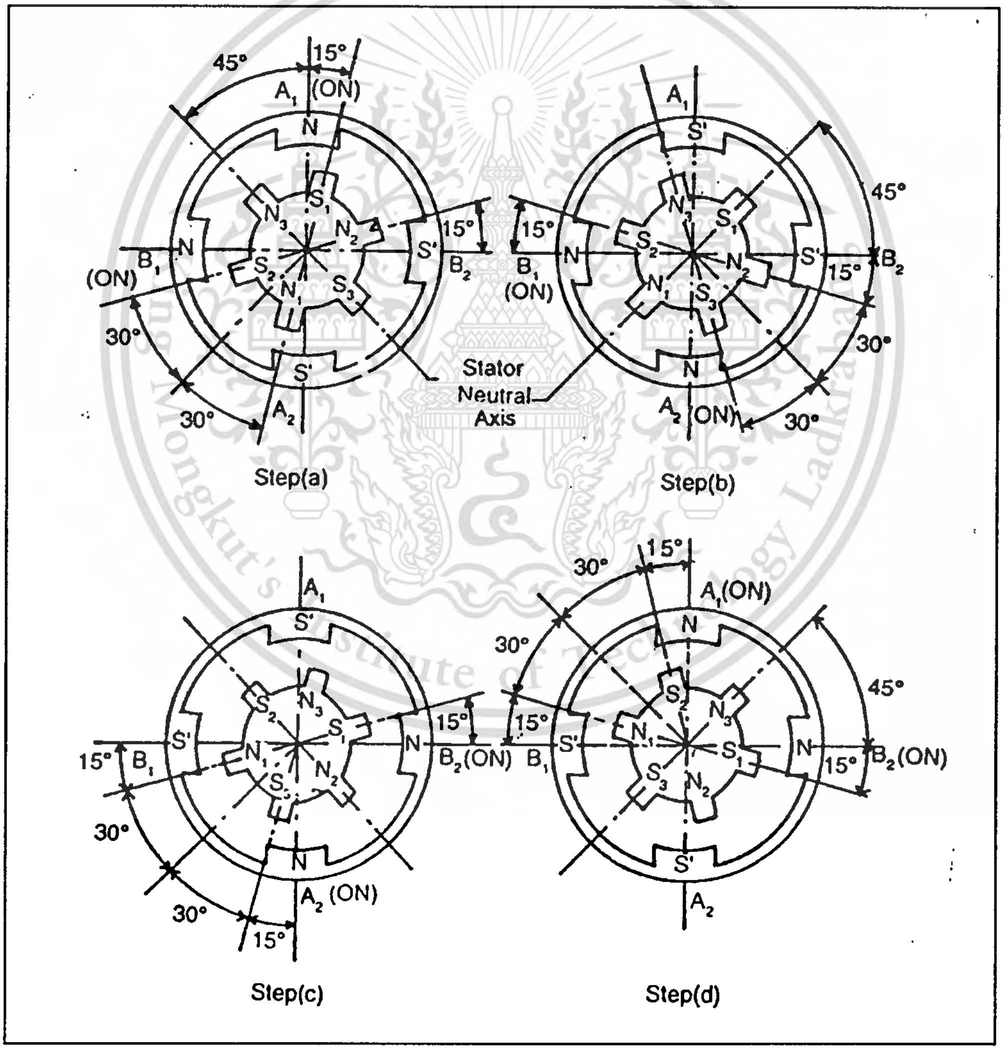
Next, when B1 and A2 are energized, S2 tends to align with B1(N) and S3 with A2(N). Under equilibrium conditions, only partial alignment is possible and N1 finds itself in the neutral region, midway between B1(N) and A2(N) [step (b)]. In step (c), A2 and B2 are on. S3 an S1 tend to align with A2(N) and B2(N), respectively, with N2 in the neutral zone. Step (d) illustrates the case when A1 and B2 are on.

The step angle is 30 degrees as in the wave scheme. However, the rotor is offset by 15 degrees in the two-phase scheme w.r.t. the wave scheme. A total of 12 steps are required to move the rotor by 360 degrees (mechanical). Two-phase drives produce more torque than the wave drives.

The switching sequence for the 2-phase scheme is given in Table 2.3.

Table 2.3 2-phase switching scheme

Anticlockwise					Clockwise				
Step	A1	A2	B1	B2	Step	A1	A2	B1	B2
1	1	0	0	1	1	1	0	1	0
2	0	1	0	1	2	0	1	1	0
3	0	1	1	0	3	0	1	0	1
4	1	0	1	0	4	1	0	0	1



Step(a)
Step(b)
Step(c)
Step(d)

Figure 2.7 2-phase drive scheme

2.4.6 Half stepping scheme

The wave scheme as well as the 2-phase scheme give step of size 30 degrees for the stepper motor under consideration. However, there is an offset of 15 degrees between these two schemes. By interleaving these two schemes, the step size can be reduced to 15 degrees, thereby improving the accuracy of the stepper motor. The half stepping scheme is a mixture of the wave scheme and the 2-phase scheme [figure 2.8 (a) to (i)]

The switching sequence is:

(i) A1 (ON) (ii) A1 and B1 (ON) (iii) B1 (ON) (iv) B1 and A2 (ON)

(v) A2 (ON) (vi) A2 and B2 (ON) (vii) B2 (ON) (viii) B2 and A1 (ON)

(ix)A1 (ON), etc.

Eight steps are required to move the shaft by 120 degrees and 24 steps for one complete revolution. By reversing the switching sequence, the direction is reversed. One major disadvantage of the half stepping scheme is torque fluctuations. This is because the aligning torque for the wave scheme is different from that for the 2-phase scheme.

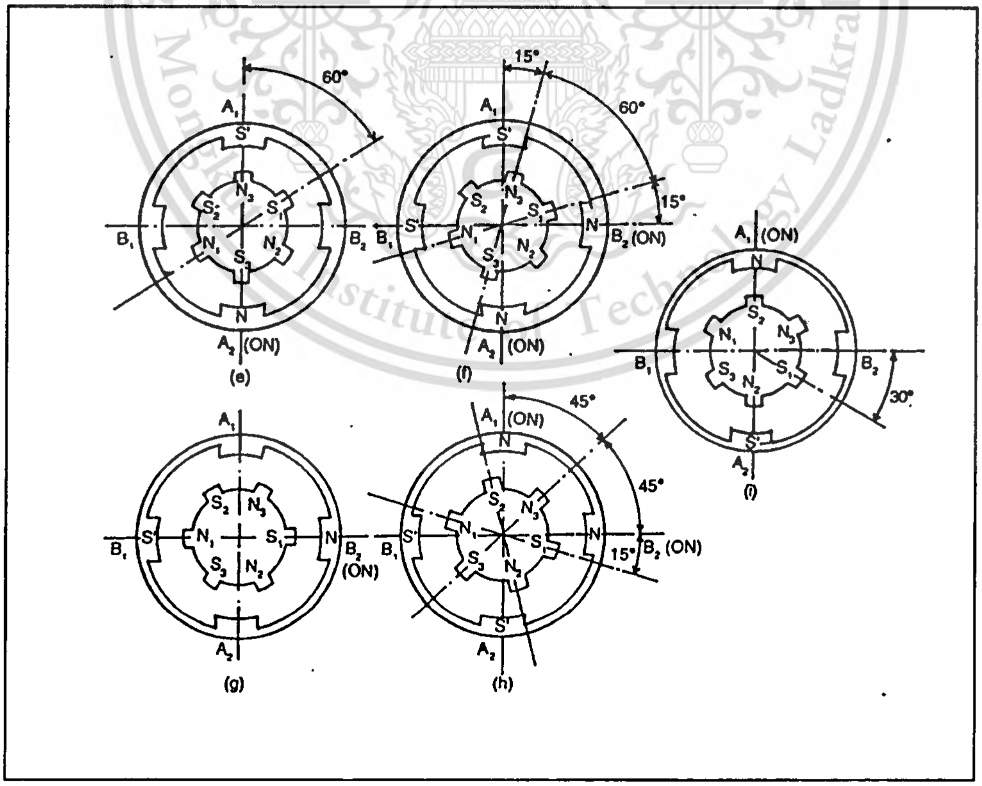


Figure 2.8 Half step scheme

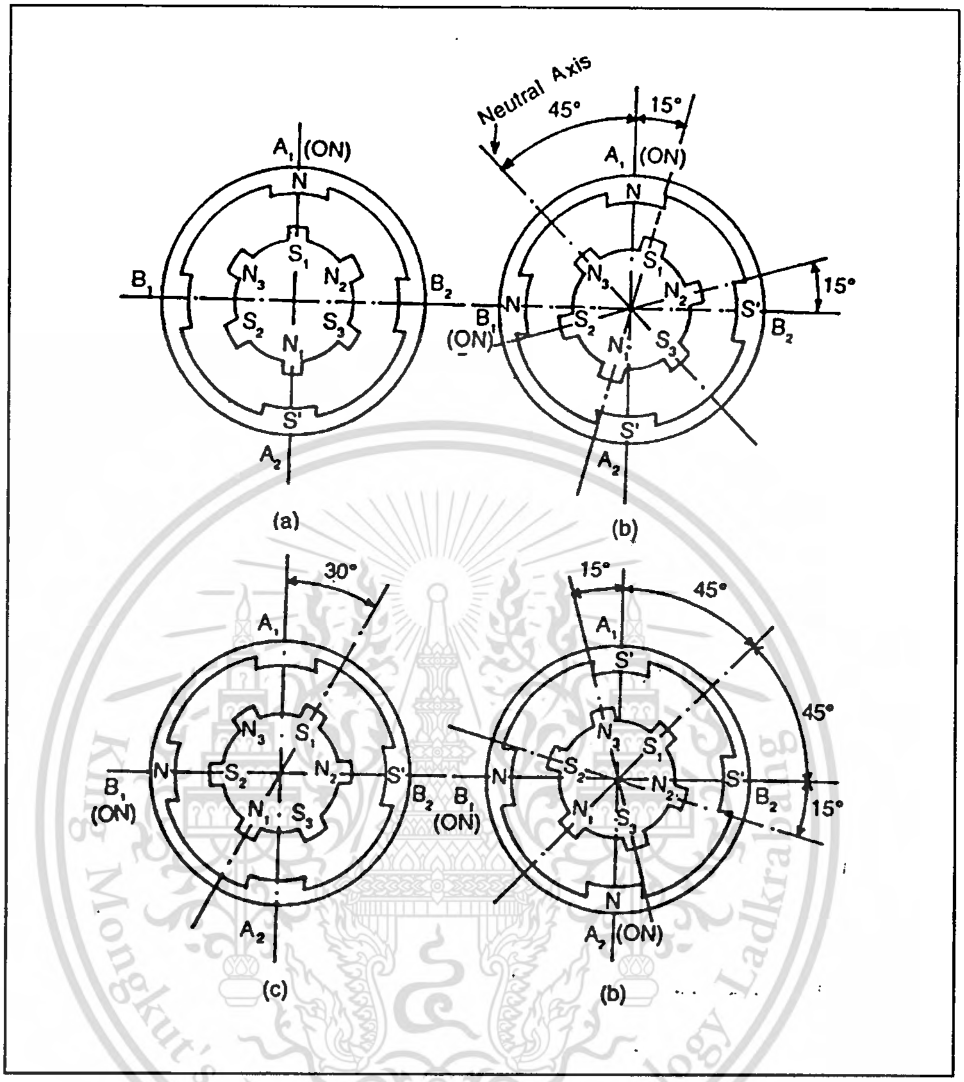


Figure 2.9 Half step scheme (continuous)

2.4.7 Stepper motor drive circuit

A two-phase stepper motor can be excited by passing a current through the individual windings on each of the four poles. Only a single-ended power supply is required to operate the motor in the unipolar mode.

Darlington transistor pairs drive the windings. The voltage rating of the zener diodes must be much smaller than the breakdown voltage of the transistors. A free wheeling diode provides a decay path for the windings current when the transistors are switched off. The individual transistors get the control signals (ON/OFF) from a port buffer into which the command word is loaded by the microprocessor or computer.

(i) for the wave drive the command words can be

1	0	0	0	0	0	0	0
0	1	0	0	0	0	0	0
0	0	1	0	0	0	0	0
0	0	0	1	0	0	0	0

(ii) for the 2-phase scheme, the command words are

1	1	0	0	0	0	0	0
0	1	1	0	0	0	0	0
0	0	1	1	0	0	0	0
1	0	0	1	0	0	0	0

(iii) for the mixed mode scheme, the command word are

1	0	0	0	0	0	0	0
1	1	0	0	0	0	0	0
0	1	0	0	0	0	0	0
0	1	1	0	0	0	0	0
0	0	1	0	0	0	0	0
0	0	1	1	0	0	0	0
0	0	0	1	0	0	0	0
1	0	0	1	0	0	0	0

2.4.8 Open loop and closed loop control of stepper motor

A stepper motor can be driven through the specified number of step by supplying the required number of pulses in the proper sequence. This number is generated during every sampling period by a computer of microprocessor along with the direction code. No feedback is necessary and the position need not be sensed if the load is small is small. However, if the load torque is large, there is a possibility of a slip taking place; i.e. even before the stepper motor can completely execute a step, the next pulse may arrive, causing the motor to miss the steps. In such situations, a shaft encoder is necessary to provide the feedback information.

The number of pulses to be executed and the actual number of steps performed by the motor are compared and the error is used for delivering further pulse proportional to the error to the stepper motor driver. The motor would come to rest only if the error becomes zero.

When the error is positive, the pulses are fed in the positive sequence and when the error is negative, the pulses are fed in a negative sequence.

In general, the computer must keep track of the total number of steps through which the motor has moved from the initial or calibration position up to the present position. The enables one to know the present joint angle of a robot w.r.t. reference frame. If the robot must move from θ_1 to θ_2, the number of steps through which the motor should move will correspond to the difference (θ_2 - θ_1)

Table 2.4 Comparison between DC motor and stepper motor

DC motor	Stepper motor
1. Torque is proportional to the armature current.	1. Torque changes are not possible.
2. Large size for the same maximum torque.	2. Small size for the given maximum torque.
3. Precise arbitrary positioning is possible.	3. Position is quantized and precise.
4. Rapid response	4. Response time is poor
5. High holding torque	5. Not suitable for high holding torque; use for light load only.
6. Must operate in the closed loop mode.	6. Can operate in the open loop or closed loop mode.
7. Non-synchronous movement.	7. Synchronous operation is possible.
8. Commutators and brushes required maintenance.	8. No maintenance is required.
9. Requires bipolar power supplies (forward and backward direction movement).	9. Can operate from a single battery.
10. The drive is smooth.	10. Accelerates and decelerates during each step, so the operation is jerky.

2.5 Worm gear [5]

2.5.1 Kinematic of worm gear

The nomenclature of a worm and worm gear is shown in figure 2.10. The worm and worm gear of a set have the same hand of helix as for crossed helical gears, but the helix angles are usually quite different. The helix angle on the worm is generally quite large, and that on the gear very small. Because of this, it is usual to specify the lead angle λ on the worm and helix angle ψ_G on the gear; the two angles are equal for a 90^o shaft angle. The warm lead angle is the complement of the worm helix angle, as shown in Figure 2.10.

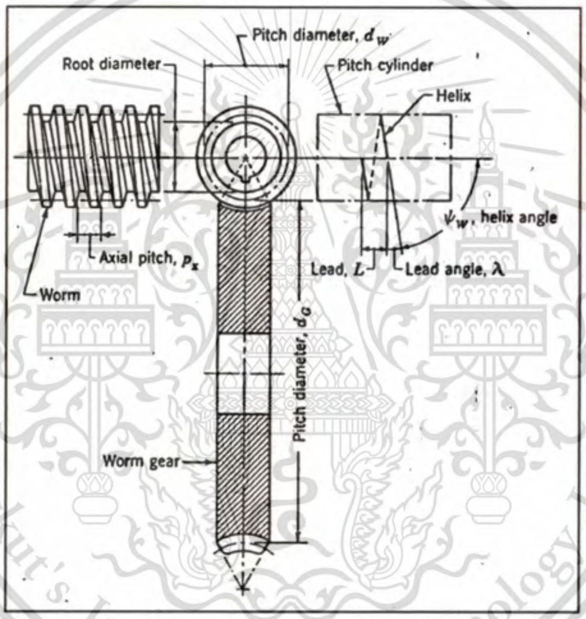


Figure 2.10 Nomenclature of a single-enveloping worm gearset.

In specifying the pitch of worm gearsets, it is customary to state the axial pitch p_x of the worm and the transverse circular pitch p_t, often simply called the circular pitch, of the mating gear. These are equal if the shaft angle is 90^o. The pitch diameter of gear is the diameter measured on a plane containing the worm axis, as shown in Figure 2.10; it is the same as for spur gears and is

$$d_G = \frac{N_G p_t}{\pi} \tag{2.2}$$

Since it is not related to the number of teeth, the worm may have any pitch diameter; this diameter should, however, be the same as the pitch diameter of the hob used to cut the worm-gear teeth. Generally, the pitch diameter of the worm should be selected so as to fail into the range

$$\frac{C^{0..875}}{3.0} \le d_w \le \frac{C^{0.875}}{1.7} \qquad (2.3)$$

where C is the center distance. These proportions appear to result in optimum horsepower capacity of the gearset.

The lead L and lead angle λ of the worm have the following relations:

$$L = p_x N_w \qquad (2.4)$$

$$\tan\lambda = \frac{L}{\pi d_w} \qquad (2.5)$$

Tooth forms the worm gearing have not been highly standardized, perhaps because there has been less need for it. The pressure angles used depend upon the lead angles and must be large enough to avoid undercutting of the worm-gear tooth on the side at which contact ends. A satisfactory tooth depth, which remains in about the right proportion to the lead angle, may be obtained by making the depth a proportion of the axial circular pitch. Table 2.5 summaries what may be regarded as good practice for pressure angle and tooth depth.

Table 2.5 Recommended pressure angles and tooth depths for worm gearing

Lead angle λ, degrees	**Pressure angle ϕ_n, degrees**	**Addendum a**	**Dedendum b_G**
0-15	14.5	0.3683 p_x	0.3683 p_x
15-30	20	0.3683 p_x	0.3683 p_x
30-35	25	0.2865 p_x	0.3314 p_x
35-40	25	0.2546 p_x	0.2947 p_x
40-45	30	0.2228 p_x	0.2578 p_x

The face width F_G of the worm gear should be made equal to the length of a tangent to the worm pith circle between its points of intersection with the addendum circle, as shown in Figure 2.11.

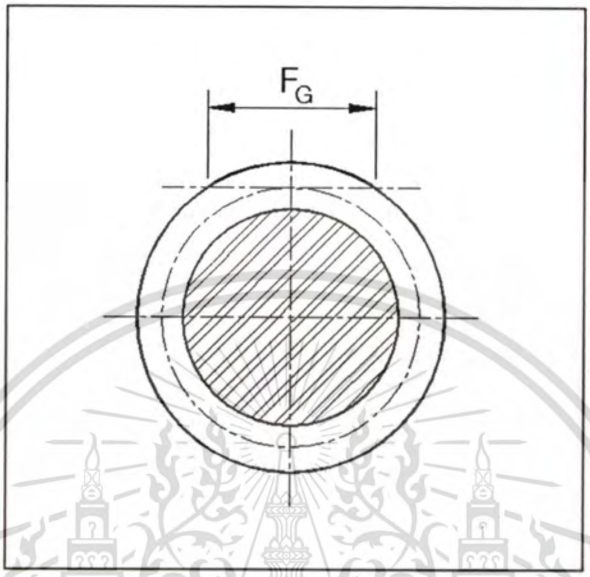


Figure 2.11 The face width F_G of the worm gear

2.5.2 Force analysis of worm gear

If friction is neglected, then the only force exerted by the gear will be the force W, shown in below figure, having the three orthogonal components W^x, W^y, and W^z

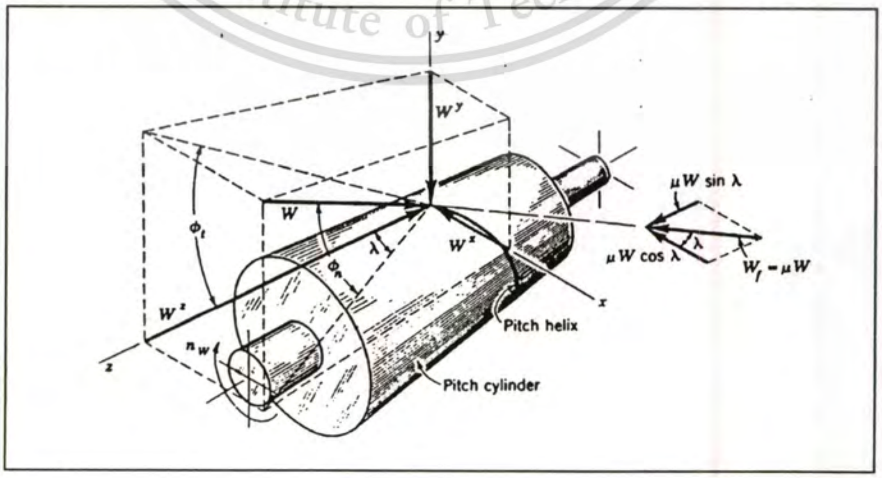


Figure 2.12 Pitch cylinder of a worm, showing the forces exerted upon by the worm gear.

From the geometry of the figure, see that

$$W^x = W\cos\phi_n \sin\lambda$$

$$W^y = W\sin\phi_n \tag{2.6}$$

$$W^z = W\cos\phi_n \cos\lambda$$

Using the subscripts W and G to indicate forces acting against the worm and gear, respectively. W^y is the separating or radial, force for both the worm and gear. The tangential force on the worm is W^x and W^z on the gear, assuming a 90^o shaft angle. The axial force on the worm is W^z, and on the gear, W^x . Since the gear forces are opposite to the worm forces can be wrote as

$$W_{W_t} = -W_{G_a} = W^x$$

$$W_{W_r} = -W_{G_r} = W^y \tag{2.7}$$

$$W_{W_a} = -W_{G_t} = W^z$$

It is helpful in using Eq.(2.6) And also Eq.(2.7) To observe that the gear axis is parallel to the x-direction and the worm axis is parallel to the z-direction and that can be employed a right-handed coordinate system.

The motion of one tooth relative to the mating tooth is primarily a rolling motion; in face, when contact occurs at the pitch point, the motion is pure rolling. In contrast, the relative motion between worm and worm-gear teeth is pure sliding, and must expect that friction plays an important role in the performance of worm gearing. By introducing a coefficient of friction, can develop another set of relations similar to those of Eq.(2.6) In figure 2.12, the force W acting normal to the worm tooth profile produces a frictional force , having a component in the negative x-direction and another component in the positive z-direction. Eq.(2.6) Therefore becomes

$$W^x = W(\cos\phi_n \sin\lambda + \mu\cos\lambda)$$

$$W^{y} = W \sin \phi_n \tag{2.8}$$

$$W^{z} = W(\cos \phi_n \cos \lambda - \mu \sin \lambda)$$

Equation, of course, still applies.

Substitution W^{z} into the third part of eq. (2.7) and multiply both sides by μ , the frictional force to be

$$W_f = \mu W = \frac{\mu W_{G_t}}{\mu \sin \lambda - \cos \phi_n \cos \lambda} \tag{2.9}$$

Another useful relation can be obtained by solving the first and third parts of Eq.(2.7) simultaneously to get a relation between the two tangential forces, the result is

$$W_{W_t} = W_{G_t} = \frac{\cos \phi_n \sin \lambda + \mu \cos \lambda}{\mu \sin \lambda - \cos \phi_n \cos \lambda} \tag{2.10}$$

Efficiency η can be defined by using the equation

$$\eta = \frac{W_{W_t}(without\ \ friction)}{W_{W_t}(with\ \ friction)} \tag{a}$$

Substitution Eq. (2.10) with $\mu = 0$ in the numerator of Eq.(a) at the same equation in the denominator. After some rearranging, the efficiency becomes

$$\eta = \frac{\cos \phi_n - \mu \tan \lambda}{\cos \phi_n + \mu \cot \lambda} \tag{2.11}$$

Selecting a typical value of the coefficient of friction, $\mu = 0.05$, and the pressure angles shown in Table 2.5, we can use Eq.(2.11) to get some useful design information. Solving this equation for helix angles from 1 to 30^{o} gives the interesting results shown in Table 2.6.

Table 2.6 Efficiency of worm gearsets for $\mu = 0.005$

Helix angle ψ, degrees	**Efficiency η, percent**
1.0	25.2
2.5	46.8
5.0	62.6
7.5	71.2
10.0	76.8
15.0	82.7
20.0	86.0
25.0	88.0
30.0	89.2

Many experiments have shown that the coefficient of friction is dependent on the relative or sliding velocity. In Figure… V_G is the pitch-line velocity of the gear and V_W the pitch-line velocity of the worm. Vectorially, $V_W = V_G + V_S$; consequently,

$$V_S = \frac{V_W}{\cos\lambda} \tag{2.12}$$

Published values of the coefficient of friction vary as much as 20 percent, undoubtedly because of the differences in surface finish materials, and lubrication. The values on the chart of Figure 2.13 is representative and indicate the general trend.

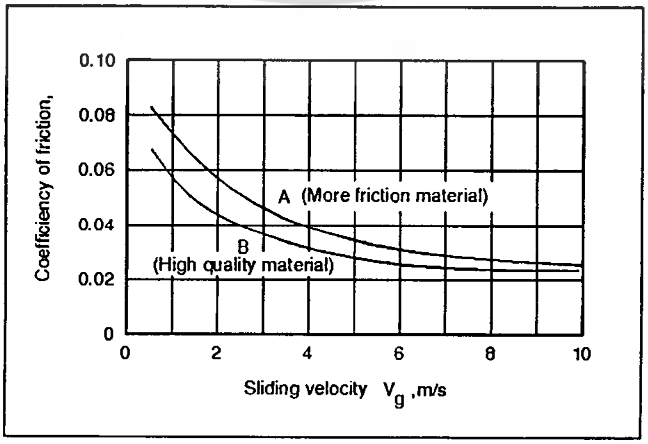


Figure 2.13 Coefficient of friction for worm gearing

CHAPTER 3

6-AXES ROBOT KINEMATICS AND CONTROL

3.1 Introduction

This chapter is involved for the robot kinematics and control algorithm. The robot kinematics deals with the analytical study of geometry of motion of a robot arm with respect to a fixed reference coordinate system without regard to the forces/moments that cause the motion is presented. There are two fundamental problems in robot arm kinematics. The first problem is usually referred to as the direct (or forward) kinematics problem. While the second problem is the inverse kinematics (or arm solution) problem. In the last of this chapter is introduced to the kinematics motion control for using in the basically control system, which can be applied for both point to point control and path control.

3.2 Working enveloped range of the 6 axes robot

The below figure presents the working range of a 6-axes robot in vertical. This figure shows the set of all positions that given manipulator can reach.

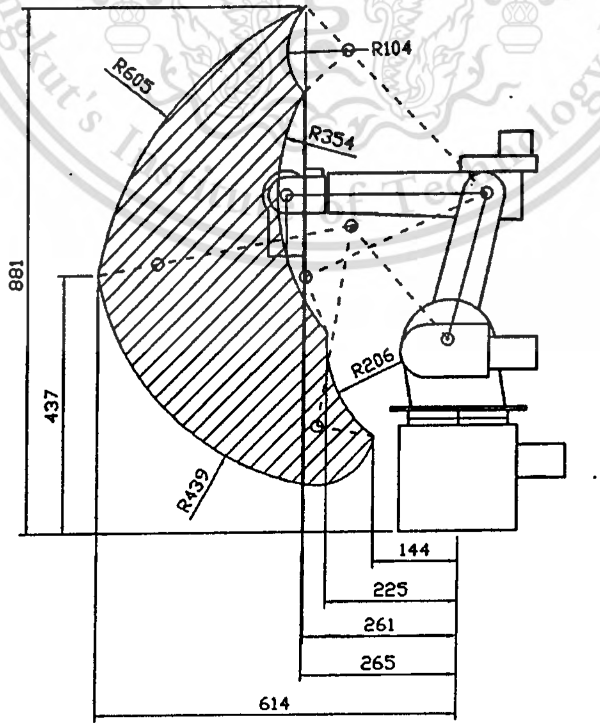


Figure 3.1 Working enveloped range of developed 6-axes robot (vertical)

The details of robot structures are presented in Appendix A (Drawings of a 6-axes robot), which shows detail in each part.

3.3 Proposed 6-axes robot's structure specifications

The 6-axes robot required specification, which is the articulated vertical robot, is presented as in table 3.1.

Table 3.1 Proposed specifications of a 6-axes robot

1. Manipulator	
■ Drive type	DC stepping motor
■ Configuration	Joint arm
■ Coordinate system	
■ Joint	Cartesian
■ Tool	Cartesian
■ Degree of freedom	6 Axes (D.O.F.)
■ Gripper actuators	Magnetic, Pneumatic
2. Classification	Point To Point control
3. Power requirement	220~240 V, 50~60 Hz
4. Working motion	(relate with the home position)
■ Arm sweep	-175 to +175 degree
■ Shoulder swivel	-110 to +45 degree
■ Elbow extension	-30 to +45 degree
■ Yaw	-175 to +175 degree
■ Pitch	-90 to 0 degree
■ Roll	-175 to +175 degree

3.4 Kinematics of 6-axes robot

3.4.1 Forward kinematics of 6-axes robot [6]

In this robot, the first joint axis points up vertically along the z_0-axis, the second joint axis is perpendicular to the first joint axis with a small offset distance $a_1 = OA$, the third joint axis is parallel to the second with an offset distance $a_2 = AB$, and the fourth joint axis is perpendicular to the third joint axis with a small offset distance $a_3 = BC$. In addition, the last three joint axes intersect one another perpendicularly in sequence at a common point *P*, which is d_4 distance away from point *C*. this robot belongs to a special class of robot where the last three joint axes intersect at the wrist center. The kinematics problem for this type of robot can be partitioned into two sub-chains: one associated with the first three moving links and the other with the last three moving links. That is, in solving the inverse kinematics problem, the position of the wrist center can be solved independently of the orientation part, therefore reducing the complexity of the problem.

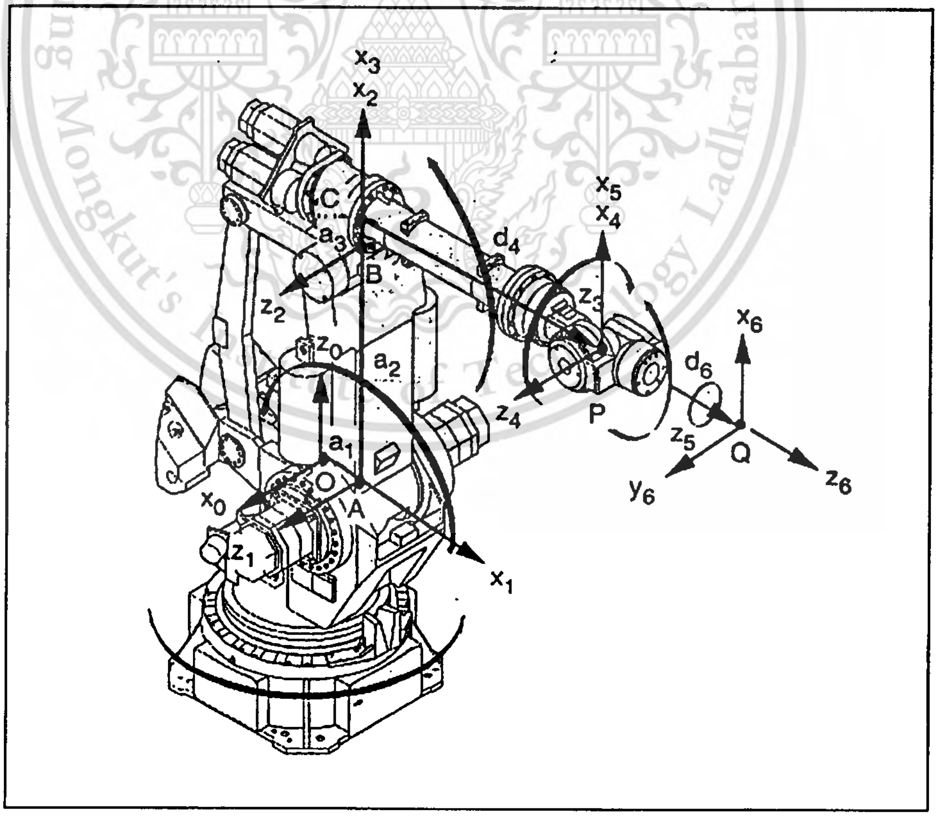


Figure 3.2 Position analysis of 6-axes robot

TABLE 3.2 D-H Parameters of the 6-axes robot

Joint *I*	α_i	a_i	d_i	θ_i
1	$\pi/2$	a_1	0	θ_1
2	0	a_2	0	θ_2
3	$\pi/2$	a_3	0	θ_3
4	$-\pi/2$	0	d_4	θ_4
5	$\pi/2$	0	0	θ_5
6	0	0	d_6	θ_6

Note that this manipulator employs a four-bar linkage to drive the third joint. The four-bar linkage simply transmits the motion of the third motor mounted on the wrist to the third joint. Otherwise, it has no effect on the kinematics of the manipulator. In the following analysis we neglect the effect of the four-bar linkage and treat the manipulator as a serial manipulator.

Using the coordinate systems established, the corresponding link parameters are listed in Table 3.2. Substituting the D-H link parameters into D-H formulation, obtain the D-H transformation matrices:

$$^{0}A_1 = \begin{bmatrix} c\theta_1 & 0 & s\theta_1 & a_1 c\theta_1 \\ s\theta_1 & 0 & -c\theta_1 & a_1 s\theta_1 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{3.1}$$

$$^{1}A_2 = \begin{bmatrix} c\theta_2 & -s\theta_2 & 0 & a_2 c\theta_2 \\ s\theta_2 & c\theta_2 & -c\theta_1 & a_2 s\theta_2 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{3.2}$$

$$^{2}A_3 = \begin{bmatrix} c\theta_3 & 0 & s\theta_3 & a_3 c\theta_3 \\ s\theta_3 & 0 & -c\theta_3 & a_3 s\theta_3 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{3.3}$$

$$ {}^{3}A_{4} = \begin{bmatrix} c\theta_4 & 0 & -s\theta_4 & 0 \\ s\theta_4 & 0 & c\theta_4 & 0 \\ 0 & -1 & 0 & d_4 \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad (3.4) $$

$$ {}^{4}A_{5} = \begin{bmatrix} c\theta_5 & 0 & s\theta_5 & 0 \\ s\theta_5 & 0 & -c\theta_5 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad (3.5) $$

$$ {}^{5}A_{6} = \begin{bmatrix} c\theta_6 & -s\theta_6 & 0 & 0 \\ s\theta_6 & c\theta_6 & 0 & 0 \\ 0 & 0 & 1 & d_6 \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad (3.6) $$

The end-effector location is given by

$$ {}^{0}A_{6} = \begin{bmatrix} u_x & v_x & w_x & q_x \\ u_y & v_y & w_y & q_y \\ u_z & v_z & w_z & q_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad (3.7) $$

The loop-closure equation is obtained in two steps. First, we multiply Equations. (3.1), (3.2) and (3.3)

$$ {}^{0}A_3 = {}^{0}A_1\,{}^{1}A_2\,{}^{2}A_3 = \begin{bmatrix} c\theta_1 c\theta_{23} & s\theta_1 & c\theta_1 s\theta_{23} & c\theta_1(a_1 + a_2 c\theta_2 + a_3 c\theta_{23}) \\ s\theta_1 c\theta_{23} & -c\theta_1 & s\theta_1 s\theta_{23} & s\theta_1(a_1 + a_2 c\theta_2 + a_3 c\theta_{23}) \\ s\theta_{23} & 0 & -c\theta_{23} & a_2 s\theta_{23} + a_3 s\theta_{23} \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad (3.8) $$

Next, we multiply Equations. (3.4), (3.5) and (3.6)

$$ {}^{3}A_6 = {}^{3}A_4\,{}^{4}A_5\,{}^{5}A_6 = \begin{bmatrix} c\theta_4 c\theta_5 c\theta_6 - s\theta_4 s\theta_6 & -c\theta_4 c\theta_5 s\theta_6 & c\theta_4 s\theta_5 & d_6 c\theta_4 s\theta_5 \\ s\theta_4 c\theta_5 c\theta_6 + c\theta_4 s\theta_6 & -s\theta_4 c\theta_5 s\theta_6 + c\theta_4 c\theta_6 & s\theta_4 s\theta_5 & d_6 s\theta_4 s\theta_5 \\ -s\theta_5 c\theta_6 & s\theta_5 s\theta_6 & c\theta_5 & d_4 + d_6 c\theta_5 \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad (3.9) $$

Hence the resulting transformation matrix is given by

$$ {}^{0}A_6 = {}^{0}A_3 \, {}^{3}A_6 \tag{3.10}$$

Where ${}^{0}A_6$ describes the end effector location.

Substituting Equations. (3.8) and (3.9), yields the elements of ${}^{0}A_6$ as follows:

$$u_x = c\theta_1[c\theta_{23}(c\theta_4 c\theta_5 c\theta_6 - s\theta_4 s\theta_6) - s\theta_{23} s\theta_5 c\theta_6] + s\theta_1(s\theta_4 c\theta_5 c\theta_6 + c\theta_4 s\theta_6),$$

$$u_y = s\theta_1[c\theta_{23}(c\theta_4 c\theta_5 c\theta_6 - s\theta_4 s\theta_6) - s\theta_{23} s\theta_5 c\theta_6] - c\theta_1(s\theta_4 c\theta_5 c\theta_6 + c\theta_4 s\theta_6),$$

$$u_z = s\theta_{23}(c\theta_4 c\theta_5 c\theta_6 - s\theta_4 s\theta_6) + c\theta_{23} s\theta_5 c\theta_6,$$

$$v_x = c\theta_1[-c\theta_{23}(c\theta_4 c\theta_5 c\theta_6 - s\theta_4 s\theta_6) + s\theta_{23} s\theta_5 c\theta_6] + s\theta_1(-s\theta_4 c\theta_5 c\theta_6 + c\theta_4 s\theta_6),$$

$$v_y = s\theta_1[-c\theta_{23}(c\theta_4 c\theta_5 c\theta_6 + s\theta_4 s\theta_6) + s\theta_{23} s\theta_5 c\theta_6] - c\theta_1(-s\theta_4 c\theta_5 c\theta_6 + c\theta_4 s\theta_6),$$

$$v_z = -s\theta_{23}(c\theta_4 c\theta_5 c\theta_6 + s\theta_4 s\theta_6) - c\theta_{23} s\theta_5 c\theta_6,$$

$$w_x = c\theta_1(c\theta_{23} c\theta_4 c\theta_5 + s\theta_{23} s\theta_5) + s\theta_1 s\theta_4 c\theta_5,$$

$$w_y = s\theta_1(c\theta_{23} c\theta_4 c\theta_5 + s\theta_{23} s\theta_5) - s\theta_1 s\theta_4 c\theta_5,$$

$$w_z = s\theta_{23} c\theta_4 s\theta_5 - c\theta_{23} c\theta_5,$$

$$q_x = c\theta_1[a_1 + a_2 c\theta_2 + a_3 c\theta_{23} + d_4 s\theta_{23} + d_6(c\theta_{23} c\theta_4 s\theta_5 + s\theta_{23} c\theta_5)] + d_6 s\theta_1 s\theta_4 s\theta_5, \tag{3.20}$$

$$q_y = s\theta_1[a_1 + a_2 c\theta_2 + a_3 c\theta_{23} + d_4 s\theta_{23} + d_6(c\theta_{23} c\theta_4 s\theta_5 + s\theta_{23} c\theta_5)] - d_6 s\theta_1 s\theta_4 s\theta_5, \tag{3.21}$$

$$q_x = a_2 s\theta_2 + a_3 s\theta_{23} - d_4 c\theta_{23} + d_6(s\theta_{23} c\theta_4 s\theta_5 - c\theta_{23} c\theta_5).$$

Although the equations above can be used to solve the inverse kinematics, they are highly nonlinear and difficult to solve. In what follows we present a more efficient method of solution by separating the wrist-center-position problem from the orientation problem.

3.4.2 Inverse kinematics of 6-axes robot [6]

3.4.2.1 Wrist Center Position

Note that the last three joint axes intersect at the wrist center point *P*. Hence rotations of the last three joints do not affect the position of *P*., The wrist center *P*, and the vector relation between them,

The wrist center position with respect to and expressed in the end-effector coordinate system is

$$^{6}p = \overline{QP} = [0,0,-d_6,1]^T . \qquad (3.11)$$

The wrist center position with respect to and expressed in the base coordinate system is

$$^{0}p = \overline{OP} = \begin{bmatrix} p_x \\ p_x \\ p_z \\ 1 \end{bmatrix} = \begin{bmatrix} q_x - d_6 w_x \\ q_x - d_6 w_y \\ q_z - d_6 w_z \\ 1 \end{bmatrix} . \qquad (3.12)$$

Hence, given the end-effector location, we can find the position of the wrist center point *P* with respect to the base coordinate system. Furthermore, we observe that the position of the wrist center *P* with respect to the link 3 coordinate system is given by

$$^{3}p = \overline{CP} = [0,0,d_4,1]^T \qquad (3.13)$$

Transforming ^{3}p into the base coordinate system, we obtain

$$^{0}p = {}^{0}A_3 \, {}^{3}p . \qquad (3.14)$$

Equation (3.14) consists of three scalar equations in three unknowns. Hence the position and orientation of the inverse kinematics problem are de-coupled.

Theoretically, we can solve Equation (3.14) for the three joint angles. In what follows we take a simpler approach. Multiplying both sides Equation (3.14) by the inverse of ${}^0A_1$, obtain that

$$({}^0A_1)^{-1}\,{}^0p={}^1A_3\,{}^3p. \tag{3.15}$$

Substituting Equations (3.1) through (3.3) into (3.15) yields

$$p_xc\theta_1+p_ys\theta_1-a_1=a_2c\theta_2+a_3c\theta_{23}+d_4s\theta_{23}, \tag{3.16}$$

$$p_z=a_2s\theta_2+a_3s\theta_{23}-d_4c\theta_{23}, \tag{3.17}$$

$$p_xs\theta_1-p_yc\theta_1=0, \tag{3.18}$$

where p_x, p_y and p_z are given by Equation (3.12).

A solution for θ_1 is found immediately by solving Equation (3.18).

$$\theta_1=\tan^{-1}\frac{p_y}{p_x}. \tag{3.19}$$

Hence there are two solutions of θ_1. Specifically, if $\theta_1=\theta_1^*$ is a solution, $\theta_1=\theta_1^*+\pi$ is also a solution, where $\pi\geq\theta_1^*\geq 0$. We call $\theta_1=\theta_1^*$ the front-reach solution and $\theta_1=\theta_1^*+\pi$ $\theta_1=\theta_1^*+\pi$ he back-reach solution. Because of the four bar linkages and other mechanical constraints, the back-reach solution is physically impossible.

An observation of the kinematics structure reveals that the distance between point A and the wrist center P is independent of θ_1 and θ_2, which implies that these two variables can be eliminated simultaneously. Summing the squares of Equations (3.16), (3.17) and (3.18), gives

$$k_1s\theta_3+k_2c\theta_3=k_3, \tag{3.20}$$

where $k_1=2a_2d_4, k_2=2a_2a_3$ and $k_3=p_x^2+p_y^2+p_z^2-2p_xa_1c\theta_1-2p_ya_1s\theta_1+a_1^2-a_2^2-a_3^2-d_4^2$.

Convert Equation (3.20) into a polynomial by making use of the following trigonometric identities:

$$c\theta_3 = \frac{1-t_3^2}{1+t_3^2} \text{ and } s\theta_3 = \frac{2t_3}{1+t_3^2}, \text{ where } t_3 = \tan\frac{\theta_3}{2}.$$

Substituting the trigonometric identities above into Equation (3.20) yields

$$(k_3 + k_2)t_3^2 - 2k_1t_3 + (k_3 - k_2) = 0. \tag{3.21}$$

Hence

$$\frac{\theta_3}{2} = \tan^{-1}\frac{k_1 \pm \sqrt{k_1^2 + k_2^2 - k_3^2}}{k_3 + k_2}. \tag{3.22}$$

Equation (3.21) yields (1) two real roots if $k_1^2 + k_2^2 + k_3^2 > 0$, (2) one double root if $k_1^2 + k_2^2 + k_3^2 = 0$, and (3) no real roots if $k_1^2 + k_2^2 + k_3^2 < 0$. When Equation (3.21) yields a double root, the arm is either in a fully stretched or a folded-back configuration. On the other hand, if Equation (3.21) yields no real roots, the position is not reachable.

Once θ_1 and θ_3 are known, θ_2 can be obtained by back substitution. Expanding Equations (3.16) and (3.17), we obtain

$$\mu_1 c\theta_2 + v_1 s\theta_2 = \gamma_1, \tag{3.23}$$

$$\mu_2 c\theta_2 + v_2 s\theta_2 = \gamma_2, \tag{3.24}$$

where

$$\mu_1 = a_2 + a_3c\theta_3 + d_4s\theta_3,$$

$$v_1 = -a_3s\theta_3 + d_4c\theta_3,$$

$$\gamma_1 = p_x c\theta_1 + p_y s\theta_1 - a_1,$$

$$\mu_2 = a_3 s\theta_3 - d_4 c\theta_3,$$

$$v_2 = a_2 + a_3 c\theta_3 + d_4 s\theta_3,$$

$$\gamma_2 = p_z.$$

Therefore, we can solve Equations (3.23) and (3.24) for $c\theta_2$ and $s\theta_2$. Once $s\theta_2$ and $c\theta_2$ are found, a unique value of θ_2 is obtained by taking

$$\theta_2 = A\tan 2(s\theta_2, c\theta_2) \tag{3.25}$$

We conclude that given the wrist center position, mathematically there are at most four possible arm configurations, but due to the mechanical limits, only two are physically possible.

3.4.2.2 End-Effector Orientation

Once θ_1, θ_2 and θ_3 are solved, ${}^0A_3$ is completely known. The remaining joint angles can be found by multiplying both sides of Equation (3.10) by $\left({}^0A_3\right)^{-1}$:

$${}^3A_6 = \left({}^0A_3\right)^{-1} {}^0A_6. \tag{3.26}$$

Note that the elements on the right-hand side of Equation (3.26) are known, and only the rotation part of Equation (3.26) is needed for computation of the last three joint angles. The rotation matrices ${}^0R_3$ and ${}^3R_6$ are given by the upper 3×3 sub-matrices of Equations (3.8) and (3.9) respectively.

Equating the 3×3 element of Equation (3.26) yields

$$\theta_5 = \cos^{-1} r_{33}, \tag{3.27}$$

where $r_{33} = w_x c\theta_1 s\theta_{23} + w_y s\theta_1 s\theta_{23} - w_z c\theta_{23}$. Hence, corresponding to each solution set of θ_1, θ_2 and θ_3, Equation (2.92) yields (1) two real roots if $|r_{33}| < 1$, and (2) $\theta_5 = 0$ or π if $|r_{33}| = 1$.

When $\theta_5 = 0$ or π, the sixth joint axis, z_5, is in line with the fourth joint axis, z_3, and the wrist is said to be in a singular configuration. The condition $|r_{33}| > 1$ cannot physically arise.

Assuming that $s\theta_5 \neq 0$, we can solve θ_4 and θ_6 as follows. Equating the 1×3 element of Equation (3.26) yields

$$c\theta_4 = \frac{w_x c\theta_1 c\theta_{23} + w_y s\theta_1 c\theta_{23} + w_z s\theta_{23}}{s\theta_5}. \tag{3.28}$$

Equating the 2×3 element of Equation (3.26) yields

$$s\theta_4 = \frac{w_x s\theta_1 - w_y c\theta_1}{s\theta_5}. \tag{3.29}$$

Hence, corresponding to each solution set of $\theta_1, \theta_2, \theta_3$ and θ_5, Equations (3.28) and (3.29) yield a unique solution of θ_4:

$$\theta_4 = A\tan 2(s\theta_4, c\theta_4). \tag{3.30}$$

Similarly, equating the 3×1 element of the Equation (3.26) yields

$$c\theta_6 = -\frac{u_x c\theta_1 s\theta_{23} + u_y s\theta_1 s\theta_{23} - u_z c\theta_{23}}{s\theta_5}. \tag{3.31}$$

Equating the 3×2 element of Equation (3.26) yields

$$s\theta_6 = \frac{v_x c\theta_1 s\theta_{23} + v_y s\theta_1 s\theta_{23} - v_z c\theta_{23}}{s\theta_5}. \tag{3.32}$$

Hence, corresponding to each solution set of $\theta_1, \theta_2, \theta_3, \theta_4$ and θ_5, Equations (3.31) and (3.32) yield a unique solution of θ_6:

$$\theta_6 = A\tan 2(s\theta_6, c\theta_6). \tag{3.33}$$

Conclude that corresponding to each solution set of the first three joint angles, there are two possible wrist configurations. Since there are four possible upper arm configurations, a total of eight manipulator postures are possible. However, due to mechanical limits, fewer than eight manipulator postures are physically realizable. When $s\theta_5 = 0$, Equations (3.28) through (3.33) degenerate. For such a singular condition, only the sum of difference of θ_4 and θ_6 can be computed.

3.4.3 Kinematics control of manipulators [7]

From the inverse kinematics of a robot manipulator arm, can know what joint values need for any particular location of P_e. Thus, to make P_e follow some specified trajectory in Cartesian space, a straight line or circular arc, for example, must be first calculated how each joint must move, specify this joint motion in term of a series of joint position reference value, and then input these, at an appropriate rate in time to the controller of each joint. The process of turning a specified Cartesian space trajectory of P_e into sequence of appropriate joint position reference value, one sequence for each joint, is called kinematics control.

The relationship between the robot program, kinematics control and basic level control of the robot is illustrate below

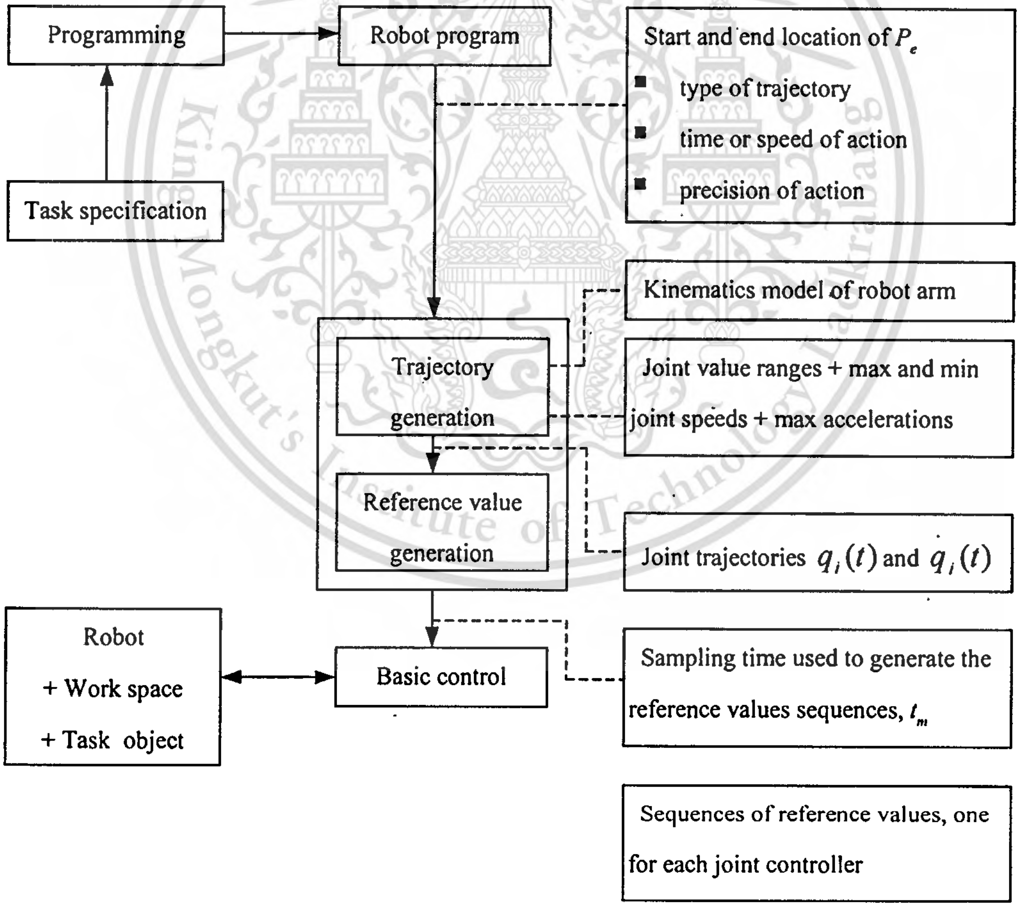


Figure 3.3 Relationship between the robot program, kinematics control and basic level control

The kinematics control process of robot manipulator arm consists of the following five steps of functions

1. Convert the (next) movement specification from the program into an analytical and continuous Cartesian space trajectory with respect to basement.

$$Q_e = [x_e(t), y_e(t), z_e(t), \psi_e(t), \vartheta_e(t), \phi_e(t)]^T$$

And do the same for the rate of change of location, if necessary to obtain

$$\dot{Q}_e(t)$$

2. Sample the Cartesian trajectory $Q_e(t)$ to obtain a finite number, *m*, of sample points on the continuous trajectory, so as to have

$$Q_e^{(i)} = [x_e^{(i)}, y_e^{(i)}, z_e^{(i)}, \psi_e^{(i)}, \vartheta_e^{(i)}, \phi_e^{(i)}]^T, i = 1,\ldots,m$$

And do the same for the rate of change of location trajectory, if necessary to produce

$$\dot{Q}_e^{(i)}, i = 1,\ldots,m$$

3.(a) Using the inverse kinematics relation of the robot manipulator arm, convert each Cartesian trajectory sample point vector, $Q_e^{(i)}$, into a corresponding joint space vector.

$$q^{(i)} = [q_1^{(i)}, q_2^{(i)}, q_n^i]^T$$

In this step, the possibility of multiple solution to the inverse kinematics relation must be treated.

(b). Using the inverse Jacobian relation, convert each instantaneous velocity vector $\dot{Q}_e^{(i)}$ into a corresponding joint speed vector $\dot{q}^{(i)}$. In this step, the possibility of singular configuration must be treated.

4. Using the sequence of vector $q^{(i)}$ and $\dot{q}^{(i)}, i = 1,...,m$, generate continuous expression $q_{(j)}(t)$ and $\dot{q}_j(t), j = 1,...,n$, which pass through or sufficiency near to each of joint space sample points, $q^{(i)}$, and rate of change sample points, $\dot{q}^{(i)}, i = 1,...,m$ to produce continuous joint space trajectories for each joint.

5. Sample each continuous joint trajectory $q_{(j)}(t)$ and $\dot{q}_j(t), j = 1,...,n$, to generate a sequence of discrete reference value for each joint. $q_j(kt_m)$ and $\dot{q}_j(kt_m), j = 1,...,n$ where t_m is the sample period used.

The above steps are applied to sample articulated 2-axes robot as following.

By specified straight line motion of P_e as figure 3.13, the continuous Cartesian space trajectory is thus the straight line between $P_e^{(s)}$ and $P_e^{(f)}$

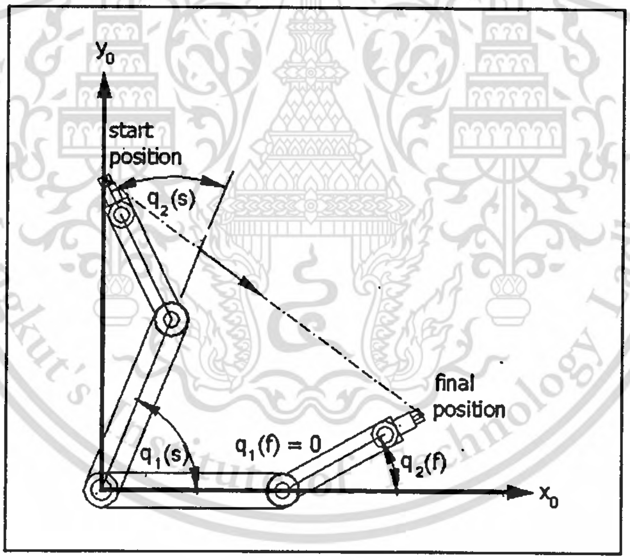


Figure 3.4 Continuous trajectory of P_e from start to finish on 2D Cartesian space

Step 2 is thus to sample this continuous Cartesian space trajectory, as shown below.

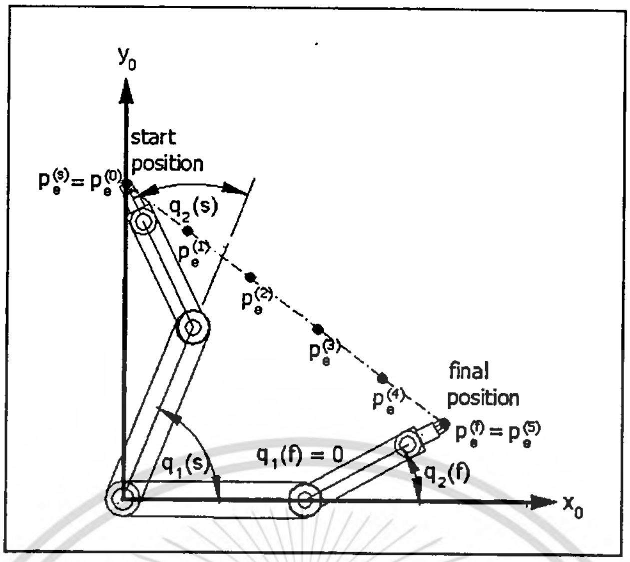


Figure 3.5 Sample points on the continuous trajectory on 2D Cartesian space

Using the inverse kinematics relation, step 3 then converts each Cartesian space sample point into a n-dimensional joint space point, where n is the number of degree of freedoms of the robot manipulator.

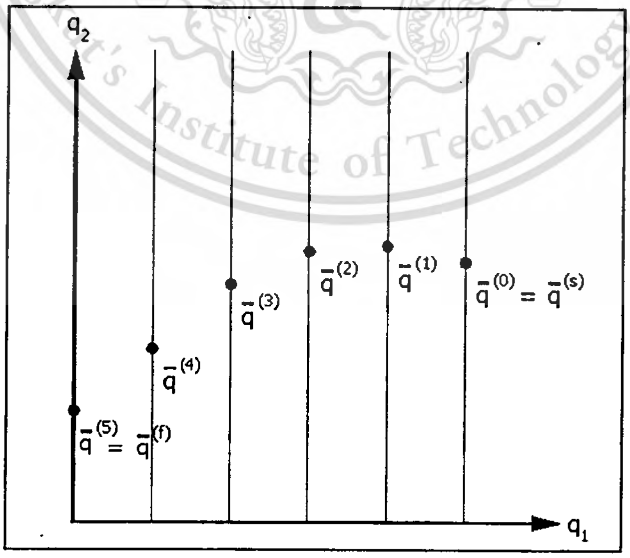


Figure 3.6 Sample trajectory points in 2D joint space

Step 4 involves fitting a smooth continuous curves to these joint space sample points.

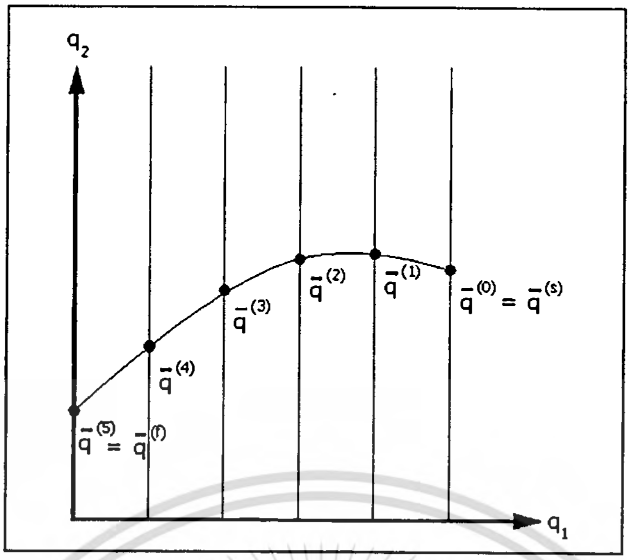


Figure 3.7 Interpolated continuous joint space trajectory

And step 5 involves sampling, over time, this joint space trajectory

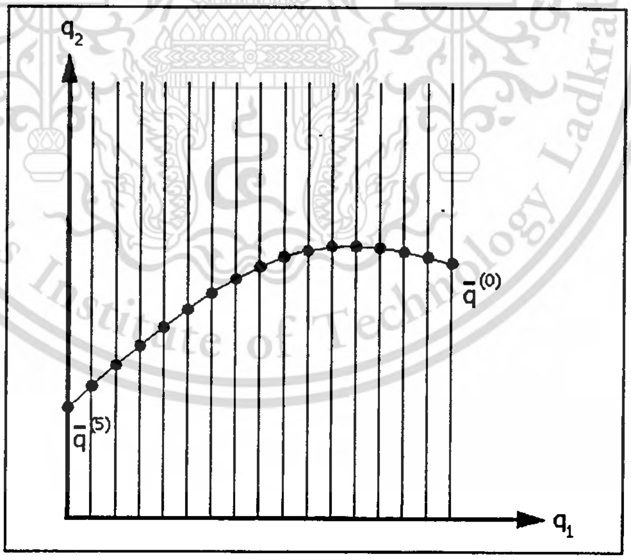


Figure 3.8 Sample joints space trajectory

to generate sequence of position reference values for the 2 joints of robot arm.

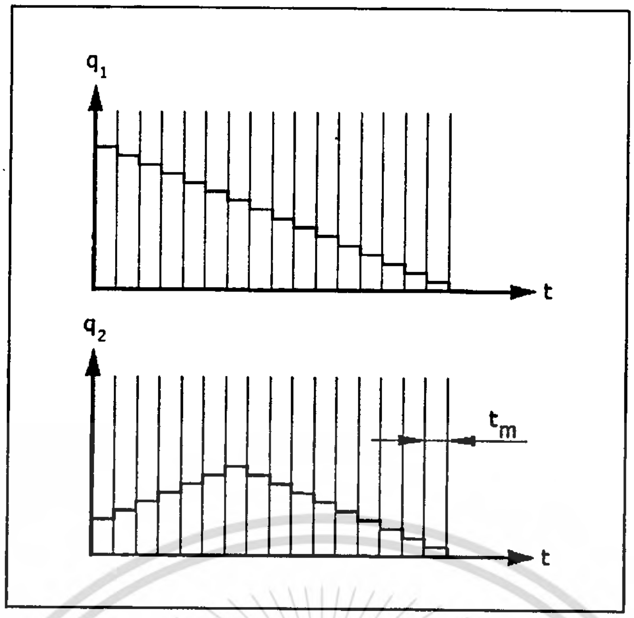


Figure 3.9 Joint reference values in time

The Cartesian space sampling, inverse kinematics calculations, joint space fitting and subsequence reference value generation, all introduce some error into the process. The resulting motion of P_e is thus, in general not exactly the same as specified trajectory, there will always be some variation from this.

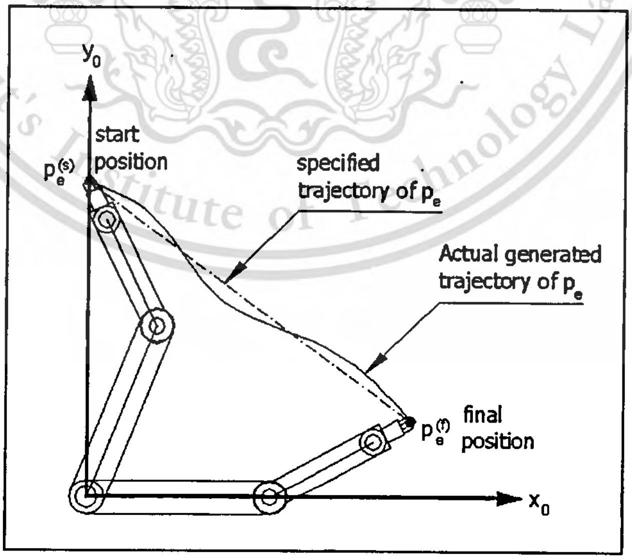


Figure 3.10 Actual and specified trajectory

By increasing t_m it can make the movement of P_e slower, and similarly by decreasing t_m it can make the movement of P_e faster. However, making t_m too small or too large may produce less precision in the movement of P_e and it is important that t_m is never made too small compared to the slowest joint rate in the basic control of the robot arm.

There are many types of trajectory in kinematics control. The trajectory of P_e, the motion of the location of P_e in Cartesian space form $P_e^{(s)}$ to $P_e^{(f)}$, can be generated by tree different types of joint space trajectories, only the last of which can be used to produce fully specified Cartesian space trajectories, such as straight lines or circular arcs.

Type 1, Point-to-point trajectories, in which each joint trajectory is generated completely independently of the other joint trajectories.

Each joint is move from the starting position to its final position at some default rate.

In this type of trajectory generation, can distinguish two subtypes,

a). Joint-by-joint motion, in which each joint is move in turn, in strict sequence. Thus, for simple 2D planar arm, it has joint space trajectories as follows, together with the resulting Cartesian space trajectory of P_e. The total motion time is therefore the sum of each joint motion time and the resulting motion of P_e is often rather jerky and non-smooth.

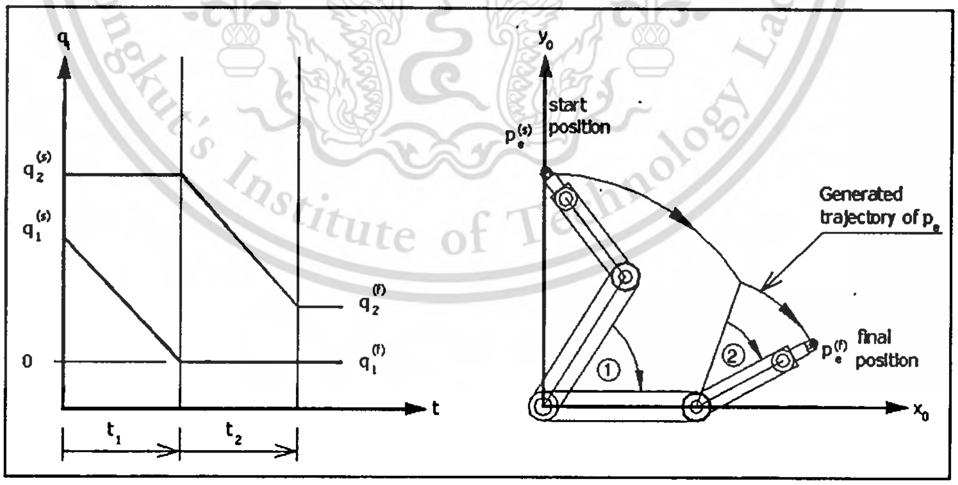


Figure 3.11 Point to point trajectory (joint by joint motion)

b). Simultaneous joint motion, in which all joint motion are started together, thus reducing the motion time to the time taken by the slowest joint or the joint which has the furthest to move. The motion of P_e is smoother, but as each joint finishes, the motion of P_e become jerky and non-smooth.

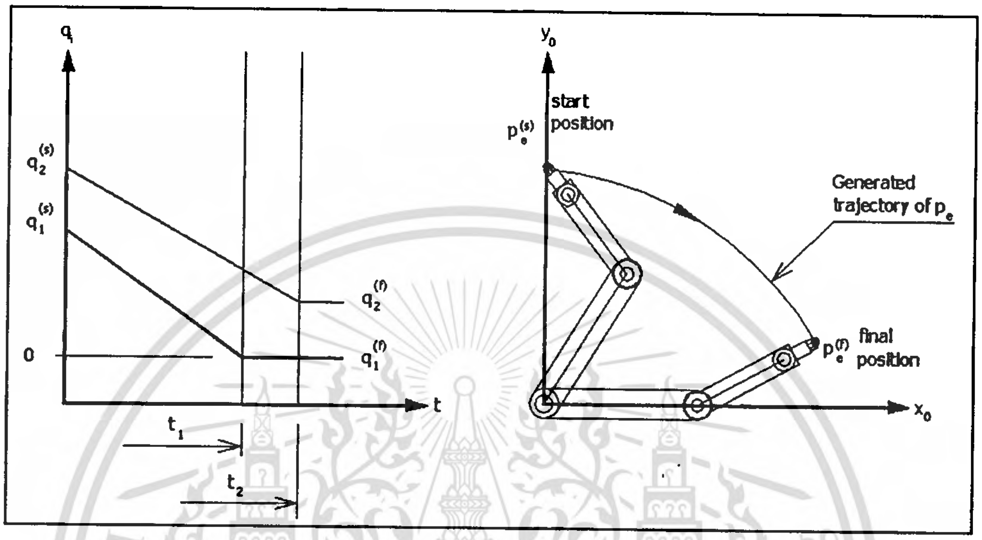


Figure 3.12 Point to point trajectory (Simultaneous joint motion)

As can be seen, in this kind of trajectory generation, it is not easy to know exactly what the motion path of P_e will be between its specified start and final locations.

Type 2, Coordinated or synchronous trajectories, in which, all the individual joint motions are arranged to both start together and to finish together. This produces much smoother P_e motion and is also energy efficient, since the amount of acceleration and de-acceleration is keep to a minimum., thus keeping to a minimum the amount of work needed to complete the complete arm motion.

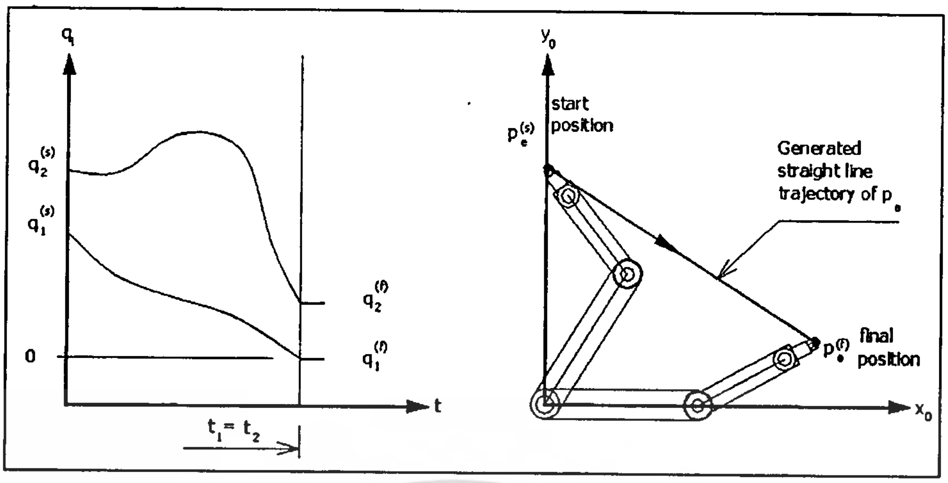


Figure 3.13 Coordinated or synchronous trajectory

To achieve this type of coordinated to synchronous trajectory, the kinematics controller first has to analyses the motion of all the joints needed to produce the motion of P_e to find the joint which needed the most time. All other joint are then made to take this time to complete their particular motion.

The total motion time is thus, again, the time taken for the slowest joint or the joint which has the furthest to travel.

As for the type 1 trajectories, although the resulting motion of P_e is smoother, it is again difficult to know exactly what trajectory it will follow between the specified start and finish locations.

Type 3, Continuous trajectories, in which P_e must follow some specified trajectory in Cartesian space, not just move (somehow) from the specified start location to the specified finish location.

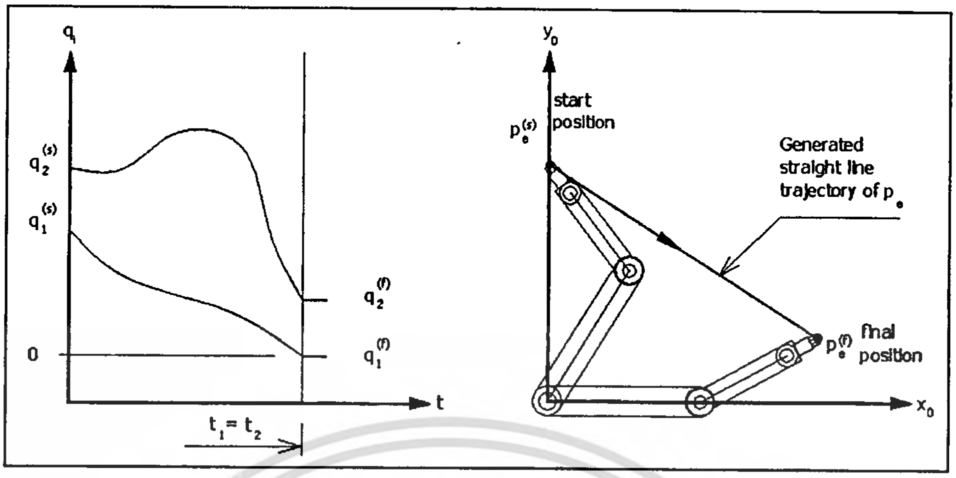


Figure 3.14 Continuous trajectory

In this case, the joint space trajectories, the motions of each joint, are typically quite complicated and will, in general, involve changes is rate of movement and changes in direction of movement.

Robot control system: Physical control system for the 6-axes robot is shown as figure 3.15.

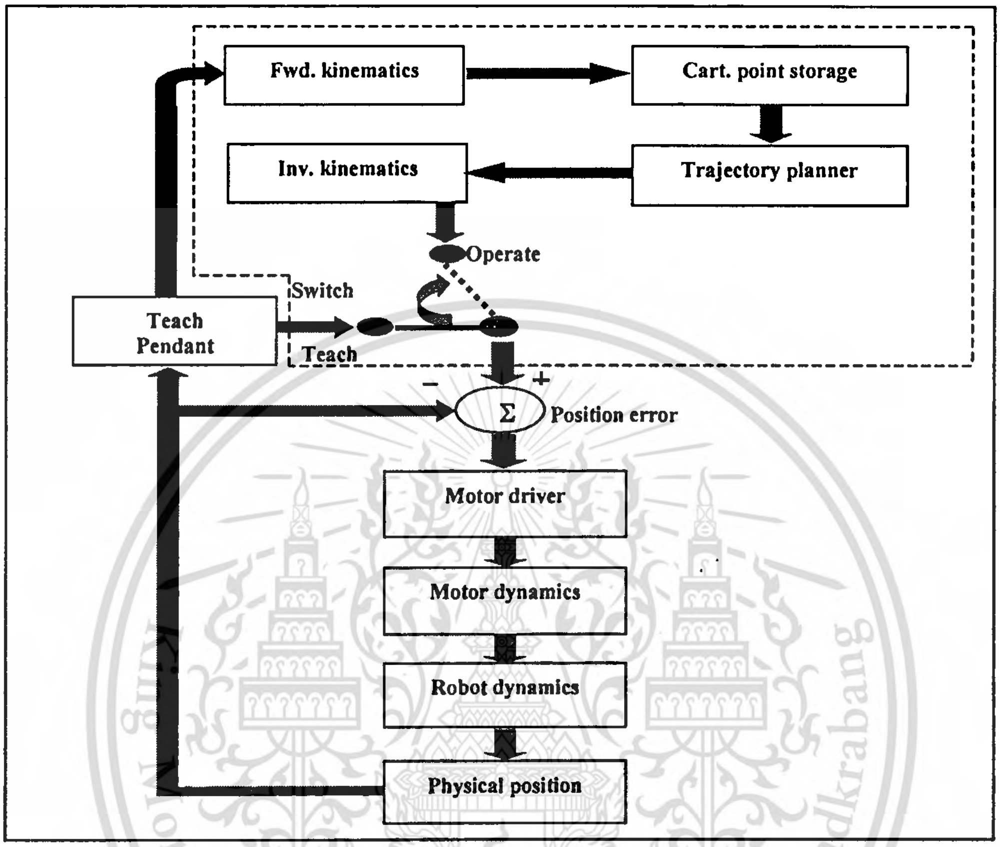


Figure 3.15 Physical control system for 6-axes robot

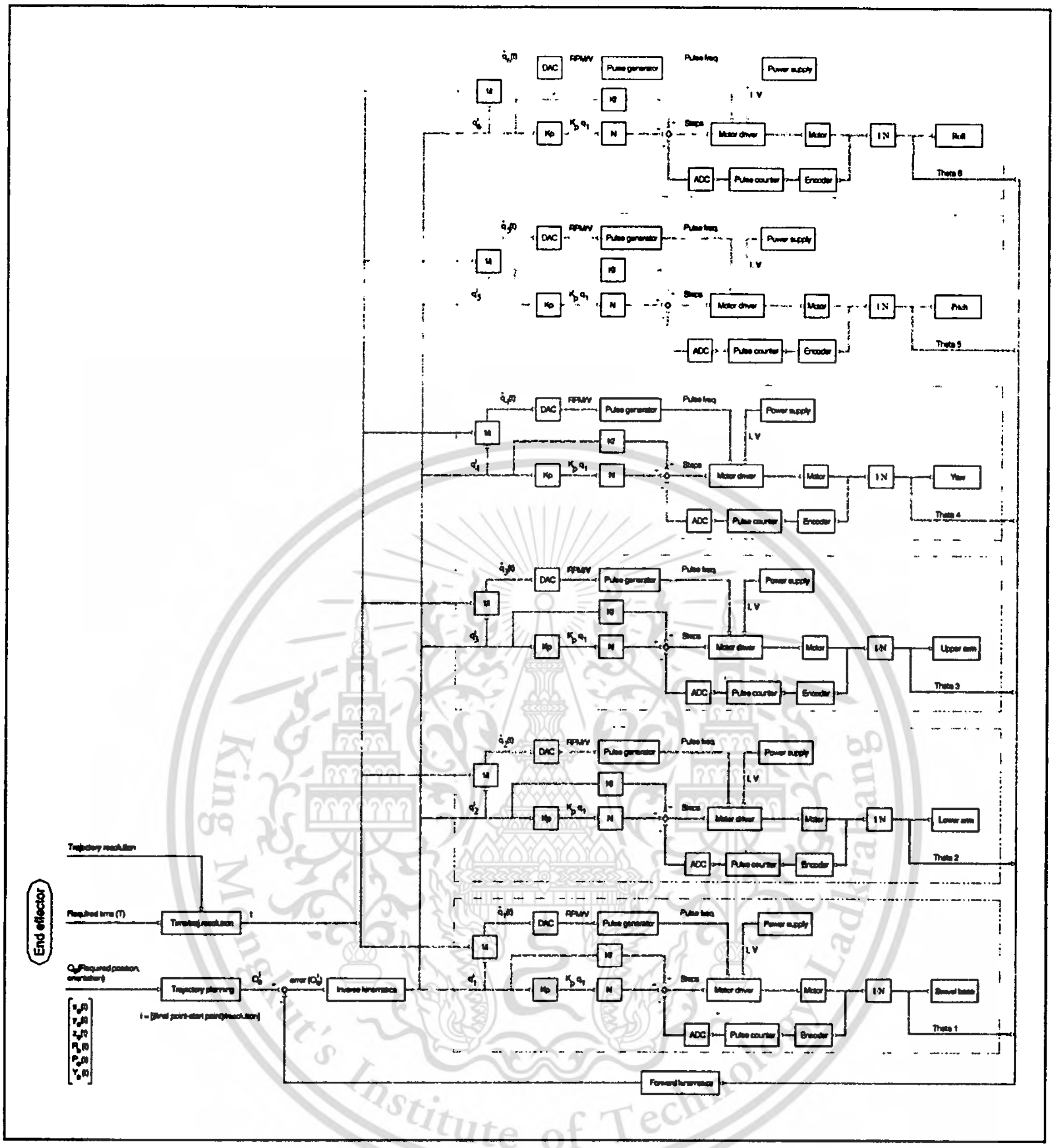


Figure 3.16 Block diagram of 6-axes robot control

3.5 Characteristics of the I/O expander for I^2C-bus system [8]

The I^2C bus is for 2-way, 2-lines communication between different ICs or modules, The two lines are serial data lines (SDA) and serial clock line (SCL). Both lines must be connected to positive supply via a pull-up resistor when connected to the output stages of a device. Data transfer may be initiated only when the bus is not busy.

For the purpose of multi-device connection, the bus is used in the robot-controlled system as shown in the figure 3.17.

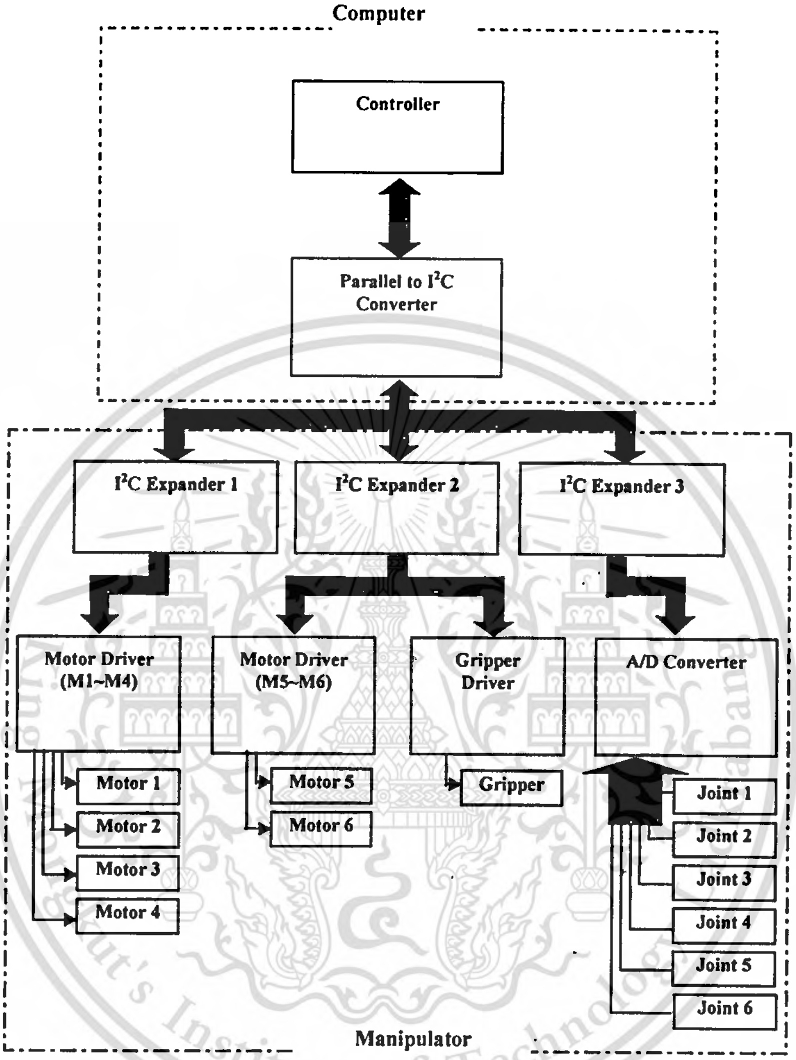


Figure 3.17 System configuration via the I^2C bus for robot control system

3.5.1 Bit transfer

One data bit is transferred during each clock pulse. The data on the SDA line must remain stable during the HIGH period of the clock pulse as changed in the data line at this time will be interpreted as control signals as shown.

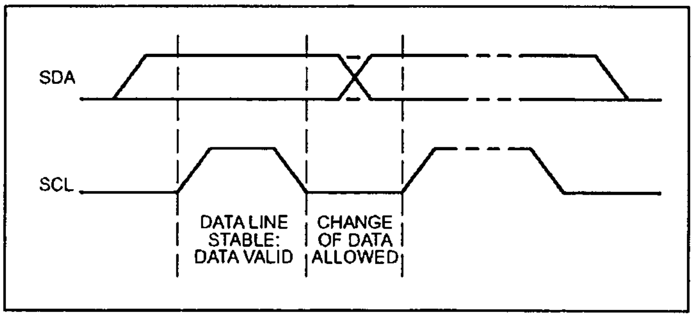


Figure 3.18 Bit transfer.

3.5.2 Start and stop conditions

Both data and clock lines remain HIGH when the bus is not busy. A HIGH to LOW transmission of the data line, while the clock is HIGH is defined as the start condition (S). A LOW to HIGH transmission of data line while the clock is HIGH is defined as the stop condition (P).

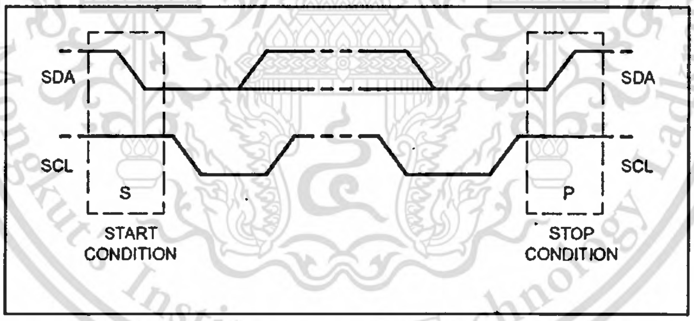


Figure 3.19 Start and stop conditions.

3.5.3 System configuration

A device generating as message is a "transmitter" , a device receiving is the "receiver". The device that controls the message is the "master" and the devices, which are controlled by the master, are the "slaves". Figure below present the system configuration for this robot control

3.5.4 Acknowledge

The number of data bytes transferred between the start and the stop conditions from transmitter to receiver is not limited. Each byte of eight bits is followed by one acknowledge bit. The acknowledge bit is a HIGH level put on the bus by the transmitter whereas the master generates an extra acknowledge related clock pulse. A slave receiver which is addressed must generate an acknowledge after the reception of each byte. Also a master must generate an acknowledge after the reception of each byte that has been clocked out of the slave transmitter. The device that acknowledges has to pull down the SDA line during the acknowledge clock pulse, so that the SDA line is stable LOW during the HIGH period of the acknowledge related clock pulse, set-up and hold times must be taken into account. A master receiver must signal an end of data to the transmitter by not generating an acknowledge on the last byte that has been clocked out of the slave. In this event the transmitter must leave the data line HIGH to enable the master to generate a stop condition.

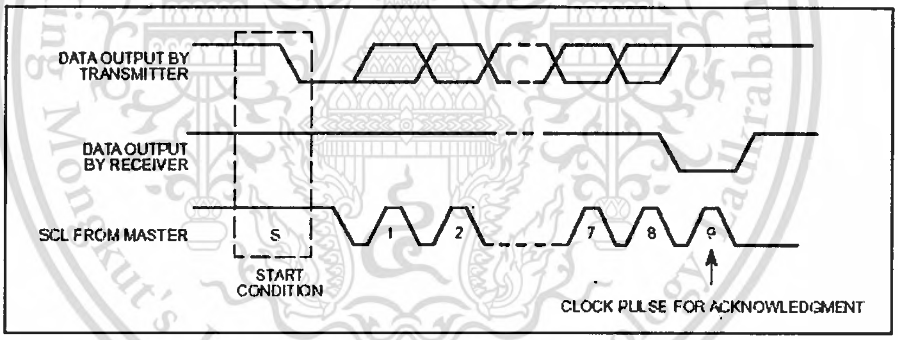


Figure 3.20 Acknowledgement on the I^{2}C-bus

The number of data bytes transferred between the start and the stop conditions from transmitter to receiver is not limited. Each type of eight bits is followed by one acknowledge bit. The acknowledge bit is a HIGH level put on the bus by the transmitter whereas the master generates an extra acknowledge related clock pulse.

The slave receiver which is addressed must generate an acknowledge after the reception of each byte. Also a master must generate an acknowledge after the reception of each byte that has been clocked out of the slave transmitter. The device that acknowledge has to pull down the SDA line during the acknowledge clock pulse, so that the SDA line is stable LOW during the

HIGH period of the acknowledge related clock pulse, set-up and hold times must be taken into account.

A receiver must signal an end of data to the transmitter by not generating an acknowledge on the last byte the has been clocked out of the slave, In this event the transmitter must leave the data line HIGH to enable the master to generate a stop condition.

3.6 Characteristics of D/A and A/D conversion [8]

This research use IC PCF8591 to be A/D and D/A converter, which is a single-chip, single supply low power 8-bit CMOS data acquisition device with four analog inputs, one analog output and a serial I^2C interface. Three address pins A0, A1 and A2 are used for up to eight devices connect to I^2C bus without additional hardware. Address, control and data to and from the device are transferred serially via the two-line bi-directional I^2C bus. The functions of the device include analog input multiplexing, on-chip track and hold function, 8-bit analog-to-digital conversion and an 8-bit digital-to-analog conversion. The maximum conversion rate is given by the maximum speed of the I^2C bus.

3.6.1 Addressing

Each PCF8951 device in an I^2C bus system is activated by sending a valid address to the device. The address consists of fixed port and a programmable part. The programmable part must be set according to the address pins A0, A1, A2. The address always has to be sent as the first byte after the start condition in the I^2C-bus protocol. The last bite of the address byte is the read/write-bit, which sets the direction of the following data transfer as figure below.

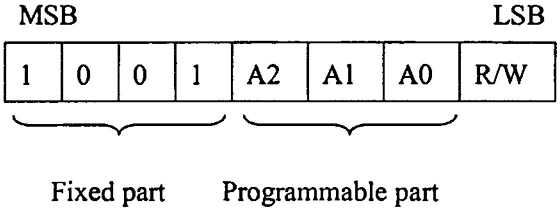


Figure 3.21 Address byte

3.6.2 Control byte

The second byte sent to PCF8591 device will be stored in its control register and is required to control the device function. The upper nibble of the control register is used for enabling the analog output, and for programming the analog inputs as single-end or differential inputs. The lower nibble select on of the analog input channels defined by the upper nibble. If the auto-increment flag is set the channel number is incremented automatically after each A/D conversion.

If the auto-increment mode is desired in applications where the internal oscillator is used, the analog output enable flag in the control byte (bit 6) should be set. This allows the internal oscillator to run continuously, thereby preventing conversion errors resulting from oscillator start-up delay. The analog output enables flag maybe reset at other times to reduce quiescent power consumption.

The selection of a non-existing input channel results in the highest available channel number being allocated. Therefore, if the auto-increment flag is set, the next selected channel will be always channel 0. The most significant bits of both nibbles are reserved for future functions and have to be set to 0. After a power-on reset condition all bits of the control register are reset to 0. The D/A converter and the oscillator are disabled for power saving. The analog output is switched to a high-impedance state.

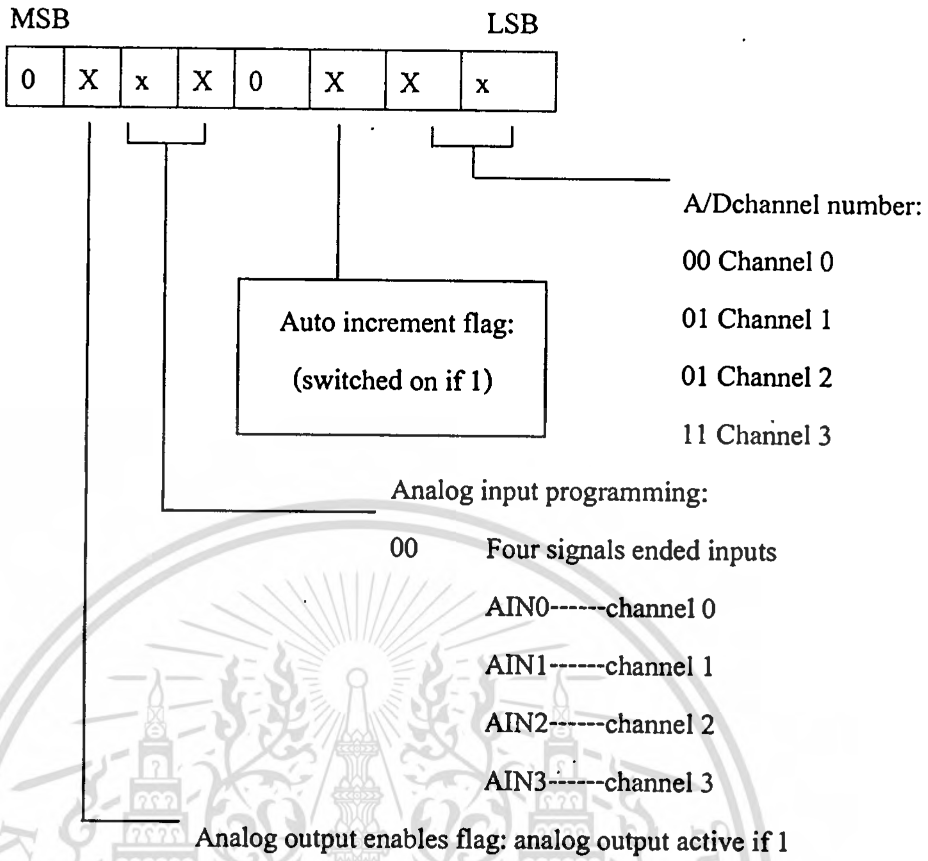


Figure 3.22 Control byte

3.6.3 Digital to analog conversion (DAC) principle

The third byte sent to a PCF8591 device is stored in the DAC data register and is converted to the corresponding analog voltage using the on-chip D/A converter. This D/A converter consists of a resistor divider chain connected to the external reference voltage with 256 taps and selection switches. The tap-decoder switches one of these taps to the DAC output line. The output voltage supplied to the analog output AOUT is given by the formula as figure.

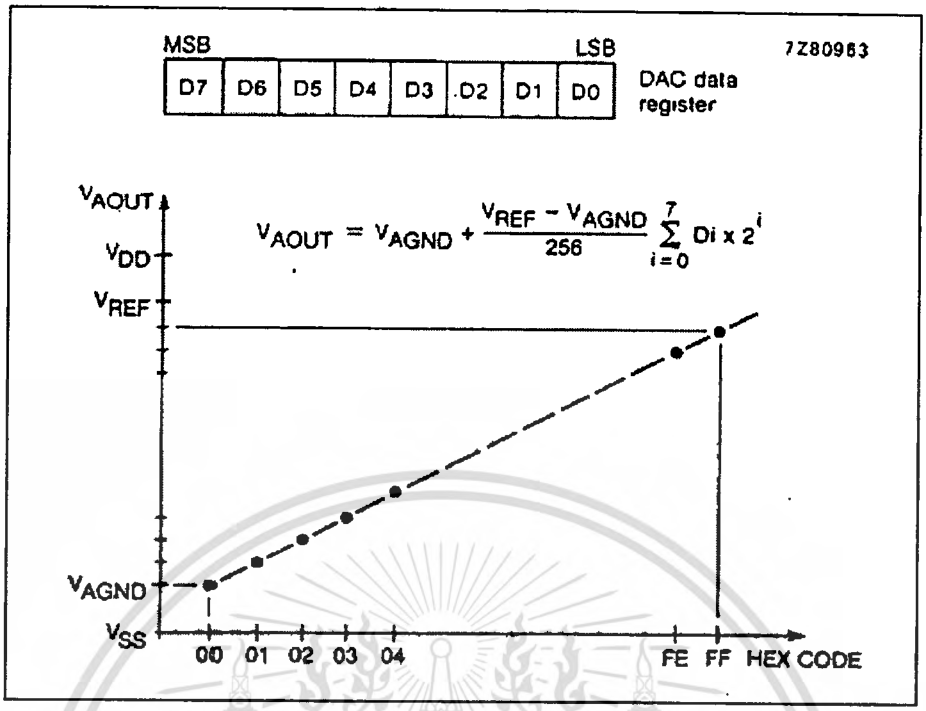


Figure 3.23 DAC data and DC conversion characteristics

The waveform of a D/A conversion sequence as below figure.

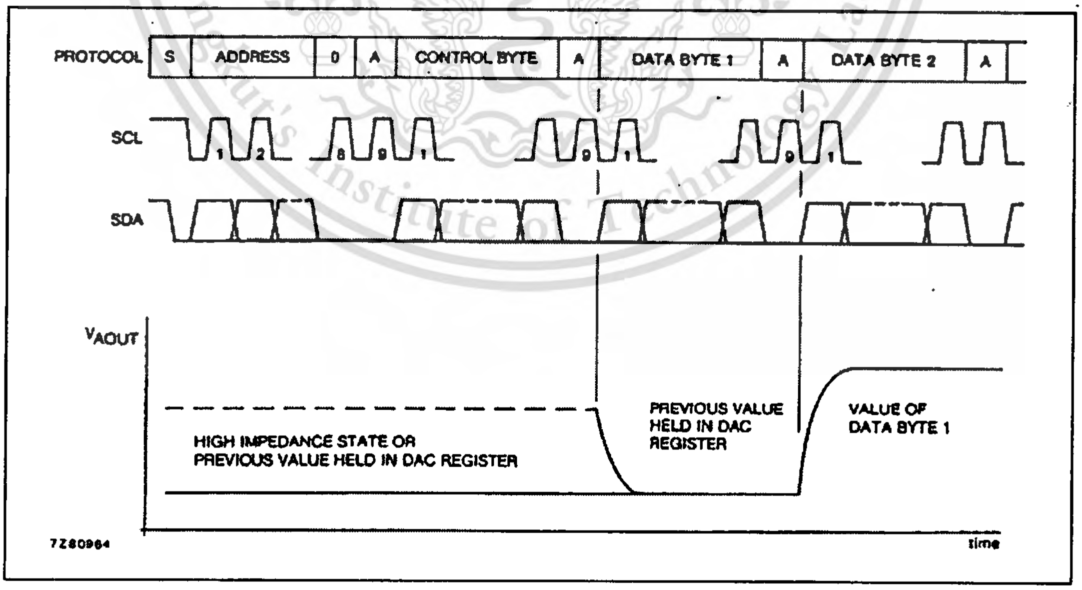


Figure 3.24 DAC conversion sequence

3.6.4 Analog to digital conversion (ADC) principle

The A/D converter makes use the successive approximation conversion technique. The on-chip D/A converter and a high-gain comparator are used temporarily during an A/D conversion cycle. An A/D conversion cycle is always started after sending a valid read mode address to a PCF8591 device. The A/D conversion cycle is trigged at the trailing edge of the acknowledge clock pulse and is executed while transmitting the result of the previous conversion as figure

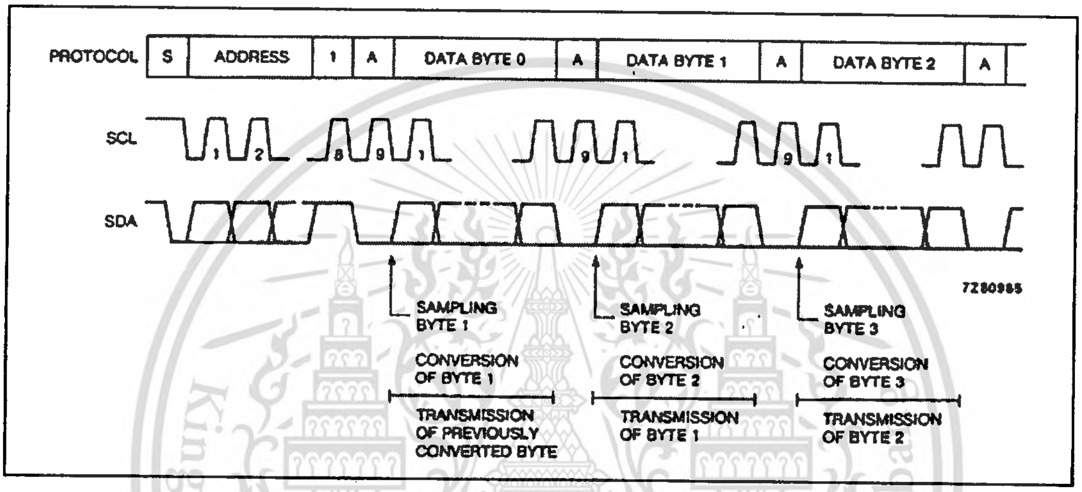


Figure 3.25 ADC conversion sequence

The conversion cycle is triggered an input voltage sample of the selected channel is stored on the chip and is converted to the corresponding 8-bit binary code. Samples picked up from single-end inputs are converted to an 8-bit two's complement code as figure below

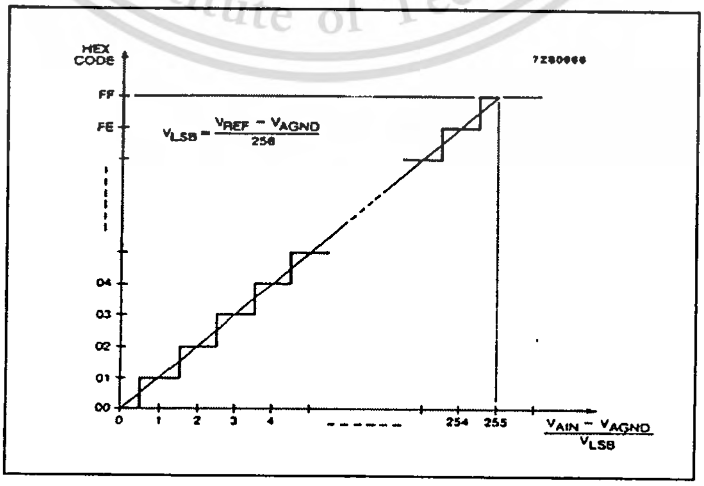


Figure 3.26 ADC conversion characteristics of single-ended inputs

3.7 Programming

Visual Basic 6.0 program is developed for controlling to remote I/O expander for I^2C (Inter-IC Communication) by PCF8574, which is a silicon CMOS circuit. It provides general-purpose remote I/O expansion for most controller families via the two-line bi-directional bus I^2C. Controller program is developed by relate to the forward and inverse kinematics formulation in the first section. This program can operate both teach mode and programmable mode. Teach mode will accept command from operator for guiding manipulator by real time controller.

Procedures for sending data (from controller) to I^2C expander boards in control system.

1. Send start signals to expander boards.
2. Send address word to expander board.
3. Waiting acknowledge signal from expander board.
4. Send data signal to expander board.
5. Waiting acknowledge signal from expander board.
6. Send Stop signal to expander board.

3.7.1 Sub-programming for generating signals of I^2C bus system via parallel port

START signal:

```
Private Sub Start()
Out &H37A, Inp(&H37A) Or 1            'SDA=1
Out &H37A, Inp(&H37A) Or 2            'SCL=1
Out &H37A, Inp(&H37A) And &HFE        'SDA=0
Out &H37A, Inp(&H37A) And &HFD        'SCL=0
End Sub
```

STOP signal:

```
Private Sub Stop()
Out &H37A, Inp(&H37A) And &HFE          'SDA=0
Out &H37A, Inp(&H37A) Or 2              'SCL=1
Out &H37A, Inp(&H37A) Or 1              'SDA=1
End Sub
```

Logic 1:

```
Private Sub Send1()
Out &H37A, Inp(&H37A) Or 1              'SDA=1
Out &H37A, Inp(&H37A) Or 2              'SCL=1
Out &H37A, Inp(&H37A) And &HFD          'SCL=0
End Sub
```

Logic 0:

```
Private Sub Send0()
Out &H37A, Inp(&H37A) And &HFE          'SDA=0
Out &H37A, Inp(&H37A) Or 2              'SCL=1
Out &H37A, Inp(&H37A) And &HFD          'SCL=0
End Sub
```

Acknowledge signal:

```
Private Sub Ack()
Out &H37A, Inp(&H37A) Or 1              'SDA=1
Out &H37A, Inp(&H37A) Or 2              'SCL=1
Out &H37A, Inp(&H37A) And &HFD          'SCL=0
End Sub
```

Send data 8-bits:

```
Private Sub Send8bit(A as Integer)
 For J =7 to Step –1                          'Loop 7
    If (A And 2^J) = 2^J Then                 'Test bit 0 or 1
        Call Send1
    Else
        Call Send0
    End if
 Next I
End sub
```

Sample program for sending data 8-bits:

```
Private Sub Senddata( B as Integer)
  Call Start                                  'Start
  Call Send8bit(&H70)                         'Send address
  Call Ack                                    'Acknowledge
  Call Send8bit(B)                            'Send data
  Call Ack                                    'Acknowledge
  Call Stop                                   'Stop
End sub
```

3.7.2 Sub-programming for A/D and D/A converter

A/D converter (continuously read 4-analog signals):

```
Private Sub ADC()
Call  Start
Call  Send8bit(&H90)
Call  Ack
Call  Send8bit(&H45)
Call  Ack
Call  Stop
Call  Start
Input1.txt = (IN*5)/255          'Channel 1
Call  CtrlAck                    'send acknowledge by controller
Input2.txt = (IN*5)/255          'Channel 2
Call  CtrlAck                    'send acknowledge by controller
Input3.txt = (IN*5)/255          'Channel 3
Call  CtrlAck                    'send acknowledge by controller
Input4.txt = (IN*5)/255          'Channel 4
Call  CtrlAck                    'send acknowledge by controller
Call  Stop
End sub
```

Sub-program CtrlAck:

```
Private Sub CtrlAck()
Out &H37A, Inp(&H37A) And &HFE       'SDA=1
Out &H37A, Inp(&H37A) Or 2           'SCL=1
Out &H37A, Inp(&H37A) And &HFD       'SDA=0
Out &H37A, Inp(&H37A) Or 1           'SCL=0
End Sub
```

Function IN:

```
Private Function IN()
  For I = 7 to 0 Step -1
    Out &H37A, Inp(&H37A) Or 1                        'SDA=1
    Out &H37A, Inp(&H37A) Or 2                        'SCL=1
      If (Inp(&379) And &H80) = &H80 Then             'Read SDA
          IN1 = 2^I Or IN1
      End if
  Out &H37A, Inp(&H37A) And &HFD                      'SCL=0
  Next I
  IN = IN1                                            'Data 8 bits
End function
```

D/A converter (send output analog signals):

```
Private Sub DAC()
If Val(Out.Txt) >5 Then Out.txt = 5
Call  Start
Call  Send8bit(&H90)
Call  Ack
Call  Send8bit(&H44)
Call  Ack
Call Send8bit(Val(Out.txt)*51.2)
Call Ack
Call  Stop
End sub
```

CHAPTER 4

METHODOLOGY

4.1 Introduction

In this chapter, the control system for 6-axes robot based on position control with the position feedback and feed-forward control is presented. The methodologies for stepper motor control and data transmission are highlighted here. The I^2C system is used as the data transmission system. Input and output devices can be taken to the computer control for processing via the digital to analog or analog to digital converter. Data transmission, controlled circuits and stepper motor drivers will be shown in the next section in this chapter. The programs for control all devices and circuits are detailed. Furthermore, robot structures and all parts are designed and drawn as the basis of required specifications.

4.2 Steps of building a 6-axes robot, controlled system and programming

The steps of building a 6-axes robot, controlled system and programming are

1. Design a 6-axes robot's structures and components (the details of all parts are shown in drawing, which are in the appendix A)
2. Build the robot's components and accessories, after that assembles them together.
3. Design the controlled circuit, print circuit boards, which includes transmission circuit, digital to analog circuit, analog to digital circuit, stepper motor controlled circuit and their wiring.
4. Assemble all boards and their wiring into the controlled box.
5. Design the controlled program by reference the concept of flow-chart, which shown in the appendix B.
6. Write source code program by using Visual Basic programming version 6.0 (Beginning from the sub programs for testing stepper motor operations are wrote. After the operations are passed, the next step is writing overall of program, which includes program display and their source code.)
7. Test the robot and controlled system (The testing includes accuracy, repeatability and load capacity by point to point control. Furthermore, for testing affect of rotating in each joint to others, the joint interaction testing is presented in chapter 5.)

4.3 Design of the robot's structure, components and motor power

This section describes the steps of design robot to achieve the required specification. Starting of designation begins from drafting the robot's structure. In this research, robot structure is referred from the Motoman robot for building structure. The designed structure outline of robot is shown as figure 4.1 and details of all parts are shown as drawing in appendix A.

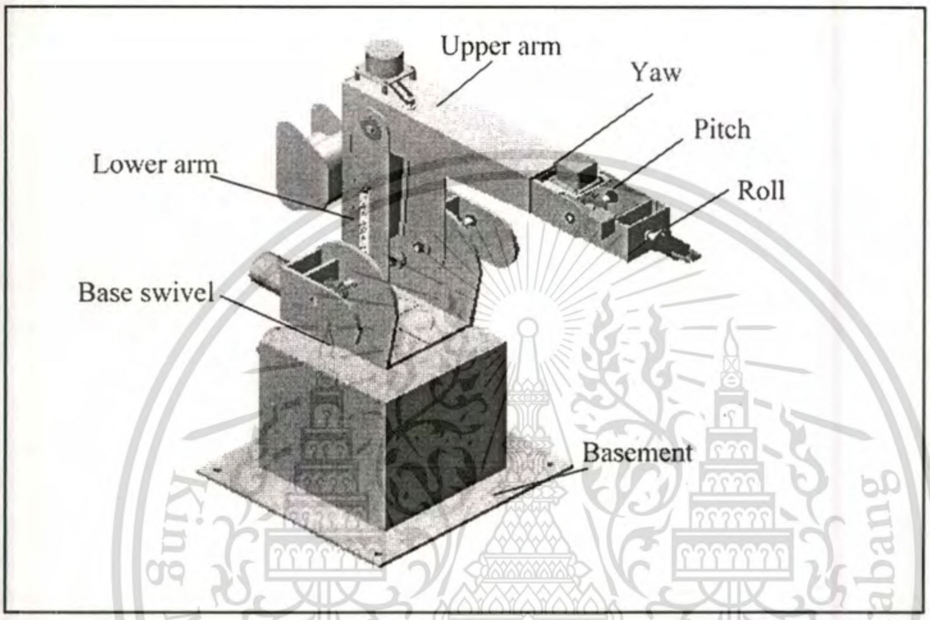


Figure 4.1 The designed outline of robot structure

The robot structure is articulated arm configuration, which has 6 degrees of freedom. The six-joints are swivel arm, lower arm, upper arm and yaw, pitch, roll for the orientation of the hand.

The next step is designation of links and joints. As the required specification of payload capacity is 0.4 Kg., so the first at all tends to the lasted link, that is supported tool which is rolled joint as shown in figure 4.2. This figure shows the designed parts of joint 6 (in assembly).

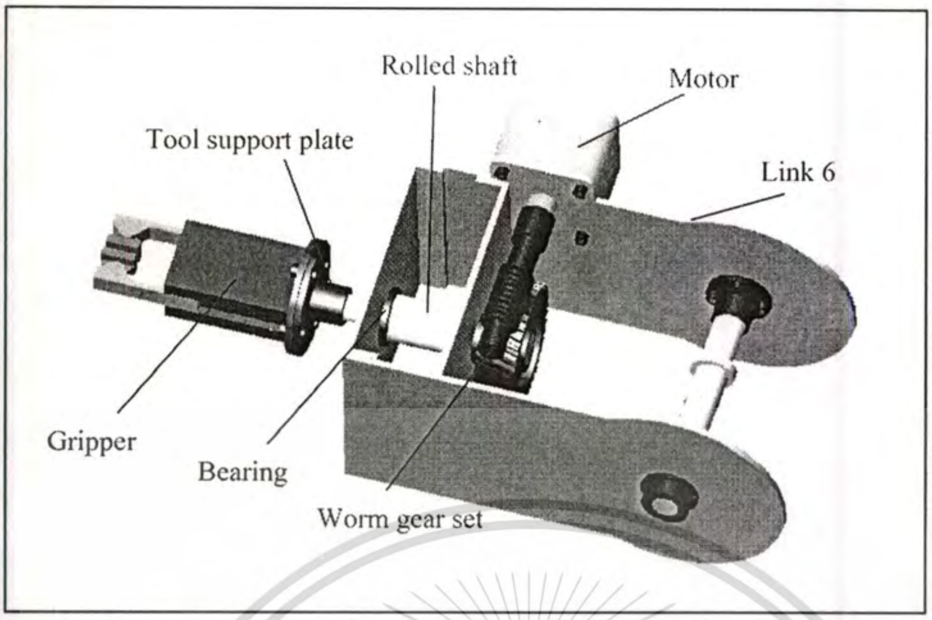


Figure 4.2 Assembly parts of rolled-joint on the hand (joint 6)

This joint can operate in range of –175 to +175 degree, which is set by the stopper and detected by the potentiometer for the actual revolution.

For the gear set, this research uses worm gears to be the power transmission system. Worm gear set can lock itself whenever no revolution from the power source (stepper motor). These gear sets have the gear ratio equal to 40:1, as shown in figure 4.3. In building this robot, the gear sets of all joints are used in the same size (details by drawing in appendix A).

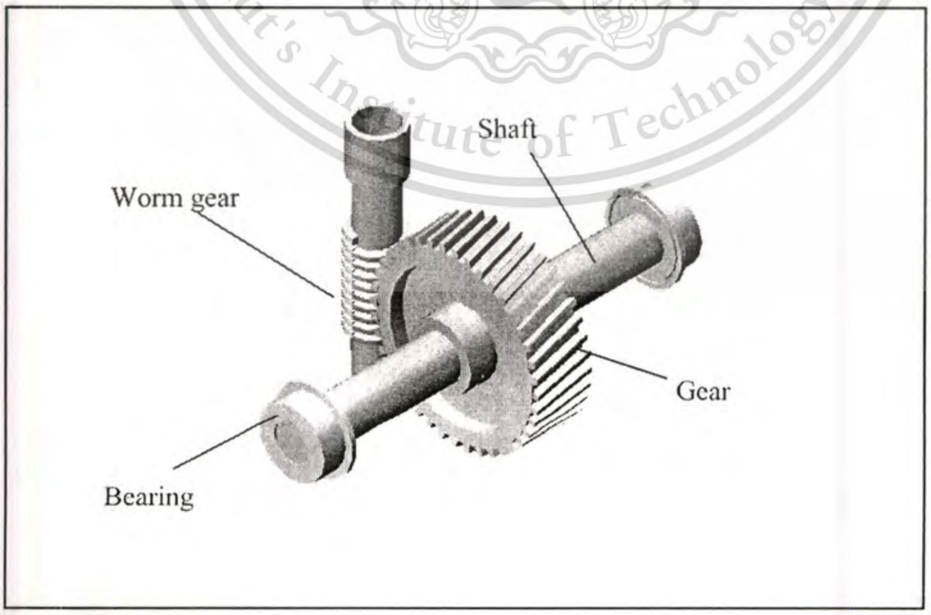


Figure 4.3 Power transmission system (Worm gear set)

The second joint on the wrist is pitch-joint or joint 5, which can move wrist to up or down direction. The pitch-joint structure is designed as figure 4.4 with its components.

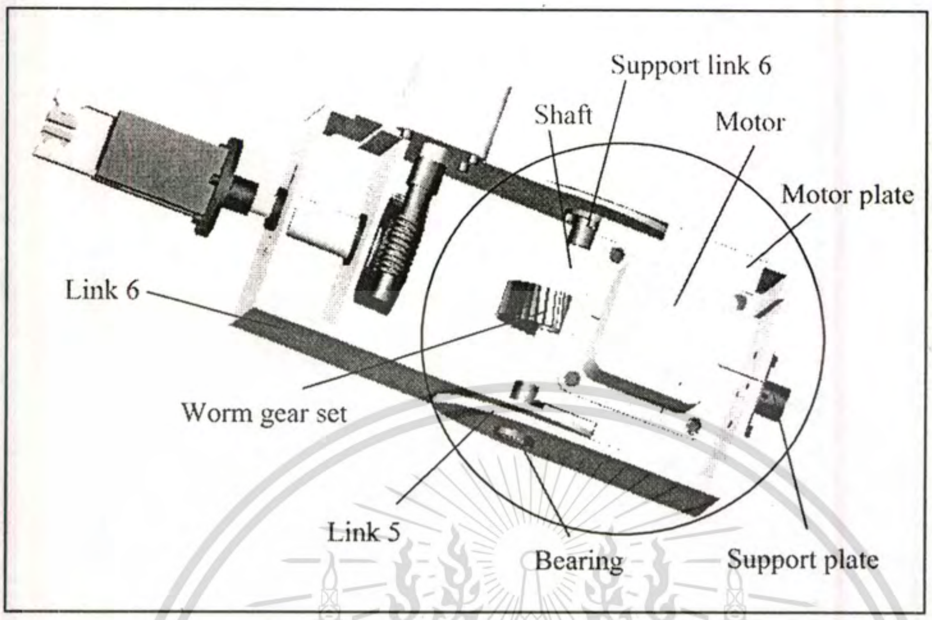


Figure 4.4 Assembly parts of pitch-joint on the hand (joint 5)

The last joint of hand orientation is yaw. This joint will make the hand move to left or right direction. The figure of yaw position is shown as below. In this joint, the flat belt is used to connect between motor and worm gear to arrange the position of gear align with the last two joints as shown details in figure.

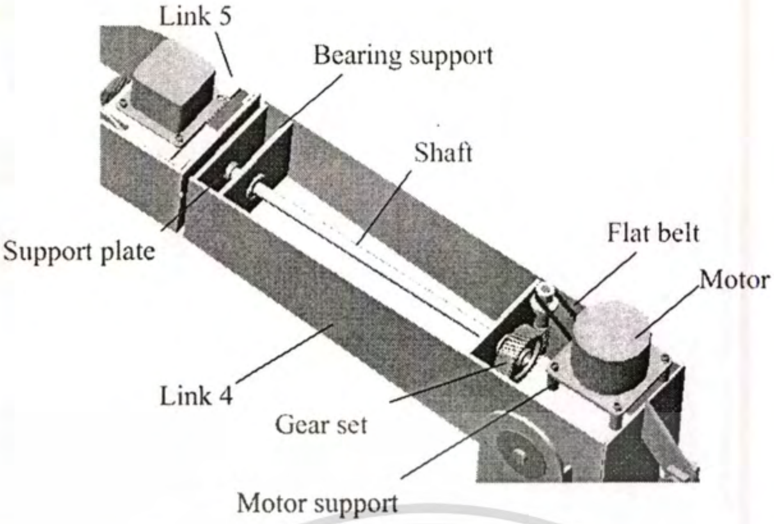


Figure 4.5 Assembly parts of power transmission on yaw (joint 4)

For balancing the weight between the front and the back of upper arm as shown in figure , weight of hand (gear sets, motors, structures of yaw, pitch and roll joint with the payload) and the weight of upper arm with motor and gear set of yaw joint, are arranged in the opposite side by using lower arm to be the pivot.

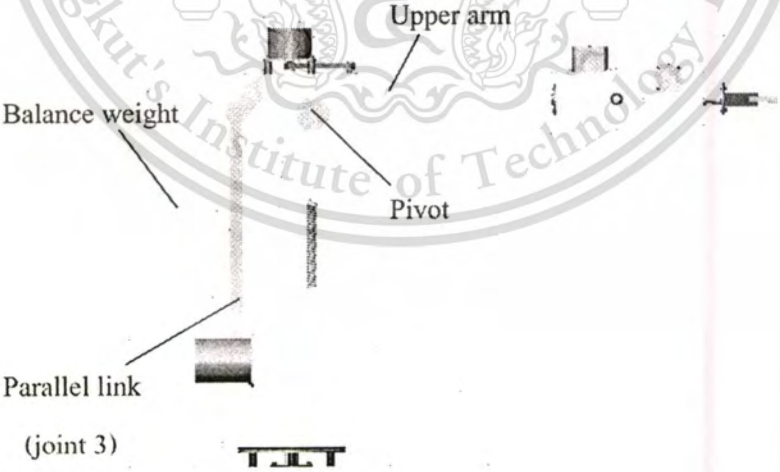
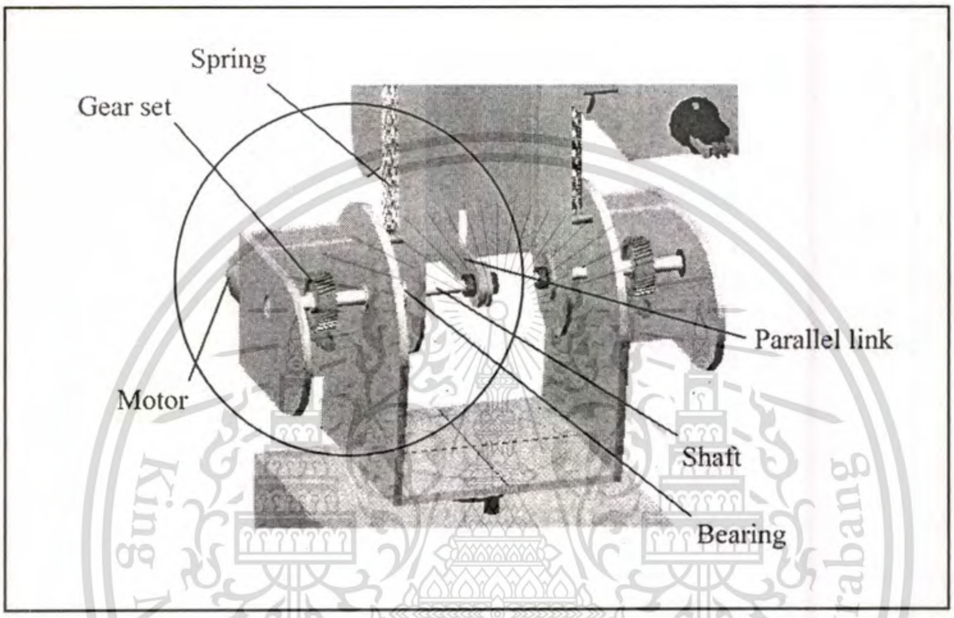


Figure 4.6 Arrangement of upper arm and balance weight

Under the upper arm is supported by lower arm. This arm support upper arm, hand, and payload. In case of moving the upper arm and lower arm from the home position, the lower arm will support unbalanced lose between the front side and back side of upper arm. To balance this matter, the balance weight as shown is taken to solve this problem. This balance weight is placed at the parallel link, which transmitted the power from motor3 to drive upper arm.



Figures 4.7 Shaft connection and parallel link for drive upper arm (joint 3)

The next is lower arm, which support all of above components. This joint is drive by motor in the left side of robot. To reduce the supporting load, tension spring is taken to balance weight as shown in the figure.

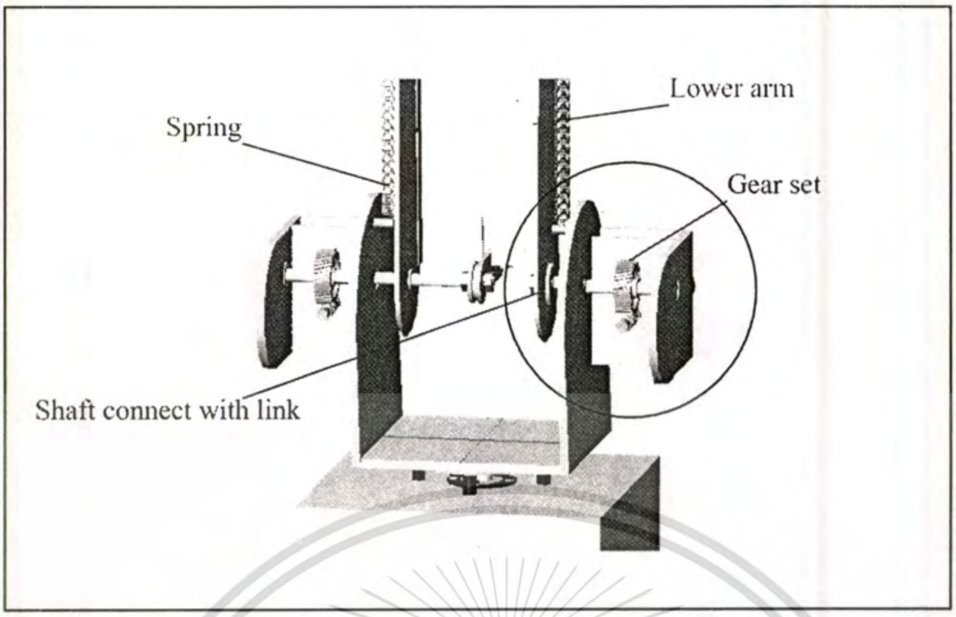


Figure 4.8 Structure of lower arm (joint 2)

The last joint of this robot structure is swivel arm. This joint supports all of other five joints load and their components. Details of this joint are shown as below.

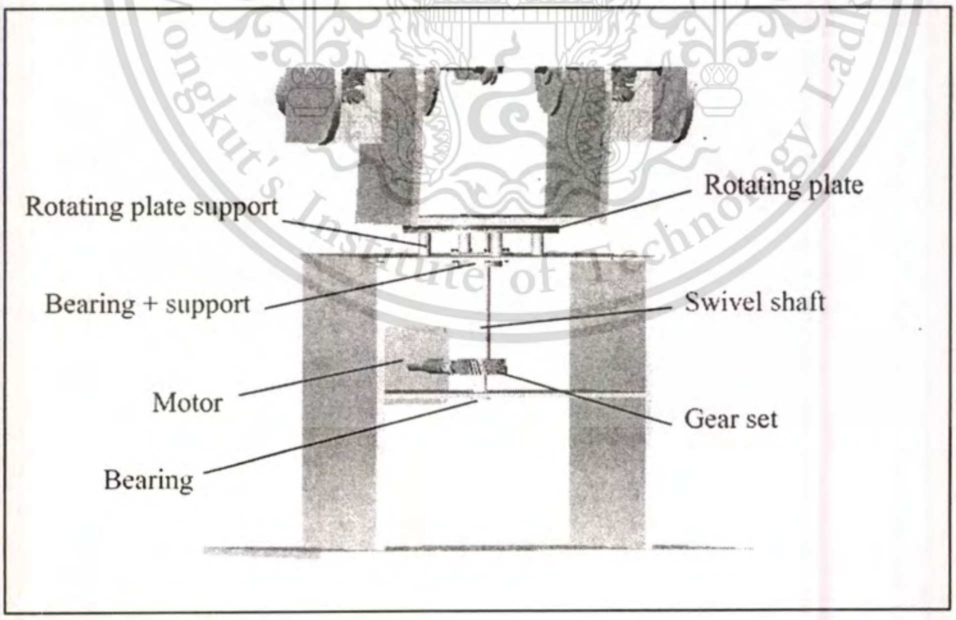


Figure 4.9 Structure of swivel (joint 1)

As this joint support load of above 5 joints, this load effect to this joint. So Rotating plate is taken as shown in below figure.

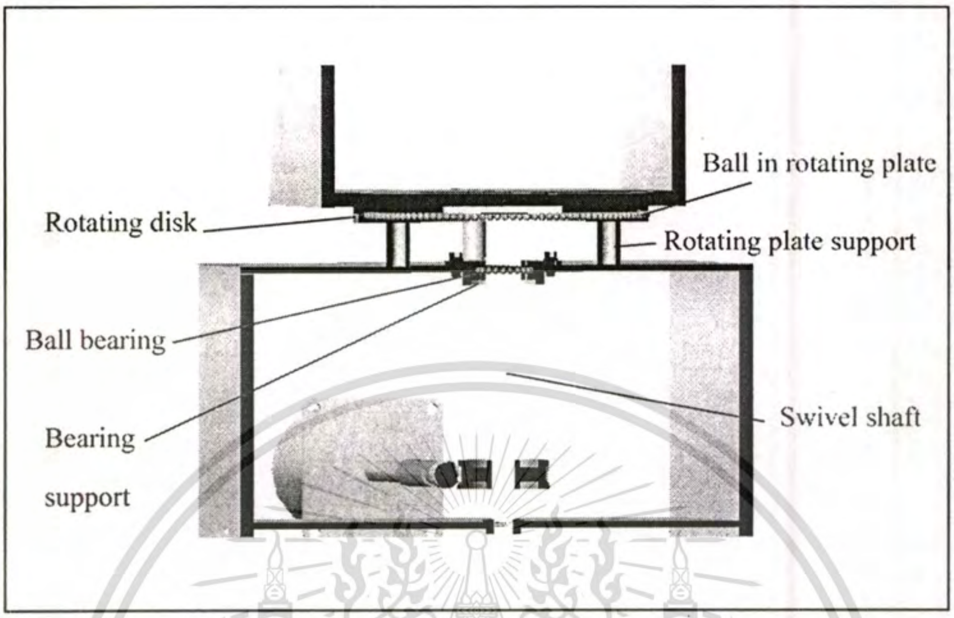


Figure 4.10 Rotating plate

The dimension of robot to obtain the specification requirements are shown as below figure.

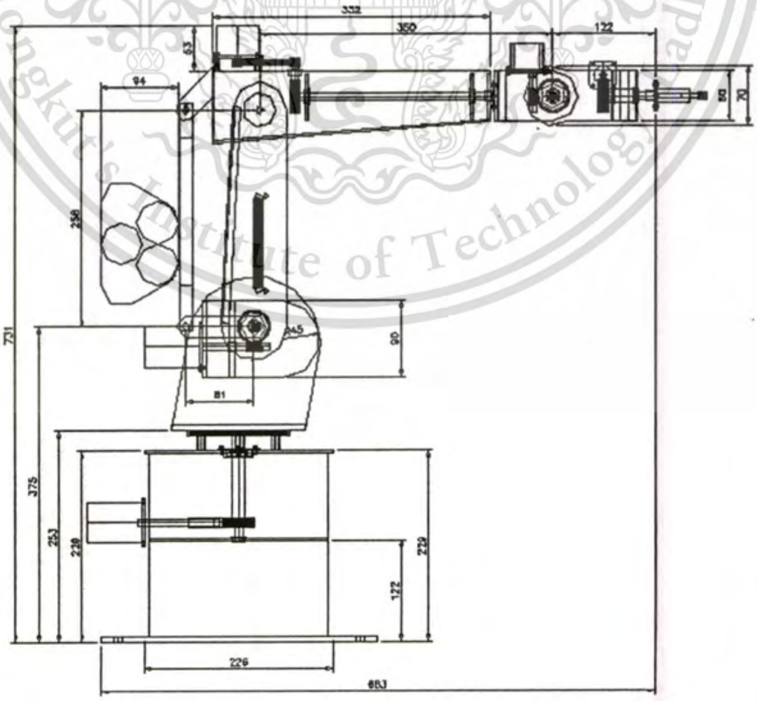


Figure 4.11 Robot dimension (side view)

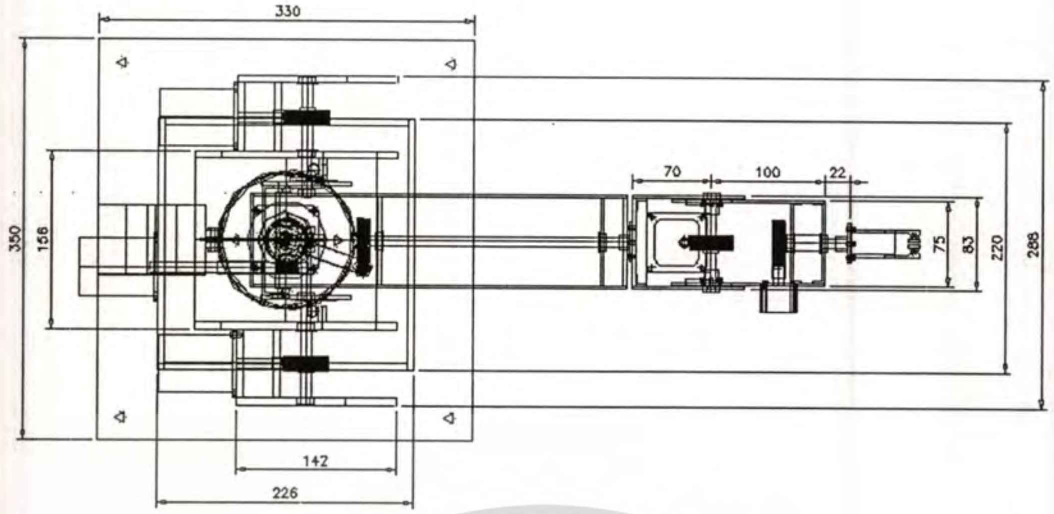


Figure 4.12 Robot dimension (top view)

4.4 Motor power calculation

This section is devoted for calculation of motor powers, which are the power source to drive robot joints. The centroid of mass in each link is calculated by using AutoCAD 2002 program. By the formula of power, . Consider a shaft subjected to a torque from its surroundings and rotating with angular velocity. The power transmitted to the shaft from the surroundings.

$$P = T\omega \qquad \text{Eq. (4.1)}$$

when P is power, watts

T is torque, Nm.

ω is angular velocity, radian/sec.

Let the torque be express in terms of a tangential force F and radius R, then $T = FR$

From the above formula, table 4.1 shows the details of power calculation. From this table can guide to select motor size for using to be power source in this robot.

Refer to Table 2.6, At helix angle 10 degrees of worm gear, the efficiency about 76.8 %.

The minimum motor power requirement (P)

= (F*9.81*R*10.47)/(motor eff.*gear eff.*40) watts Eq. (4.2)

= 5.57 * F * R watts Eq. (4.3)

by unit of F is Kg., R is meter.

Table 4.1 Motor power calculation (gear ratio 40:1)

Joint	Total mass x mass centroid	Motor eff.(%)	Angular velocity	Min. power (W)
1	0.6 kg. * 0.03 m.	60%	15 deg./sec.	0.1
2	(0.6+0.8) kg.* 0.087 m.	60%	15 deg./sec.	0.7
3	(0.8+0.9+0.6) kg. * 0.238 m.	60%	15 deg./sec.	3.1
4	1.3 (after balance weight) * 0.315 m.	60%	15 deg./sec.	2.3
5	1.5 (after balance by spring) * 0.387 m.	60%	15 deg./sec.	3.3
6	(0.8+0.9+0.6+2.8+1.9+1.5+1.5+1.3) * 0.18 m.	60%	15 deg./sec.	11.4

Angular velocity at motor equal to 40x15x(0.01745) = 10.47 radian/second.

4.5 Design of the control circuit and print circuit board

This section describe the detail of designation and method of robot control (including digital to analog converter, analog to digital converter, expander board, stepper motor control board)

4.5.1 Parallel signals from controller to I^{2}C bus system circuit

This circuit presents the communication between parallel port to I^{2}C bus devices. Data from computer is transferred to SDA line of I^{2}C devices via pin 11 (or pin C0) of parallel port. The clock signal is transferred to SCL line of I^{2}C devices via pin 14 (or C1) of parallel port. Details of this circuit and print circuit board are shown as figure below.

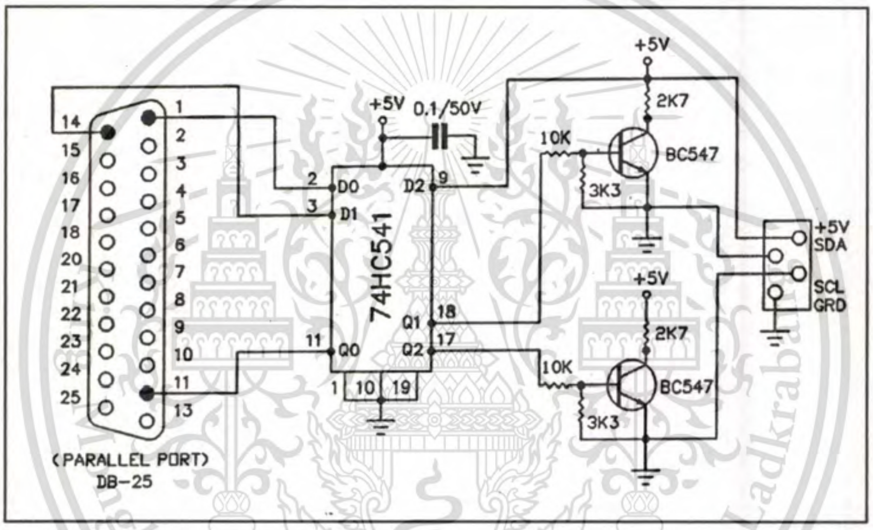


Figure 4.13 Parallel to I^{2}C circuit

Figure 4.14 Parallel to I^{2}C print circuit board

4.5.2 Input/output expander circuit

For multi I/O application, only pins from parallel port are not enough to apply. It is necessary to expand the I/O ports by using I^2C bus IC. Therefore the I^2C bus IC PCF8574 and PCF8574A are used to obtain this purpose. These IC can expand to 8 bites each unit and can be addressed to 8 addresses, so 64 bites data can be obtained for PCF8574 and 64 bites data can be obtained from PCF8574A. These IC are applied to the expander circuit as shown with the print circuit board in figure below.

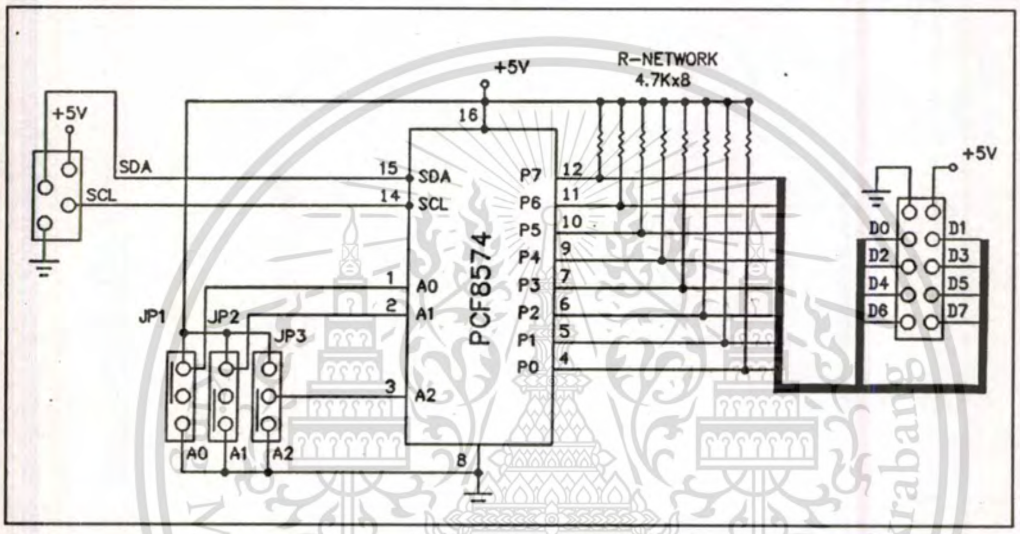


Figure 4.15 I/O expander circuit

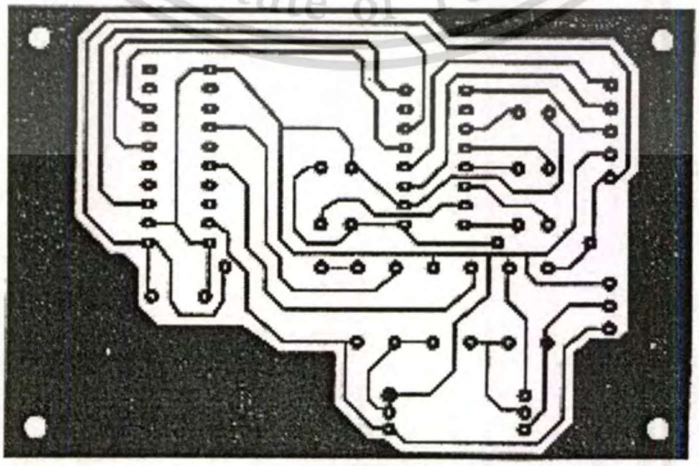


Figure 4.16 I/O expander print circuit board

4.5.3 Stepper motor driving circuit

After generating the signals from computer and convert to I^2C signal on the parallel to I^2C system circuit and expanded signals by expander circuit for multi-device. One of multi-device is stepper motor driving circuit, which convert digital signal to analog signal for generating the pulse and electrical power to drive stepper motor. This circuit is shown as figure below.

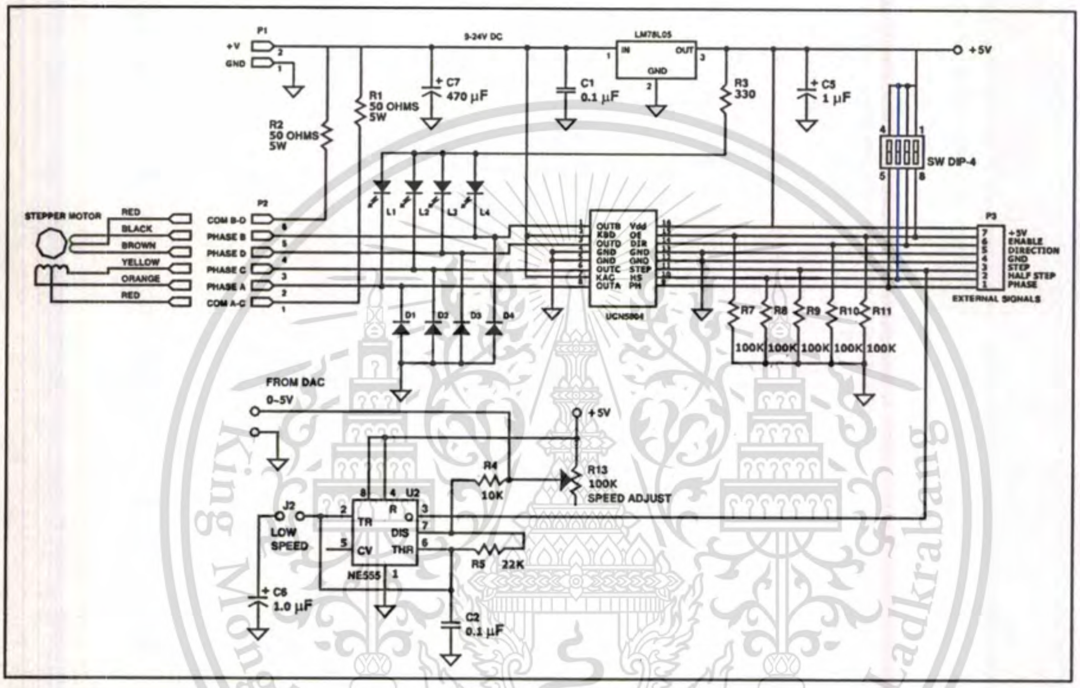


Figure 4.17 Stepper motor driving circuit

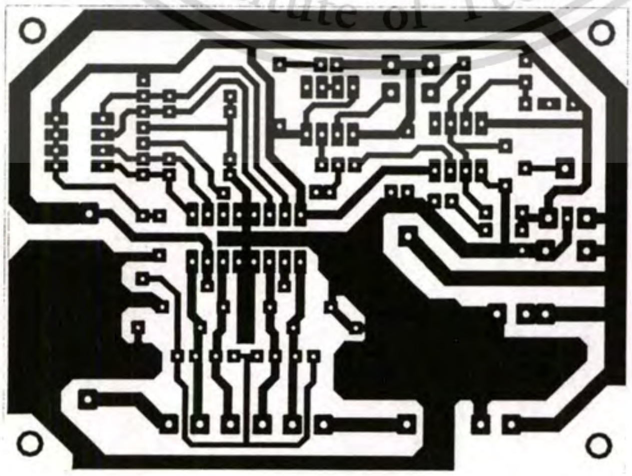


Figure 4.18 Stepper motor driving print circuit board

4.5.4 A/D and D/A converter circuit

For receiving the signal from the peripherals or external devices to the system, analog to digital converter (ADC) is used for this operation. And digital to analog converter (DAC) is used for sending the signal, which is the voltage signal, to stepper motor driving board. This signal can control the speed of stepper motor, which vary on the voltage as shown in figure below.

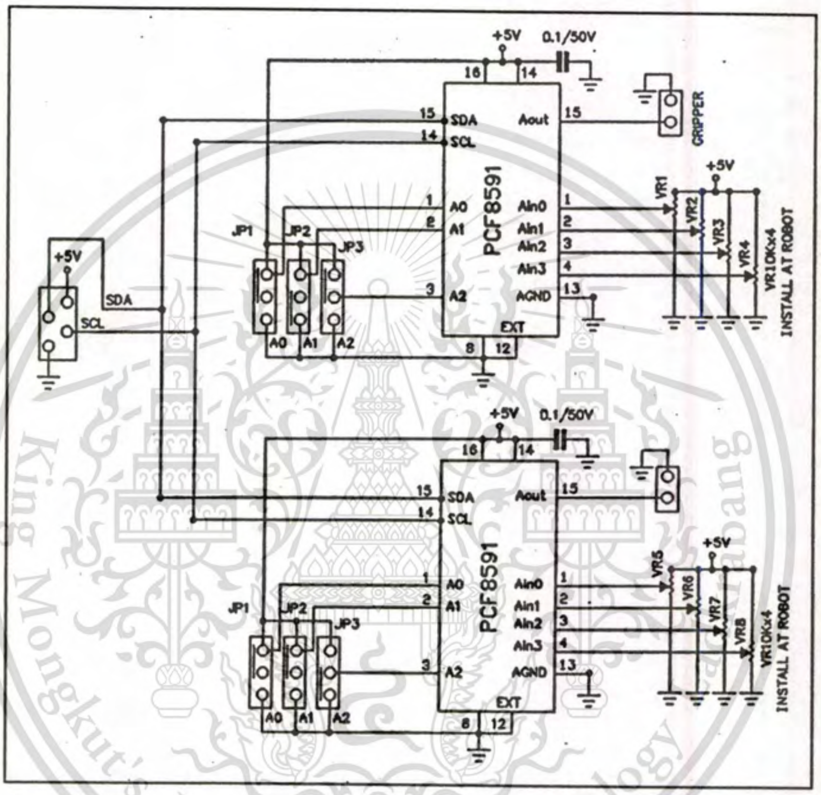


Figure 4.19 A/D and D/A converter circuit

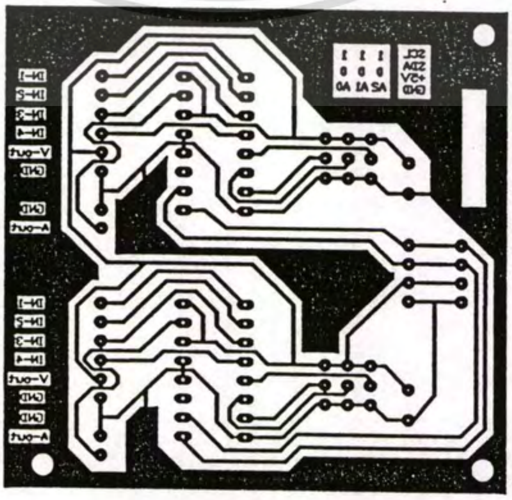


Figure 4.20 A/D and D/A converter print circuit board

4.5.5 Circuit connection

After designing and building all of controlled set (including parallel to I2C board, expander board, DAC and ADC board and stepper motor driving board), the next is to assembly all components. To connect these boards, the wiring diagram of circuit connection is

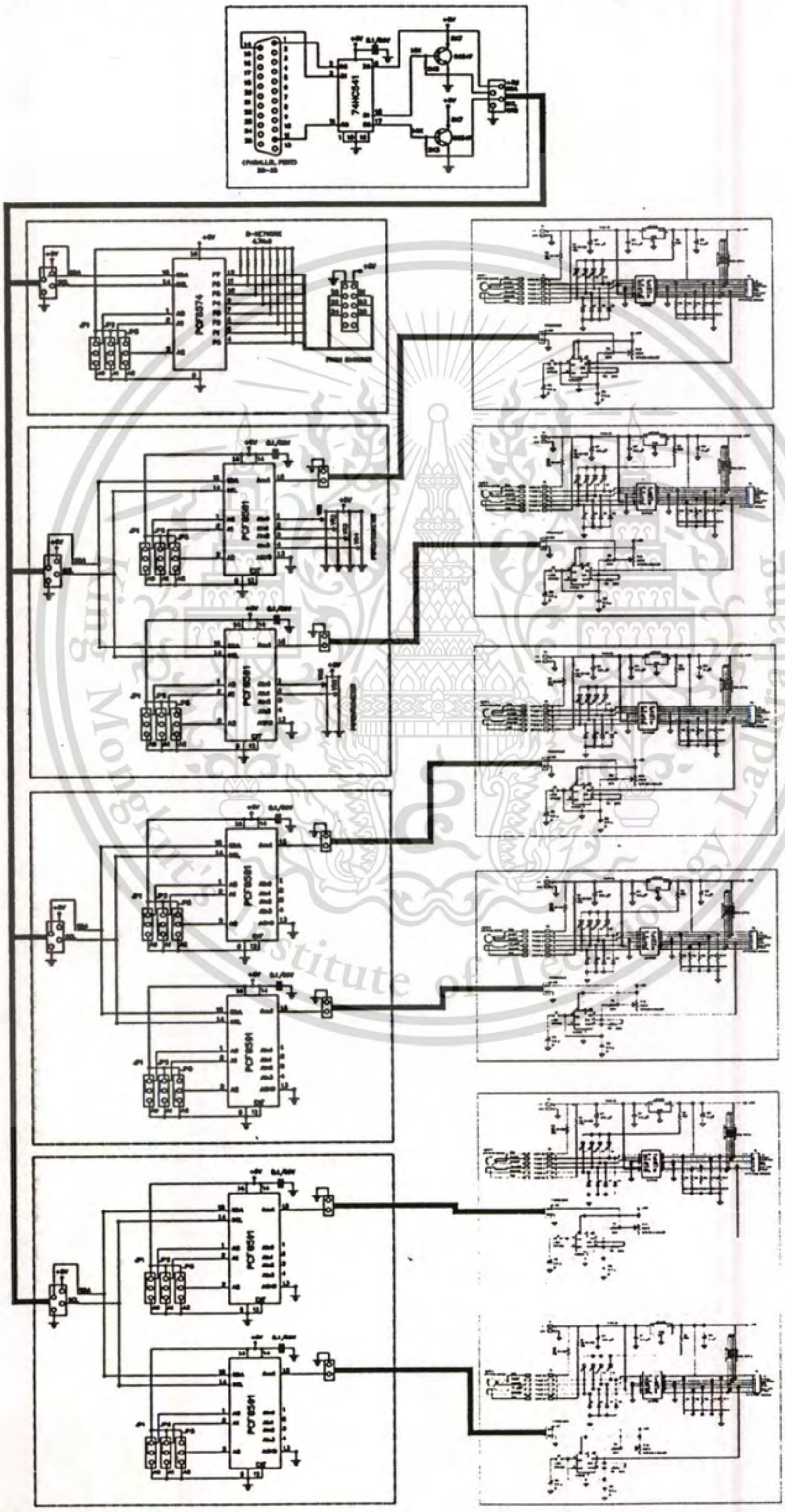


Figure 4.21 Overall circuit wiring connection

4.6 Position feedback equipment

4.6.1 Encoder

To count the steps of stepper motor in revolution, the encoder is mounted at shaft-end of motor as shown in figure 4.17. The resolution of stepper motor motion is 1.8 deg./step, so in each revolution must generate 200 steps or pulses of signals for sending to motor driver board. For matching with the stepper motor resolution, the encoder's resolutions with 200 points/revolution are used in this research.

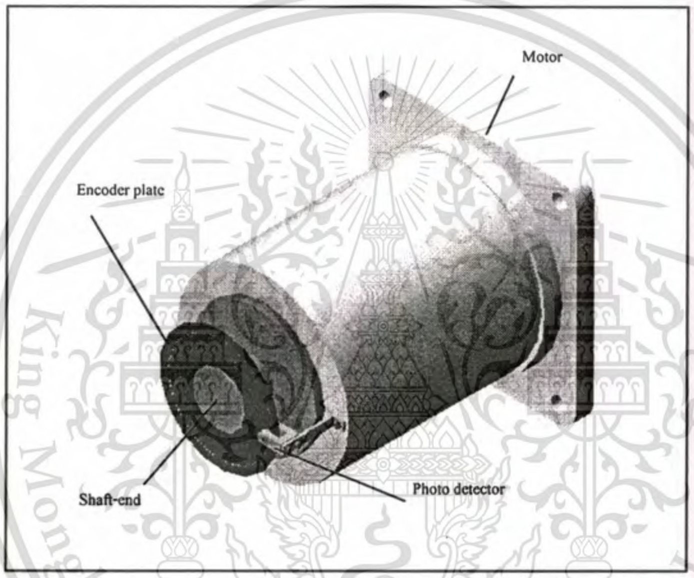


Figure 4.22 Installation encoder at shaft-end of motor

4.6.2 Potentiometer

To check the motion angle in each joint of robot, potentiometer is mounted at the shaft of gear as shown in below figure and sends signal to ADC board. The purpose of installation this equipment is to recheck rotation of shaft. For this research, wire wound potentiometers, 1 Kohms 5 watts, are used for support the DC current 15 mA. The figure of potentiometer is installed to each joint as below.

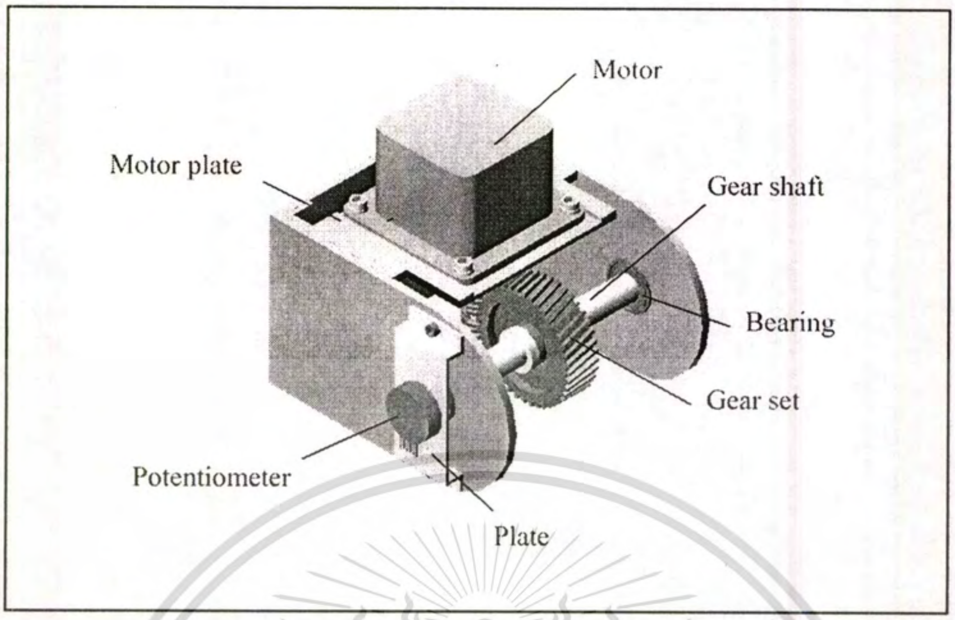


Figure 4.23 Potentiometer installation

CHAPTER 5

EXPERIMENTATIONS AND TESTING

5.1 Introduction

To verify the capability of the robot and controlled system, this chapter is devoted for robot testing. The testing is separated to four-topics, that are

1. Payload capacity and accuracy testing
2. Repeatability testing
3. Joint interaction testing
4. Joint response testing

Next sections will describe details in each topic. The details includes testing method, testing results and discussions.

5.2 Payload capacity and accuracy testing

5.2.1 Testing method

This experiment is designed to measure the payload capacity and accuracy of robot mechanism and controlled system.. For each observation, the robot's gripper is commanded to move from the home position to desired position. After the motion is completed, the actual position of gripper is measured. The robot's gripper is commanded to return to home position. The procedure is repeated 10 cycles, but change the desired positions. Speeds and payload capacities are changed in each experiment. In this experiment, robot is tested in the working range, X-axis is in range between 144 to 614 mm., Y-axis is in range between 144 to 614 mm. and Z-axis is in range between -330 to 550 mm.

Payload capability and accuracy testing are separated to 12 sets of parameters, with operating frequency of control loop is 10 Hz. By changing parameters as following.

1. Set 1: Speed on level 1 (5 degree/sec.) with load 0.2 kg.
2. Set 2: Speed on level 1 (5 degree/sec.) with load 0.3 kg.
3. Set 3: Speed on level 1 (5 degree/sec.) with load 0.4 kg.
4. Set 4: Speed on level 1 (5 degree/sec.) with load 0.5 kg.
5. Set 5: Speed on level 2 (10 degree/sec.) with load 0.2 kg.

6. Set 6: Speed on level 2 (10 degree/sec.) with load 0.3 kg.
7. Set 7: Speed on level 2 (10 degree/sec.) with load 0.4 kg.
8. Set 8: Speed on level 2 (10 degree/sec.) with load 0.5 kg.
9. Set 9: Speed on level 3 (15 degree/sec.) with load 0.2 kg.
10. Set 10: Speed on level 3 (15 degree/sec.) with load 0.3 kg.
11. Set 11: Speed on level 3 (15 degree/sec.) with load 0.4 kg.
12. Set 12: Speed on level 3 (15 degree/sec.) with load 0.5 kg.

5.2.2 Testing results and discussions

This section describes the result of robot testing. Figure 5.1 is an example of payload and accuracy testing. The other testing are shown in appendix C.

Figure 5.1 shows an example of ten test runs in payload capacity and accuracy testing, with the dotted line indicates the desired point and the solid line the actually followed. This case is set 1, the desired velocity is 5 degrees/second, payload is 0.2 kg.

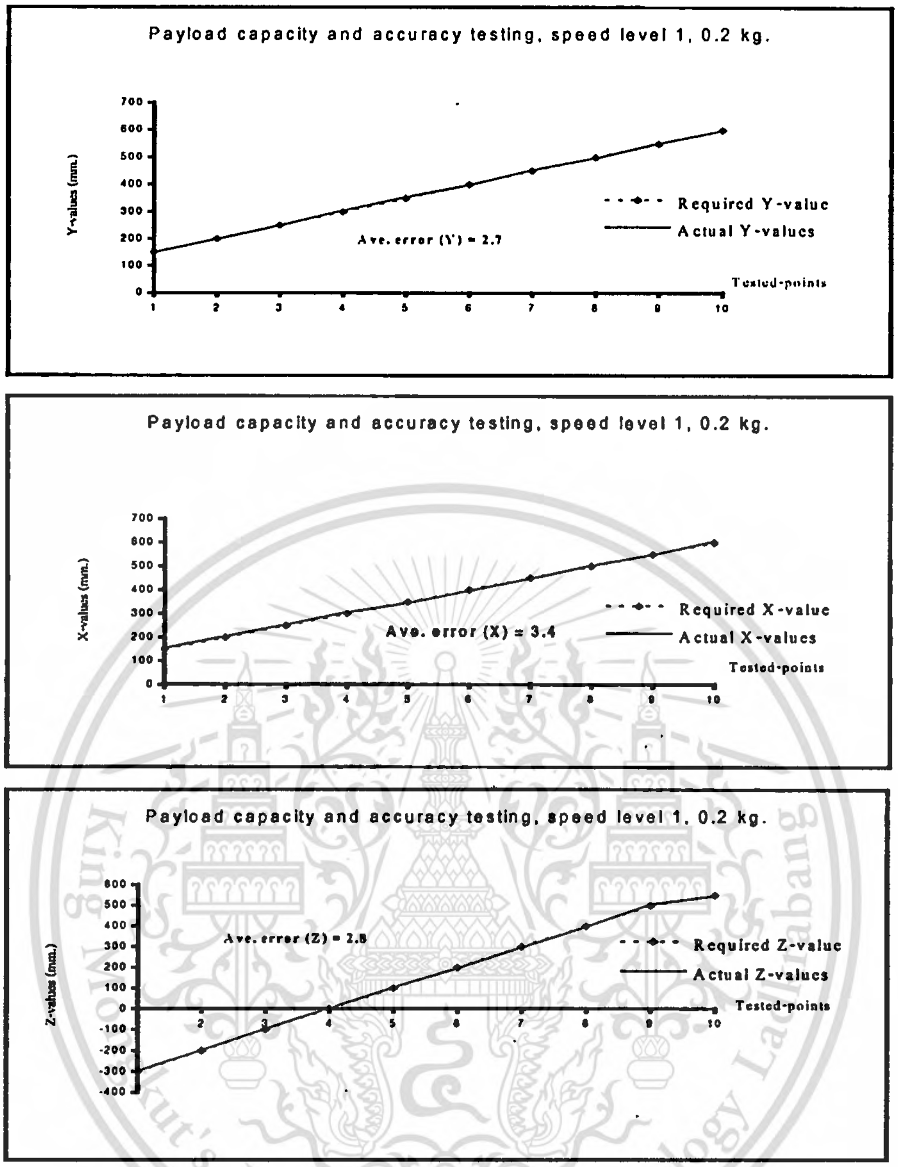


Figure 5.1 Example of payload capacity and accuracy testing (speed level 1, 0.2 kg. load.)

Figure 5.1, in the first graph shows the comparison between desired point and actual points on x-axis. This graph indicates that the average error in x-axis is 2.7 mm.

In the second graph shows the comparison between desired point and actual points on y-axis. This graph indicates that the average error in y-axis is 3.4 mm.

In the third graph shows the comparison between desired point and actual points on z-axis. This graph indicates that the average error in z-axis is 2.8 mm.

After experimentation, all of data is kept in appendix C. From this data, position error in each experiment, which is grouped by the speed, can be summarized as table 5.1.

Table 5.1 : Position error on each axis compares with speed level (mm.)

Axis	Speed level 1	Speed level 2	Speed level 3	Average
X	3.27	3.40	3.57	3.41
Y	2.80	2.83	2.97	2.87
Z	2.70	2.80	2.90	2.80

Figure 5.2 To Figure 5.4 are comparison graphs between load capacity and position error on each axis.

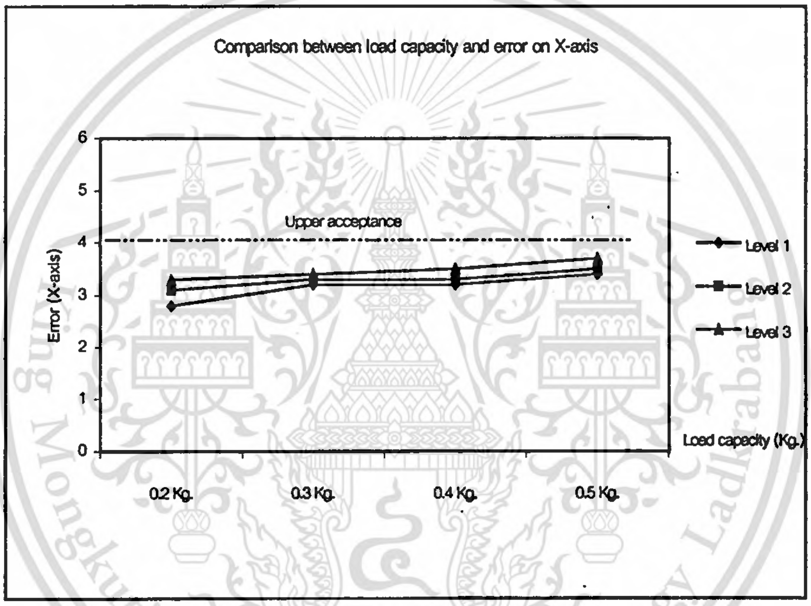


Figure 5.2 Comparison between load capacity and error on X-axis

Figure 5.2 shows the position error on x-axis. Limit of upper error is 4 mm. In this graph, all of errors are in specificative limit. As speed is increased, the error increase. In the same way, the error is increased as increasing payload capacity. The maximum error is 3.7 mm.. This error is occurred when running test on speed level 3 (15 degrees/sec.), with 0.5 kg. load.

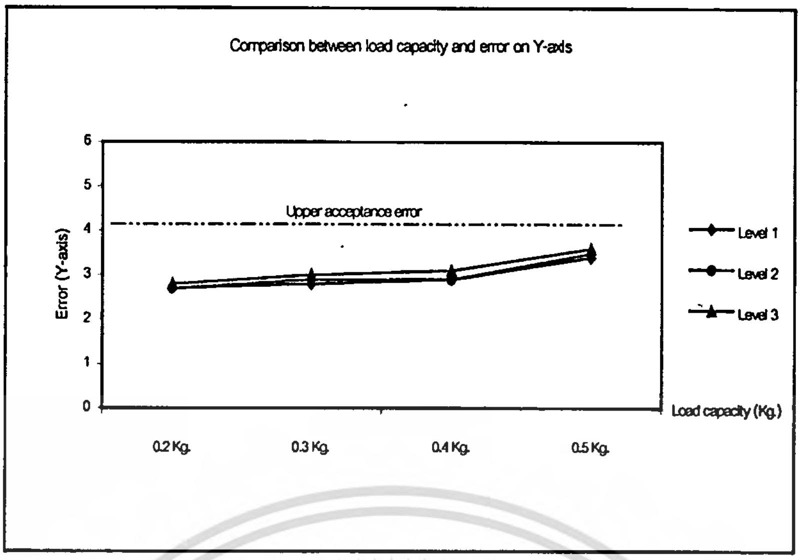


Figure 5.3 Comparison between load capacity and position error on Y-axis

Figure 5.3 shows the position error on y-axis. Limit of upper error is 4 mm. In this graph, all of errors are in specificative limit. Speed is increased, the error increase. In the same way, the error is increased as increasing payload capacity. The maximum error is 3.6 mm.. This error is occurred when running test on speed level 3 (15 degrees/sec.), with 0.5 kg. load.

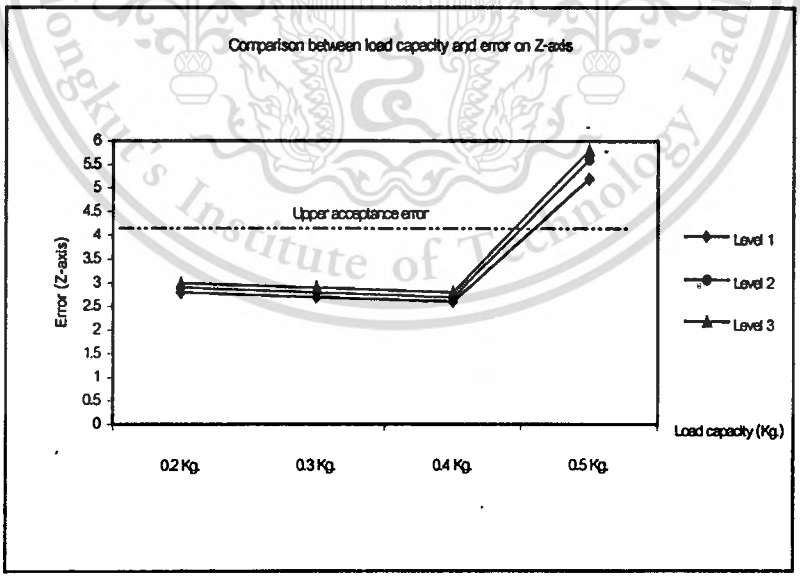


Figure 5.4 Comparison between load capacity and position error on Z-axis

The last axis is z-axis. Figure 5.3 shows the position error on z-axis. Limit of upper error is 4 mm. In this graph, some errors are not in specificative limit. Payload capacity directly effects to position error. As running test on 0.5 kg. load, errors are over the upper acceptance error line. This graph shows that payload capacity of robot is limited at 0.4 kg. load. The maximum error is 2.8 mm. (in limit of upper acceptance error). This error is occurred when running test on speed level 3 (15 degrees/sec.), with 0.4 kg. load.

Due to the target of acceptance error is less than 4.0 mm. From the experimentation, found that the maximum payload capacity should be 0.4 kg. for keeping the acceptance error target.

5.3 Repeatability testing

5.3.1 Testing method

This experiment is designed to measure the repeatability mechanism and controlled system of robot. For each observation, the robot's gripper is commanded to move from the home position to desired position. After the motion is completed, the actual position of gripper is measured. The robot's gripper is commanded to return to home position. The procedure is repeated 10 cycles in the same desired position. Speeds and payload capacities are changed in each experiment. In this experiment, robot is tested in the working range, X-axis is in range between 144 to 614 mm., Y-axis is in range between 144 to 614 mm. and Z-axis is in range between -330 to 550 mm.

Repeatability experiments are separated to six sets of parameters, with operating frequency of control loop is 10 Hz. By changing parameters as following.

1. Set 1: Speed on level 1 (5 degree/sec.) without load, test 10 cycles.
2. Set 2: Speed on level 2 (10 degree/sec.) without load, test 10 cycles.
3. Set 3: Speed on level 3 (15 degree/sec.) without load, test 10 cycles.
4. Set 4: Speed on level 1 (5 degree/sec.) with maximum load, test 10 cycles.
5. Set 5: Speed on level 2 (10 degree/sec.) with maximum load, test 10 cycles.
6. Set 6: Speed on level 3 (15 degree/sec.) with maximum load, test 10 cycles.

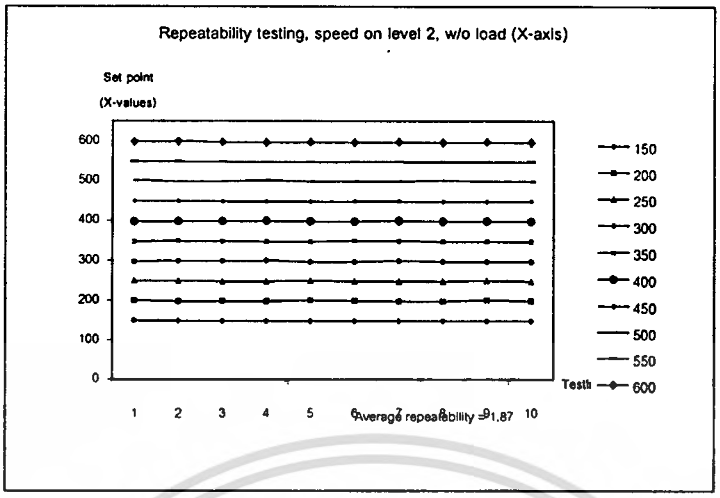


Figure 5.5 Repeatability experiment (set 1: speed level 2, without load) on x-axis

Figure 5.5 shows the example of repeatability experiment (set 1) on x-axis. The vertical axis of this graph indicates desired position. The horizontal axis indicates the cycle no. of running. Desired points are 10 points, with test runs 10 cycles in each point. Average repeatability on this experiment is 1.87 mm.

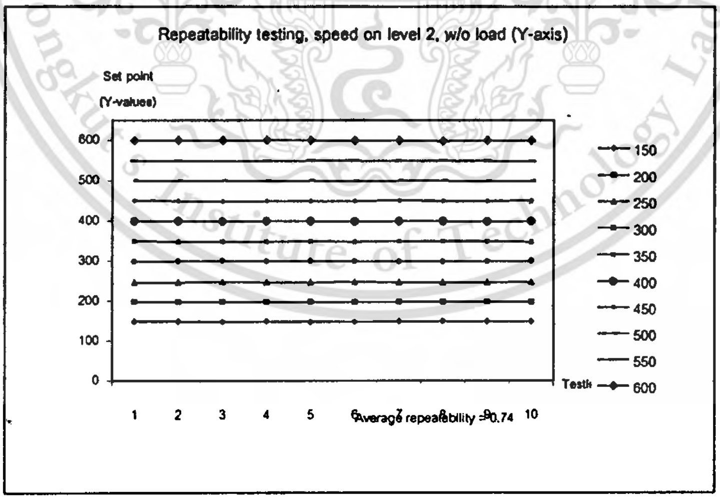


Figure 5.6 Repeatability experiment (set 1: speed level 2, without load) on y-axis

Figure 5.6 shows the example of repeatability experiment (set 1) on y-axis. The vertical axis of this graph indicates desired position. The horizontal axis indicates the cycle no. of running. Desired points are 10 points, with test runs 10 cycles in each point. Average repeatability on this experiment is 0.74 mm.

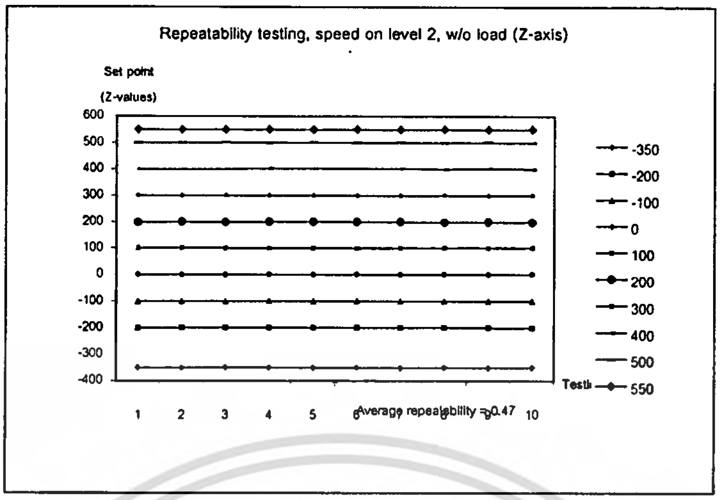


Figure 5.7 Repeatability experiment (set 1: speed level 2, without load) on z-axis

Figure 5.7 shows the example of repeatability experiment (set 1) on z-axis. The vertical axis of this graph indicates desired position. The horizontal axis indicates the cycle no. of running. Desired points are 10 points, with test runs 10 cycles in each point. Average repeatability on this experiment is 0.47 mm.

For other 5 sets of experimentation data are kept in appendix C, with their graphs. Table 5.2 shows the repeatability at speed on level 1 to level 3, without load. and distinguished on figure 5.8.

Table 5.2 : Repeatability (without load), mm.

Axis	Speed level 1	Speed level 2	Speed level 3	Average
X	1.66	1.87	1.93	1.82
Y	0.71	0.74	0.76	0.74
Z	0.43	0.47	0.47	0.46

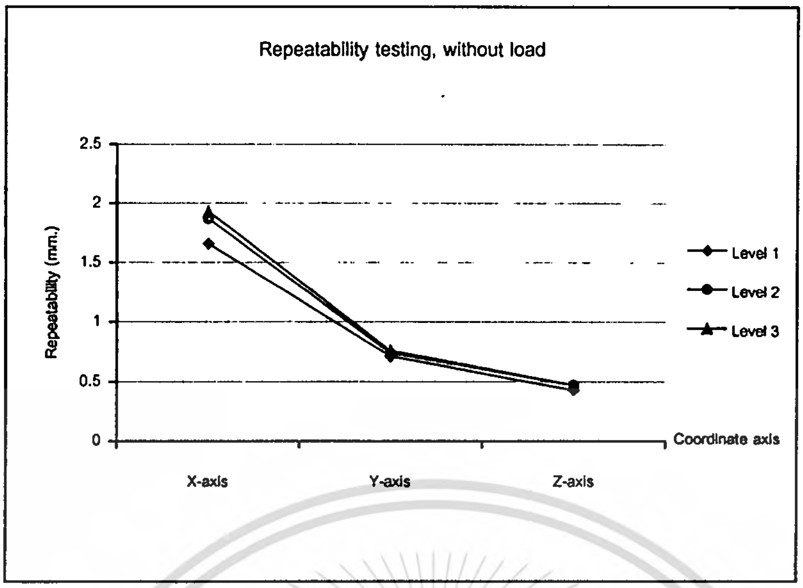


Figure 5.8 Repeatability testing, without load

Figure 5.8 shows the comparison of repeatability in each axis. This graph shows the comparison between three speed levels. Vertical axis indicates repeatability in mm. Horizontal axis indicates coordinate axis. From the graph, speed level directly effects to repeatability. Maximum repeatability come from maximum speed (level 3). Minimum repeatability come from minimum speed (level 1). Repeatability fall to the lowest point from x-axis to z-axis. Average repeatability on x-axis is 1.82 mm., on y-axis is 0.84 mm. and z-axis is 0.46 mm.

Peak-repeatability on the x-axis is came from the joint 1 of robot's structure. This joint directly effects to x-axis because it is the robot basement.

Table 5.3 shows the repeatability at speed on level 1 to level 3, without load. and distinguished on figure 5.9.

Table 5.3 : Repeatability (with maximum load), mm.

Axis	Speed level 1	Speed level 2	Speed level 3	Average
X	1.98	2.03	2.04	2.02
Y	0.80	0.82	0.85	0.82
Z	0.50	0.53	0.59	0.54

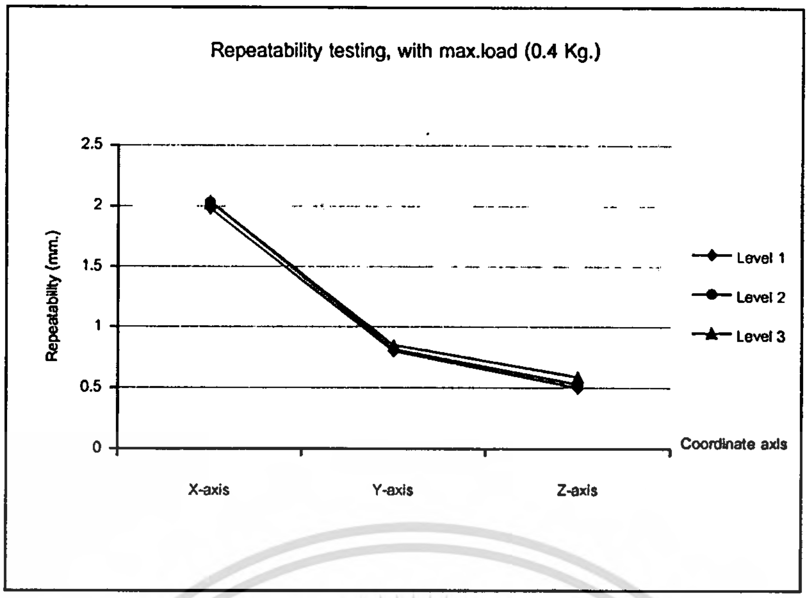


Figure 5.9 Repeatability testing, with maximum load

Figure 5.9 shows the comparison of repeatability in each axis (test on maximum load). This graph shows the comparison between three speed levels. Vertical axis indicates repeatability in mm. Horizontal axis indicates coordinate axis. From the graph, speed level directly effect to repeatability. Maximum repeatability come from maximum speed (level 3). Minimum repeatability come from minimum speed (level 1). Repeatability fall to the lowest point from x-axis to z-axis. Average repeatability on x-axis is 2.02 mm., on y-axis is 0.82 mm. and on z-axis is 0.54 mm.

5.4 Joint interaction testing

5.4.1 Testing method

This experiment is designed to observe the joint interaction. The experiment is performed by revolution a tested joint while other joints are not commanded to move. While tested joint is moving, motion of six joints are record. Tested joint is began from joint 1 to joint 6. The operating frequency of control loop is 10 Hz.

Figure 5.10 shows the joint interaction while moving joint 2. Vertical axis indicates joint angle and horizontal axis indicates running time. As moving joint 2, Joint 3 is effected from this motion as shown in third graph of figure 5.10. These joint interaction come from structure of robot. Friction in each joint connection and alignment of parallel link between joint 2 and joint 3 are the answer for this matter.

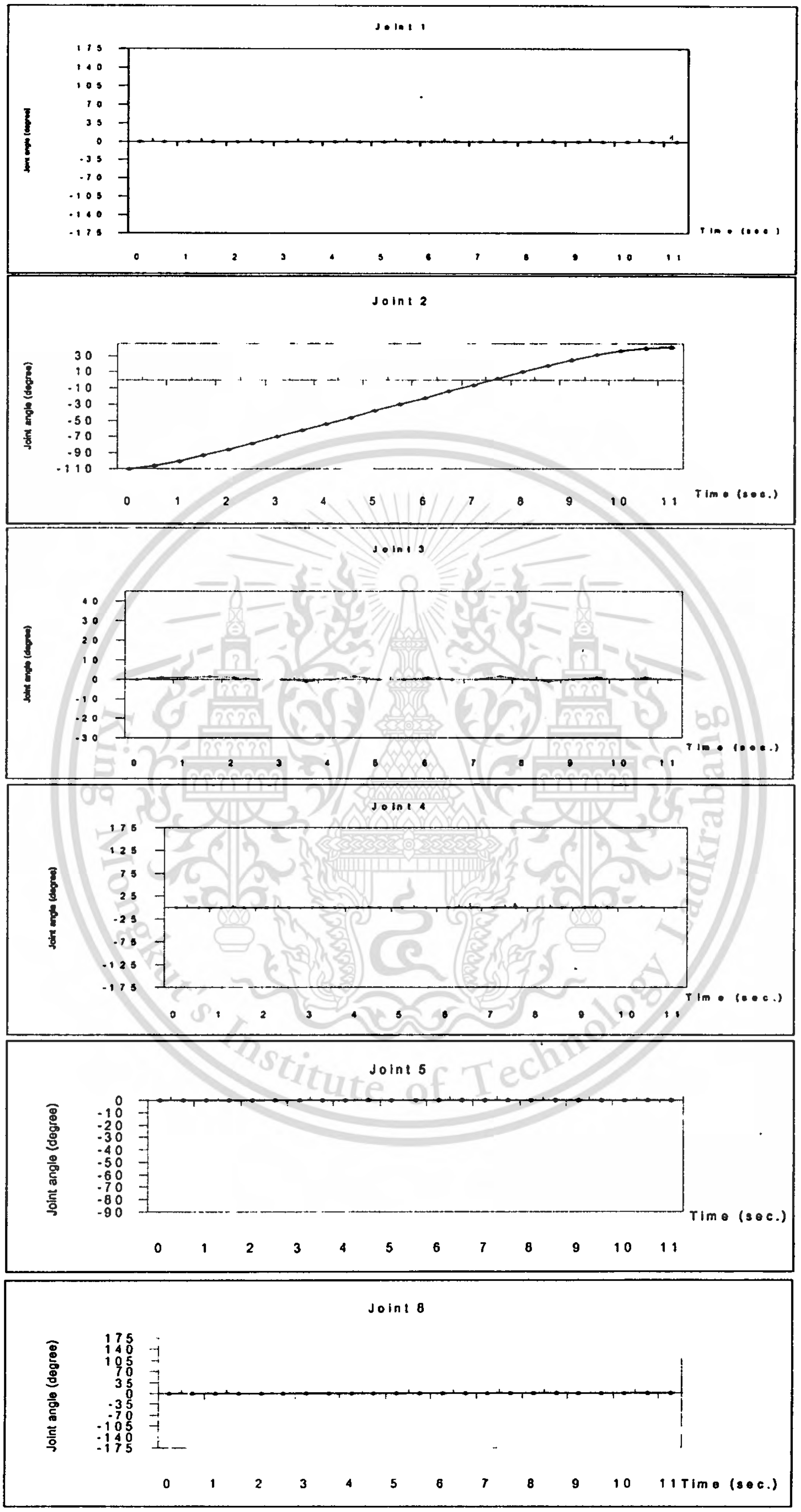


Figure 5.10 Joint-interaction testing (command to move joint 2)

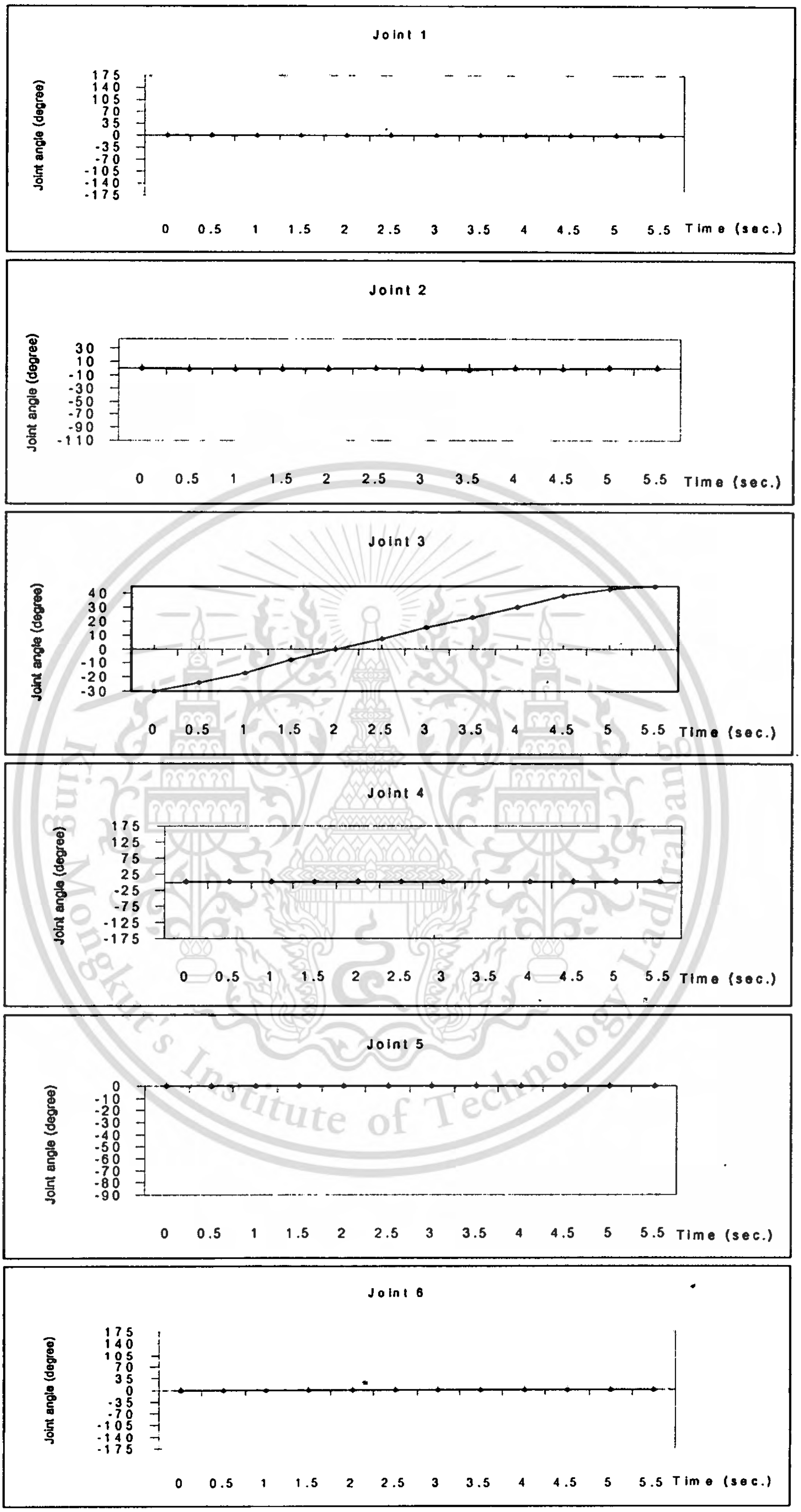


Figure 5.11 Joint-interaction testing (command to move joint 3)

Figure 5.11 shows the joint interaction while moving joint 3. Vertical axis indicates joint angle and horizontal axis indicates running time. As moving joint 3, Joint 2 is effected from this motion as shown in third graph of figure 5.11. This effect come from structure of robot. Friction in each joint connection and alignment of parallel link between joint 3 and joint 2.

For tested joints, joint 1, 4, 5 and 6 not effect to the other joints while they are moving. Their experimental results are illustrated in appendix C.

5.5 Joint response

5.5.1 Testing method

This section is devoted for joint response testing. Testing is done by record the joint revolution. Robot's gripper is commanded to move from point (0, 560, 642), which is the home position of robot, to target point (-191, 162, 572). While moving, angle changing are record in each sampling time. Sampling time for keeping data is 0.01 second. The data is shown in the comparison graph between position of angle and time in each controlled system. These controlled system are open loop control, feedback control and feedback with feed forward control.

As the required target point (-191, 162, 572), the inverse kinematics solution for revolution in each joint are joint1 at +90 degrees, joint2 at +45 degrees, joint3 at –45 degrees, joint4 at –90 degrees, joint5 at –90 degrees and joint6 at +45 degrees.

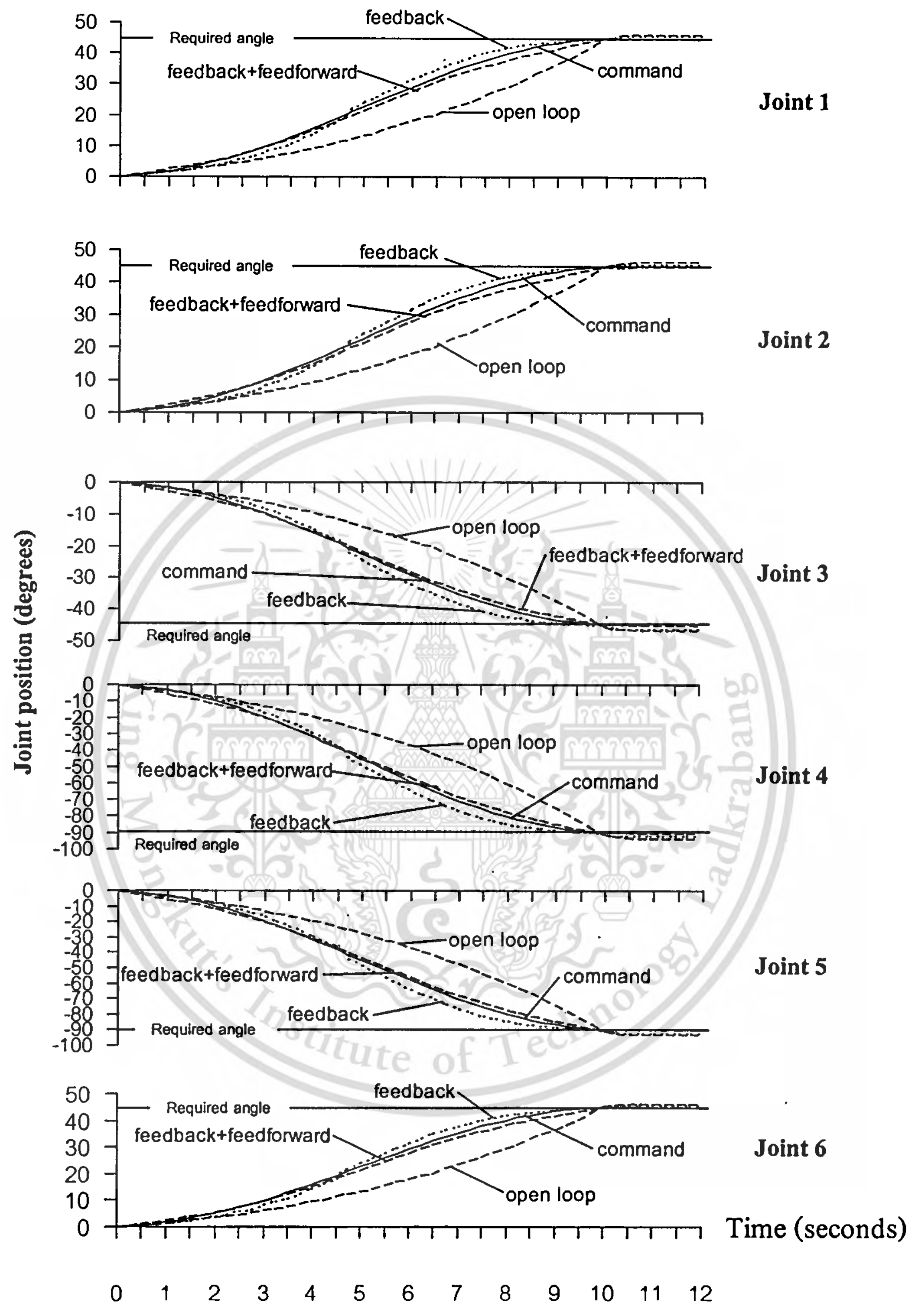


Figure 5.12 Joint response

Figure 5.12 shows the joint response graph. This graph shows response in each joint ,which compares the response in each controlled system. Controlled system includes open loop control, feedback control and feedback with feedforward controlled system. These graph is operate under value of K*f* (feedforward gain) equal to 10, while value of K*p* (proportional gain) equal to 5.

From testing, found that feedback with feedforward controlled system can control robot to track nearly required angle. While alone open loop or feedback controlled system can not track as required angle. The feedback with feedforward can control robot to the target, but alone open loop or feedback controlled system cannot control robot to the target. Error come from these controlled system. Graphs show the error, which produce from open loop and feedback control system. Error in open loop controlled system is higher than feedback controlled system. Error in feedback with feedforward controlled system is smallest.

CHAPTER 6

CONCLUSIONS

6.1 Introduction

The previous chapters introduced literature review of robot, kinematics of robot, robot control system, methodology, experimentation and testing. This chapter is the final unit, which summarize the result of overall in this research. Furthermore the ways to improve in the future are suggested in this chapter.

6.2 Conclusions

This thesis presents the principle of 6-axes robot designation and controlled system. The 6-axes robot is designed and built by lightweight material. Robot structure is combined from parallel and serial links. Stepper motors are used as the power source in each joint. Worm gear set is used for power transmission system in each joint of robot. Controlled program is objected to develop for point-to-point motions (PTP). User can manually enter required end-effector position values in XYZ coordinate system. Dialog box can control robot's movement, graphic program and keyboard, which based on the position control by the feedback with feed-forward control system. Visual Basic program is used to be the source code controlled and user interfaced programming. Encoders are selected to be the position feedback equipment for sending the present status signal to the controlled system. Controller is built for support both point-to-point control and path control. This controller includes data transmission circuit (I^2C to parallel transmission), analog to digital converter (ADC), digital to analog converter (DAC) and stepper motor driving board.

In side of controlled system, Inertia is always changed as robot move. So it is difficult to control with it. So in this thesis, inertia is not considered in controlled system because the motion is slow movement. Feedforward control system is applied to solve this problem. Input dynamic compensation is employed as the feedforward part of control system. It is used in conjunction with an inner loop feedback compensator in order to improve the dynamical behavior of a system.

From the testing, Error from alone open loop control system is more than feedback control system. Increasing value of K*f* (feedforward gain) and appropriated K*p* (proportional gain) can reduce error. But high values of K*p* can make system unstable. In this thesis, appropriate value for K*f* is 10 and K*p* is 5.

Some error came from the robot structure. Because of designation of robot structure is parallel and serial links. Most error came from these parallel links. This error can be avoided by design with serial links. High accuracy can be achieved using a heavy rigid structure, which is in contradiction to light and flexible structure as designed.

The resolutions of feedback equipment are only 8 bites. Higher resolution should be applied for increasing efficiency.

This thesis is completed with building of a 6-axes robot and controlled system. The robot can be the laboratory demonstration manipulator or the works that accept its specification. In additional, the objectives can be achieved as described. The success is the beginning point of local-designation, which can reduce cost of expenditure in investment. And more, know-how can be obtained from this research and it can be developed for the advance technology.

REFERENCES

[1] K.C. Jain, L.N. Aggarwal. **Robotics Principles and practice.** Delhi, India : Afif Printers, 1997.

[2] K.S. Fu, R.C. Gonzalez. **Robotics, control, sensing, vision and intelligence.** Singapore : McGraw-Hill publishing, 1986.

[3] William A. Wolovich. **Robotics: Basic Analysis and Design.** New York : CBS college publishing, 1987.

[4] Coiffet. **Motor analysis and control.** New Jersy : Prentice Hall, 1984.

[5] Joseph E. Shigley and Charles R. Mischke. **Standard handbook of machine design.** New York : McGraw-Hill, 1986.

[6] Lung-Wen Tsai. **Robot analysis, the mechanics of serial and parallel manipulators.** New York : John Wiley&Son, Inc. 1991.

[7] Tim Smithers. "Robot Control and Programming." [Online]. Available : http://www.modernrobot.com/search/tema7_trajec.pdf. 2001.

[8] Gritsada J. and Chaiwat L. **PC-Parallel port Interfacing text-lab manual.** Bangkok : Innovative Experiment Co.,Ltd. 2000.

[9] John G. Bollinger, Neil A. Duffie. **Computor control of machines and processes.** Reading : Addison-Wesley publishing Company, Inc. 1988.

[10] Sermsiri Chareonkid and Anan Kongyoo. "Industrial Robot." B.Eng. (industrial) dissertation, Faculty of engineering, Burapha University. 1998. (In Thai).

[11] Compton. **Understanding robot.** USA Alfred publishing Co.,Ltd. 1983.

[12] Hockwood S and Beni. G. **Recent advances in Robotics.** New York : John Wiley and sons, 1985.

[13] Liptak K. **Robotics basic.** New Jersy : Prentice Hall, 1984.

[14] Philips. **Remote 8-bit I/O expander for I^2C bus.** New York : Philips Semiconductor, 1997.

[15] Takase K 1979. "Skill of intelligent Robot." Pp. 1095-1100. In Proc. 6 th Int. Conf. Art Intell. Tokyo.

APPENDIX A

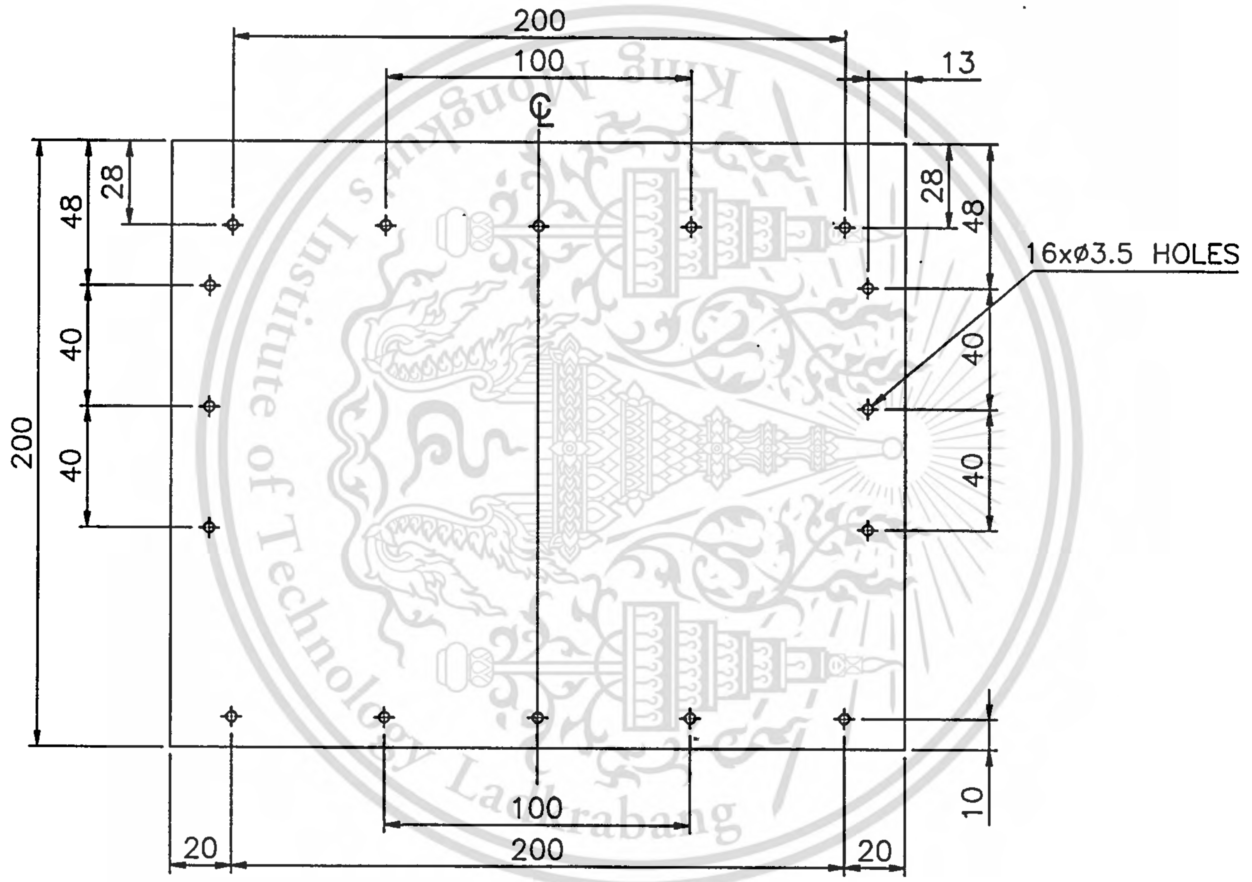
Drawings of a 6-axes robot

(REVISION)

DWG.STATUS { STANDARD ..... 0 PRE-STANDARD ..... 1 TEMPORARY 2

DWG.NO.	BA001D001	13 *	14 0	COMPONENT PART NO.			DEF { MFR : MAKE FROM WRK : WORK INSTRUCTION	DWG : DRAWING REF : REFERANCE								CHG.CODE 15 16	ITEM	CARD NO 2	REQD PER SET
CHG.CODE 15 16	ITEM	CARD NO. 0	DESCRIPTION	DEF	MATERIAL CODE	G.NO.	L.NO	CARD NO 1	QUANTITY	MATERIAL CODE	LENGTH	UNIT	CUT	PUR	FINISH PAINT	FINISH OTHER	HT TR				
	-01		SIDE PLATE (L)						200X240–ALUMINUM A6063S–T5 t5.0												

CHG.CODE A.Add D.Delete E.Change



STD.	TOLERANCE EXCEPT ENTRY IN DWG.		
PSTD.	PLASTIC	14	
	WORK		GRADE
TEM.	CUTTING(S-1001)	MIDLE	ROUGH
	CASTING(S-1131)	GOOD	NORMAL
	PRESS(S-1251)	GOOD	[✓ NORMAL]

*	CHANGE		

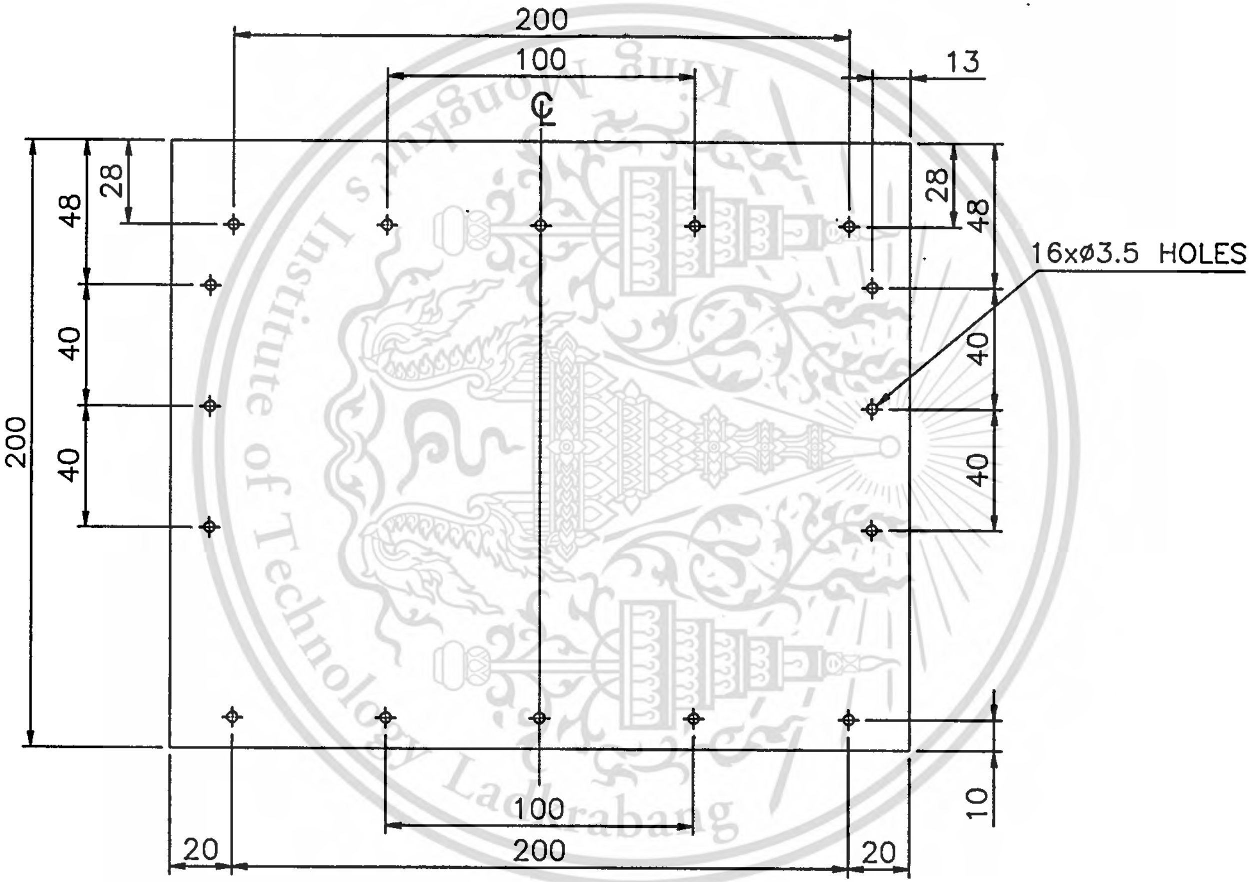
	KING MONGKUT'S INSTITUTE OF TECHNOLOGY LADKRABANG			
DIM.IN mm	DATE	05/01/2002	APPROVED KMITL JAN.26.2002 T. TAWEE	
SCALE	DRAWN	ANAN K.		
: NTS	CHECKED	TAWEE T.		
	DESIGNED	ANAN K.		

APPAR 6-AXES ROBOT	ITEM BASEMENT
TITLE SIDE PLATE (L)	
BA001D001	

(REVISION) 13 — DWG.STATUS { STANDARD ..... 0 / PRE-STANDARD ..... 1 } TEMPORARY 2

E.Change D.Delete A.Add CHG.CODE

DWG.NO.	BA001D002	*	0	COMPONENT PART NO.				DEF { MFR : MAKE FROM WRK : WORK INSTRUCTION	DWG : DRAWING REF : REFERANCE											
CHG.CODE 15 16	ITEM	CARD NO. 0	DESCRIPTION	DEF	MATERIAL CODE	G.NO.	L.NO	CARD NO. 1	QUANTITY	MATERIAL CODE	LENGTH	UNIT	CUT	PUR	FINISH PAINT	FINISH OTHER	HT TR	CHG.CODE 15 16	ITEM	CARD NO. 2	REQD PER SET
	-01		SIDE PLATE (R)						200X240-ALUMINUM A6063S-T5 t5.0											-



STD.	TOLERANCE EXCEPT ENTRY IN DWG.	
PSTD.	PLASTIC	14
	WORK	GRADE
TEM.	CUTTING(S-1001)	MIDLE | ROUGH
	CASTING(S-1131)	GOOD | NORMAL
	PRESS(S-1251)	GOOD | [✓ NORMAL]

CHANGE	*			

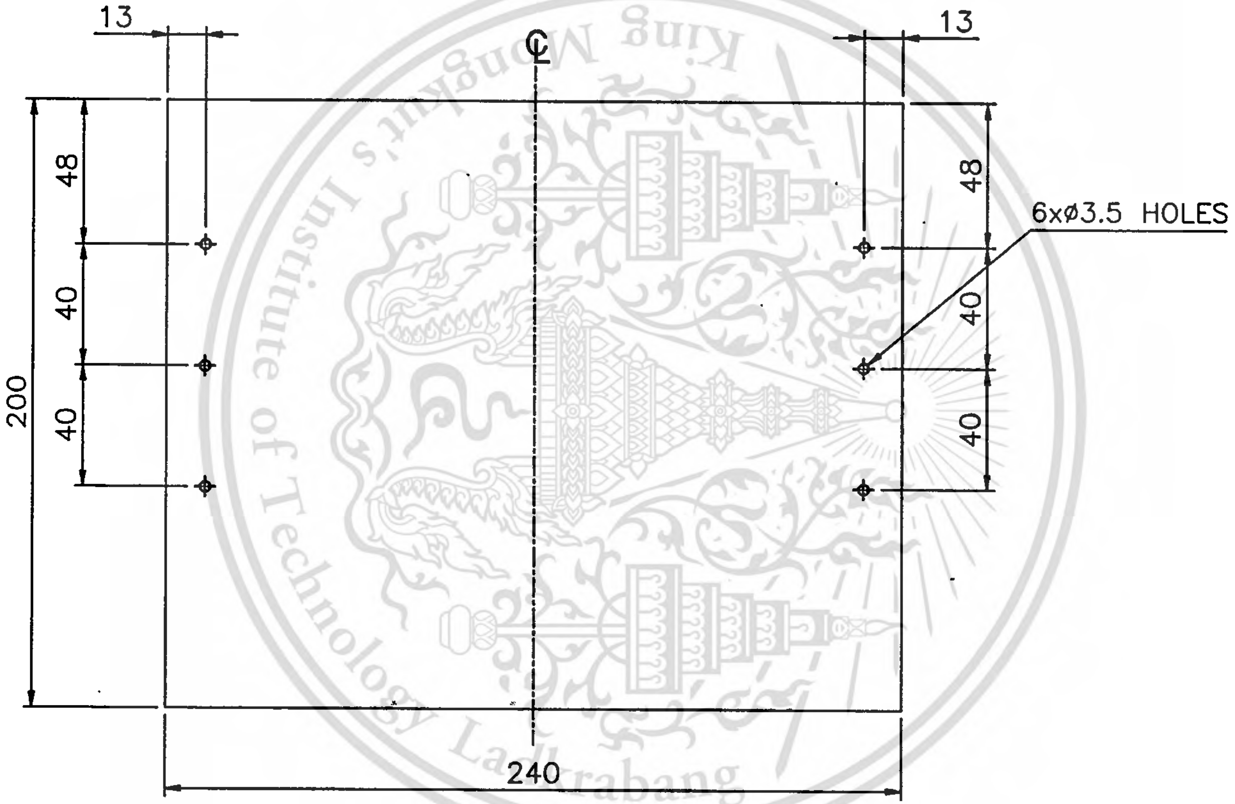
	KING MONGKUT'S INSTITUTE OF TECHNOLOGY LADKRABANG		APPAR 6-AXES ROBOT	ITEM BASEMENT
DIM.IN mm	DATE	05/01/2002	APPROVED KMITL JAN.26.2002 T. TAWEE	TITLE SIDE PLATE (R)
SCALE	DRAWN	ANAN K.		BA001D002
: NTS	CHECKED	TAWEE T.		
	DESIGNED	ANAN K.		

(REVISION) DWG.STATUS { STANDARD ..... 0 / PRE-STANDARD ..... 1 / TEMPORARY 2

CHG.CODE A.Add D.Delete E.Change

DWG.NO.	BA001D003	13 *	14 0	COMPONENT PART NO.	DEF { MFR : MAKE FROM / WRK : WORK INSTRUCTION	DWG : DRAWING / REF : REFERANCE

CHG.CODE 15	ITEM 16	CARD NO 0	DESCRIPTION	DEF	MATERIAL CODE	G.NO.	L.NO	CARD NO 1	QUANTITY	MATERIAL CODE	LENGTH	UNIT	CUT	PUR	FINISH PAINT	FINISH OTHER	HT TR	CHG.CODE 15	ITEM 16	CARD NO 2	REQD PER SET
	-01		SIDE PLATE (FRONT)						200X240-ALUMINUM A6063S-T5 t5.0												



STD.	TOLERANCE EXCEPT ENTRY IN DWG.		
	PLASTIC	14	
PSTD.	WORK	GRADE	
TEM.	CUTTING(S-1001)	MIDLE	ROUGH
	CASTING(S-1131)	GOOD	NORMAL
	PRESS(S-1251)	GOOD	[✓ NORMAL]

CHANGE	*

KING MONGKUT'S INSTITUTE OF TECHNOLOGY LADKRABANG		
DIM.IN mm	DATE	05/01/2002
SCALE	DRAWN	ANAN K.
: NTS	CHECKED	TAWEE T.
	DESIGNED	ANAN K.

APPROVED KMITL JAN.26.2002 T. TAWEE

APPAR	ITEM
6-AXES ROBOT	BASEMENT

TITLE

SIDE PLATE (FRONT)

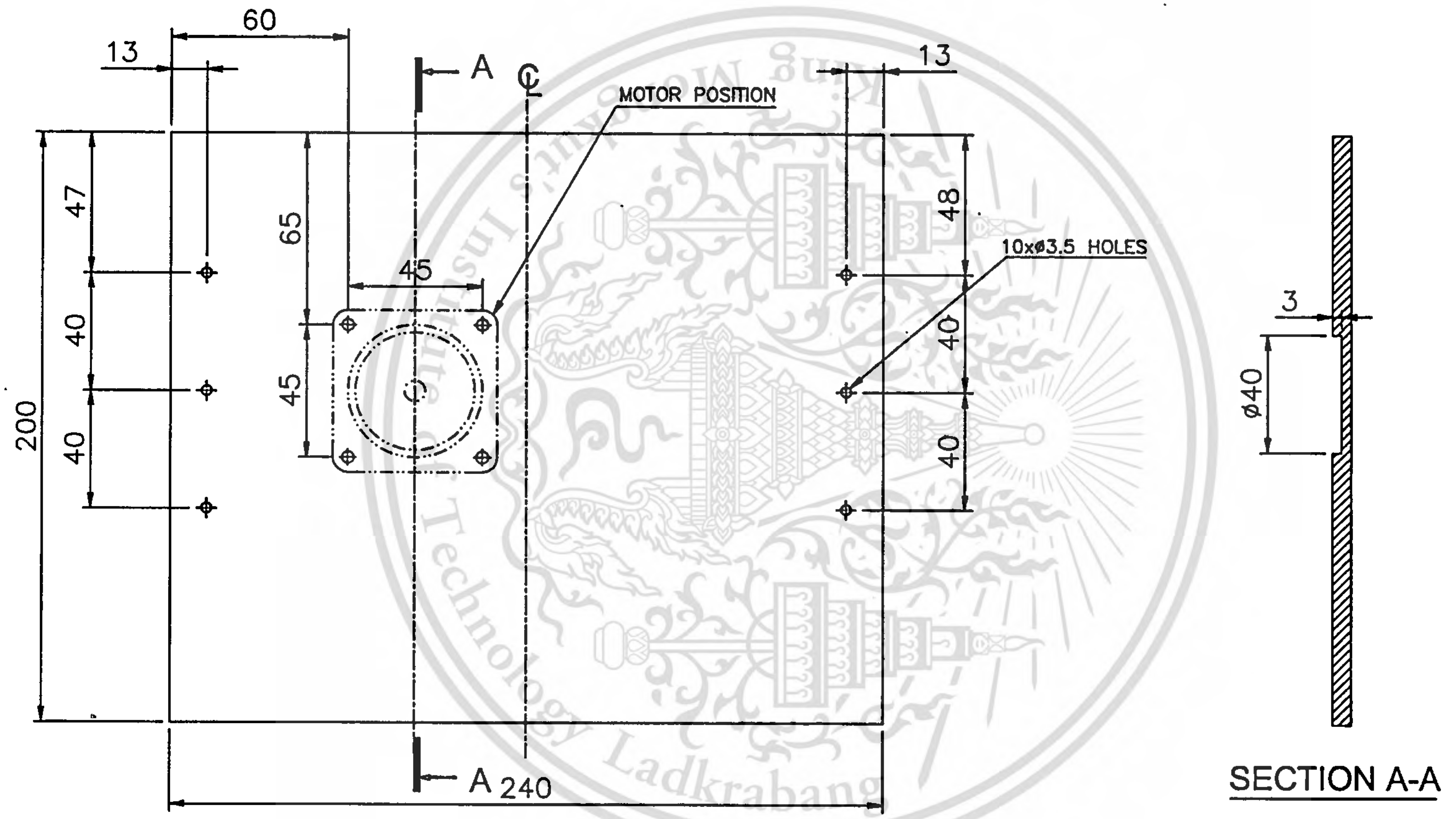
BA001D003

(REVISION)

DWG.STATUS { STANDARD ..... 0 / PRE-STANDARD ..... 1 / TEMPORARY 2

DEF { MFR : MAKE FROM / WRK : WORK INSTRUCTION DWG : DRAWING / REF : REFERANCE

DWG.NO.	BA001D004	*	0	COMPONENT PART NO.												
CHG.CODE	ITEM	CARD NO 0	DESCRIPTION	DEF	MATERIAL CODE	G.NO.	L.NO	CARD NO 1	QUANTITY / MATERIAL CODE / LENGTH	UNIT	CUT	PUR	FINISH PAINT	FINISH OTHER	HT TR	CHG.CODE / ITEM / CARD NO 2 / REQD PER SET
	-01		SIDE PLATE (BACK)						200X240-ALUMINUM A6063S-T5 t5.0							



SECTION A-A

STD.	TOLERANCE EXCEPT ENTRY IN DWG.	
	PLASTIC	14
PSTD.	WORK	GRADE
TEM.	CUTTING(S-1001)	MIDLE / ROUGH
	CASTING(S-1131)	GOOD / NORMAL
	PRESS(S-1251)	GOOD / [✓ NORMAL]

KING MONGKUT'S INSTITUTE OF TECHNOLOGY
LADKRABANG

DIM.IN mm	DATE	05/01/2002	APPROVED
SCALE	DRAWN	ANAN K.	KMITL JAN.26.2002 T. TAWEE
: NTS	CHECKED	TAWEE T.	
	DESIGNED	ANAN K.	

APPAR 6-AXES ROBOT
ITEM BASEMENT
TITLE SIDE PLATE (BACK)

BA001D004

CHANGE *

CHG.CODE A.Add D.Delete E.Change

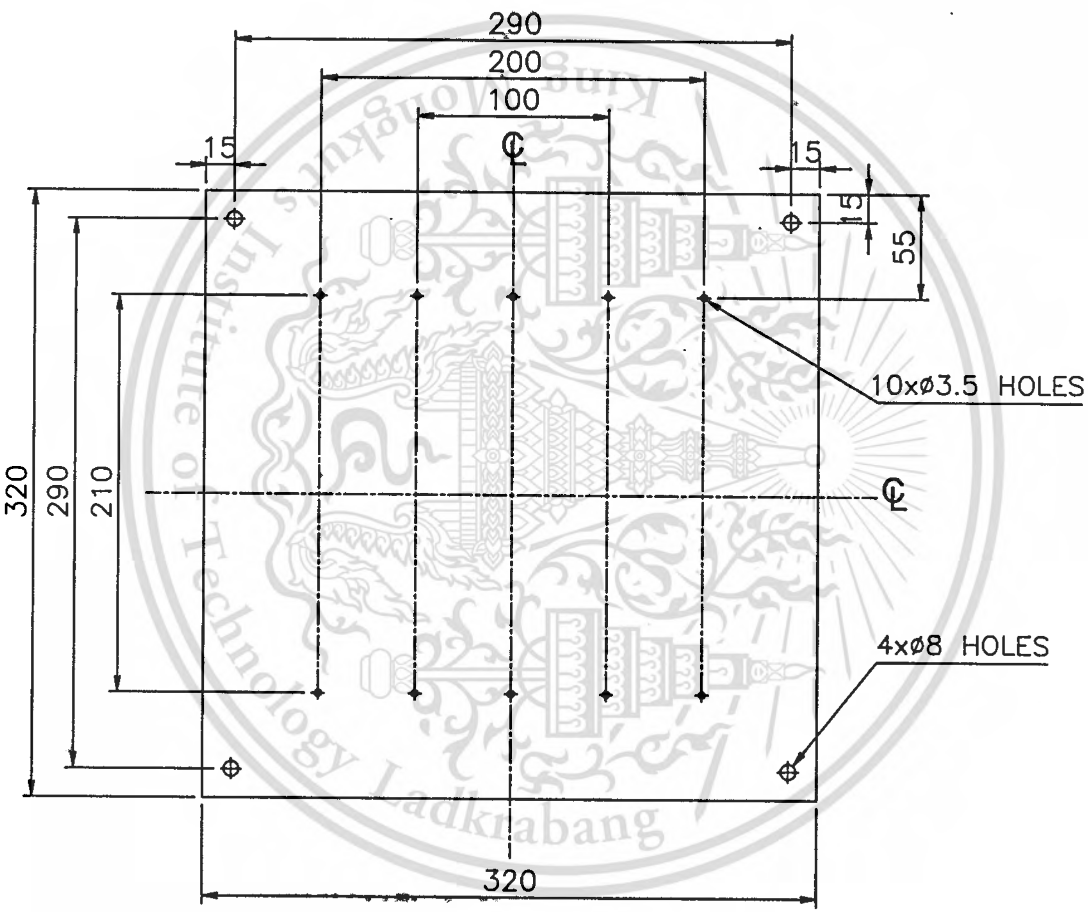
(REVISION) 13 *

DWG.STATUS { STANDARD ..... 0 PRE-STANDARD ..... 1 TEMPORARY 2

DEF { MFR : MAKE FROM WRK : WORK INSTRUCTION DWG : DRAWING REF : REFERANCE

DWG.NO.	BA001D005	14 0	COMPONENT PART NO.			
CHG.CODE 15 / ITEM 16 / CARD NO. 0	DESCRIPTION	DEF	MATERIAL CODE	G.NO.	L.NO	CARD NO. 1
-01	BASE PLATE					

QUANTITY	MATERIAL CODE	LENGTH	UNIT	CUT	PUR	FINISH PAINT	FINISH OTHER	HT TR	CHG.CODE 15	ITEM 16	CARD NO. 2	REQD PER SET
320X320-SPCC t10.0						D44						



STD.	TOLERANCE EXCEPT ENTRY IN DWG.	
PSTD.	PLASTIC	14
	WORK	GRADE
TEM.	CUTTING(S-1001)	MIDLE / ROUGH
	CASTING(S-1131)	GOOD / NORMAL
	PRESS(S-1251)	GOOD / [✓ NORMAL]

CHANGE *

KING MONGKUT'S INSTITUTE OF TECHNOLOGY
LADKRABANG

DIM.IN mm	DATE	05/01/2002
SCALE	DRAWN	ANAN K.
: NTS	CHECKED	TAWEE T.
	DESIGNED	ANAN K.

APPROVED KMITL JAN.26.2002 T. TAWEE

APPAR 6-AXES ROBOT
ITEM BASEMENT

TITLE
BASE PLATE

BA001D005

CHG.CODE A.Add D.Delete E.Change

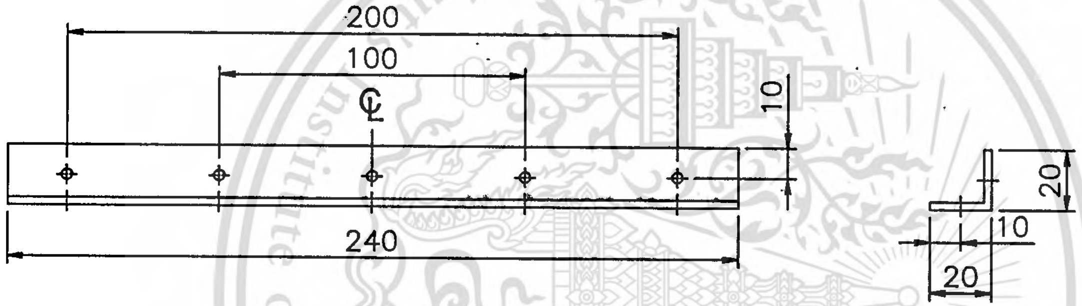
CHG.CODE
A.Add D.Delete E.Change

(REVISION) DWG.STATUS { STANDARD ..... 0 PRE-STANDARD ..... 1 TEMPORARY 2

DWG.NO. BA001D006 | 13 * | 14 0 | COMPONENT PART NO.

DEF { MFR : MAKE FROM DWG : DRAWING
WRK : WORK INSTRUCTION REF : REFERANCE

CHG.CODE 15 16	ITEM	CARD NO. 0	DESCRIPTION	DEF	MATERIAL CODE	G.NO.	L.NO	CARD NO 1	QUANTITY	MATERIAL CODE	LENGTH	UNIT	CUT	PUR	FINISH PAINT	FINISH OTHER	HT TR	CHG.CODE 15 16	ITEM	CARD NO. 2	REQD PER SET
	-01		BRACKET (HORIZONTAL)						240-L-BAR ALUMINUM A6063S-T5 t5.0												



CHG.CODE 15 16	GROUP	DESCRIPTION	FINISH PAINT ALL FACES	FINISH PAINT BACK FACES	HT TR	OTHERS

	TOLERANCE EXCEPT ENTRY IN DWG.	
STD.	PLASTIC	14
PSTD.	WORK	GRADE
TEM.	CUTTING(S-1001)	MIDLE	ROUGH
	CASTING(S-1131)	GOOD	NORMAL
	PRESS(S-1251)	GOOD	[✓ NORMAL]

KING MONGKUT'S INSTITUTE OF TECHNOLOGY
LADKRABANG

APPAR 6-AXES ROBOT
ITEM BASEMENT
TITLE BRACKET (HORIZONTAL)

DIM.IN mm	DATE	05/01/2002	APPROVED
SCALE	DRAWN	ANAN K.	
: NTS	CHECKED	TAWEE T.	
	DESIGNED	ANAN K.	

APPROVED KMITL JAN.26.2002 T. TAWEE

BA001D006

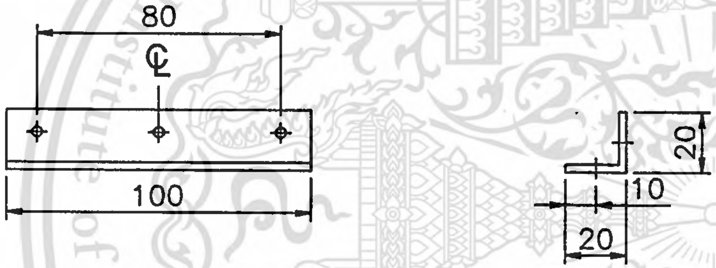
CHANGE *

(REVISION) DWG.STATUS { STANDARD ..... 0 PRE-STANDARD ..... 1 TEMPORARY 2

CHG.CODE A.Add D.Delete E.Change

DEF { MFR : MAKE FROM WRK : WORK INSTRUCTION DWG : DRAWING REF : REFERANCE

DWG.NO.	BA001D007	*	0	COMPONENT PART NO.												
ITEM	DESCRIPTION	DEF	MATERIAL CODE	G.NO.	L.NO	QUANTITY	MATERIAL CODE	LENGTH	UNIT	CUT	PUR	FINISH PAINT	FINISH OTHER	HT TR	ITEM	REQD PER SET
-01	BRACKET (VERTICAL)					240-L-BAR ALUMINUM A6063S-T5 t5.0										



CHG.CODE	GROUP	DESCRIPTION	PAINT ALL FACES	PAINT BACK FACES	HT TR	OTHERS

STD.	TOLERANCE EXCEPT ENTRY IN DWG.	
	PLASTIC	14
PSTD.	WORK	GRADE
TEM.	CUTTING(S-1001)	MIDLE / ROUGH
	CASTING(S-1131)	GOOD / NORMAL
	PRESS(S-1251)	GOOD / NORMAL

KING MONGKUT'S INSTITUTE OF TECHNOLOGY
LADKRABANG

DIM.IN mm	DATE	05/01/2002
SCALE	DRAWN	ANAN K.
: NTS	CHECKED	TAWEE T.
	DESIGNED	ANAN K.

APPROVED KMITL JAN.26.2002 T. TAWEE

APPAR 6-AXES ROBOT

ITEM BASEMENT

TITLE BRACKET (VERTICAL)

BA001D007

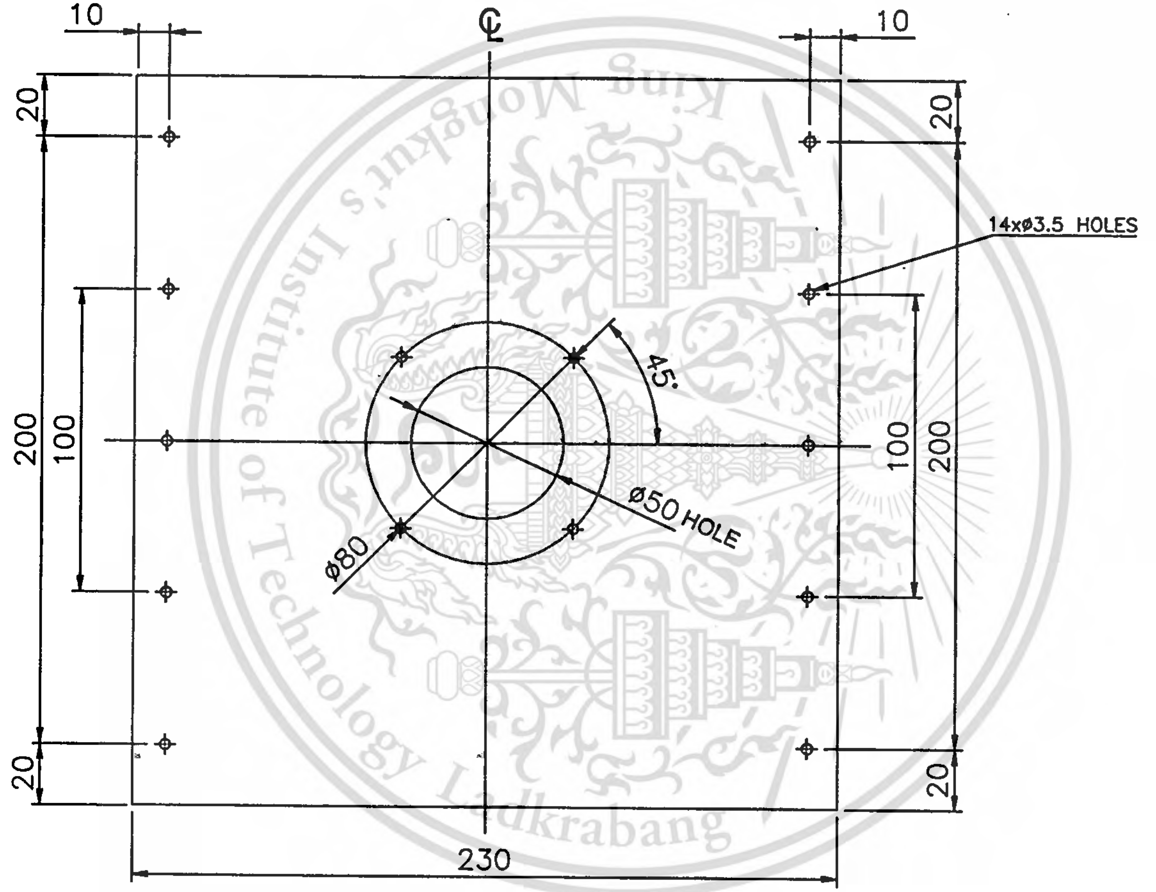
CHANGE *

(REVISION) DWG.STATUS { STANDARD ..... 0 PRE-STANDARD ..... 1 TEMPORARY 2

DWG.NO. BA001D009 * 0

DEF { MFR : MAKE FROM WRK : WORK INSTRUCTION DWG : DRAWING REF : REFERANCE

CHG.CODE	ITEM	CARD NO 0	DESCRIPTION	DEF	MATERIAL CODE	G.NO.	L.NO	CARD NO 1	QUANTITY	MATERIAL CODE	LENGTH	UNIT	CUT	PUR	FINISH PAINT	FINISH OTHER	HT TR	CHG.CODE	ITEM	CARD NO 2	REQD PER SET
	-01		SUPPORT FLANGE (U)						230X240–ALUMINUM A6063S–T5 t5.0												



STD.	TOLERANCE EXCEPT ENTRY IN DWG.	
	PLASTIC	14
PSTD.	WORK	GRADE
TEM.	CUTTING(S-1001)	MIDLE · ROUGH
	CASTING(S-1131)	GOOD · NORMAL
	PRESS(S-1251)	GOOD · [✓ NORMAL]

CHANGE *

KING MONGKUT'S INSTITUTE OF TECHNOLOGY
LADKRABANG

DIM.IN mm	DATE	05/01/2002	APPROVED
SCALE	DRAWN	ANAN K.	
: NTS	CHECKED	TAWEE T.	
	DESIGNED	ANAN K.	

KMITL
JAN.26.2002
T. TAWEE

APPAR 6-AXES ROBOT
ITEM BASEMENT
TITLE SUPPORT FLANGE(U)

BA001D009

(REVISION)

DWG.STATUS { STANDARD ..... 0 / PRE-STANDARD ..... 1 / TEMPORARY 2

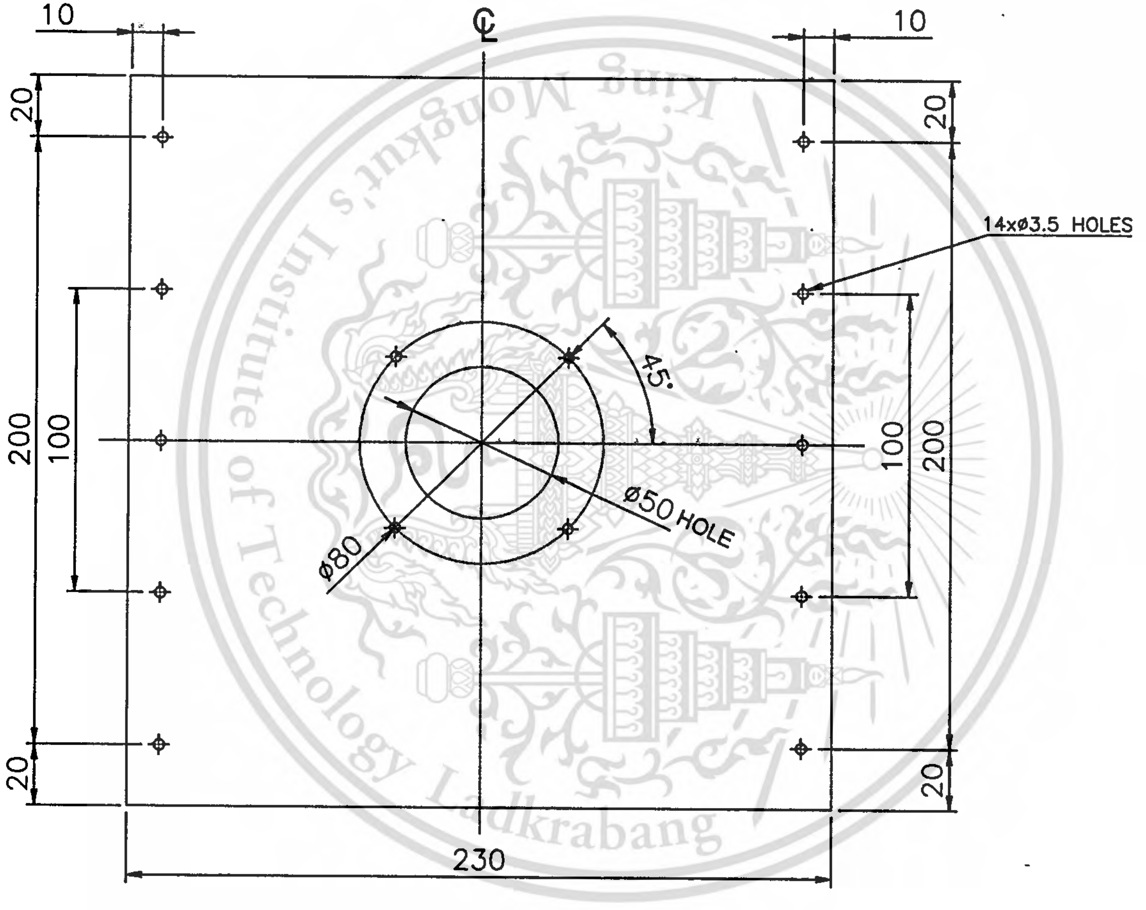
DWG.NO. BA001D010 | 13 * | 14 0

DEF { MFR : MAKE FROM / WRK : WORK INSTRUCTION } DWG : DRAWING / REF : REFERANCE

CHG.CODE 15	ITEM 16	CARD NO 0	DESCRIPTION	DEF	COMPONENT PART NO.: MATERIAL CODE	G.NO.	L.NO	CARD NO 1	QUANTITY	MATERIAL CODE	LENGTH	UNIT	CUT	PUR	FINISH: PAINT	FINISH: OTHER	HT TR
	-01		SUPPORT FLANGE (L)						230X240-ALUMINUM A6063S-T5 t5.0								

CHG.CODE 15	ITEM 16	CARD NO 2	REQD PER SET

CHG.CODE A.Add D.Delete E.Change



STD.	TOLERANCE EXCEPT ENTRY IN DWG.	
	PLASTIC	14
PSTD.	WORK	GRADE
TEM.	CUTTING(S-1001)	MIDLE ROUGH
	CASTING(S-1131)	GOOD NORMAL
	PRESS(S-1251)	GOOD [✓ NORMAL]

CHANGE *

KING MONGKUT'S INSTITUTE OF TECHNOLOGY
LADKRABANG

DIM.IN mm	DATE	05/01/2002	APPROVED KMITL JAN.26.2002 T. TAWEE
SCALE	DRAWN	ANAN K.	
: NTS	CHECKED	TAWEE T.	
	DESIGNED	ANAN K.	

APPAR 6-AXES ROBOT
ITEM BASEMENT

TITLE SUPPORT FLANGE(L)

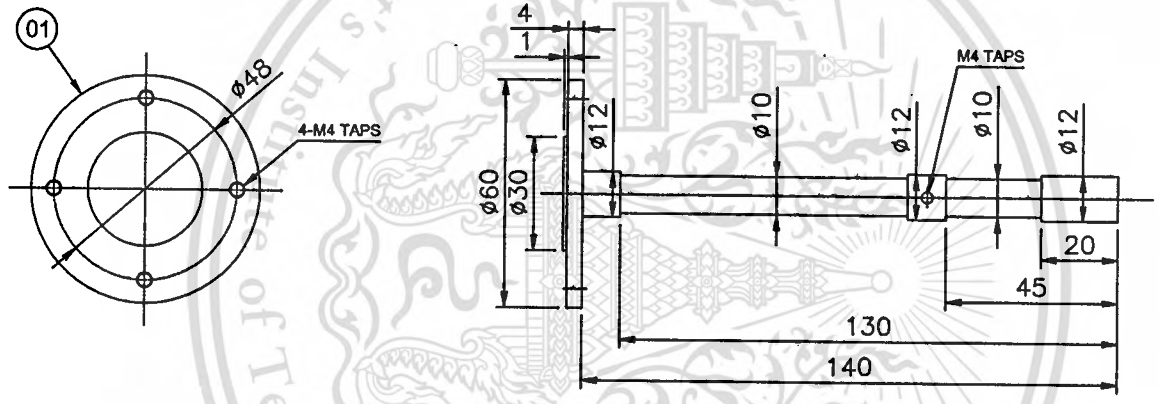
BA001D010

(REVISION) DWG.STATUS { STANDARD ..... 0 PRE-STANDARD ..... 1 TEMPORARY 2

DEF { MFR : MAKE FROM WRK : WORK INSTRUCTION DWG : DRAWING REF : REFERANCE

DWG.NO.	BA001D011	*	0	COMPONENT PART NO.											
ITEM	DESCRIPTION	DEF	MATERIAL CODE	G.NO.	L.NO	QUANTITY	MATERIAL CODE	LENGTH	UNIT	CUT	PUR	FINISH PAINT	FINISH OTHER	HT TR	ITEM / REQD PER SET
-01	SWIVEL SHAFT						ø60x140-SPCC								

CHG.CODE A.Add D.Delete E.Change



CHG.CODE	GROUP	DESCRIPTION	PAINT ALL FACES	PAINT BACK FACES	HT TR	OTHERS
			FINISH	FINISH		

STD.	TOLERANCE EXCEPT ENTRY IN DWG.		
PSTD.	PLASTIC	14	
TEM.	WORK	GRADE	
	CUTTING(S-1001)	MIDLE	ROUGH
	CASTING(S-1131)	GOOD	NORMAL
	PRESS(S-1251)	GOOD	[✓ NORMAL]

KING MONGKUT'S INSTITUTE OF TECHNOLOGY
LADKRABANG

DIM.IN mm	DATE	05/01/2002
SCALE	DRAWN	ANAN K.
: NTS	CHECKED	TAWEE T.
	DESIGNED	ANAN K.

APPROVED KMITL JAN.26.2002 T. TAWEE

APPAR 6-AXES ROBOT
ITEM BASEMENT
TITLE SWIVEL SHAFT

BA001D011

CHANGE *

(REVISION)

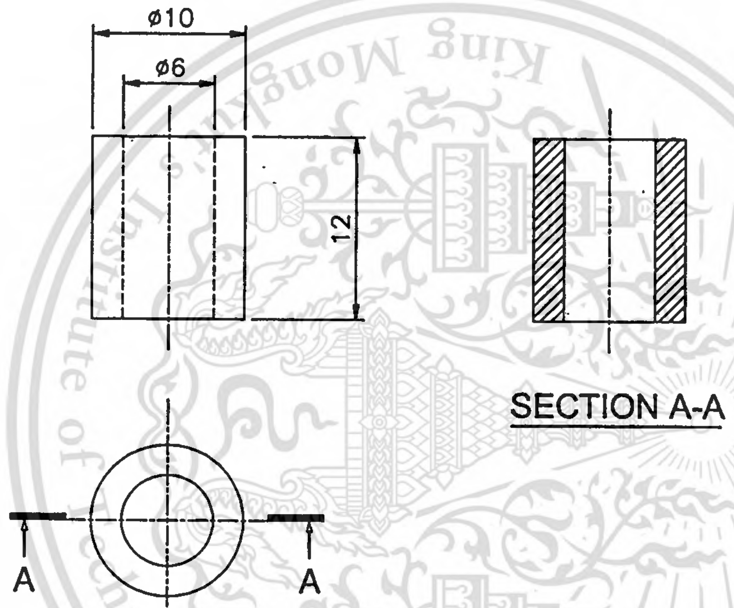
DWG.STATUS { STANDARD ..... 0 / PRE-STANDARD ..... 1 / TEMPORARY 2

CHG.CODE: A.Add D.Delete E.Change

DWG.NO. BA001D012 * 0

DEF { MFR : MAKE FROM / WRK : WORK INSTRUCTION } DWG : DRAWING / REF : REFERANCE

CHG.CODE	ITEM	CARD NO 0 DESCRIPTION	DEF	COMPONENT PART NO. MATERIAL CODE	G.NO.	L.NO	CARD NO 1 QUANTITY	MATERIAL CODE	LENGTH	UNIT	CUT	PUR	FINISH PAINT	FINISH OTHER	HT TR	CHG.CODE	ITEM	CARD NO 2 REQD PER SET
	-01	ROTATE PLATE SUPPORT					ø10X12–ALUMINUM A6063S–T5											



CHG.CODE	GROUP	DESCRIPTION	PAINT ALL FACES	PAINT BACK FACES	HT TR	OTHERS
			FINISH	FINISH		

STD.	TOLERANCE EXCEPT ENTRY IN DWG.	
	PLASTIC	14
PSTD.	WORK	GRADE
TEM.	CUTTING(S–1001)	MIDLE / ROUGH
	CASTING(S–1131)	GOOD / NORMAL
	PRESS(S–1251)	GOOD / NORMAL

CHANGE *

KING MONGKUT'S INSTITUTE OF TECHNOLOGY
LADKRABANG

DIM.IN mm	DATE	05/01/2002
SCALE	DRAWN	ANAN K.
	CHECKED	TAWEE T.
: NTS	DESIGNED	ANAN K.

APPROVED KMITL JAN.26.2002 T. TAWEE

APPAR 6–AXES ROBOT
ITEM BASEMENT
TITLE ROTATE PLATE SUPPORT

BA001D012

CHG.CODE A.Add D.Delete E.Change

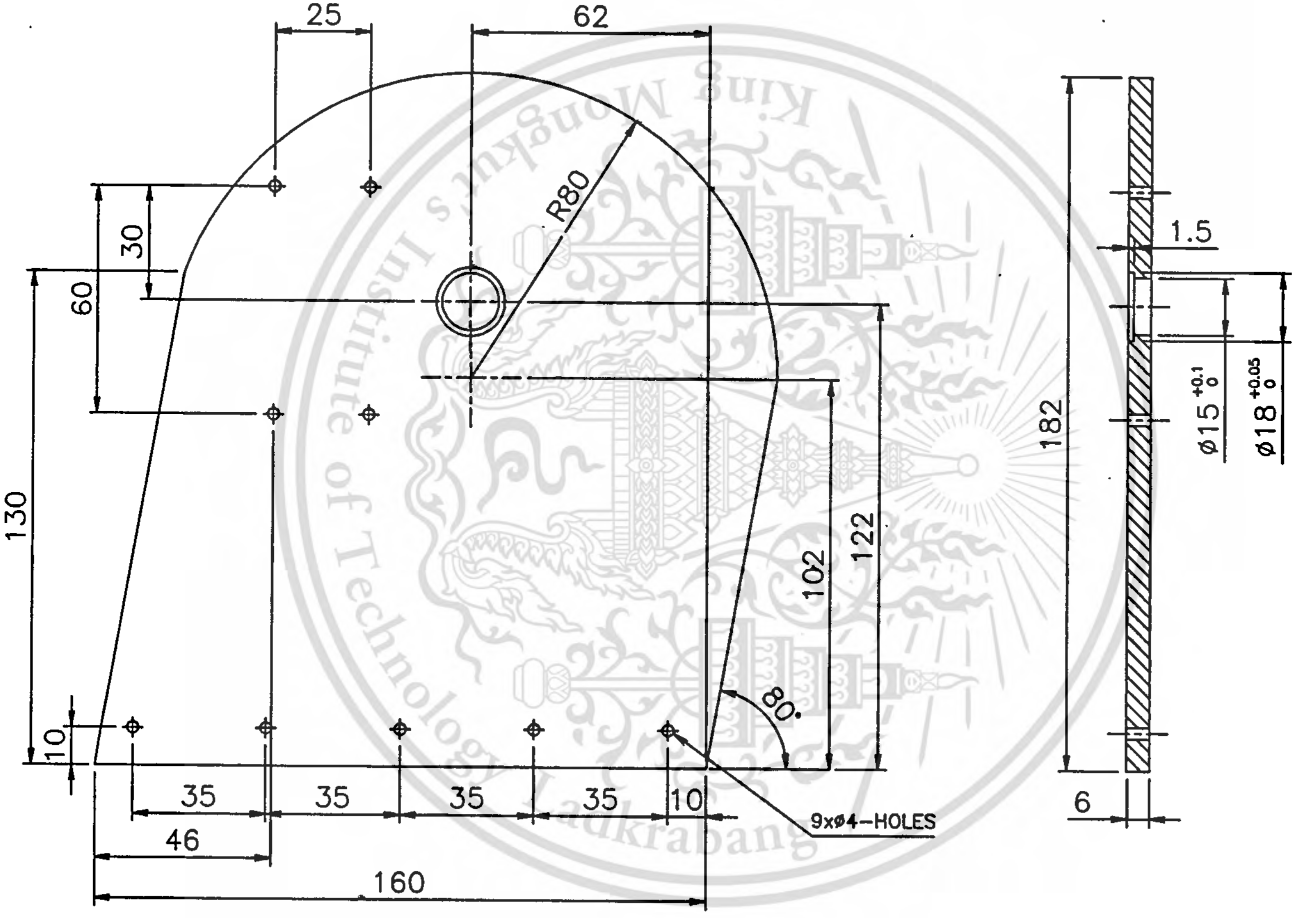
(REVISION)

DWG.STATUS { STANDARD ..... 0 / PRE-STANDARD ..... 1 / TEMPORARY 2

DWG.NO. BA001D014 | 13 * | 14 0 | COMPONENT PART NO.

DEF { MFR : MAKE FROM / WRK : WORK INSTRUCTION   DWG : DRAWING / REF : REFERANCE

CHG.CODE 15	ITEM 16	CARD NO 0	DESCRIPTION	DEF	MATERIAL CODE	G.NO.	L.NO	CARD NO 1	QUANTITY	MATERIAL CODE	LENGTH	UNIT	CUT	PUR	FINISH PAINT	FINISH OTHER	HT TR	CHG.CODE 15	ITEM 16	CARD NO 2	REQD PER SET
	-01		SIDE PLATE (R)						160x182-ALUMINUM A6063S-T5 t5.0												



STD.	TOLERANCE EXCEPT ENTRY IN DWG.	
	PLASTIC	14
PSTD.	WORK	GRADE
	CUTTING(S-1001)	MIDLE / ROUGH
TEM.	CASTING(S-1131)	GOOD / NORMAL
	PRESS(S-1251)	GOOD / [✓ NORMAL]

CHANGE *

KING MONGKUT'S INSTITUTE OF TECHNOLOGY
LADKRABANG

DIM.IN mm	DATE	.05/01/2002	APPROVED
SCALE	DRAWN	ANAN K.	
: NTS	CHECKED	TAWEE T.	
	DESIGNED	ANAN K.	

KMITL JAN.26.2002 T. TAWEE

APPAR 6-AXES ROBOT   ITEM SWIVEL

TITLE

SIDE PLATE (R)

BA001D014

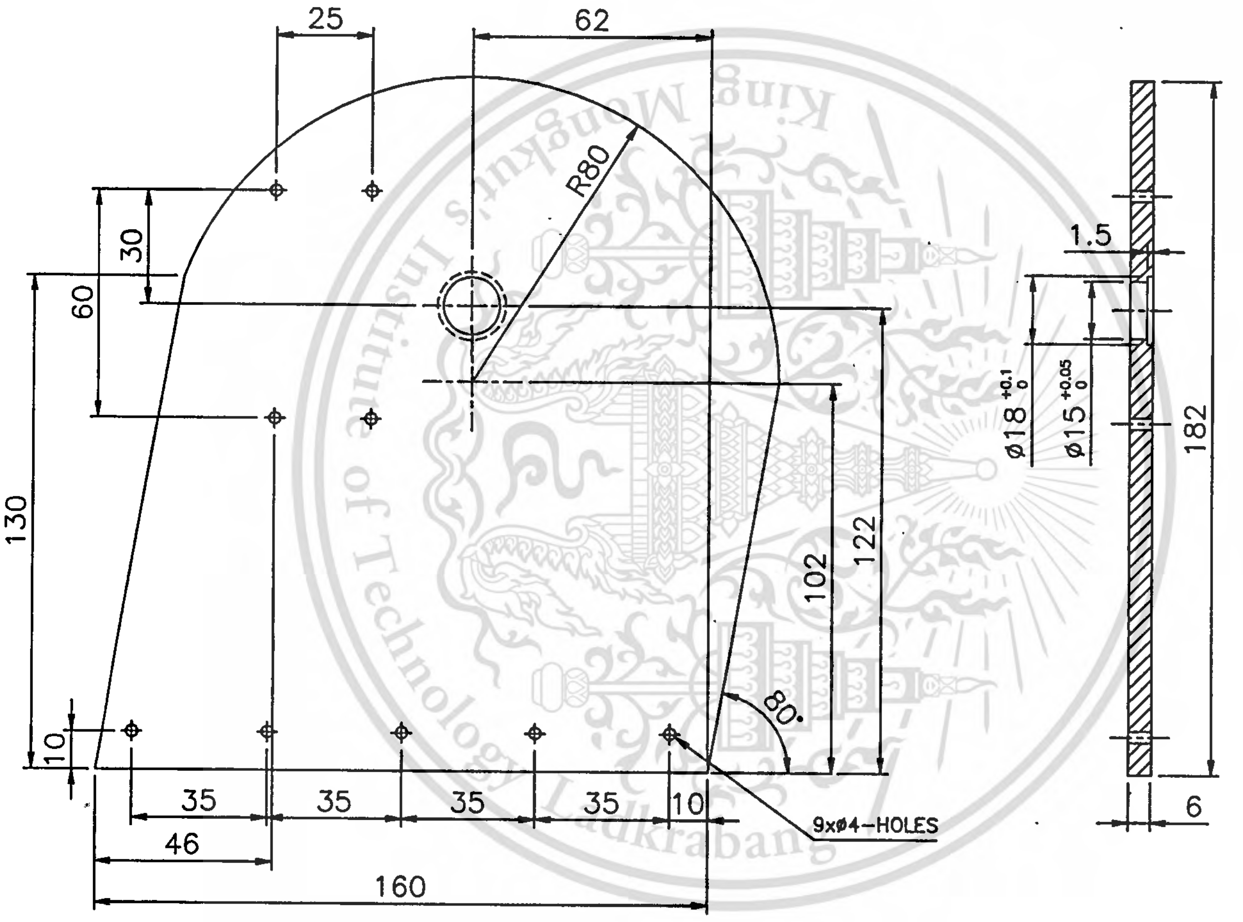
CHG.CODE
A.Add
D.Delete
E.Change

DWG.NO. BA001D015 (REVISION) * DWG.STATUS { STANDARD ..... 0 PRE-STANDARD ..... 1 TEMPORARY ..... 2 } 0

COMPONENT PART NO.

DEF { MFR : MAKE FROM WRK : WORK INSTRUCTION } DWG : DRAWING REF : REFERANCE

CHG.CODE	ITEM	CARD NO 0	DESCRIPTION	DEF	MATERIAL CODE	G.NO.	L.NO	CARD NO 1	QUANTITY	MATERIAL CODE	LENGTH	UNIT	CUT	PUR	FINISH PAINT	FINISH OTHER	HT TR	CHG.CODE	ITEM	CARD NO 2	REQD PER SET
	-01		SIDE PLATE (L)						160x182-ALUMINUM A6063S-T5 t5.0												



STD.	TOLERANCE EXCEPT ENTRY IN DWG.	
	PLASTIC	14
PSTD.	WORK	GRADE
	CUTTING(S-1001) MIDLE	ROUGH
TEM.	CASTING(S-1131) GOOD	NORMAL
	PRESS(S-1251) GOOD	NORMAL

CHANGE *

KING MONGKUT'S INSTITUTE OF TECHNOLOGY
LADKRABANG

DIM.IN mm	DATE	05/01/2002	APPROVED
SCALE	DRAWN	ANAN K.	KMITL JAN.26.2002 T. TAWEE
: NTS	CHECKED	TAWEE T.	
	DESIGNED	ANAN K.	

APPAR 6-AXES ROBOT
ITEM SWIVEL
TITLE
SIDE PLATE (L)

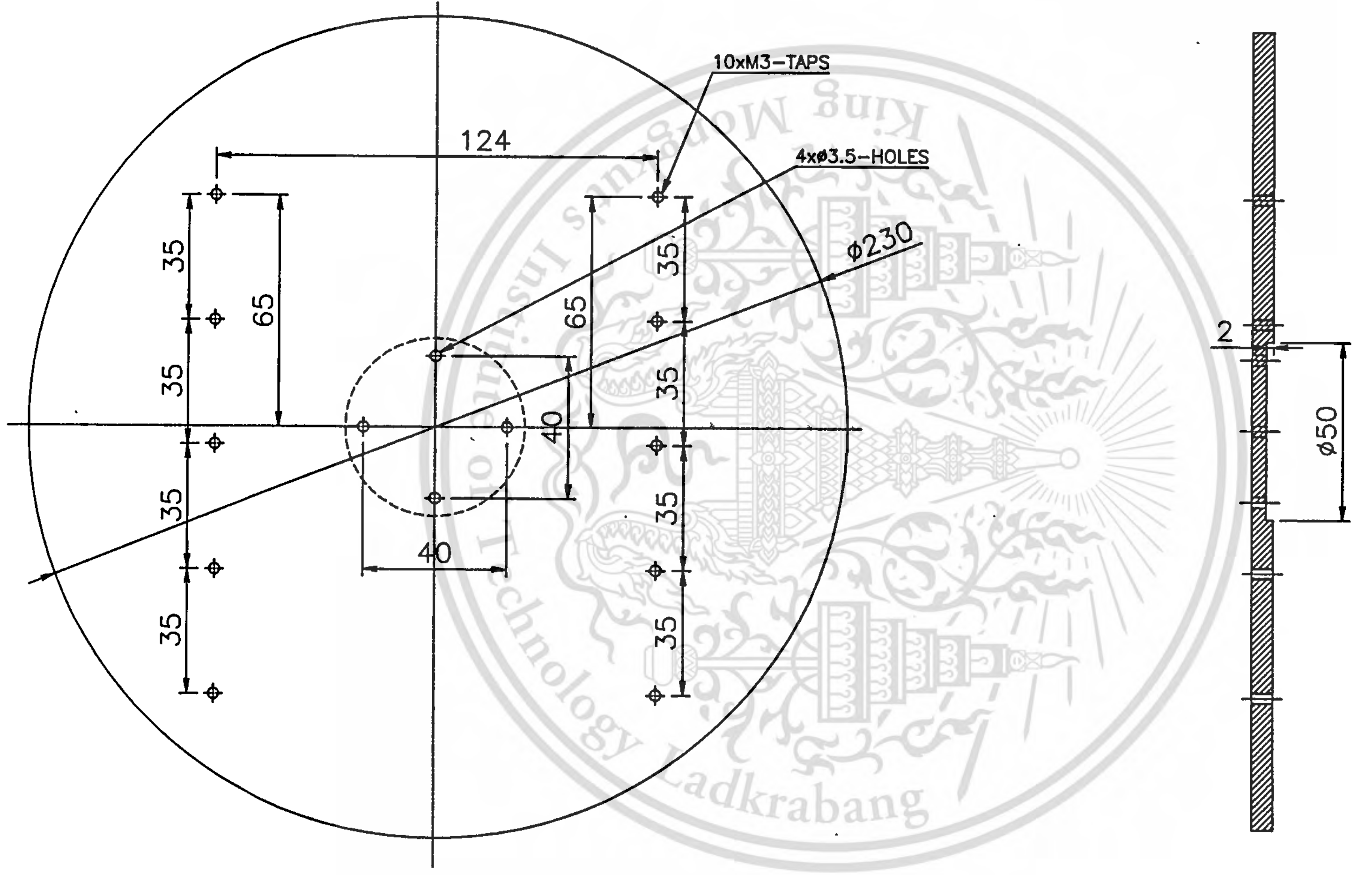
BA001D015

(REVISION) DWG.STATUS { STANDARD ..... 0 / PRE-STANDARD ..... 1 / TEMPORARY 2

DWG.NO.	BA001D016	*	0	COMPONENT PART NO.	DEF { MFR : MAKE FROM / WRK : WORK INSTRUCTION	DWG : DRAWING / REF : REFERANCE

CHG.CODE	ITEM	CARD NO 0	DESCRIPTION	DEF	MATERIAL CODE	G.NO.	L.NO	CARD NO 1	QUANTITY	MATERIAL CODE	LENGTH	UNIT	CUT	PUR	FINISH PAINT	FINISH OTHER	HT TR	CHG.CODE	ITEM	CARD NO 2	REQD PER SET
	-01		SWIVEL PLATE						ø230-ALUMINUM A6063S-T5 t5.0												

CHG.CODE A.Add D.Delete E.Change



STD.	TOLERANCE EXCEPT ENTRY IN DWG.	
PSTD.	PLASTIC	14
	WORK.	GRADE
TEM.	CUTTING(S-1001)	MIDLE / ROUGH
	CASTING(S-1131)	GOOD / NORMAL
	PRESS(S-1251)	GOOD / [✓ NORMAL]

CHANGE *

KING MONGKUT'S INSTITUTE OF TECHNOLOGY
LADKRABANG

DIM.IN mm	DATE	05/01/2002	APPROVED
SCALE	DRAWN	ANAN K.	KMITL JAN.26.2002 T. TAWEE
: NTS	CHECKED	TAWEE T.	
	DESIGNED	ANAN K.	

APPAR 6-AXES ROBOT
ITEM SWIVEL
TITLE SWIVEL PLATE

BA001D016

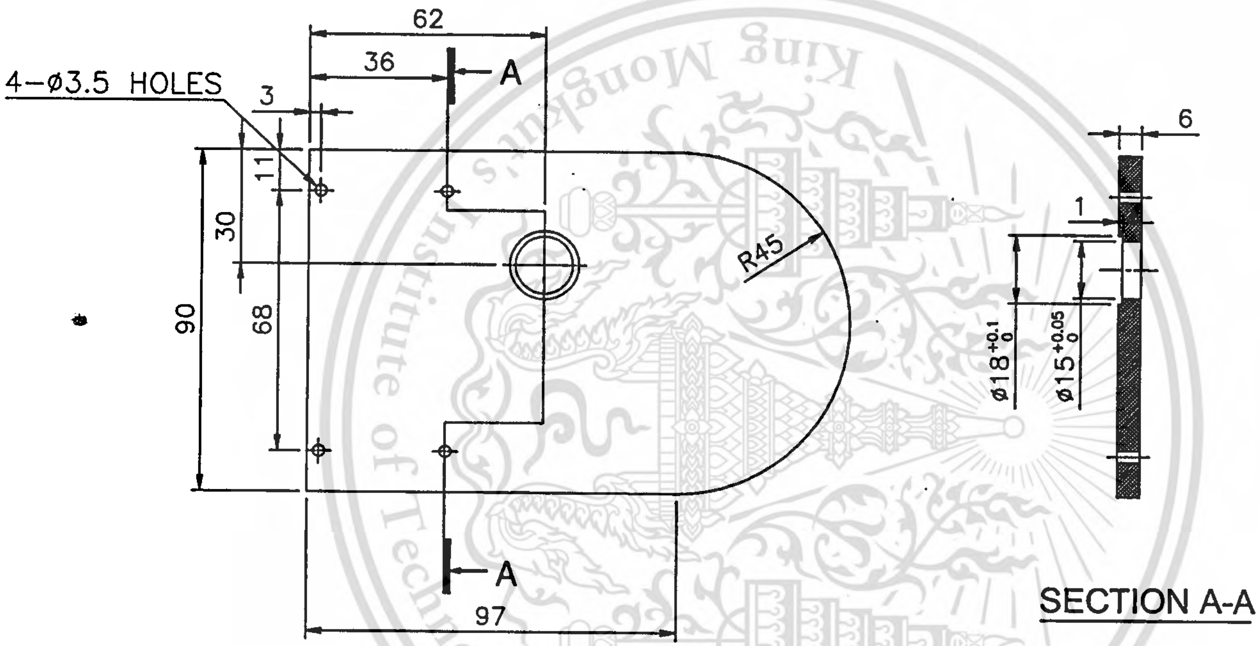
CHG.CODE A.Add D.Delete E.Change

(REVISION) DWG.STATUS { STANDARD ..... 0 PRE-STANDARD ..... 1 TEMPORARY 2

DEF { MFR : MAKE FROM WRK : WORK INSTRUCTION DWG : DRAWING REF : REFERANCE

DWG.NO.	BA001D017	*	0	COMPONENT PART NO.										
CHG.CODE 15 16	ITEM	CARD NO 0	DESCRIPTION	DEF	MATERIAL CODE	G.NO.	L.NO	CARD NO 1	QUANTITY	MATERIAL CODE	LENGTH	UNIT	CUT	PUR
	-01		SIDE SUPPORT PLATE (R)						90X142–ALUMINUM A6063S–T5 t6.0					

FINISH					
PAINT	OTHER	HT TR	CHG.CODE 15 16	ITEM CARD NO 2	REQD PER SET



CHG.CODE 15 16	GROUP	DESCRIPTION	PAINT ALL FACES	PAINT BACK FACES	HT TR	OTHERS
			FINISH			

STD.	TOLERANCE EXCEPT ENTRY IN DWG.		
	PLASTIC	14	
PSTD.	WORK	GRADE	
TEM.	CUTTING(S-1001)	MIDLE	ROUGH
	CASTING(S-1131)	GOOD	NORMAL
	PRESS(S-1251)	GOOD	NORMAL

CHANGE
*

	KING MONGKUT'S INSTITUTE OF TECHNOLOGY LADKRABANG		
DIM.IN mm	DATE	05/01/2002	APPROVED KMITL JAN.26.2002 T. TAWEE
SCALE	DRAWN	ANAN K.	
: NTS	CHECKED	TAWEE T.	
	DESIGNED	ANAN K.	

APPAR 6–AXES ROBOT

ITEM SWIVEL

TITLE

SIDE SUPPORT PLATE (R)

BA001D017

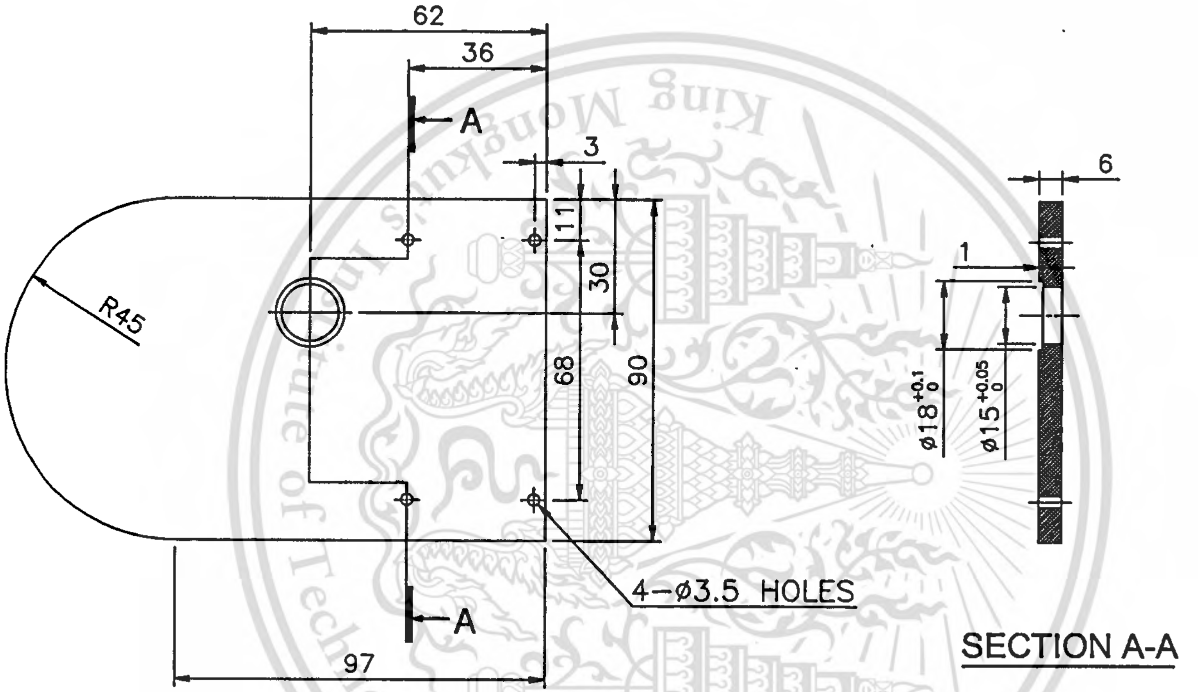
(REVISION) DWG.STATUS { STANDARD ..... 0 PRE-STANDARD ..... 1 TEMPORARY 2

DWG.NO. BA001D018 ＊ 0 COMPONENT PART NO.

DEF { MFR : MAKE FROM WRK : WORK INSTRUCTION DWG : DRAWING REF : REFERANCE

CHG.CODE: A.Add D.Delete E.Change

CHG.CODE	ITEM	CARD NO 0	DESCRIPTION	DEF	MATERIAL CODE	G.NO.	L.NO	CARD NO 1	QUANTITY	MATERIAL CODE	LENGTH	UNIT	CUT	PUR	FINISH PAINT	FINISH OTHER	HT TR	CHG.CODE	ITEM	CARD NO 2	REQD PER SET
	-01		SIDE SUPPORT PLATE (L)						90X142-ALUMINUM A6063S-T5 t6.0												



CHG.CODE	GROUP	DESCRIPTION	PAINT ALL FACES	PAINT BACK FACES	HT TR	OTHERS
			FINISH	FINISH		

STD.	TOLERANCE EXCEPT ENTRY IN DWG.	
	PLASTIC	14
PSTD.	WORK	GRADE
TEM.	CUTTING(S-1001)	MIDLE | ROUGH
	CASTING(S-1131)	GOOD | NORMAL
	PRESS(S-1251)	GOOD | NORMAL

KING MONGKUT'S INSTITUTE OF TECHNOLOGY
LADKRABANG

APPAR 6-AXES ROBOT
ITEM SWIVEL
TITLE SIDE SUPPORT PLATE (L)

DIM.IN mm	DATE	05/01/2002	APPROVED
SCALE	DRAWN	ANAN K.	KMITL
: NTS	CHECKED	TAWEE T.	JAN.26.2002
	DESIGNED	ANAN K.	T. TAWEE

BA001D018

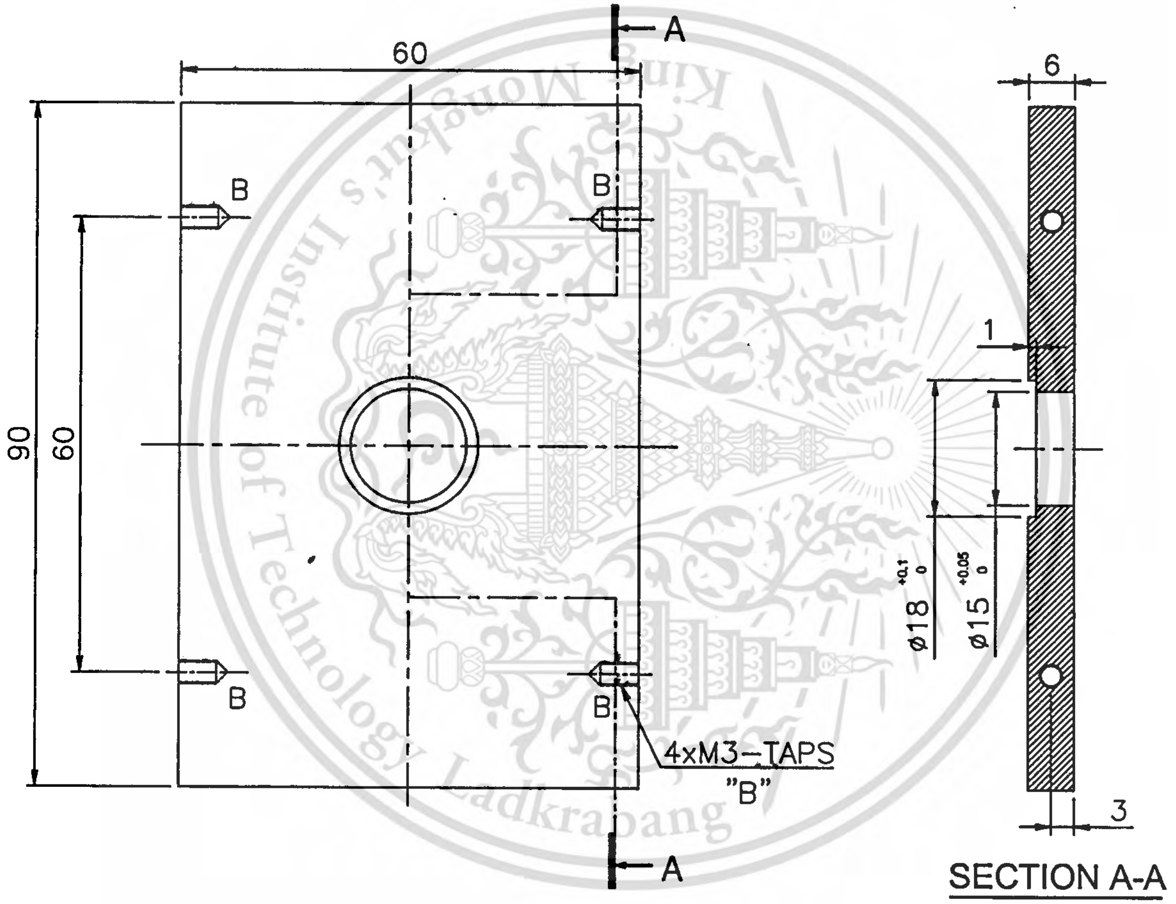
CHANGE ＊

1 (REVISION) DWG.STATUS { STANDARD ..... 0 PRE-STANDARD ..... 1 TEMPORARY 2 4 5 6

CHG.CODE | DWG.NO. 4 BA001D019 | 13 * | 14 0 | COMPONENT PART NO. | DEF { MFR : MAKE FROM / WRK : WORK INSTRUCTION | DWG : DRAWING / REF : REFERANCE

CHG.CODE 15 16	ITEM	CARD NO. 0	DESCRIPTION	DEF	MATERIAL CODE	G.NO.	L.NO	CARD NO 1	QUANTITY	MATERIAL CODE	LENGTH	UNIT	CUT	PUR	FINISH PAINT	FINISH OTHER	HT TR	CHG.CODE 15 16	ITEM	CARD NO. 2	REQD PER SET
	-01		PARTITION SUPPORT						60X90-ALUMINUM A6063S-T5 t6.0												

A.Add D.Delete E.Change



SECTION A-A

STD.	TOLERANCE EXCEPT ENTRY IN DWG.	
	PLASTIC	14
PSTD.	WORK	GRADE
TEM.	CUTTING(S-1001)	MIDLE	ROUGH
	CASTING(S-1131)	GOOD	NORMAL
	PRESS(S-1251)	GOOD	NORMAL

CHANGE *

KING MONGKUT'S INSTITUTE OF TECHNOLOGY
LADKRABANG

DIM.IN mm	DATE	05/01/2002	APPROVED
SCALE	DRAWN	ANAN K.	KMITL JAN.26.2002 T. TAWEE
: NTS	CHECKED	TAWEE T.	
	DESIGNED	ANAN K.	

APPAR 6-AXES ROBOT
ITEM SWIVEL
TITLE
PARTITION SUPPORT

BA001D019

A B C D

1 2 3 4 5 6

(REVISION) 13

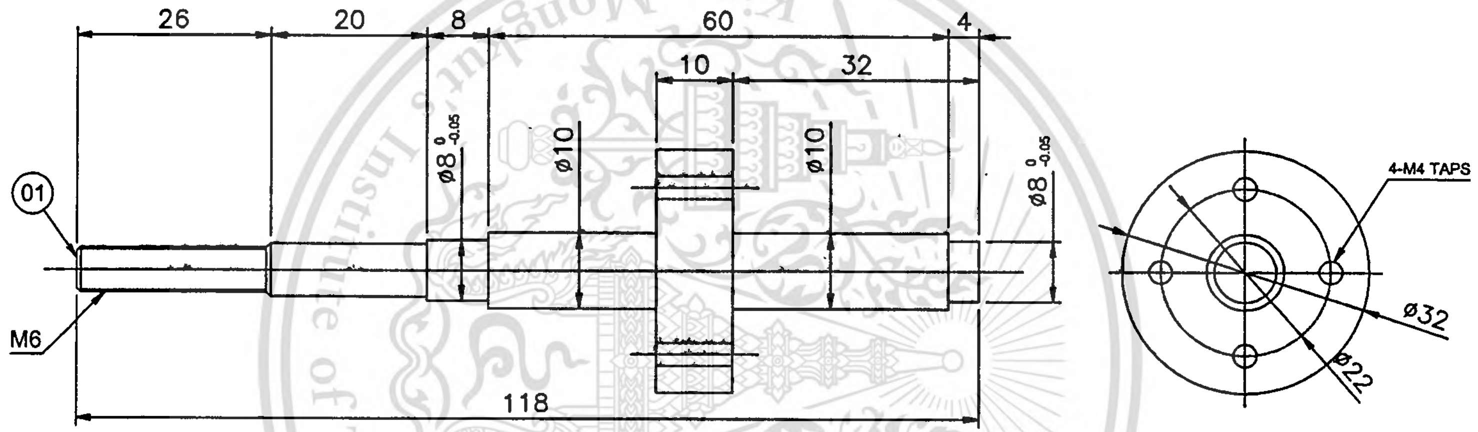
DWG.STATUS { STANDARD ..... 0 / PRE-STANDARD ..... 1 / TEMPORARY ..... 2 } 14

DWG.NO. BA001D020 * 0

DEF { MFR : MAKE FROM / WRK : WORK INSTRUCTION } DWG : DRAWING / REF : REFERANCE

CHG.CODE / A.Add / D.Delete / E.Change

CHG.CODE 15 16	ITEM	CARD NO 0	DESCRIPTION	DEF	MATERIAL CODE	G.NO.	L.NO	CARD NO 1	QUANTITY	MATERIAL CODE	LENGTH	UNIT	CUT	PUR	FINISH PAINT	FINISH OTHER	HT TR	CHG.CODE 15 16	ITEM	CARD NO 2	REQD PER SET
	-01		SHAFT (LOWER ARM)						ø32x118-SPCC												



CHG.CODE 15 16	GROUP	DESCRIPTION	PAINT ALL FACES	PAINT BACK FACES	HT TR	OTHERS
			FINISH			

STD. TOLERANCE EXCEPT ENTRY IN DWG.

STD.	PLASTIC	14
PSTD.	WORK	GRADE
TEM.	CUTTING(S-1001)	MIDLE / ROUGH
	CASTING(S-1131)	GOOD / NORMAL
	PRESS(S-1251)	GOOD / [✓ NORMAL]

CHANGE *

KING MONGKUT'S INSTITUTE OF TECHNOLOGY
LADKRABANG

DIM.IN mm	DATE	05/01/2002	APPROVED
SCALE	DRAWN	ANAN K.	KMITL JAN.26.2002 T. TAWEE
: NTS	CHECKED	TAWEE T.	
	DESIGNED	ANAN K.	

APPAR 6-AXES ROBOT
ITEM SWIVEL
TITLE SHAFT (LOWER ARM)

BA001D020

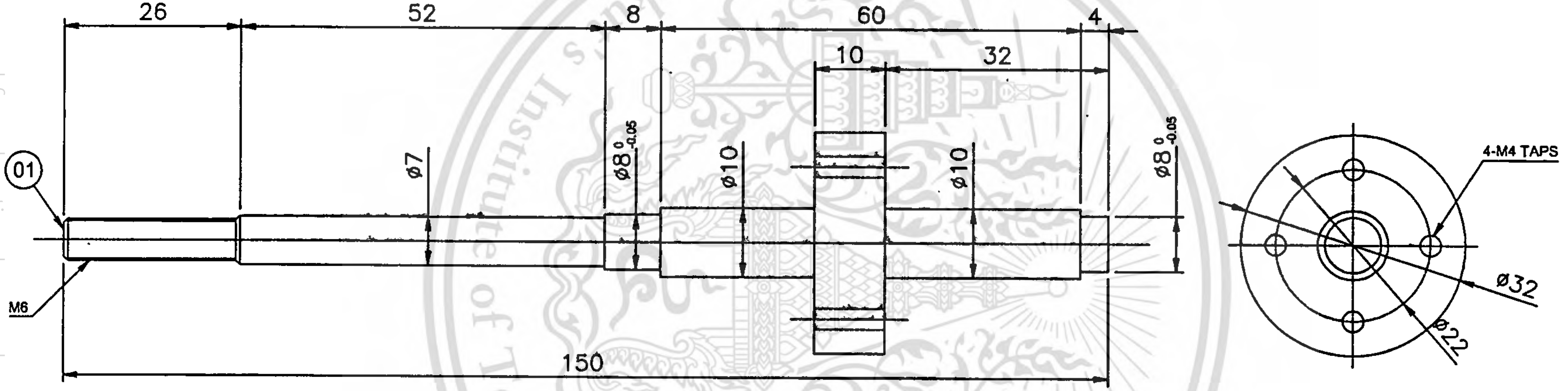
CHG.CODE
A.Add
D.Delete
E.Change

(REVISION)
DWG.STATUS { STANDARD 0
PRE-STANDARD 1
TEMPORARY 2

DWG.NO.	4 BA001D021	13 *	14 0	COMPONENT PART NO.

DEF { MFR : MAKE FROM
WRK : WORK INSTRUCTION
DWG : DRAWING
REF : REFERANCE

CHG.CODE 15 16	ITEM	CARD NO 0	DESCRIPTION	DEF	MATERIAL CODE	G.NO.	L.NO	CARD NO 1	QUANTITY	MATERIAL CODE	LENGTH	UNIT	CUT	PUR	FINISH PAINT	FINISH OTHER	HT TR	CHG.CODE 15 16	ITEM	CARD NO 2	REQD PER SET
	-01		SHAFT (UPPER ARM)						ø32x150-SPCC												



CHG.CODE 15 16	GROUP	DESCRIPTION	FINISH PAINT ALL FACES	FINISH PAINT BACK FACES	HT TR	OTHERS

STD.	TOLERANCE EXCEPT ENTRY IN DWG.	
	PLASTIC	14
PSTD.	WORK	GRADE
TEM.	CUTTING(S-1001)	MIDLE / ROUGH
	CASTING(S-1131)	GOOD / NORMAL
	PRESS(S-1251)	GOOD / [✓ NORMAL]

CHANGE	*

KING MONGKUT'S INSTITUTE OF TECHNOLOGY
LADKRABANG

DIM.IN mm	DATE	05/01/2002	APPROVED
SCALE	DRAWN	ANAN K.	KMITL JAN.26.2002 T. TAWEE
: NTS	CHECKED	TAWEE T.	
	DESIGNED	ANAN K.	

APPAR 6-AXES ROBOT
ITEM SWIVEL
TITLE
SHAFT (UPPER ARM)
BA001D021

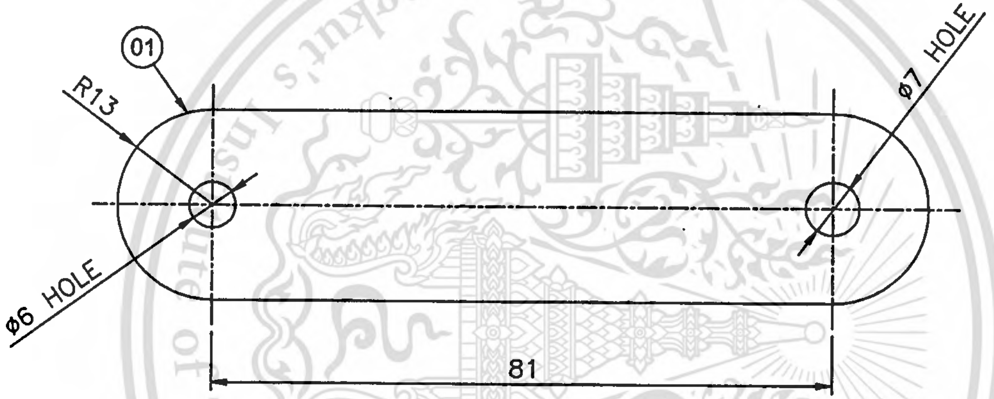
(REVISION)

DWG.STATUS { STANDARD ..... 0 / PRE-STANDARD ..... 1 / TEMPORARY 2

DEF { MFR : MAKE FROM / WRK : WORK INSTRUCTION DWG : DRAWING / REF : REFERANCE

CHG.CODE	DWG.NO.	BA001D022	*	0	COMPONENT PART NO.													
CHG.CODE	ITEM	CARD NO 0	DESCRIPTION	DEF	MATERIAL CODE	G.NO.	L.NO	CARD NO 1	QUANTITY	MATERIAL CODE	LENGTH	UNIT	CUT	PUR	FINISH PAINT	FINISH OTHER	HT TR	CHG.CODE ITEM CARD NO 2 REQD PER SET
	-01		PARALLEL LINK (LOWER)						26x106-ALUMINUM 6063S-T5 t5.0									

A.Add D.Delete E.Change



CHG.CODE	GROUP	DESCRIPTION	PAINT ALL FACES	PAINT BACK FACES	HT TR	OTHERS
			FINISH			

STD.	TOLERANCE EXCEPT ENTRY IN DWG.	
	PLASTIC	14
PSTD.	WORK	GRADE
TEM.	CUTTING(S-1001)	MIDLE	ROUGH
	CASTING(S-1131)	GOOD	NORMAL
	PRESS(S-1251)	GOOD	NORMAL

CHANGE

*

KING MONGKUT'S INSTITUTE OF TECHNOLOGY
LADKRABANG

DIM.IN mm	DATE	05/01/2002
SCALE	DRAWN	ANAN K.
: NTS	CHECKED	TAWEE T.
	DESIGNED	ANAN K.

APPROVED
KMITL
JAN.26.2002
T. TAWEE

APPAR 6-AXES ROBOT
ITEM SWIVEL
TITLE
PARALLEL LINK (L)

BA001D022

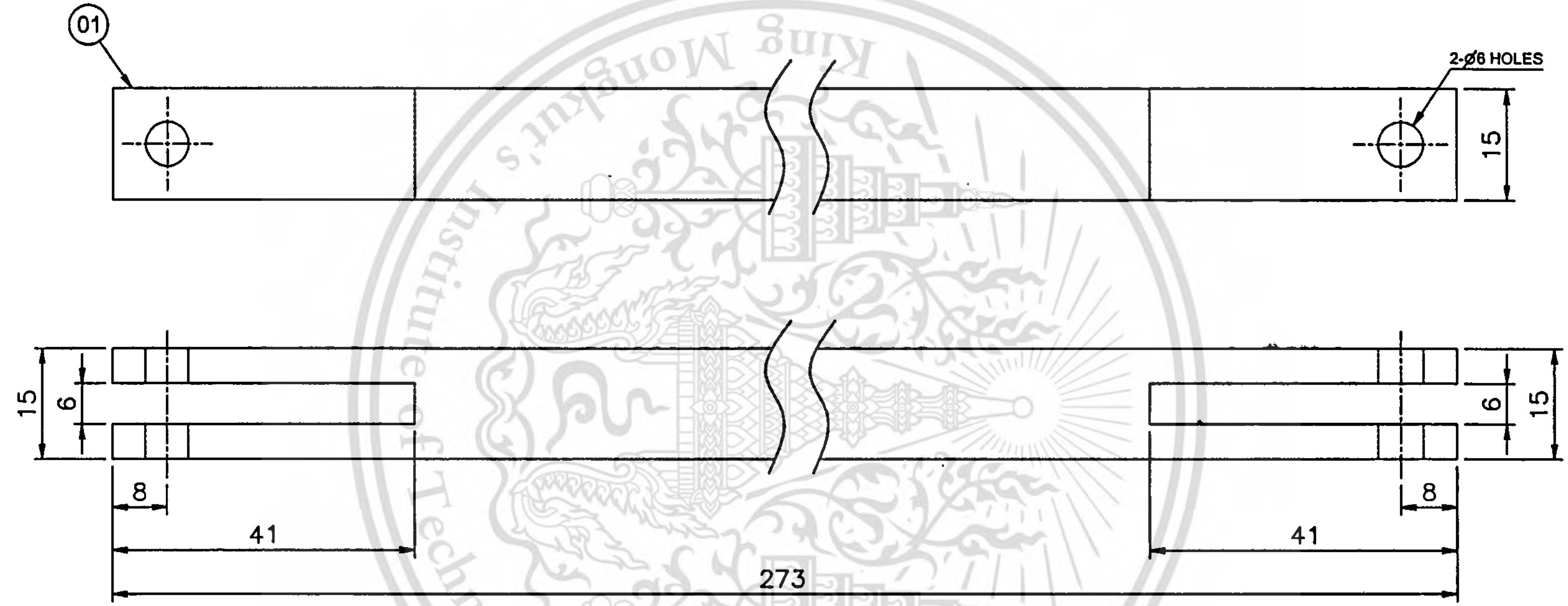
DWG.NO. BA001D023 (REVISION) * DWG.STATUS { STANDARD ..... 0 PRE-STANDARD ..... 1 TEMPORARY ..... 2 } 0

DEF { MFR : MAKE FROM WRK : WORK INSTRUCTION DWG : DRAWING REF : REFERANCE }

COMPONENT PART NO.

CHG.CODE	ITEM	CARD NO 0	DESCRIPTION	DEF	MATERIAL CODE	G.NO.	L.NO	CARD NO 1	QUANTITY	MATERIAL CODE	LENGTH	UNIT	CUT	PUR	FINISH PAINT	FINISH OTHER	HT TR	CHG.CODE	ITEM	CARD NO 2	REQD PER SET
	-01		PARALLEL LINK (M)						15x15x273-ALUMINUM 6063S T5												

CHG.CODE: A.Add, D.Delete, E.Change



CHG.CODE	GROUP	DESCRIPTION	PAINT ALL FACES	PAINT BACK FACES	HT TR	OTHERS
			FINISH			

	TOLERANCE EXCEPT ENTRY IN DWG.		
STD.	PLASTIC	14	
PSTD.	WORK	GRADE	
TEM.	CUTTING(S-1001)	MIDLE	ROUGH
	CASTING(S-1131)	GOOD	NORMAL
	PRESS(S-1251)	GOOD	NORMAL

KING MONGKUT'S INSTITUTE OF TECHNOLOGY
LADKRABANG

DIM.IN mm	DATE	05/01/2002	APPROVED
SCALE	DRAWN	ANAN K.	KMITL JAN.26.2002 T. TAWEE
: NTS	CHECKED	TAWEE T.	
	DESIGNED	ANAN K.	

APPAR 6-AXES ROBOT
ITEM SWIVEL
TITLE PARALLEL LINK (M)

BA001D023

CHANGE *

(REVISION)

DWG.STATUS { STANDARD 0
PRE-STANDARD 1
TEMPORARY 2

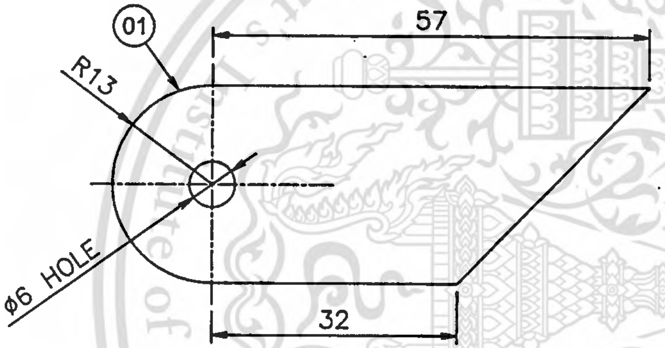
DWG.NO. BA001D024 | 13 * | 14 0 | COMPONENT PART NO.

DEF { MFR : MAKE FROM
WRK : WORK INSTRUCTION

DWG : DRAWING
REF : REFERANCE

CHG.CODE 15 16	ITEM	CARD NO. 0	DESCRIPTION	DEF	MATERIAL CODE	G.NO.	L.NO	CARD NO 1	QUANTITY	MATERIAL CODE	LENGTH	UNIT	CUT	PUR	FINISH PAINT	FINISH OTHER	HT TR	CHG.CODE 15 16	ITEM	CARD NO 2	REQD PER SET
	-01		PARALLEL LINK (UPPER)						26x70-ALUMINUM 6063S T5 t5.0												

CHG.CODE
A.Add
D.Delete
E.Change



CHG.CODE 15 16	GROUP	DESCRIPTION	PAINT ALL FACES	PAINT BACK FACES	HT TR	OTHERS
			FINISH			

STD.	TOLERANCE EXCEPT ENTRY IN DWG.		
	PLASTIC	14	
PSTD.	WORK		GRADE
TEM.	CUTTING(S-1001)	MIDLE	ROUGH
	CASTING(S-1131)	GOOD	NORMAL
	PRESS(S-1251)	GOOD	[✓ NORMAL]

CHANGE

KING MONGKUT'S INSTITUTE OF TECHNOLOGY
LADKRABANG

DIM.IN mm	DATE	05/01/2002
SCALE	DRAWN	ANAN K.
: NTS	CHECKED	TAWEE T.
	DESIGNED	ANAN K.

APPROVED KMITL JAN.26.2002 T. TAWEE

APPAR 6-AXES ROBOT
ITEM SWIVEL
TITLE
PARALLEL LINK (U)

BA001D024

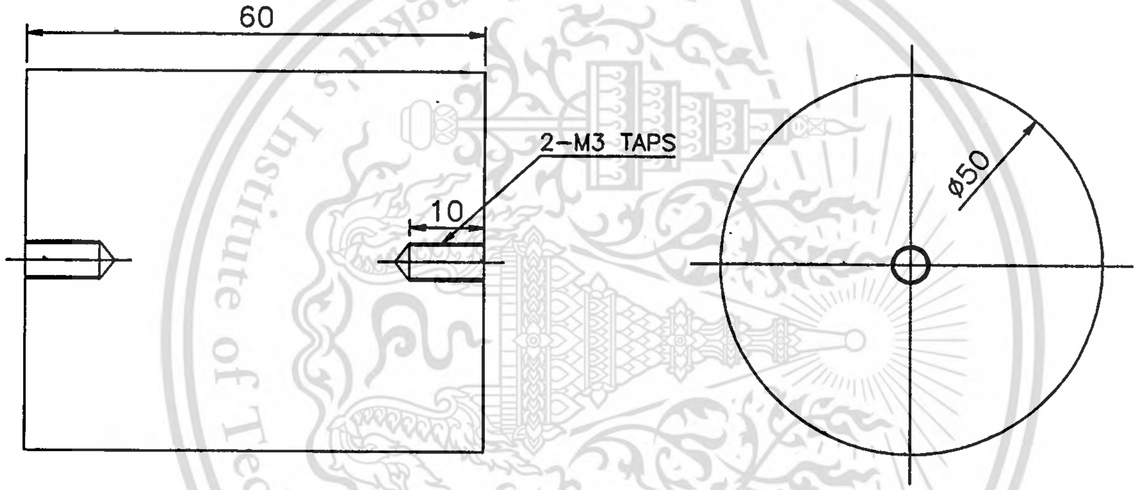
(REVISION) DWG.STATUS { STANDARD .... 0 PRE-STANDARD .... 1 TEMPORARY 2

DWG.NO. BA001D025 * 0

COMPONENT PART NO.

DEF { MFR : MAKE FROM WRK : WORK INSTRUCTION DWG : DRAWING REF : REFERANCE

CHG.CODE	ITEM	CARD NO. 0	DESCRIPTION	DEF	MATERIAL CODE	G.NO.	L.NO	CARD NO 1	QUANTITY	MATERIAL CODE	LENGTH	UNIT	CUT	PUR	FINISH PAINT	FINISH OTHER	HT TR	CHG.CODE	ITEM	CARD NO 2	REQD PER SET
	-01		COUNTER WEIGHT						ø50x60-SPCC						D44						



CHG.CODE	GROUP	DESCRIPTION	PAINT ALL FACES	PAINT BACK FACES	HT TR	OTHERS
			FINISH			

STD. TOLERANCE EXCEPT ENTRY IN DWG.

PSTD.	PLASTIC	14
	WORK	GRADE
TEM.	CUTTING(S-1001)	MIDLE	ROUGH
	CASTING(S-1131)	GOOD	NORMAL
	PRESS(S-1251)	GOOD	[✓ NORMAL]

KING MONGKUT'S INSTITUTE OF TECHNOLOGY
LADKRABANG

APPAR 6-AXES ROBOT
ITEM SWIVEL

TITLE
COUNTER WEIGHT

DIM.IN mm	DATE	05/01/2002
SCALE	DRAWN	ANAN K.
: NTS	CHECKED	TAWEE T.
	DESIGNED	ANAN K.

APPROVED KMITL JAN.26.2002 T. TAWEE

BA001D025

CHANGE *

A.Add D.Delete E.Change

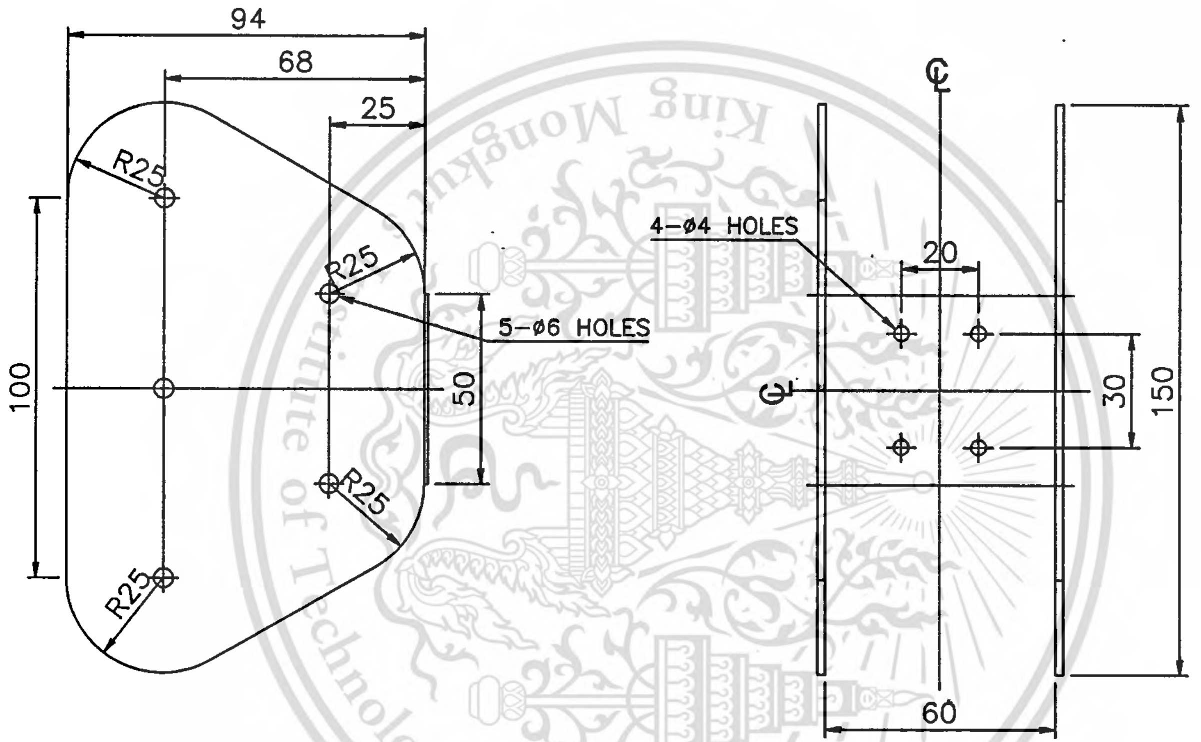
(REVISION) DWG.STATUS { STANDARD ..... 0 PRE-STANDARD ..... 1 TEMPORARY 2

CHG.CODE: A.Add D.Delete E.Change

DWG.NO. BA001D026 * 0 COMPONENT PART NO.

DEF { MFR : MAKE FROM WRK : WORK INSTRUCTION DWG : DRAWING REF : REFERANCE

ITEM	CARD NO 0	DESCRIPTION	DEF	MATERIAL CODE	G.NO.	L.NO	CARD NO 1	QUANTITY	MATERIAL CODE	LENGTH	UNIT	CUT	PUR	FINISH PAINT	FINISH OTHER	HT TR	ITEM	CARD NO 2	REQD PER SET
-01		COUNTER WEIGHT (COVER)						246X150-ALUMINUM 6063S-T5 t1.5											



CHG.CODE	GROUP	DESCRIPTION	PAINT ALL FACES	PAINT BACK FACES	HT TR	OTHERS
			FINISH			

STD.	TOLERANCE EXCEPT ENTRY IN DWG.	
PSTD.	PLASTIC	14
	WORK	GRADE
TEM.	CUTTING(S-1001) MIDLE	ROUGH
	CASTING(S-1131) GOOD	NORMAL
	PRESS(S-1251) GOOD	NORMAL

CHANGE *

KING MONGKUT'S INSTITUTE OF TECHNOLOGY
LADKRABANG

DIM.IN mm	DATE	05/01/2002
SCALE	DRAWN	ANAN K.
: NTS	CHECKED	TAWEE T.
	DESIGNED	ANAN K.

APPROVED KMITL JAN.26.2002 T. TAWEE

APPAR 6-AXES ROBOT
ITEM SWIVEL

TITLE
COUNTER WEIGHT COVER

BA001D026

(REVISION)

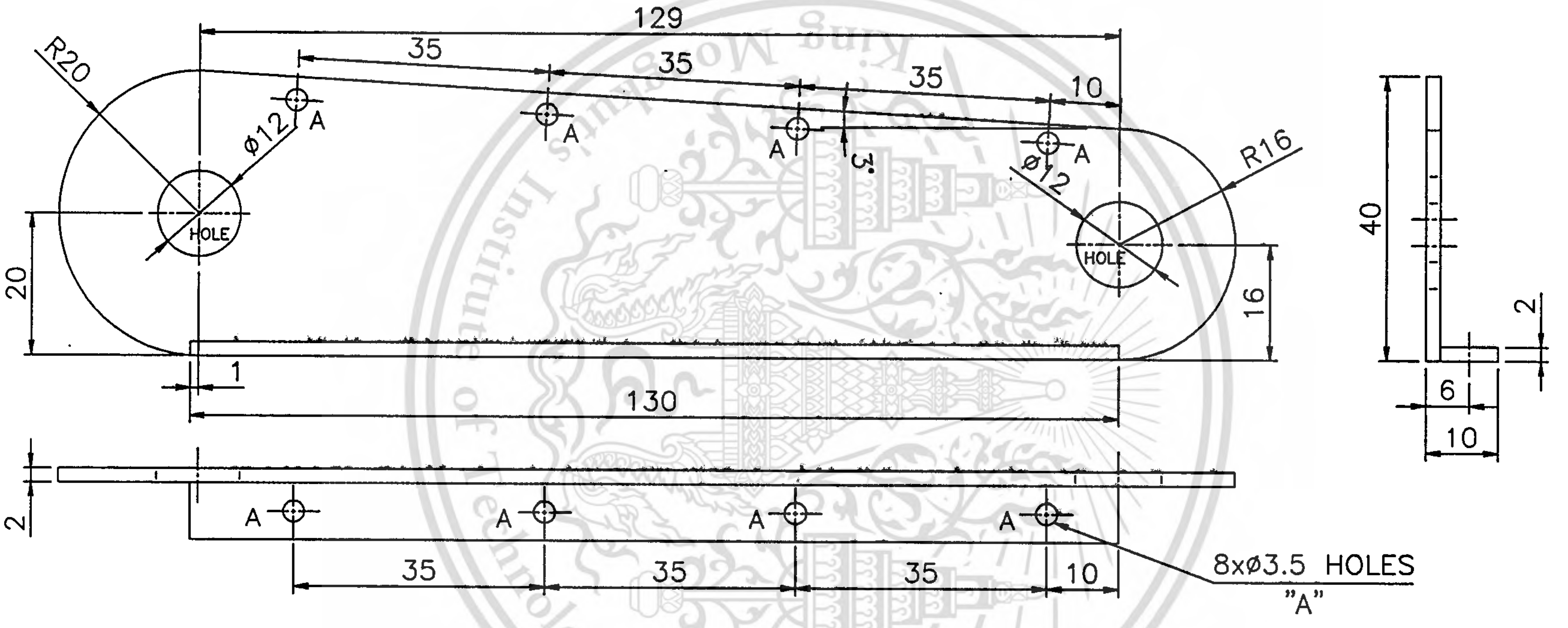
DWG.STATUS { STANDARD ..... 0 / PRE-STANDARD ..... 1 / TEMPORARY 2

DEF { MFR : MAKE FROM / WRK : WORK INSTRUCTION } DWG : DRAWING / REF : REFERANCE

CHG.CODE / A.Add / D.Delete / E.Change

DWG.NO.	BA001D027	*	0	COMPONENT PART NO.										
CHG.CODE 15 16	ITEM	CARD NO 0	DESCRIPTION	DEF	MATERIAL CODE	G.NO.	L.NO	CARD NO 1	QUANTITY	MATERIAL CODE	LENGTH	UNIT	CUT	PUR
	-01		SIDE PLATE (R)						166X48-ALUMINUM 6063S-T5 t2.0					

FINISH PAINT	FINISH OTHER	HT TR	CHG.CODE 15 16	ITEM	CARD NO 2	REQD PER SET



CHG.CODE 15 16	GROUP	DESCRIPTION	PAINT ALL FACES	PAINT BACK FACES	HT TR	OTHERS
			FINISH			

STD.	TOLERANCE EXCEPT ENTRY IN DWG.	
	PLASTIC	14
PSTD.	WORK	GRADE
TEM.	CUTTING(S-1001)	MIDLE · ROUGH
	CASTING(S-1131)	GOOD · NORMAL
	PRESS(S-1251)	GOOD · [✓ NORMAL]

CHANGE

*

KING MONGKUT'S INSTITUTE OF TECHNOLOGY
LADKRABANG

DIM.IN mm	DATE	05/01/2002	APPROVED
SCALE	DRAWN	ANAN K.	KMITL JAN.26.2002 T. TAWEE
: NTS	CHECKED	TAWEE T.	
	DESIGNED	ANAN K.	

APPAR 6-AXES ROBOT
ITEM LOWER ARM
TITLE

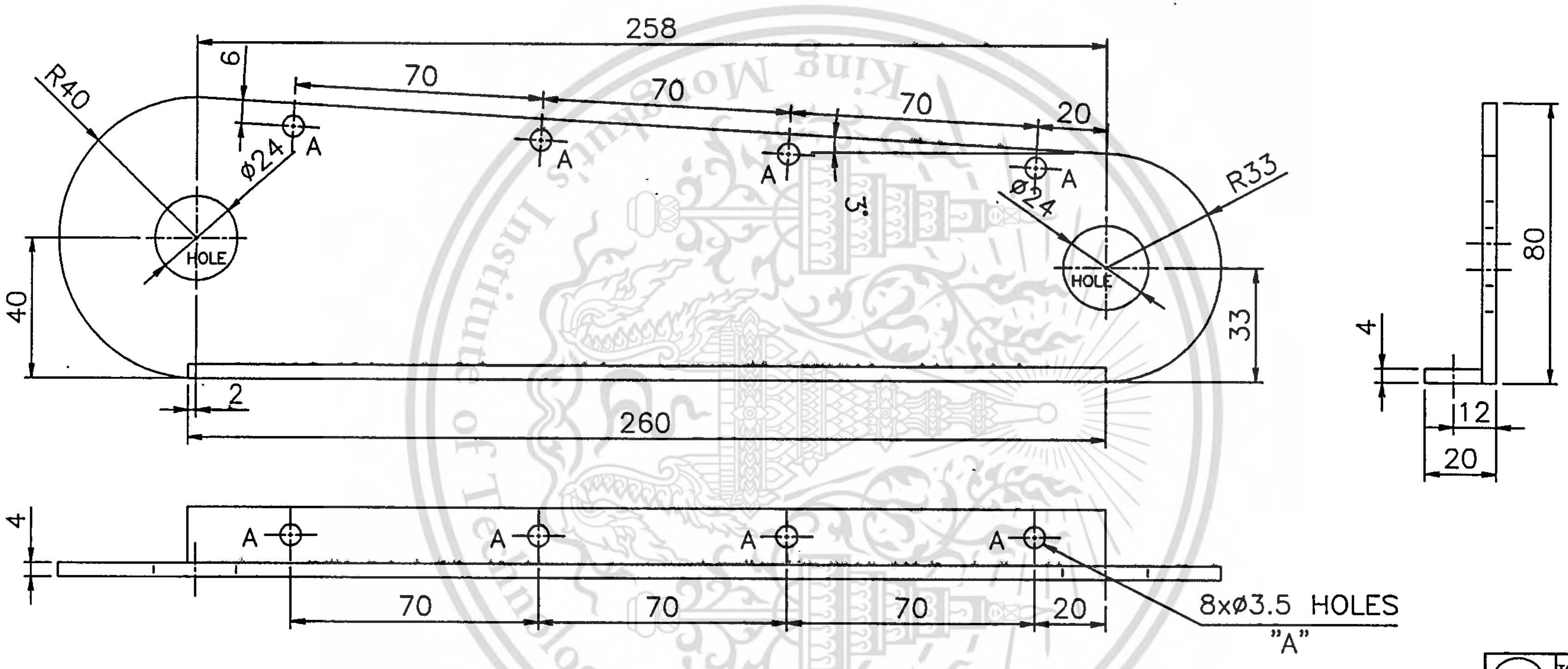
SIDE PLATE (R)

BA001D027

(REVISION) DWG.STATUS { STANDARD ..... 0 PRE-STANDARD ..... 1 TEMPORARY 2

DEF { MFR : MAKE FROM WRK : WORK INSTRUCTION DWG : DRAWING REF : REFERANCE

CHG.CODE	DWG.NO.	BA001D028	*	0	COMPONENT PART NO.													
CHG.CODE	ITEM	DESCRIPTION	DEF	MATERIAL CODE	G.NO.	L.NO	QUANTITY	MATERIAL CODE	LENGTH	UNIT	CUT	PUR	FINISH PAINT	FINISH OTHER	HT TR	CHG.CODE	ITEM	REQD PER SET
	-01	SIDE PLATE (L)					166X48-ALUMINUM 6063S-T5 t2.0											



CHG.CODE	GROUP	DESCRIPTION	FINISH PAINT ALL FACES	FINISH PAINT BACK FACES	HT TR	OTHERS	STD.	TOLERANCE EXCEPT ENTRY IN DWG.	
							PSTD.	PLASTIC	14
							TEM.	WORK	GRADE
								CUTTING(S-1001) MIDLE	ROUGH
								CASTING(S-1131) GOOD	NORMAL
								PRESS(S-1251) GOOD	[✓ NORMAL]

CHANGE *

KING MONGKUT'S INSTITUTE OF TECHNOLOGY
LADKRABANG

DIM.IN mm	DATE	05/01/2002	APPROVED KMITL JAN.26.2002 T. TAWEE
SCALE	DRAWN	ANAN K.	
: NTS	CHECKED	TAWEE T.	
	DESIGNED	ANAN K.	

APPAR 6-AXES ROBOT
ITEM LOWER ARM
TITLE SIDE PLATE (L)

BA001D028

E.Change D.Delete A.Add CHG.CODE

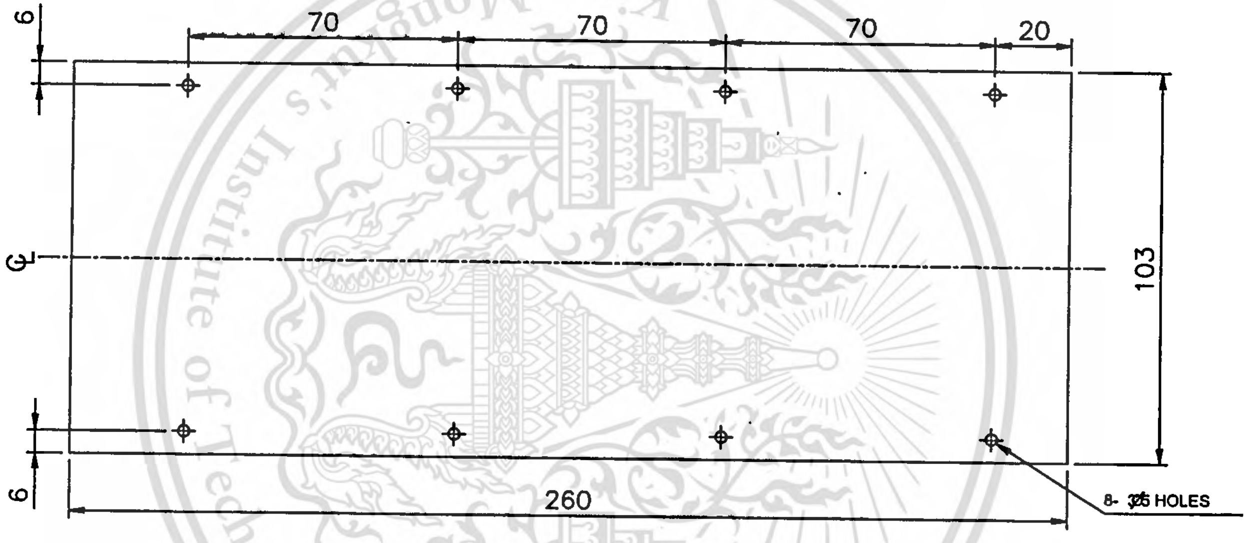
(REVISION)

DWG.STATUS { STANDARD 0
PRE-STANDARD 1
TEMPORARY 2

DEF { MFR : MAKE FROM
WRK : WORK INSTRUCTION
DWG : DRAWING
REF : REFERANCE

CHG.CODE
A.Add
D.Delete
E.Change

DWG.NO.	BA001D029	*	0	COMPONENT PART NO.															
CHG.CODE	ITEM	CARD NO 0	DESCRIPTION	DEF	MATERIAL CODE	G.NO.	L.NO	CARD NO 1	QUANTITY	MATERIAL CODE	LENGTH	UNIT	CUT	PUR	FINISH PAINT	FINISH OTHER	HT TR	CHG.CODE	ITEM	CARD NO 2	REQD PER SET
	-01		FRONT PLATE						103x260-ALUMINUM 6063S-T5 t2.0												



CHG.CODE	GROUP	DESCRIPTION	PAINT ALL FACES	PAINT BACK FACES	HT TR	OTHERS
			FINISH	FINISH		

STD.	TOLERANCE EXCEPT ENTRY IN DWG.	
PSTD.	PLASTIC	14
	WORK	GRADE
TEM.	CUTTING(S-1001)	MIDLE / ROUGH
	CASTING(S-1131)	GOOD / NORMAL
	PRESS(S-1251)	GOOD / NORMAL

	KING MONGKUT'S INSTITUTE OF TECHNOLOGY LADKRABANG			APPAR 6-AXES ROBOT	ITEM LOWER ARM
DIM.IN mm	DATE	05/01/2002	APPROVED	TITLE FRONT PLATE	
SCALE	DRAWN	ANAN K.	KMITL JAN.26.2002 T. TAWEE		
: NTS	CHECKED	TAWEE T.		BA001D029	
	DESIGNED	ANAN K.			

CHANGE

*

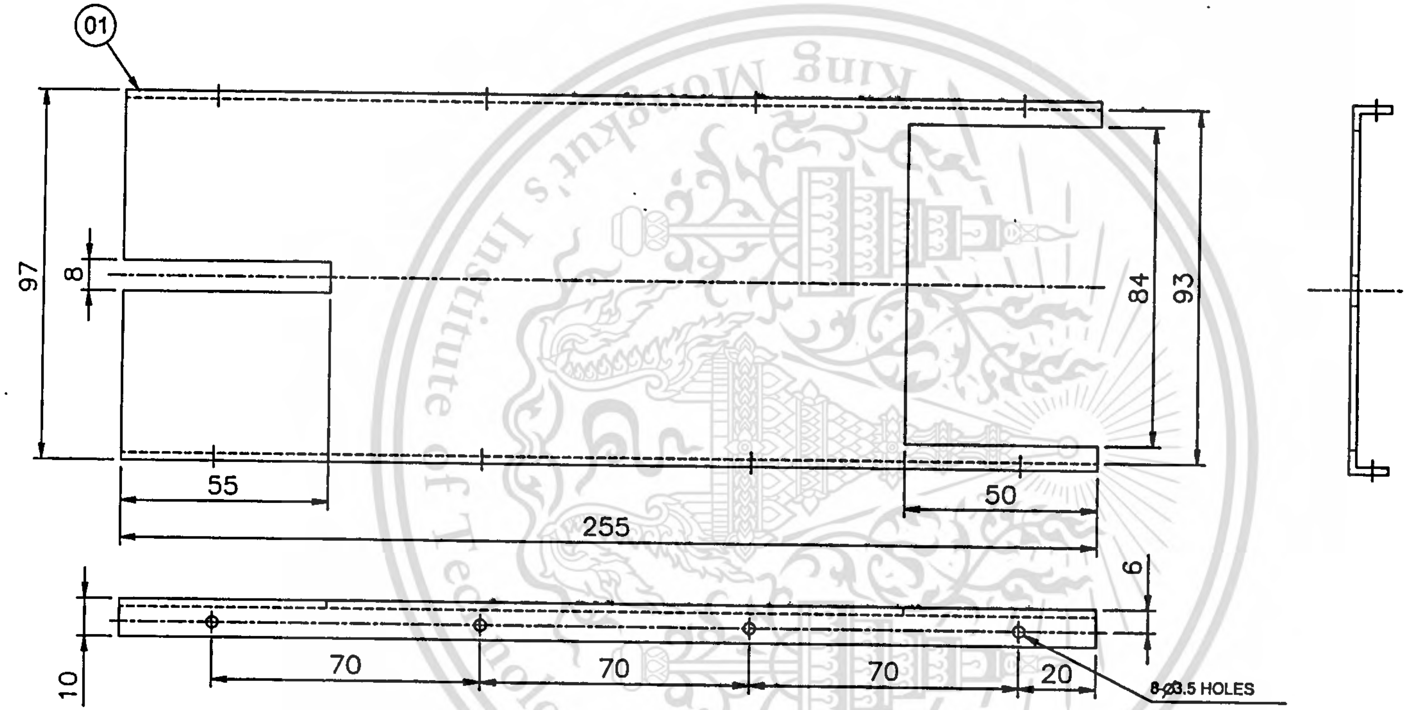
DWG.NO. BA001D030 | (REVISION) * | DWG.STATUS 0

DWG.STATUS { STANDARD ..... 0 / PRE-STANDARD ..... 1 / TEMPORARY 2

DEF { MFR : MAKE FROM / WRK : WORK INSTRUCTION — DWG : DRAWING / REF : REFERANCE

CHG.CODE	ITEM (CARD NO 0)	DESCRIPTION	DEF	MATERIAL CODE (COMPONENT PART NO.)	G.NO.	L.NO (CARD NO 1)	QUANTITY	MATERIAL CODE	LENGTH	UNIT	CUT	PUR	FINISH PAINT	FINISH OTHER	HT TR	CHG.CODE	ITEM (CARD NO 2)	REQD PER SET
	-01	BACK PLATE					111x255-ALUMINUM 6063S-T5 t2.0											

CHG.CODE: A.Add, D.Delete, E.Change



STD.	TOLERANCE EXCEPT ENTRY IN DWG.		
PSTD.	PLASTIC	14	
	WORK	GRADE	
TEM.	CUTTING(S-1001)	MIDLE	ROUGH
	CASTING(S-1131)	GOOD	NORMAL
	PRESS(S-1251)	GOOD	[✓ NORMAL]

KING MONGKUT'S INSTITUTE OF TECHNOLOGY
LADKRABANG

DIM.IN mm	DATE	05/01/2002
SCALE	DRAWN	ANAN K.
: NTS	CHECKED	TAWEE T.
	DESIGNED	ANAN K.

APPROVED KMITL JAN.26.2002 T. TAWEE

APPAR 6-AXES ROBOT — ITEM LOWER ARM

TITLE BACK PLATE

BA001D030

CHANGE *

CHG.CODE A.Add D.Delete E.Change

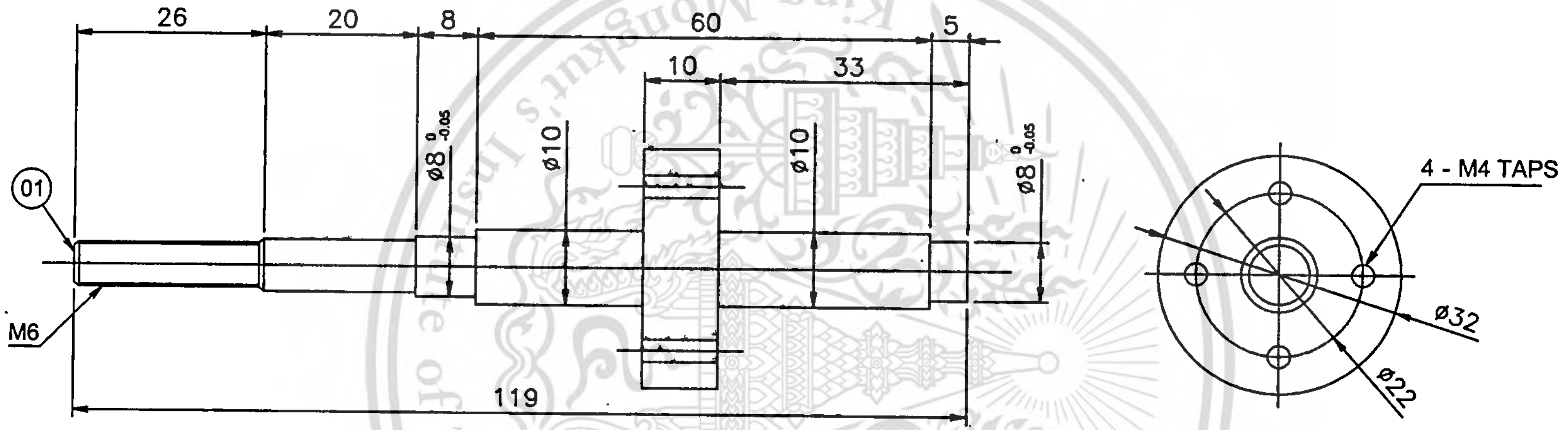
(REVISION) DWG.STATUS { STANDARD ..... 0 PRE-STANDARD ..... 1 TEMPORARY 2

DWG.NO. BA001D031 13 * 14 0

COMPONENT PART NO.

DEF { MFR : MAKE FROM WRK : WORK INSTRUCTION DWG : DRAWING REF : REFERANCE

CHG.CODE 15 16	ITEM	CARD NO 0	DESCRIPTION	DEF	MATERIAL CODE	G.NO.	L.NO	CARD NO 1	QUANTITY	MATERIAL CODE	LENGTH	UNIT	CUT	PUR	FINISH PAINT	FINISH OTHER	HT TR	CHG.CODE 15 16	ITEM	CARD NO 2	REQD PER SET
	-01		SHAFT							ø32x119–SPCC											



CHG.CODE 15 16	GROUP	DESCRIPTION	PAINT ALL FACES	PAINT BACK FACES	HT TR	OTHERS
			FINISH			

STD.	TOLERANCE EXCEPT ENTRY IN DWG.		
	PLASTIC		14
PSTD.	WORK		GRADE
TEM.	CUTTING(S-1001)	MIDLE	ROUGH
	CASTING(S-1131)	GOOD	NORMAL
	PRESS(S-1251)	GOOD	[✓ NORMAL]

CHANGE	*	

KING MONGKUT'S INSTITUTE OF TECHNOLOGY
LADKRABANG

DIM.IN mm	DATE	05/01/2002	APPROVED
SCALE	DRAWN	ANAN K.	
: NTS	CHECKED	TAWEE T.	
	DESIGNED	ANAN K.	

KMITL
JAN.26.2002
T. TAWEE

APPAR 6-AXES ROBOT
ITEM LOWER ARM
TITLE
SHAFT

BA001D031

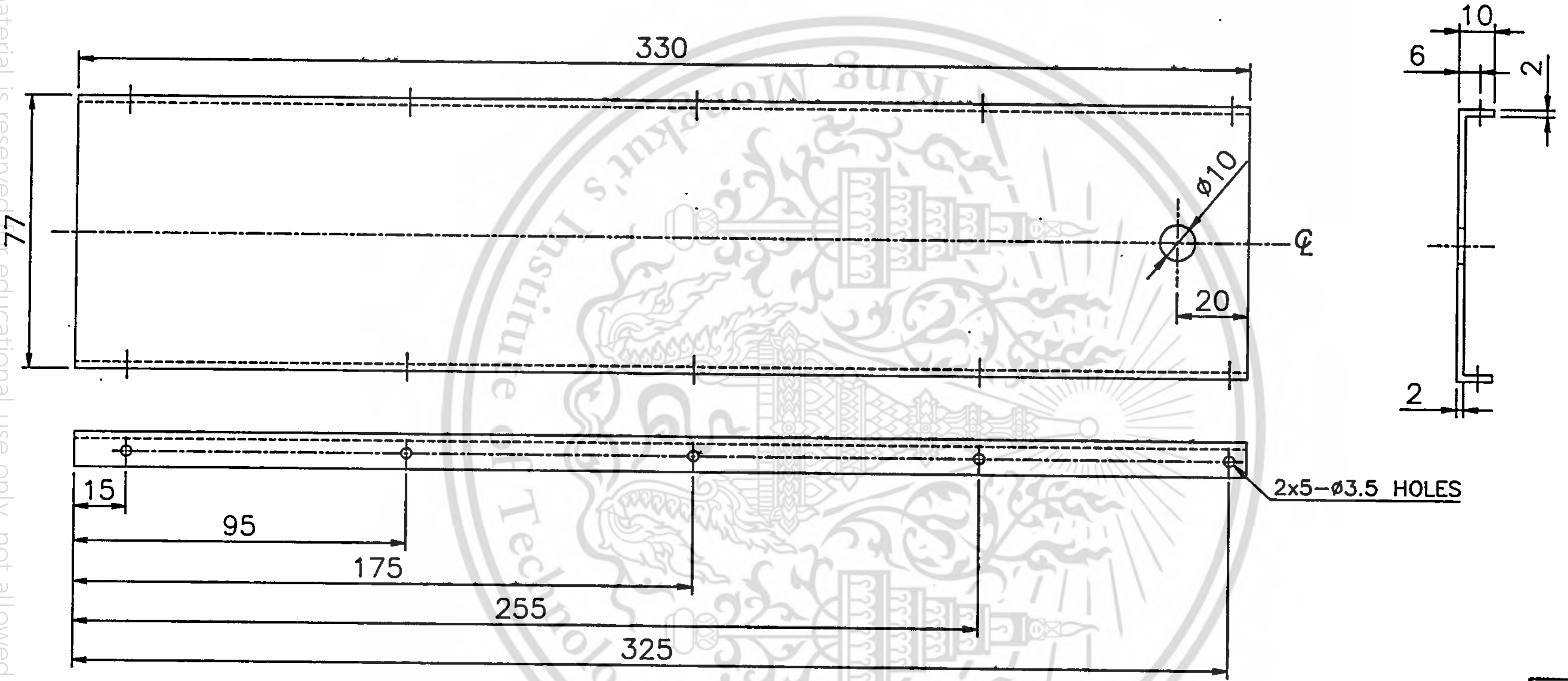
(REVISION)

DWG.STATUS { STANDARD ..... 0 / PRE-STANDARD ..... 1 / TEMPORARY 2

DEF { MFR : MAKE FROM / WRK : WORK INSTRUCTION; DWG : DRAWING / REF : REFERANCE

CHG.CODE: A.Add, D.Delete, E.Change

DWG.NO.	BA001D035	*	0	COMPONENT PART NO.											
ITEM	DESCRIPTION	DEF	MATERIAL CODE	G.NO.	L.NO	QUANTITY	MATERIAL CODE	LENGTH	UNIT	CUT	PUR	FINISH PAINT	FINISH OTHER	HT TR	ITEM / REQD PER SET
-01	TOP PLATE					96x325–ALUMINUM 6063S–T5 t2.0									



CHG.CODE	GROUP	DESCRIPTION	PAINT ALL FACES	PAINT BACK FACES	HT TR	OTHERS
			FINISH			

STD.	TOLERANCE EXCEPT ENTRY IN DWG.	
	PLASTIC	14
PSTD.	WORK	GRADE
TEM.	CUTTING(S–1001)	MIDLE / ROUGH
	CASTING(S–1131)	GOOD / NORMAL
	PRESS(S–1251)	GOOD / [✓ NORMAL]

KING MONGKUT'S INSTITUTE OF TECHNOLOGY
LADKRABANG

DIM.IN mm	DATE	05/01/2002	APPROVED
SCALE	DRAWN	ANAN K.	KMITL JAN.26.2002 T. TAWEE
: NTS	CHECKED	TAWEE T.	
	DESIGNED	ANAN K.	

APPAR 6–AXES ROBOT
ITEM UPPER ARM
TITLE TOP PLATE

BA001D035

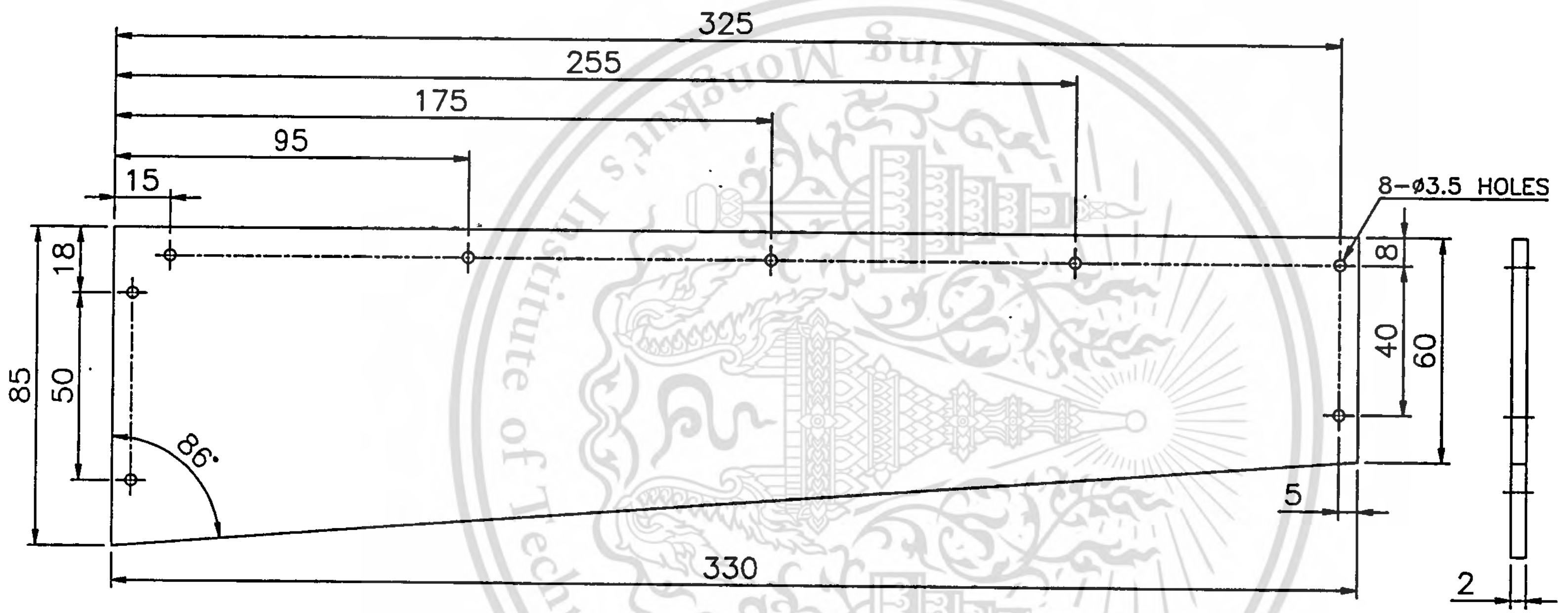
CHANGE *

(REVISION) DWG.STATUS { STANDARD ..... 0 / PRE-STANDARD ..... 1 TEMPORARY 2

DWG.NO.	BA001D036	13 *	14 0	COMPONENT PART NO.	DEF { MFR : MAKE FROM / WRK : WORK INSTRUCTION	DWG : DRAWING / REF : REFERANCE

CHG.CODE 15	ITEM 16	CARD NO 0	DESCRIPTION	DEF	MATERIAL CODE	G.NO.	L.NO	CARD NO 1	QUANTITY	MATERIAL CODE	LENGTH	UNIT	CUT	PUR	FINISH PAINT	FINISH OTHER	HT TR	CHG.CODE 15	ITEM 16	CARD NO 2	REQD PER SET
	-01		SIDE PLATE (R)						85x325–ALUMINUM 6063S–T5 t2.0												

CHG.CODE A.Add D.Delete E.Change



CHG.CODE 15	GROUP 16	DESCRIPTION	FINISH PAINT ALL FACES	FINISH PAINT BACK FACES	HT TR	OTHERS

STD.	TOLERANCE EXCEPT ENTRY IN DWG.		
	PLASTIC	14	
PSTD.	WORK	GRADE	
TEM.	CUTTING(S–1001)	MIDLE	ROUGH
	CASTING(S–1131)	GOOD	NORMAL
	PRESS(S–1251)	GOOD	NORMAL

CHANGE *

KING MONGKUT'S INSTITUTE OF TECHNOLOGY
LADKRABANG

DIM.IN mm	DATE	05/01/2002	APPROVED
SCALE	DRAWN	ANAN K.	
: NTS	CHECKED	TAWEE T.	
	DESIGNED	ANAN K.	

KMITL JAN.26.2002 T. TAWEE

APPAR 6–AXES ROBOT ITEM UPPER ARM

TITLE

SIDE PLATE (R)

BA001D036

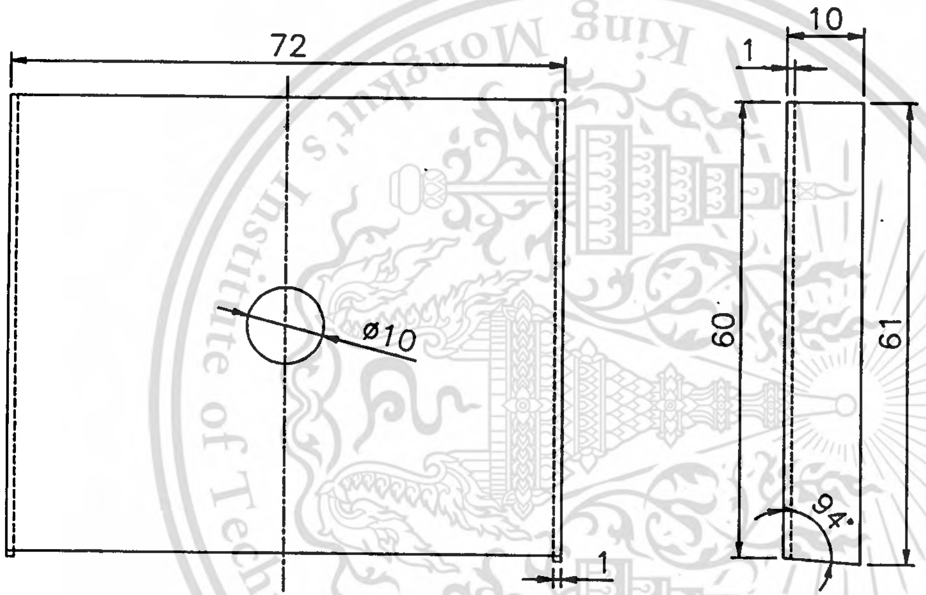
(REVISION) DWG.STATUS { STANDARD ..... 0 PRE-STANDARD ..... 1 TEMPORARY 2

DWG.NO. BA001D039 * 0

DEF { MFR : MAKE FROM WRK : WORK INSTRUCTION DWG : DRAWING REF : REFERANCE

CHG.CODE	ITEM	CARD NO 0	DESCRIPTION	DEF	MATERIAL CODE (COMPONENT PART NO.)	G.NO.	L.NO	CARD NO 1	QUANTITY	MATERIAL CODE	LENGTH	UNIT	CUT	PUR	FINISH PAINT	FINISH OTHER	HT TR	CHG.CODE	ITEM	CARD NO 2	REQD PER SET
	-01		FRONT PLATE						86x61-ALUMINUM 6063S-T5 t2.0												

CHG.CODE A.Add D.Delete E.Change



CHG.CODE	GROUP	DESCRIPTION	PAINT ALL FACES	PAINT BACK FACES	HT TR	OTHERS
			FINISH	FINISH		

(STD.) TOLERANCE EXCEPT ENTRY IN DWG.

PSTD.	PLASTIC	14
TEM.	WORK	GRADE
	CUTTING(S-1001)	MIDLE / ROUGH
	CASTING(S-1131)	GOOD / NORMAL
	PRESS(S-1251)	GOOD / NORMAL

KING MONGKUT'S INSTITUTE OF TECHNOLOGY LADKRABANG

APPAR 6-AXES ROBOT

ITEM UPPER ARM

TITLE FRONT PLATE

DIM.IN mm	DATE	05/01/2002
SCALE	DRAWN	ANAN K.
: NTS	CHECKED	TAWEE T.
	DESIGNED	ANAN K.

APPROVED KMITL JAN.26.2002 T. TAWEE

BA001D039

CHANGE *

(REVISION)

DWG.STATUS { STANDARD ..... 0 / PRE-STANDARD ..... 1 / TEMPORARY 2

DWG.NO.	BA001D048	*	0	COMPONENT PART NO.

DEF { MFR : MAKE FROM / WRK : WORK INSTRUCTION   DWG : DRAWING / REF : REFERANCE

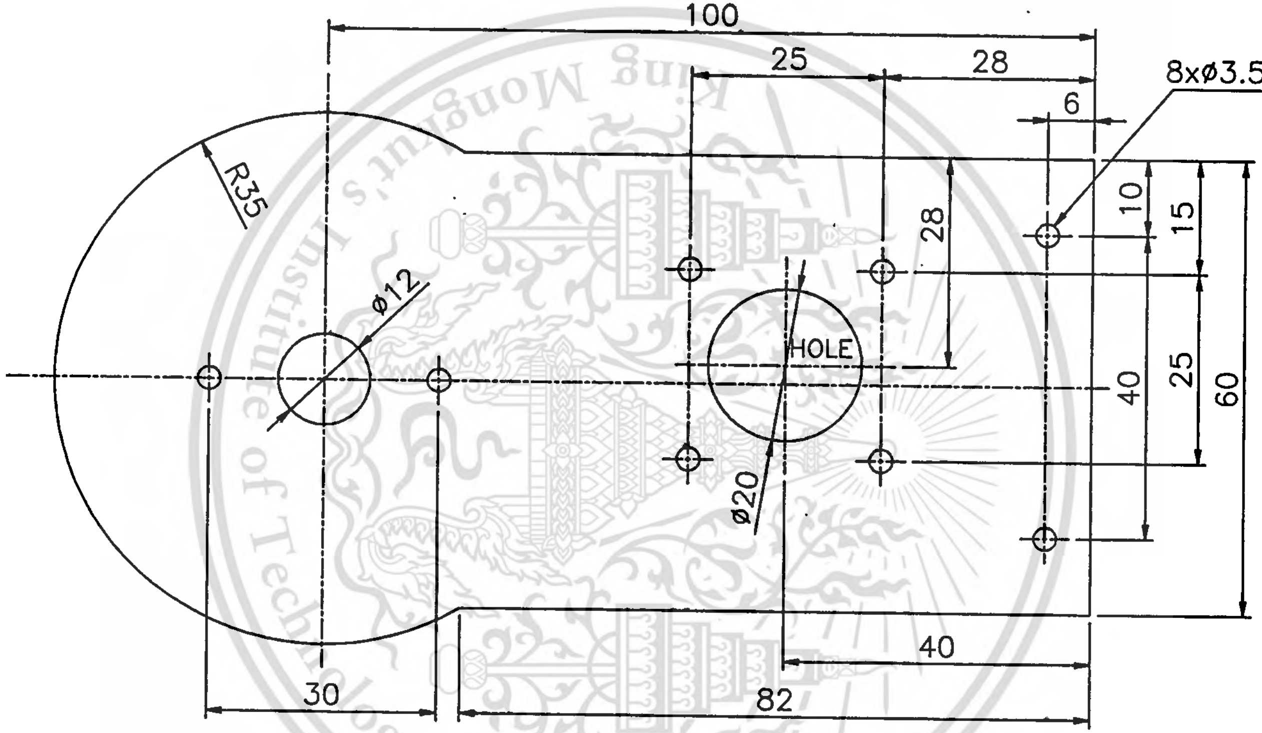
CHG.CODE 15 16	ITEM	CARD NO. 0	DESCRIPTION	DEF	MATERIAL CODE	G.NO.	L.NO	CARD NO 1	QUANTITY	MATERIAL CODE	LENGTH	UNIT	CUT	PUR	FINISH PAINT	FINISH OTHER	HT TR	CHG.CODE 15 16	ITEM	CARD NO. 2	REQD PER SET
	-01		SIDE PLATE (R)						70X135-ALUMINUM A6063S-T5 t2.0												

CHG.CODE

A.Add

D.Delete

E.Change



CHG.CODE 15 16	GROUP	DESCRIPTION	PAINT ALL FACES	PAINT BACK FACES	HT TR	OTHERS
			FINISH	FINISH		

STD.	TOLERANCE EXCEPT ENTRY IN DWG.		
	PLASTIC	14	
PSTD.	WORK	GRADE	
TEM.	CUTTING(S-1001)	MIDLE	ROUGH
	CASTING(S-1131)	GOOD	NORMAL
	PRESS(S-1251)	GOOD	[✓ NORMAL]

CHANGE	*

KING MONGKUT'S INSTITUTE OF TECHNOLOGY
LADKRABANG

DIM.IN mm	DATE	05/01/2002	APPROVED
SCALE	DRAWN	ANAN K.	KMITL JAN.26.2002 T. TAWEE
: NTS	CHECKED	TAWEE T.	
	DESIGNED	ANAN K.	

APPAR	6-AXES ROBOT	ITEM	WRIST

TITLE

SIDE PLATE (R)

BA001D048

(REVISION)

DWG.STATUS { STANDARD ..... 0 / PRE-STANDARD ..... 1 / TEMPORARY 2

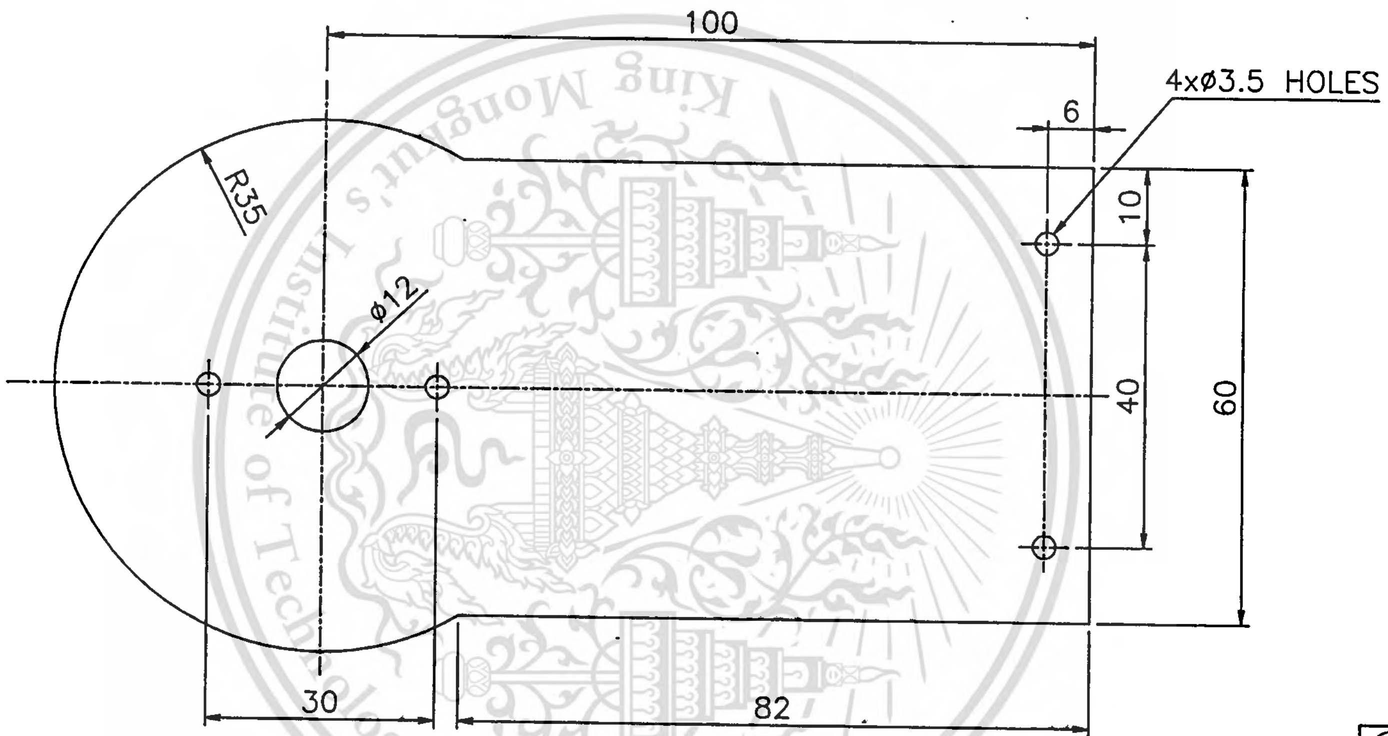
DEF { MFR : MAKE FROM / WRK : WORK INSTRUCTION

DWG : DRAWING
REF : REFERANCE

DWG.NO.	BA001D049	*	0	COMPONENT PART NO.									
CHG.CODE 15 16 ITEM CARD NO 0	DESCRIPTION	DEF	MATERIAL CODE	G.NO.	L.NO	CARD NO 1	QUANTITY	MATERIAL CODE	LENGTH	UNIT	CUT	PUR	FINISH PAINT / OTHER
-01	SIDE PLATE (R)						70X135-ALUMINUM A6063S-T5 t2.0						

CHG.CODE 15 16	ITEM CARD NO 2	HT TR	REQD PER SET

CHG.CODE
A.Add
D.Delete
E.Change



CHG.CODE 15 16 GROUP	DESCRIPTION	PAINT ALL FACES	PAINT BACK FACES	HT TR	OTHERS
		FINISH			

STD.	TOLERANCE EXCEPT ENTRY IN DWG.	
PSTD.	PLASTIC	14
TEM.	WORK	GRADE
	CUTTING(S-1001) MIDLE	ROUGH
	CASTING(S-1131) GOOD	NORMAL
	PRESS(S-1251) GOOD	[✓ NORMAL]

CHANGE	*

KING MONGKUT'S INSTITUTE OF TECHNOLOGY
LADKRABANG

DIM.IN mm	DATE	05/01/2002
SCALE	DRAWN	ANAN K.
: NTS	CHECKED	TAWEE T.
	DESIGNED	ANAN K.

APPROVED
KMITL
JAN.26.2002
T. TAWEE

APPAR 6-AXES ROBOT
ITEM WRIST

TITLE
SIDE PLATE (L)

BA001D049

(REVISION) 13 *

DWG.STATUS { STANDARD ..... 0 / PRE-STANDARD ..... 1 / TEMPORARY ..... 2 } 14 0

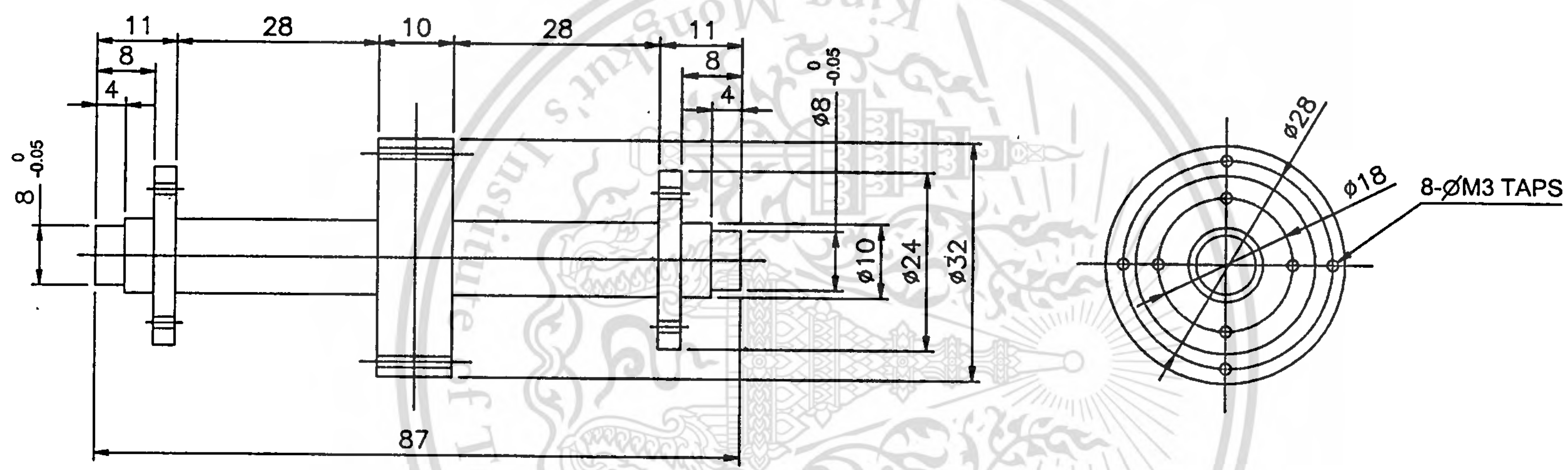
DWG.NO. BA001D050

DEF { MFR : MAKE FROM / WRK : WORK INSTRUCTION } DWG : DRAWING / REF : REFERANCE

COMPONENT PART NO.

CHG.CODE 15 16	ITEM	CARD NO. 0	DESCRIPTION	DEF	MATERIAL CODE	G.NO.	L.NO	CARD NO. 1	QUANTITY	MATERIAL CODE	LENGTH	UNIT	CUT	PUR	FINISH PAINT	FINISH OTHER	HT TR	CHG.CODE 15 16	ITEM	CARD NO. 2	REQD PER SET
	-01		GEAR SHAFT						ø32x87–ALUMINUM A6063S												

CHG.CODE A.Add D.Delete E.Change



CHG.CODE 15 16	GROUP	DESCRIPTION	FINISH PAINT ALL FACES	FINISH PAINT BACK FACES	HT TR	OTHERS

STD.	TOLERANCE EXCEPT ENTRY IN DWG.		
PSTD.	PLASTIC	14	
	WORK	GRADE	
TEM.	CUTTING(S-1001)	MIDLE	ROUGH
	CASTING(S-1131)	GOOD	NORMAL
	PRESS(S-1251)	GOOD	[✓ NORMAL]

KING MONGKUT'S INSTITUTE OF TECHNOLOGY
LADKRABANG

DIM.IN mm	DATE	05/01/2002
SCALE	DRAWN	ANAN K.
: NTS	CHECKED	TAWEE T.
	DESIGNED	ANAN K.

APPROVED KMITL JAN.26.2002 T. TAWEE

APPAR 6-AXES ROBOT

ITEM WRIST

TITLE GEAR SHAFT

BA001D050

CHANGE *

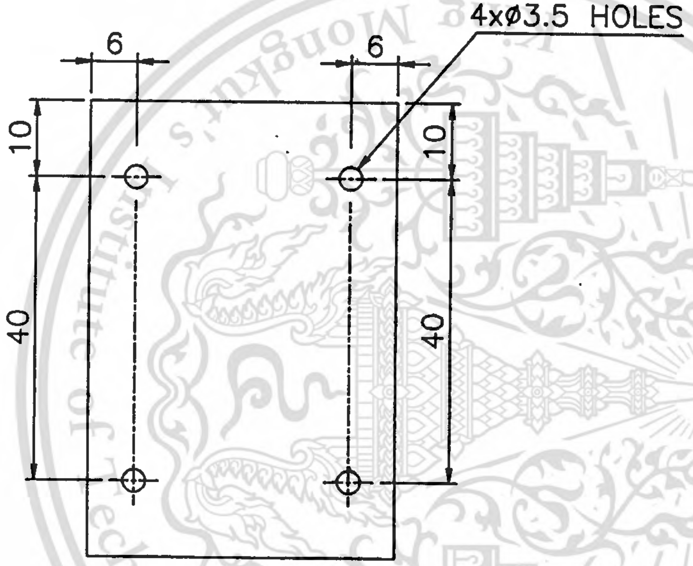
CHG.CODE A.Add D.Delete E.Change

(REVISION)

DWG.STATUS { STANDARD ..... 0 / PRE-STANDARD ..... 1 TEMPORARY 2

DEF { MFR : MAKE FROM / WRK : WORK INSTRUCTION DWG : DRAWING / REF : REFERANCE

DWG.NO.	BA001D052	*	0	COMPONENT PART NO.													
CHG.CODE 15	ITEM 16 CARD NO 0	DESCRIPTION	DEF	MATERIAL CODE	G.NO.	L.NO CARD NO 1	QUANTITY	MATERIAL CODE	LENGTH	UNIT	CUT	PUR	FINISH PAINT	FINISH OTHER	HT TR	CHG.CODE 15	ITEM 16 CARD NO 2	REQD PER SET
	-01	SIDE PLATE (R)						40X60-ALUMINUM A6063S-T5 t2.0										



CHG.CODE 15 16	GROUP	DESCRIPTION	PAINT ALL FACES	PAINT BACK FACES	HT TR	OTHERS
			FINISH			

STD.	TOLERANCE EXCEPT ENTRY IN DWG.	
	PLASTIC	14
PSTD.	WORK	GRADE
TEM.	CUTTING(S-1001)	MIDLE ROUGH
	CASTING(S-1131)	GOOD NORMAL
	PRESS(S-1251)	GOOD [✓ NORMAL]

CHANGE *

KING MONGKUT'S INSTITUTE OF TECHNOLOGY
LADKRABANG

APPAR 6-AXES ROBOT
ITEM YAW

DIM.IN mm	DATE	05/01/2002
SCALE	DRAWN	ANAN K.
: NTS	CHECKED	TAWEE T.
	DESIGNED	ANAN K.

APPROVED KMITL JAN.26.2002 T. TAWEE

TITLE
SIDE PLATE (R)

BA001D052

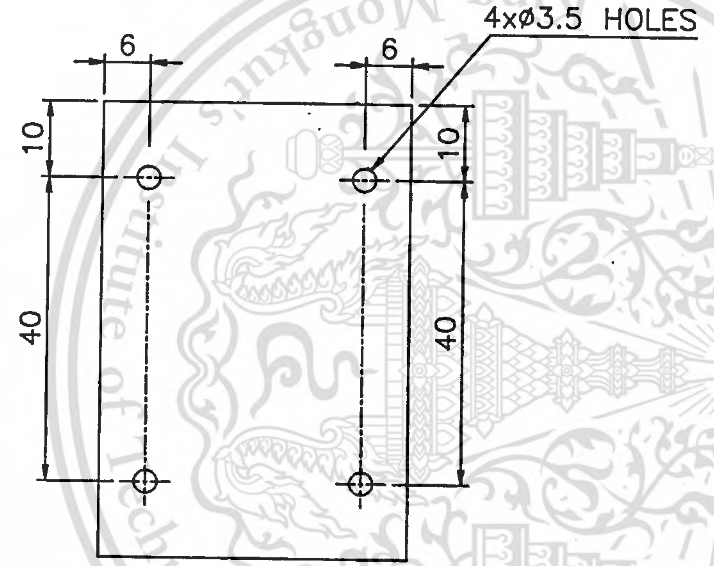
(REVISION) DWG.STATUS { STANDARD ..... 0 PRE-STANDARD ..... 1 TEMPORARY 2

DWG.NO. BA001D053 * 0

DEF { MFR : MAKE FROM WRK : WORK INSTRUCTION DWG : DRAWING REF : REFERANCE

CHG.CODE	ITEM	CARD NO 0	DESCRIPTION	DEF	COMPONENT PART NO. MATERIAL CODE	G.NO.	L.NO	CARD NO 1	QUANTITY	MATERIAL CODE	LENGTH	UNIT	CUT	PUR	FINISH PAINT	FINISH OTHER	HT TR	CHG.CODE	ITEM	CARD NO 2	REQD PER SET
	-01		SIDE PLATE (L)						40X60-ALUMINUM A6063S-T5 t2.0												

CHG.CODE A.Add D.Delete E.Change



CHG.CODE	GROUP	DESCRIPTION	PAINT ALL FACES	PAINT BACK FACES	HT TR	OTHERS
			FINISH	FINISH		

STD.	TOLERANCE EXCEPT ENTRY IN DWG.	
PSTD.	PLASTIC	14
	WORK	GRADE
TEM.	CUTTING(S-1001)	MIDLE / ROUGH
	CASTING(S-1131)	GOOD / NORMAL
	PRESS(S-1251)	GOOD / [✓ NORMAL]

CHANGE *

KING MONGKUT'S INSTITUTE OF TECHNOLOGY
LADKRABANG

DIM.IN mm	DATE	05/01/2002
SCALE	DRAWN	ANAN K.
: NTS	CHECKED	TAWEE T.
	DESIGNED	ANAN K.

APPROVED KMITL JAN.26.2002 T. TAWEE

APPAR 6-AXES ROBOT
ITEM YAW
TITLE SIDE PLATE (L)

BA001D053

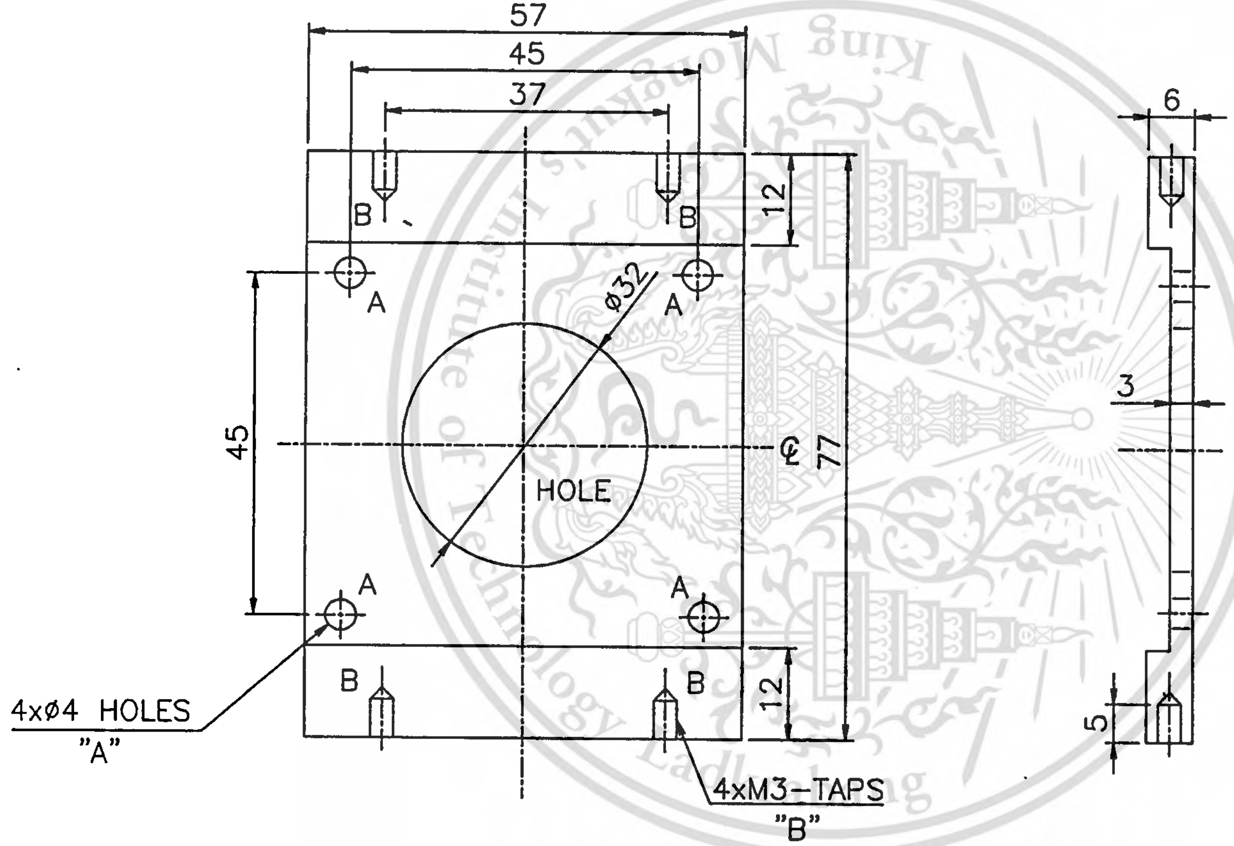
(REVISION)

DWG.STATUS { STANDARD ..... 0 / PRE-STANDARD ..... 1 / TEMPORARY 2

DEF { MFR : MAKE FROM / WRK : WORK INSTRUCTION   DWG : DRAWING / REF : REFERANCE

DWG.NO.	BA001D054	*	0	COMPONENT PART NO.												
ITEM	DESCRIPTION	DEF	MATERIAL CODE	G.NO.	L.NO	QUANTITY	MATERIAL CODE	LENGTH	UNIT	CUT	PUR	FINISH PAINT	FINISH OTHER	HT TR	ITEM	REQD PER SET
-01	MOTOR SUPPORT PLATE					57X77-ALUMINUM A6063S-T5 t6.0										

CHG.CODE A.Add D.Delete E.Change



STD.	TOLERANCE EXCEPT ENTRY IN DWG.	
	PLASTIC	14
PSTD.	WORK	GRADE
TEM.	CUTTING(S-1001)	MIDLE / ROUGH
	CASTING(S-1131)	GOOD / NORMAL
	PRESS(S-1251)	GOOD / [✓ NORMAL]

CHANGE *

KING MONGKUT'S INSTITUTE OF TECHNOLOGY
LADKRABANG

DIM.IN mm	DATE	05/01/2002	APPROVED
SCALE	DRAWN	ANAN K.	
: NTS	CHECKED	TAWEE T.	
	DESIGNED	ANAN K.	

KMITL JAN.26.2002 T. TAWEE

APPAR 6-AXES ROBOT   ITEM YAW

TITLE
MOTOR SUPPORT PLATE

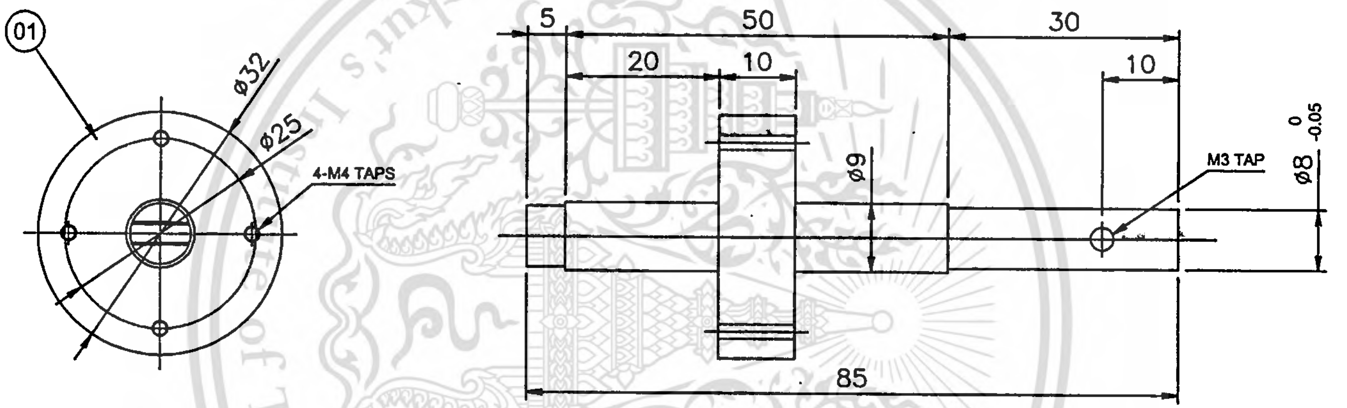
BA001D054

(REVISION)
DWG.STATUS { STANDARD .... 0 / PRE-STANDARD .... 1 / TEMPORARY 2

CHG.CODE · A.Add · D.Delete · E.Change

DWG.NO.	BA001D056	*	0	COMPONENT PART NO.	DEF { MFR : MAKE FROM / WRK : WORK INSTRUCTION	DWG : DRAWING / REF : REFERANCE

CHG.CODE 15 16	ITEM	CARD NO. 0	DESCRIPTION	DEF	MATERIAL CODE	G.NO.	L.NO	CARD NO 1	QUANTITY	MATERIAL CODE	LENGTH	UNIT	CUT	PUR	FINISH PAINT	FINISH OTHER	HT TR	CHG.CODE 15 16	ITEM	CARD NO 2	REQD PER SET
	-01		ROLL SHAFT						ø32x85–ALUMINUM 6063S–T5												



CHG.CODE 15 16	GROUP	DESCRIPTION	PAINT ALL FACES	PAINT BACK FACES	HT TR	OTHERS
			FINISH	FINISH		

STD.	TOLERANCE EXCEPT ENTRY IN DWG.		
PSTD.	PLASTIC	14	
	WORK	GRADE	
TEM.	CUTTING(S-1001)	MIDLE	ROUGH
	CASTING(S-1131)	GOOD	NORMAL
	PRESS(S-1251)	GOOD	[✓ NORMAL]

CHANGE *

KING MONGKUT'S INSTITUTE OF TECHNOLOGY
LADKRABANG

DIM.IN mm	DATE	05/01/2002
SCALE	DRAWN	ANAN K.
: NTS	CHECKED	TAWEE T.
	DESIGNED	ANAN K.

APPROVED KMITL JAN.26.2002 T. TAWEE

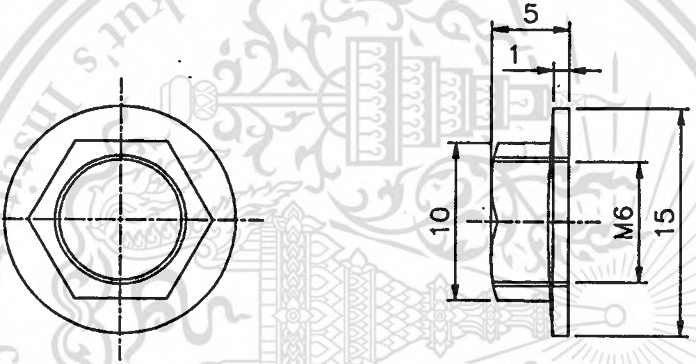
APPAR 6-AXES ROBOT
ITEM ROLL
TITLE ROLL SHAFT

BA001D056

(REVISION)
DWG.STATUS { STANDARD ..... 0 / PRE-STANDARD ..... 1 / TEMPORARY 2
CHG.CODE: A.Add D.Delete E.Change

DWG.NO. BA001D058 | 13 * | 14 0 | COMPONENT PART NO.
DEF { MFR : MAKE FROM / WRK : WORK INSTRUCTION   DWG : DRAWING / REF : REFERANCE

CHG.CODE 15 16	ITEM	CARD NO. 0	DESCRIPTION	DEF	MATERIAL CODE	G.NO.	L.NO	CARD NO 1	QUANTITY	MATERIAL CODE	LENGTH	UNIT	CUT	PUR	FINISH PAINT	FINISH OTHER	HT TR	CHG.CODE 15 16	ITEM	CARD NO 2	REQD PER SET
	-01		SHAFT NUT						M6												



CHG.CODE 15 16	GROUP	DESCRIPTION	PAINT ALL FACES	PAINT BACK FACES	HT TR	OTHERS
			FINISH			

STD.	TOLERANCE EXCEPT ENTRY IN DWG.	
PSTD.	PLASTIC	14
	WORK	GRADE
TEM.	CUTTING(S-1001)	MIDLE / ROUGH
	CASTING(S-1131)	GOOD / NORMAL
	PRESS(S-1251)	GOOD / [✓ NORMAL]

KING MONGKUT'S INSTITUTE OF TECHNOLOGY
LADKRABANG

DIM.IN mm	DATE	05/01/2002	APPROVED
SCALE	DRAWN	ANAN K.	KMITL JAN.26.2002 T. TAWEE
: NTS	CHECKED	TAWEE T.	
	DESIGNED	ANAN K.	

APPAR 6-AXES ROBOT
ITEM YAW
TITLE
SHAFT NUT

BA001D058

CHANGE *

(REVISION)

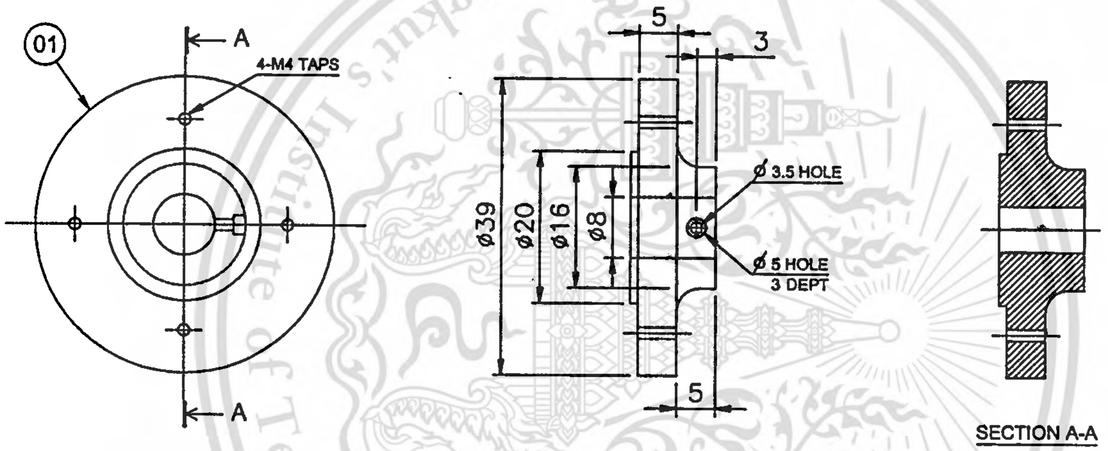
DWG.STATUS { STANDARD ..... 0 / PRE-STANDARD 1   TEMPORARY 2

CHG.CODE: A.Add D.Delete E.Change

DWG.NO. BA001D059 | 13 * | 14 0 | COMPONENT PART NO.

DEF { MFR : MAKE FROM / WRK : WORK INSTRUCTION   DWG : DRAWING / REF : REFERANCE

CHG.CODE 15 16	ITEM	CARD NO 0	DESCRIPTION	DEF	MATERIAL CODE	G.NO.	L.NO	CARD NO 1	QUANTITY	MATERIAL CODE	LENGTH	UNIT	CUT	PUR	FINISH PAINT	FINISH OTHER	HT TR	CHG.CODE 15 16	ITEM	CARD NO 2	REQD PER SET
	-01		TOOL FLANGE						ø39x14–ALUMINUM												



CHG.CODE 15 16	GROUP	DESCRIPTION	FINISH: PAINT ALL FACES	FINISH: PAINT BACK FACES	HT TR	OTHERS

STD.	TOLERANCE EXCEPT ENTRY IN DWG.	
PSTD.	PLASTIC	14
	WORK	GRADE
TEM.	CUTTING(S-1001) MIDLE	ROUGH
	CASTING(S-1131) GOOD	NORMAL
	PRESS(S-1251) GOOD	[✓ NORMAL]

CHANGE *

KING MONGKUT'S INSTITUTE OF TECHNOLOGY
LADKRABANG

DIM.IN mm	DATE	05/01/2002	APPROVED
SCALE	DRAWN	ANAN K.	KMITL JAN.26.2002 T. TAWEE
: NTS	CHECKED	TAWEE T.	
	DESIGNED	ANAN K.	

APPAR 6-AXES ROBOT | ITEM YAW

TITLE
TOOL FLANGE

BA001D059

(REVISION)

DWG.STATUS { STANDARD ..... 0 / PRE-STANDARD ..... 1 / TEMPORARY 2

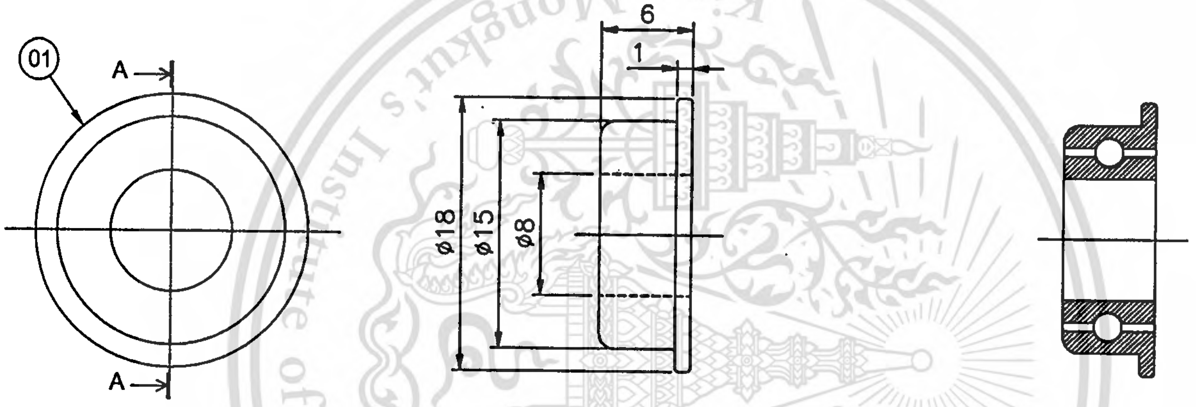
DWG.NO. BA001D061 | 13 * | 14 0

DEF { MFR : MAKE FROM / WRK : WORK INSTRUCTION — DWG : DRAWING / REF : REFERANCE

COMPONENT PART NO.

CHG.CODE 15 16	ITEM	CARD NO 0	DESCRIPTION	DEF	MATERIAL CODE	G.NO.	L.NO	CARD NO 1	QUANTITY	MATERIAL CODE	LENGTH	UNIT	CUT	PUR	FINISH PAINT	FINISH OTHER	HT TR	CHG.CODE 15 16	ITEM	CARD NO 2	REQD PER SET
	-01		BEARING						INSIDE DIA. ø8, OUTSIDE ø15												–

CHG.CODE: A.Add, D.Delete, E.Change



SECTION A-A

CHANGE *

CHG.CODE 15 16	GROUP	DESCRIPTION	FINISH PAINT ALL FACES	FINISH PAINT BACK FACES	HT TR	OTHERS

STD.	TOLERANCE EXCEPT ENTRY IN DWG.		
PSTD.	PLASTIC	14	
	WORK	GRADE	
TEM.	CUTTING(S-1001)	MIDLE	ROUGH
	CASTING(S-1131)	GOOD	NORMAL
	PRESS(S-1251)	GOOD	[✓ NORMAL]

KING MONGKUT'S INSTITUTE OF TECHNOLOGY
LADKRABANG

DIM.IN mm	DATE	05/01/2002
SCALE	DRAWN	ANAN K.
	CHECKED	TAWEE T.
: NTS	DESIGNED	ANAN K.

APPROVED KMITL JAN.26.2002 T. TAWEE

APPAR 6-AXES ROBOT
ITEM (COMMON)
TITLE BEARING

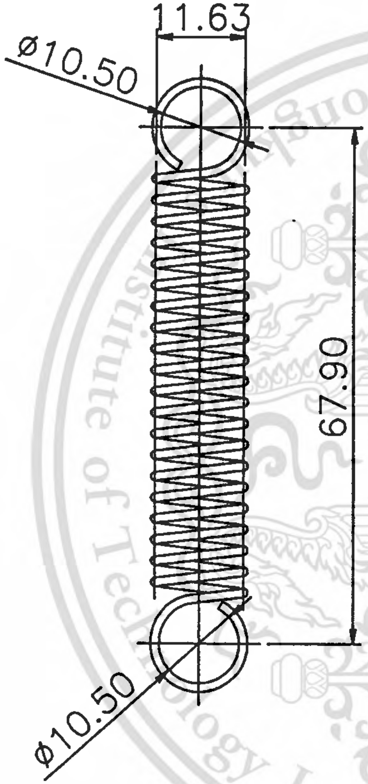
BA001D061

DWG.NO.	BA001D062	13 *	14 0	COMPONENT PART NO.	DEF { MFR : MAKE FROM WRK : WORK INSTRUCTION	DWG : DRAWING REF : REFERANCE

(REVISION)

DWG.STATUS { STANDARD ..... 0 / PRE-STANDARD ..... 1 / TEMPORARY 2

CHG.CODE 15 16	ITEM	CARD NO 0	DESCRIPTION	DEF	MATERIAL CODE	G.NO.	L.NO	CARD NO 1	QUANTITY	MATERIAL CODE	LENGTH	UNIT	CUT	PUR	FINISH PAINT	FINISH OTHER	HT TR	CHG.CODE 15 16	ITEM	CARD NO 2	REQD PER SET



CHG.CODE 15 16	GROUP	DESCRIPTION	PAINT ALL FACES	PAINT BACK FACES	HT TR	OTHERS

FINISH

STD.	TOLERANCE EXCEPT ENTRY IN DWG.	
	PLASTIC	14
PSTD.	WORK	GRADE
TEM.	CUTTING(S-1001)	MIDLE / ROUGH
	CASTING(S-1131)	GOOD / NORMAL
	PRESS(S-1251)	GOOD / NORMAL

KING MONGKUT'S INSTITUTE OF TECHNOLOGY
LADKRABANG

DIM.IN mm	DATE	05/01/2002	APPROVED
SCALE	DRAWN	ANAN K.	
: NTS	CHECKED	TAWEE T.	
	DESIGNED	ANAN K.	

KMITL
JAN.26.2002
T. TAWEE

APPAR 6-AXES ROBOT
ITEM (COMMON)
TITLE

TENSION SPRING

BA001D062

CHANGE
*

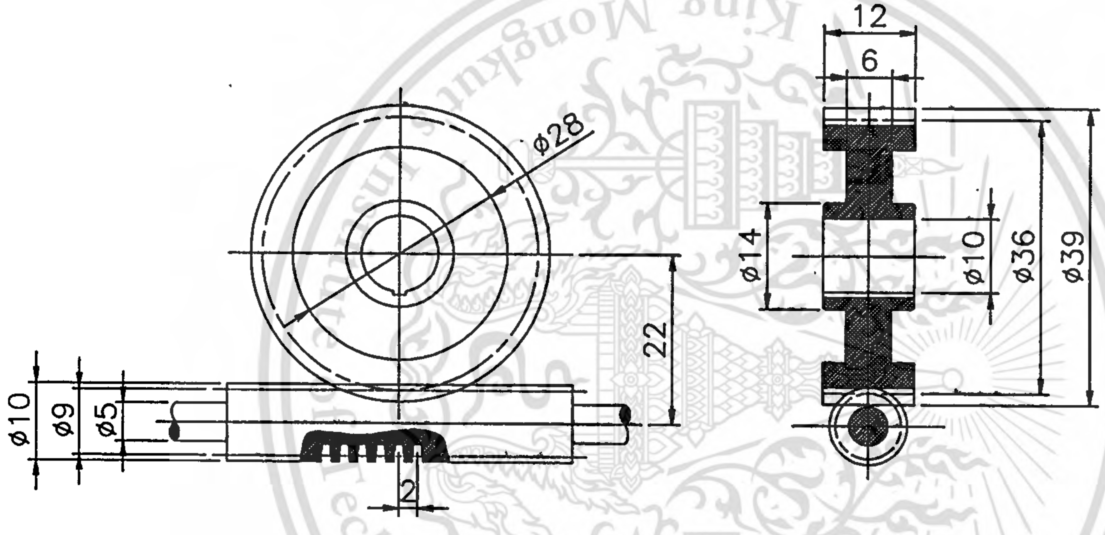
A.Add D.Delete E.Change

CHG.CODE A.Add D.Delete E.Change

(REVISION) DWG.STATUS { STANDARD ..... 0 PRE-STANDARD ..... 1 TEMPORARY 2

DWG.NO. BA001D064	*	0 COMPONENT PART NO.	DEF { MFR : MAKE FROM WRK : WORK INSTRUCTION	DWG : DRAWING REF : REFERANCE		

CHG.CODE	ITEM	CARD NO 0	DESCRIPTION	DEF	MATERIAL CODE	G.NO.	L.NO	CARD NO 1	QUANTITY	MATERIAL CODE	LENGTH	UNIT	CUT	PUR	FINISH PAINT	FINISH OTHER	HT TR	CHG.CODE	ITEM	CARD NO 2	REQD PER SET



CHG.CODE	GROUP	DESCRIPTION	PAINT ALL FACES	PAINT BACK FACES	HT TR	OTHERS
			FINISH			

STD.	TOLERANCE EXCEPT ENTRY IN DWG.	
PSTD.	PLASTIC	14
	WORK	GRADE
TEM.	CUTTING(S-1001)	MIDLE / ROUGH
	CASTING(S-1131)	GOOD / NORMAL
	PRESS(S-1251)	GOOD / NORMAL

KING MONGKUT'S INSTITUTE OF TECHNOLOGY
LADKRABANG

DIM.IN mm	DATE	05/01/2002	APPROVED
SCALE	DRAWN	ANAN K.	
: NTS	CHECKED	TAWEE T.	
	DESIGNED	ANAN K.	

KMITL
JAN.26.2002
T. TAWEE

APPAR 6-AXES ROBOT
ITEM (COMMON)
TITLE

WARM GEAR SET

BA001D064

CHANGE *

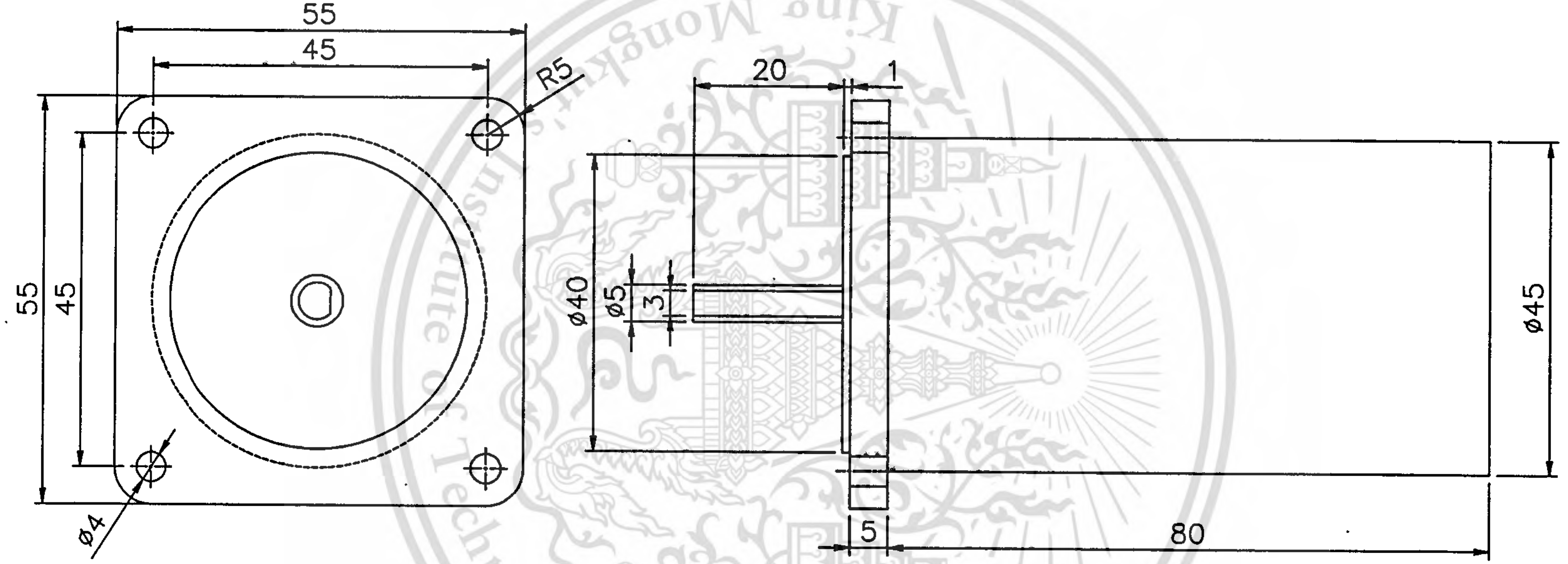
CHG.CODE A.Add D.Delete E.Change

(REVISION) DWG.STATUS { STANDARD ..... 0 PRE-STANDARD ..... 1 TEMPORARY 2

DEF { MFR : MAKE FROM WRK : WORK INSTRUCTION DWG : DRAWING REF : REFERANCE

DWG.NO.	BA001D065	*	0	COMPONENT PART NO.												
CHG.CODE	ITEM	CARD NO. 0	DESCRIPTION	DEF	MATERIAL CODE	G.NO.	L.NO	CARD NO. 1	QUANTITY	MATERIAL CODE	LENGTH	UNIT	CUT	PUR	FINISH PAINT	FINISH OTHER
	-01		STEPPER MOTOR						UNI-POLAR STEPPER MOTOR 12V 1.0A							

CHG.CODE	ITEM	CARD NO. 2	HT TR	REQD PER SET



CHG.CODE	GROUP	DESCRIPTION	PAINT ALL FACES	PAINT BACK FACES	HT TR	OTHERS
			FINISH			

STD.	TOLERANCE EXCEPT ENTRY IN DWG.		
PSTD.	PLASTIC	14	
	WORK	GRADE	
TEM.	CUTTING(S-1001)	MIDLE	ROUGH
	CASTING(S-1131)	GOOD	NORMAL
	PRESS(S-1251)	GOOD	NORMAL

CHANGE *

KING MONGKUT'S INSTITUTE OF TECHNOLOGY
LADKRABANG

DIM.IN mm	DATE	05/01/2002	APPROVED
SCALE	DRAWN	ANAN K.	KMITL JAN.26.2002 T. TAWEE
: NTS	CHECKED	TAWEE T.	
	DESIGNED	ANAN K.	

APPAR 6-AXES ROBOT
ITEM SWIVEL
TITLE

SWIVEL MOTOR

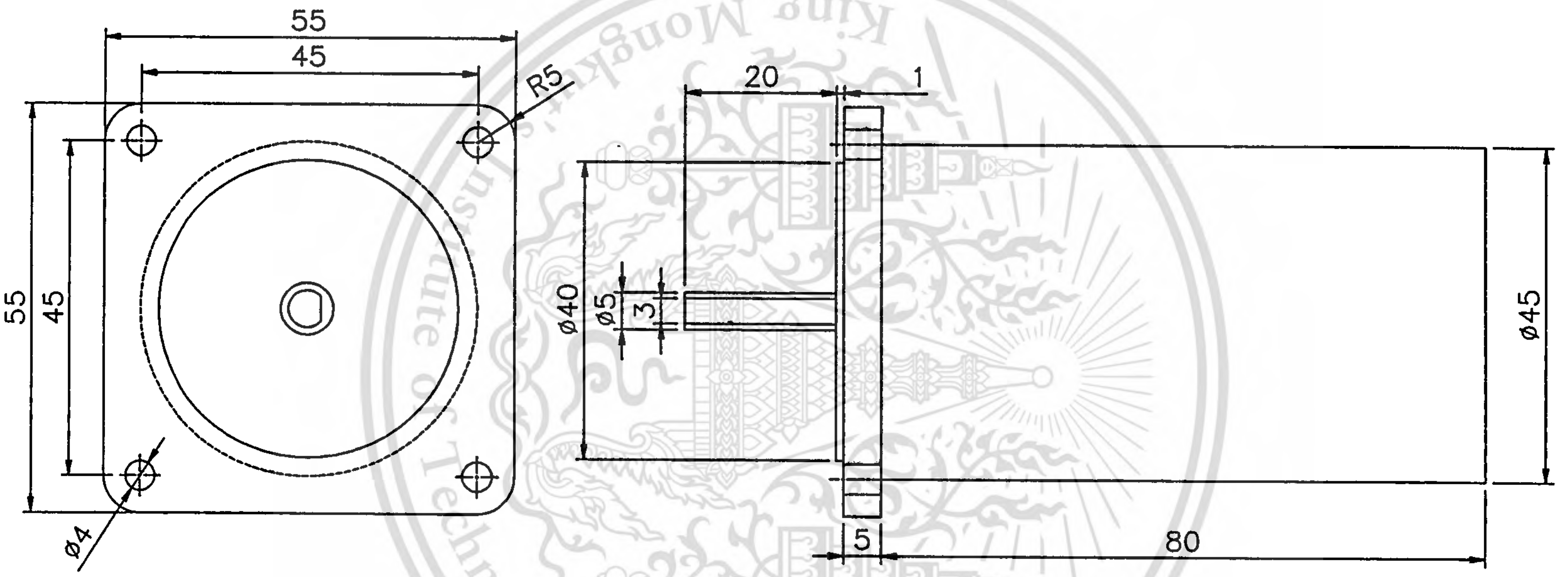
BA001D065

DWG.NO. BA001D066 (REVISION) * DWG.STATUS 0 { STANDARD ..... 0 PRE-STANDARD ..... 1 TEMPORARY ..... 2 }

COMPONENT PART NO.

DEF { MFR : MAKE FROM WRK : WORK INSTRUCTION } DWG : DRAWING REF : REFERANCE

CHG.CODE 15 16	ITEM	CARD NO 0	DESCRIPTION	DEF	MATERIAL CODE	G.NO.	L.NO	CARD NO 1	QUANTITY	MATERIAL CODE	LENGTH	UNIT	CUT	PUR	FINISH PAINT	FINISH OTHER	HT TR	CHG.CODE 15 16	ITEM	CARD NO 2	REQD PER SET
	-01		STEPPER MOTOR						UNI-POLAR STEPPER MOTOR 12V 1.0A												



CHG.CODE 15 16	GROUP	DESCRIPTION	PAINT ALL FACES	PAINT BACK FACES	HT TR	OTHERS
			FINISH	FINISH		

STD.	TOLERANCE EXCEPT ENTRY IN DWG.	
PSTD.	PLASTIC	14
	WORK	GRADE
TEM.	CUTTING(S-1001)	MIDLE / ROUGH
	CASTING(S-1131)	GOOD / NORMAL
	PRESS(S-1251)	GOOD / [✓ NORMAL]

KING MONGKUT'S INSTITUTE OF TECHNOLOGY
LADKRABANG

DIM.IN mm	DATE	05/01/2002	APPROVED KMITL JAN.26.2002 T. TAWEE
SCALE	DRAWN	ANAN K.	
: NTS	CHECKED	TAWEE T.	
	DESIGNED	ANAN K.	

APPAR 6-AXES ROBOT

ITEM LOWER ARM

TITLE

LOWER ARM MOTOR

BA001D066

CHANGE *

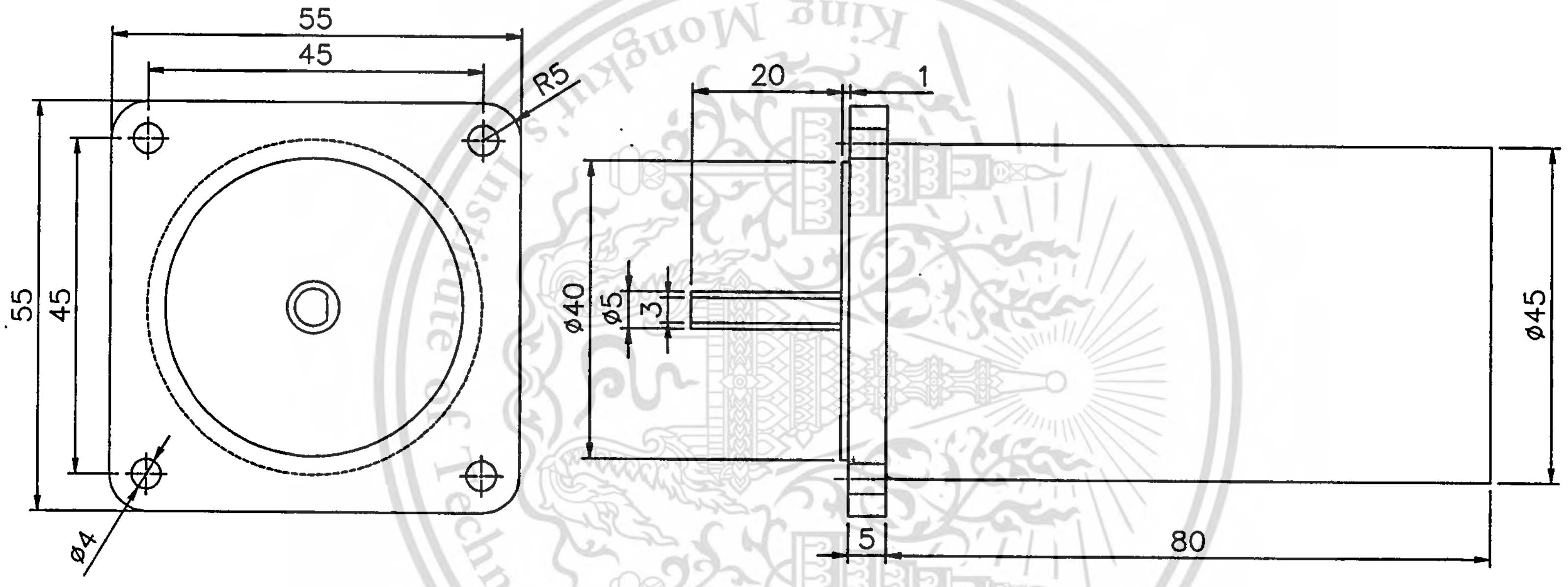
A.Add D.Delete E.Change

CHG.CODE A.Add D.Delete E.Change

(REVISION) DWG.STATUS { STANDARD ..... 0 PRE-STANDARD ..... 1 TEMPORARY 2

DEF { MFR : MAKE FROM WRK : WORK INSTRUCTION DWG : DRAWING REF : REFERANCE

DWG.NO.	BA001D067	*	0	COMPONENT PART NO.												
ITEM (CARD NO 0)	DESCRIPTION	DEF	MATERIAL CODE	G.NO.	L.NO (CARD NO 1)	QUANTITY	MATERIAL CODE	LENGTH	UNIT	CUT	PUR	FINISH PAINT	FINISH OTHER	HT TR	ITEM (CARD NO 2)	REQD PER SET
-01	STEPPER MOTOR					UNI-POLAR STEPPER MOTOR 12V 1.0A										



CHG.CODE 15 16	GROUP	DESCRIPTION	PAINT ALL FACES	PAINT BACK FACES	HT TR	OTHERS
			FINISH			

STD.	TOLERANCE EXCEPT ENTRY IN DWG.		
PSTD.	PLASTIC	14	
	WORK		GRADE
TEM.	CUTTING(S-1001)	MIDLE	ROUGH
	CASTING(S-1131)	GOOD	NORMAL
	PRESS(S-1251)	GOOD	NORMAL

CHANGE *

KING MONGKUT'S INSTITUTE OF TECHNOLOGY
LADKRABANG

DIM.IN mm	DATE	05/01/2002	APPROVED
SCALE	DRAWN	ANAN K.	KMITL JAN.26.2002 T. TAWEE
: NTS	CHECKED	TAWEE T.	
	DESIGNED	ANAN K.	

APPAR 6-AXES ROBOT
ITEM LOWER ARM
TITLE

UPPER ARM MOTOR

BA001D067

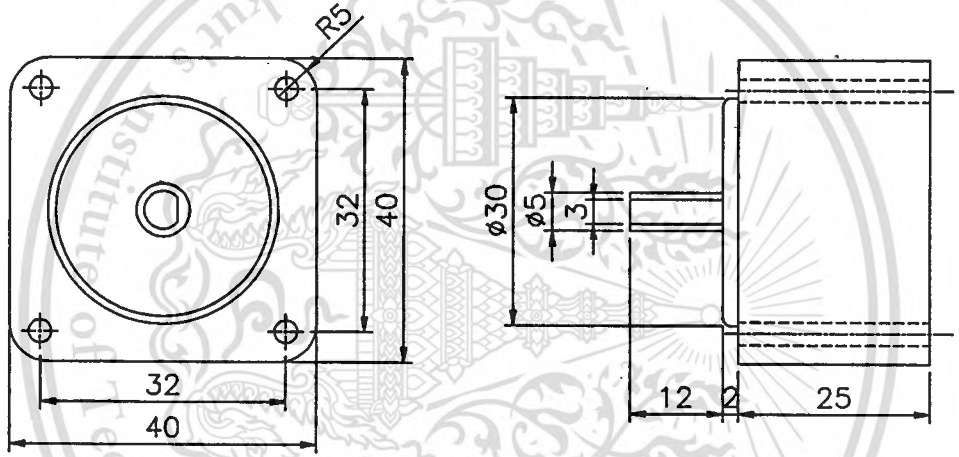
CHG.CODE A.Add D.Delete E.Change

(REVISION) DWG.STATUS { STANDARD .... 0 PRE-STANDARD .... 1 TEMPORARY 2

DWG.NO. BA001D068 * 0 COMPONENT PART NO.

DEF { MFR : MAKE FROM WRK : WORK INSTRUCTION DWG : DRAWING REF : REFERANCE

CHG.CODE	ITEM	CARD NO. 0	DESCRIPTION	DEF	MATERIAL CODE	G.NO.	L.NO	CARD NO. 1	QUANTITY	MATERIAL CODE	LENGTH	UNIT	CUT	PUR	FINISH PAINT	FINISH OTHER	HT TR	CHG.CODE	ITEM	CARD NO. 2	REQD PER SET
	-01		STEPPER MOTOR						UNI-POLAR STEPPER MOTOR 12V 0.5A												



CHG.CODE	GROUP	DESCRIPTION	PAINT ALL FACES	PAINT BACK FACES	HT TR	OTHERS
			FINISH	FINISH		

STD.	TOLERANCE EXCEPT ENTRY IN DWG.		
	PLASTIC	14	
PSTD.	WORK	GRADE	
TEM.	CUTTING(S-1001)	MIDLE	ROUGH
	CASTING(S-1131)	GOOD	NORMAL
	PRESS(S-1251)	GOOD	NORMAL

CHANGE *

KING MONGKUT'S INSTITUTE OF TECHNOLOGY
LADKRABANG

APPAR 6-AXES ROBOT
ITEM WRIST
TITLE PITCH MOTOR

DIM.IN mm	DATE	05/01/2002	APPROVED
SCALE	DRAWN	ANAN K.	
: NTS	CHECKED	TAWEE T.	
	DESIGNED	ANAN K.	

APPROVED KMITL JAN.26.2002 T. TAWEE

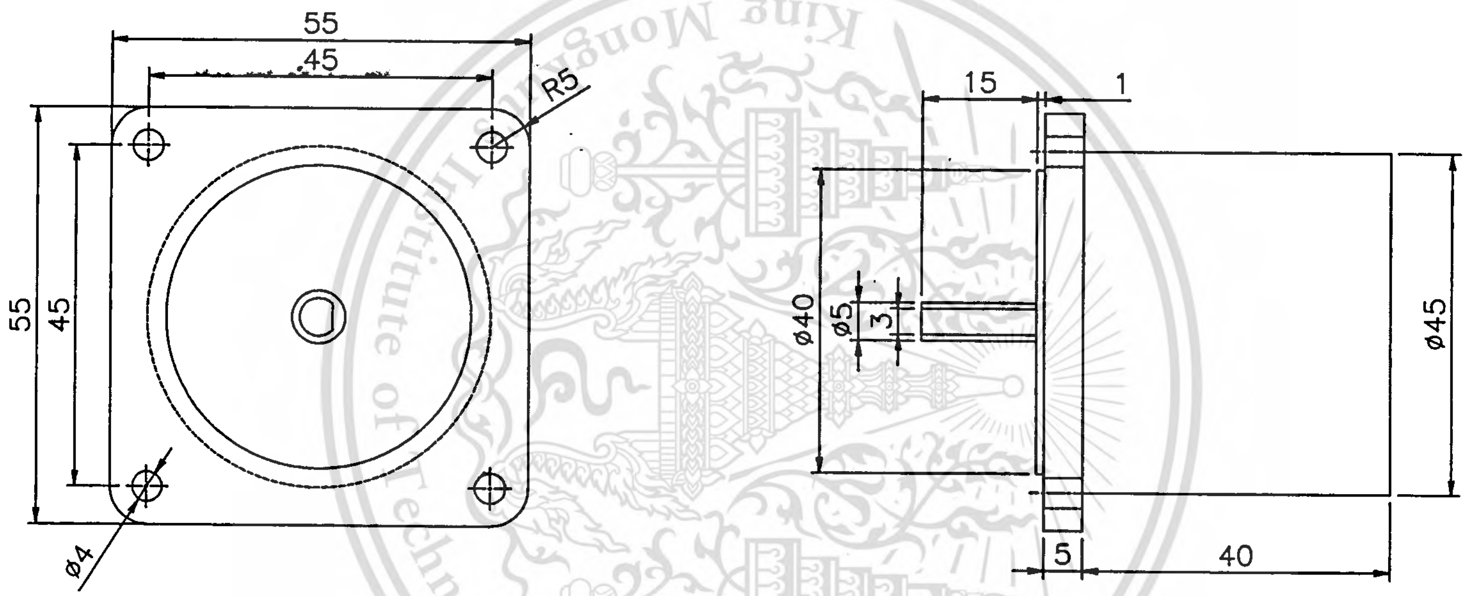
BA001D068

(REVISION) DWG.STATUS { STANDARD ..... 0 / PRE-STANDARD ..... 1 } TEMPORARY 2

CHG.CODE A.Add D.Delete E.Change

DEF { MFR : MAKE FROM / WRK : WORK INSTRUCTION } DWG : DRAWING / REF : REFERANCE

DWG.NO.	BA001D069	*	0	COMPONENT PART NO.												
CHG.CODE 15 16	ITEM CARD NO 0	DESCRIPTION	DEF	MATERIAL CODE	G.NO.	L.NO CARD NO 1	QUANTITY	MATERIAL CODE	LENGTH	UNIT	CUT PUR	FINISH PAINT	FINISH OTHER	HT TR	CHG.CODE 15 16 ITEM CARD NO 2	REQD PER SET
	-01	STEPPER MOTOR					UNI-POLAR STEPPER MOTOR 12V 0.7A									



CHG.CODE 15 16	GROUP	DESCRIPTION	PAINT ALL FACES	PAINT BACK FACES	HT TR	OTHERS
			FINISH			

STD.	TOLERANCE EXCEPT ENTRY IN DWG.	
	PLASTIC	14
PSTD.	WORK	GRADE
TEM.	CUTTING(S-1001)	MIDLE / ROUGH
	CASTING(S-1131)	GOOD / NORMAL
	PRESS(S-1251)	GOOD / [✓ NORMAL]

KING MONGKUT'S INSTITUTE OF TECHNOLOGY	APPAR 6-AXES ROBOT
LADKRABANG	ITEM YAW
DIM.IN mm	TITLE YAW MOTOR
SCALE : NTS	
DATE	05/01/2002
DRAWN	ANAN K.
CHECKED	TAWEE T.
DESIGNED	ANAN K.
APPROVED	KMITL JAN.26.2002 T. TAWEE

BA001D069

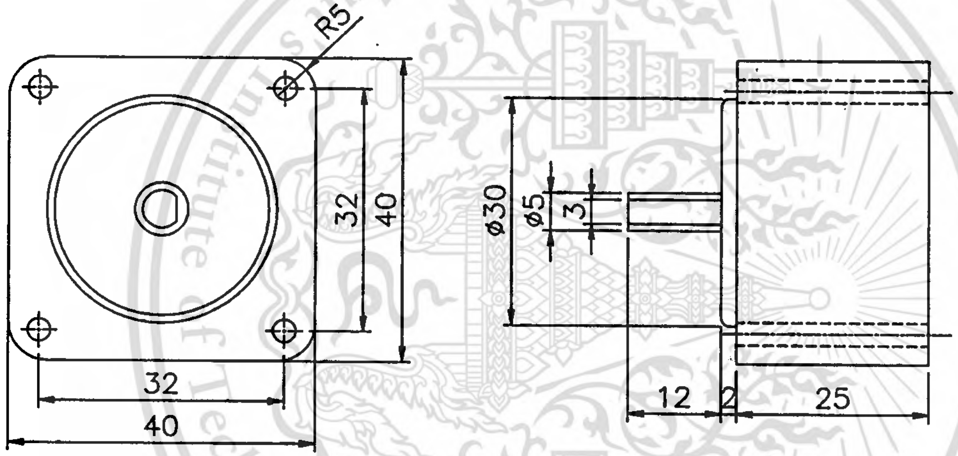
CHANGE *

(REVISION) DWG.STATUS { STANDARD ..... 0 / PRE-STANDARD ..... 1 / TEMPORARY 2

DWG.NO. BA001D070 * 0 COMPONENT PART NO.

DEF { MFR : MAKE FROM / WRK : WORK INSTRUCTION   DWG : DRAWING / REF : REFERANCE

CHG.CODE 15 16	ITEM	CARD NO 0	DESCRIPTION	DEF	MATERIAL CODE	G.NO.	L.NO	CARD NO 1	QUANTITY	MATERIAL CODE	LENGTH	UNIT	CUT	PUR	FINISH PAINT	FINISH OTHER	HT TR	CHG.CODE 15 16	ITEM	CARD NO 2	REQD PER SET
	-01		STEPPER MOTOR						UNI-POLAR STEPPER MOTOR 12V 0.5A												



CHG.CODE 15 16	GROUP	DESCRIPTION	PAINT ALL FACES	PAINT BACK FACES	HT TR	OTHERS
			FINISH			

STD. TOLERANCE EXCEPT ENTRY IN DWG.

	PLASTIC	14
PSTD.	WORK	GRADE
TEM.	CUTTING(S-1001)	MIDLE	ROUGH
	CASTING(S-1131)	GOOD	NORMAL
	PRESS(S-1251)	GOOD	[✓ NORMAL]

KING MONGKUT'S INSTITUTE OF TECHNOLOGY
LADKRABANG

DIM.IN mm	DATE	05/01/2002
SCALE	DRAWN	ANAN K.
: NTS	CHECKED	TAWEE T.
	DESIGNED	ANAN K.

APPROVED KMITL JAN.26.2002 T. TAWEE

APPAR 6-AXES ROBOT ITEM ROLL

TITLE ROLL MOTOR

BA001D070

CHANGE *

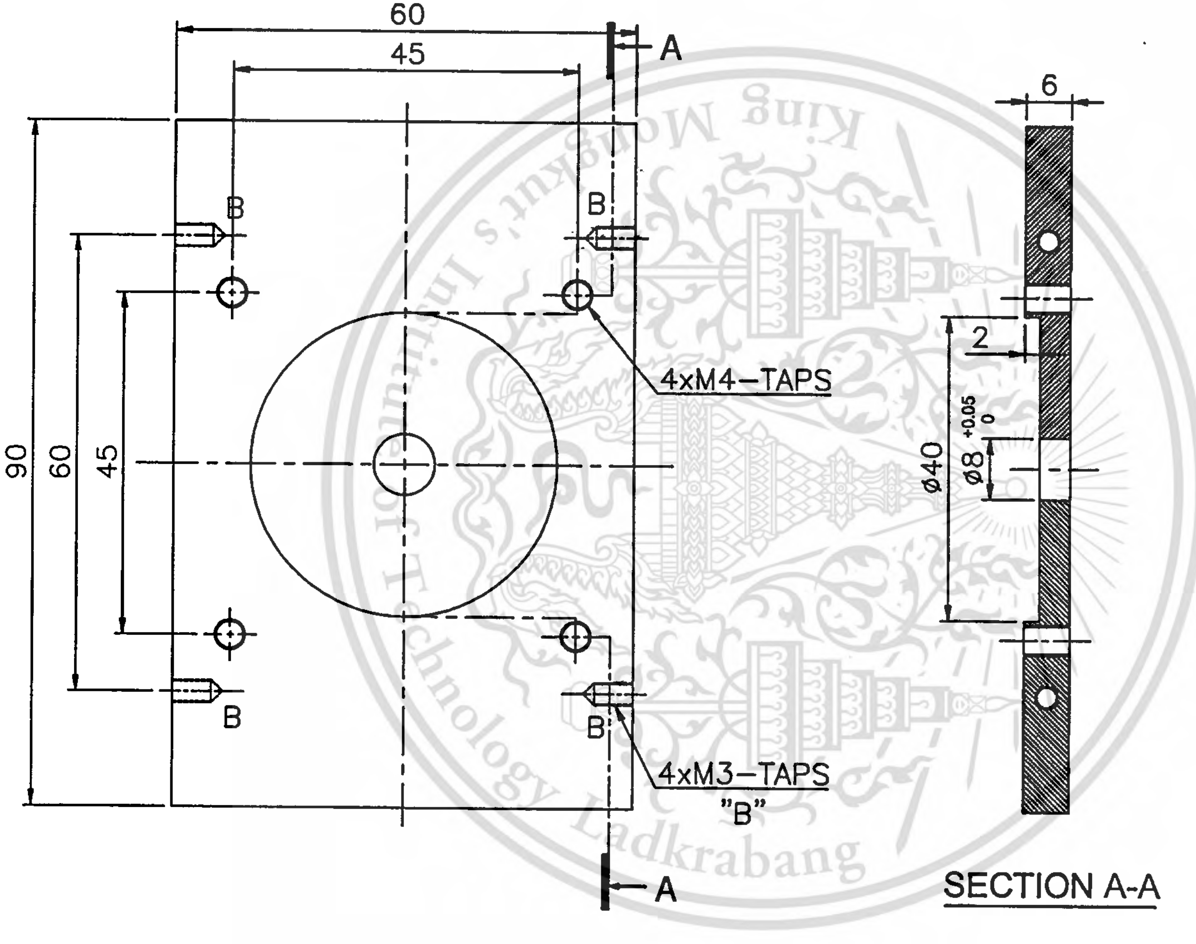
CHG.CODE A.Add D.Delete E.Change

1 (REVISION) DWG.STATUS { STANDARD ..... 0 PRE-STANDARD ..... 1 TEMPORARY 2

CHG.CODE A.Add D.Delete E.Change

DWG.NO.	BA001D072	*	0	COMPONENT PART NO.	DEF { MFR : MAKE FROM WRK : WORK INSTRUCTION	DWG : DRAWING REF : REFERANCE

CHG.CODE 15 16	ITEM	CARD NO 0	DESCRIPTION	DEF	MATERIAL CODE	G.NO.	L.NO	CARD NO 1	QUANTITY	MATERIAL CODE	LENGTH	UNIT	CUT	PUR	FINISH PAINT	FINISH OTHER	HT TR	CHG.CODE 15 16	ITEM	CARD NO. 2	REQD PER SET
	-01		MOTOR PLATE						60X90-ALUMINUM A6063S-T5 t6.0												



SECTION A-A

STD.	TOLERANCE EXCEPT ENTRY IN DWG.	
PSTD.	PLASTIC	14
	WORK	GRADE
TEM.	CUTTING(S-1001)	MIDLE ROUGH
	CASTING(S-1131)	GOOD NORMAL
	PRESS(S-1251)	GOOD [✓ NORMAL]

CHANGE	*

KING MONGKUT'S INSTITUTE OF TECHNOLOGY
LADKRABANG

DIM.IN mm	DATE	05/01/2002	APPROVED
SCALE	DRAWN	ANAN K.	KMITL JAN.26.2002 T. TAWEE
1 : 1	CHECKED	TAWEE T.	
	DESIGNED	ANAN K.	

APPAR 6-AXES ROBOT

ITEM LOWER ARM UPPER ARM

TITLE

MOTOR PLATE

BA001D072

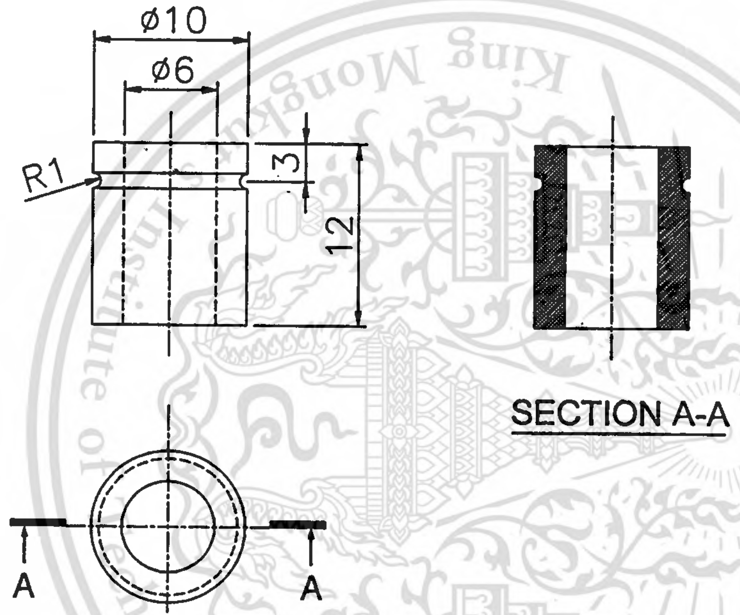
(REVISION) DWG.STATUS { STANDARD .... 0 PRE-STANDARD .... 1 TEMPORARY 2

DWG.NO. BA001D073 * 0

COMPONENT PART NO.

DEF { MFR : MAKE FROM WRK : WORK INSTRUCTION DWG : DRAWING REF : REFERANCE

ITEM	DESCRIPTION	DEF	MATERIAL CODE	G.NO.	L.NO	QUANTITY	MATERIAL CODE	LENGTH	UNIT	CUT	PUR	FINISH PAINT	FINISH OTHER	HT TR	ITEM	REQD PER SET
-01	SPRING HANGER					ø10X12-ALUMINUM	A6063S-T5									



CHG.CODE A.Add D.Delete E.Change

CHANGE

CHG.CODE	GROUP	DESCRIPTION	PAINT ALL FACES	PAINT BACK FACES	HT TR	OTHERS
			FINISH			

STD.	TOLERANCE EXCEPT ENTRY IN DWG.		
PSTD.	PLASTIC	14	
	WORK	GRADE	
TEM.	CUTTING(S-1001)	MIDLE	ROUGH
	CASTING(S-1131)	GOOD	NORMAL
	PRESS(S-1251)	GOOD	[✓ NORMAL]

KING MONGKUT'S INSTITUTE OF TECHNOLOGY
LADKRABANG

DIM.IN mm	DATE	05/01/2002	APPROVED
SCALE	DRAWN	ANAN K.	KMITL JAN.26.2002 T. TAWEE
: NTS	CHECKED	TAWEE T.	
	DESIGNED	ANAN K.	

APPAR 6-AXES ROBOT

ITEM (COMMON)

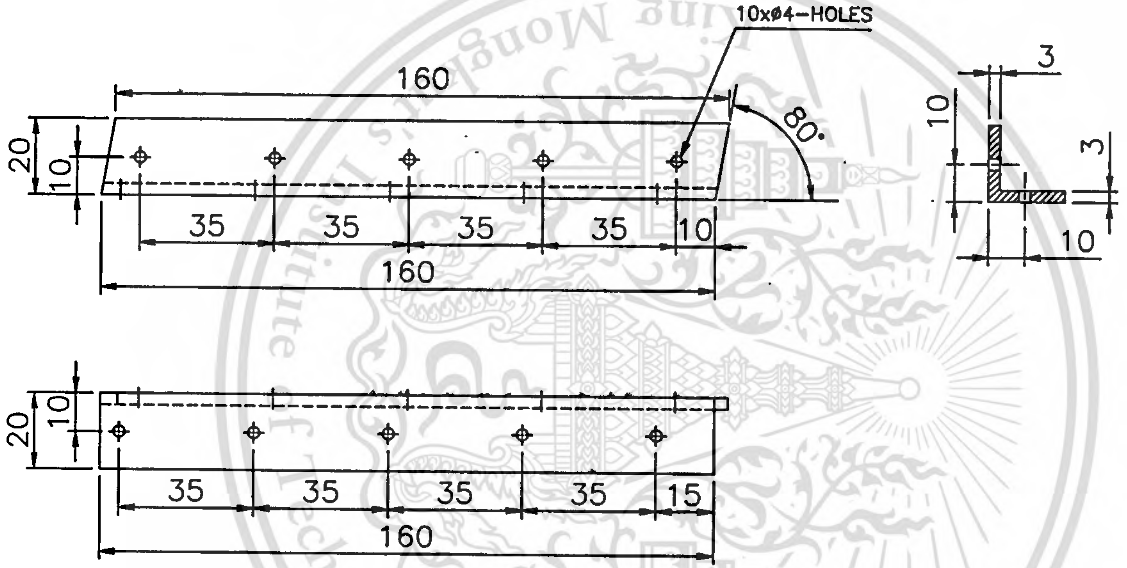
TITLE SPRING HANGER

BA001D073

(REVISION) DWG.STATUS { STANDARD .... 0 PRE-STANDARD .... 1 TEMPORARY 2

DEF { MFR : MAKE FROM WRK : WORK INSTRUCTION DWG : DRAWING REF : REFERANCE

DWG.NO.	BA001D074	*	0	COMPONENT PART NO.													
ITEM	CARD NO 0	DESCRIPTION	DEF	MATERIAL CODE	G.NO.	L.NO	CARD NO 1	QUANTITY	MATERIAL CODE	LENGTH	UNIT	CUT	PUR	FINISH PAINT	FINISH OTHER	HT TR	ITEM CARD NO 2 REQD PER SET
-01		SIDE PLATE SUPPORT (R)						165x34-ALUMINUM A6063S-T5 t3.0									



CHG.CODE	GROUP	DESCRIPTION	PAINT ALL FACES	PAINT BACK FACES	HT TR	OTHERS
			FINISH			

STD.	TOLERANCE EXCEPT ENTRY IN DWG.		
PSTD.	PLASTIC	14	
	WORK	GRADE	
TEM.	CUTTING(S-1001)	MIDLE	ROUGH
	CASTING(S-1131)	GOOD	NORMAL
	PRESS(S-1251)	GOOD	[✓ NORMAL]

CHANGE *

KING MONGKUT'S INSTITUTE OF TECHNOLOGY
LADKRABANG

DIM.IN mm	DATE	05/01/2002	APPROVED
SCALE	DRAWN	ANAN K.	AMITL JAN.26.2002 T. TAWEE
: NTS	CHECKED	TAWEE T.	
	DESIGNED	ANAN K.	

APPAR 6-AXES ROBOT
ITEM SWIVEL

TITLE
SIDE PLATE SUPPORT (R)

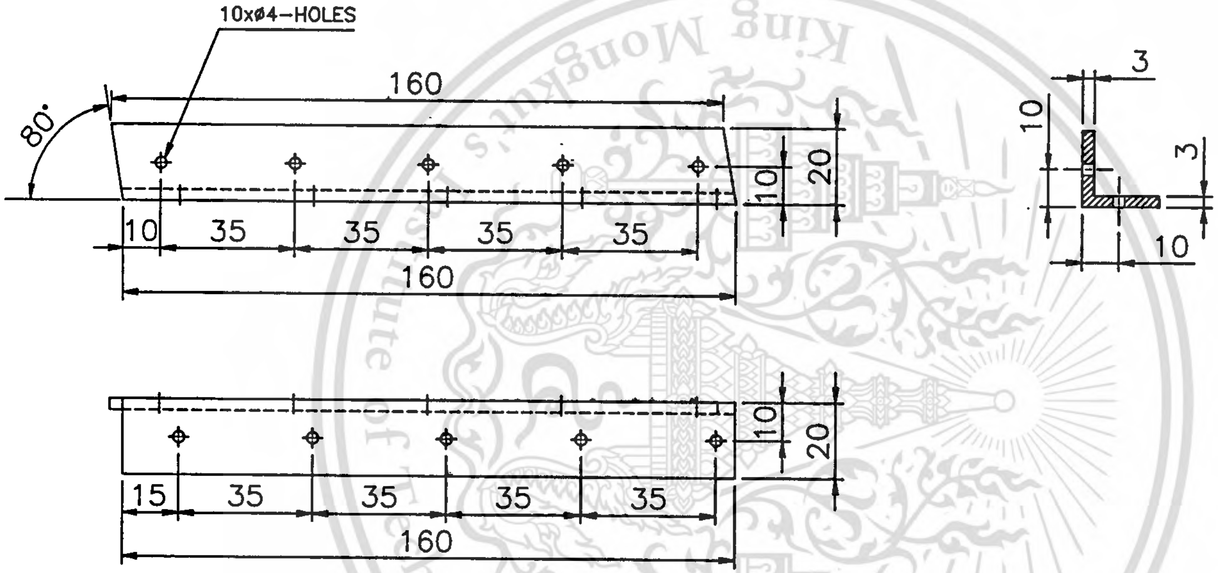
BA001D074

(REVISION) DWG.STATUS { STANDARD ..... 0 PRE-STANDARD ..... 1 TEMPORARY 2

DEF { MFR : MAKE FROM WRK : WORK INSTRUCTION DWG : DRAWING REF : REFERANCE

DWG.NO.	BA001D075	*	0	COMPONENT PART NO.

CHG.CODE	ITEM	CARD NO. 0	DESCRIPTION	DEF	MATERIAL CODE	G.NO.	L.NO	CARD NO. 1	QUANTITY	MATERIAL CODE	LENGTH	UNIT	CUT	PUR	FINISH PAINT	FINISH OTHER	HT TR	CHG.CODE	ITEM	CARD NO. 2	REQD PER SET
	-01		SIDE PLATE SUPPORT (L)						165x34-ALUMINUM A6063S-T5 t3.0												



CHG.CODE	GROUP	DESCRIPTION	PAINT ALL FACES	PAINT BACK FACES	HT TR	OTHERS
			FINISH	FINISH		

STD.	TOLERANCE EXCEPT ENTRY IN DWG.	
PSTD.	PLASTIC	14
TEM.	WORK	GRADE
	CUTTING(S-1001)	MIDLE | ROUGH
	CASTING(S-1131)	GOOD | NORMAL
	PRESS(S-1251)	GOOD | [✓ NORMAL]

CHANGE *

KING MONGKUT'S INSTITUTE OF TECHNOLOGY LADKRABANG			
DIM.IN mm	DATE	05/01/2002	APPROVED KMITL JAN.26.2002 T. TAWEE
SCALE	DRAWN	ANAN K.	
: NTS	CHECKED	TAWEE T.	
	DESIGNED	ANAN K.	

APPAR 6-AXES ROBOT

ITEM SWIVEL

TITLE

SIDE PLATE SUPPORT (L)

BA001D075

DWG.STATUS { STANDARD ..... 0 / PRE-STANDARD ..... 1 / TEMPORARY 2

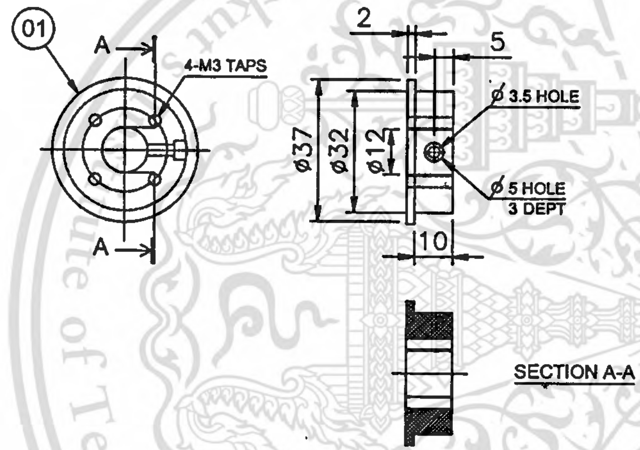
(REVISION) *

DWG.NO. BA001D076 | 0

DEF { MFR : MAKE FROM / WRK : WORK INSTRUCTION | DWG : DRAWING / REF : REFERANCE

CHG.CODE	ITEM	CARD NO 0	DESCRIPTION	DEF	MATERIAL CODE	G.NO.	L.NO	CARD NO 1	QUANTITY	MATERIAL CODE	LENGTH	UNIT	CUT	PUR	FINISH PAINT	FINISH OTHER	HT TR	CHG.CODE	ITEM	CARD NO 2	REQD PER SET
	-01		LOCK-GEAR PLATE						ø60x140-ALUMINUM												

CHG.CODE: A.Add D.Delete E.Change



CHG.CODE	GROUP	DESCRIPTION	FINISH: PAINT ALL FACES	FINISH: PAINT BACK FACES	HT TR	OTHERS

STD. | TOLERANCE EXCEPT ENTRY IN DWG.
PLASTIC | 14
PSTD. | WORK | GRADE
TEM. | CUTTING(S-1001) MIDLE ROUGH
CASTING(S-1131) GOOD NORMAL
PRESS(S-1251) GOOD [✓ NORMAL]

CHANGE *

KING MONGKUT'S INSTITUTE OF TECHNOLOGY
LADKRABANG

DIM.IN mm	DATE	05/01/2002	APPROVED
SCALE	DRAWN	ANAN K.	
: NTS	CHECKED	TAWEE T.	
	DESIGNED	ANAN K.	

KMITL
JAN.26.2002
T. TAWEE

APPAR 6-AXES ROBOT | ITEM COMMON

TITLE LOCK GEAR PLATE

BA001D076

APPENDIX B

Programming flow chart

Programming flow chart

To describe the outline of robot controlled programming, controlled flow charts are presented as figure B.1 ~B.5. And the displays of developed program are shown as in figure B.6 and figure B.7.

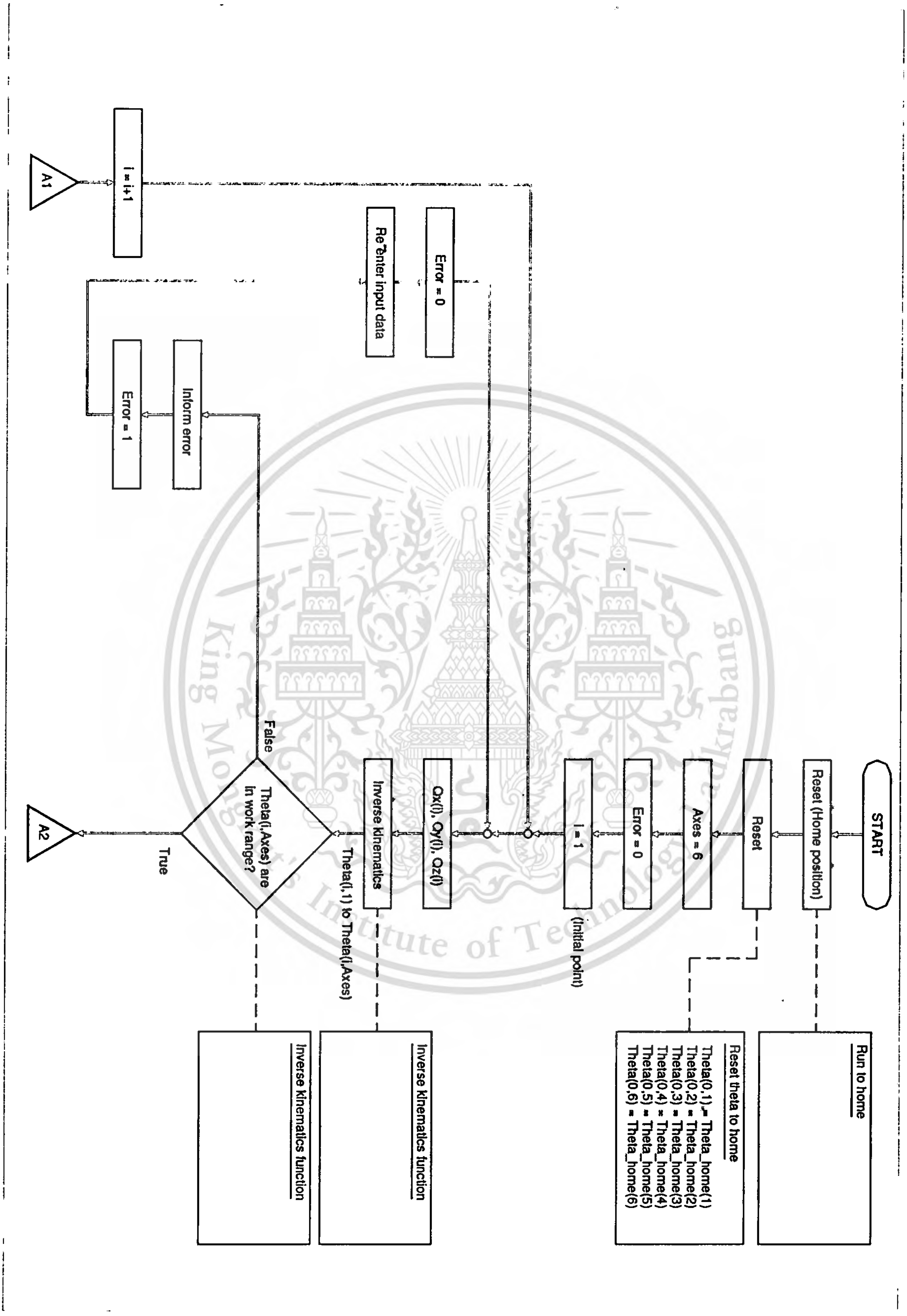


Figure B.1 Programming flow chat for 6-axes robot control (page 1)

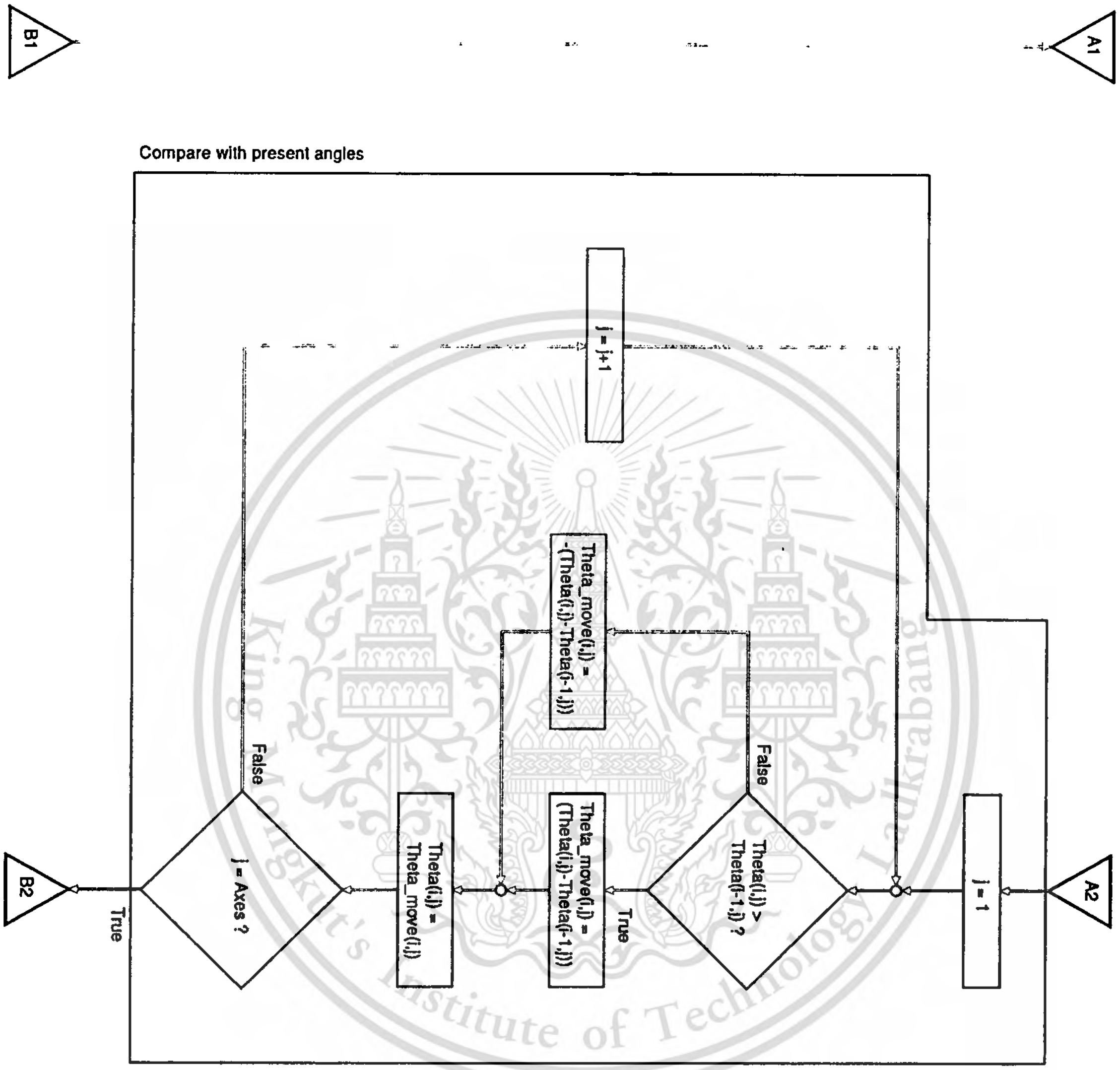


Figure B.2 Programming flow chat for 6-axes robot control (page 2)

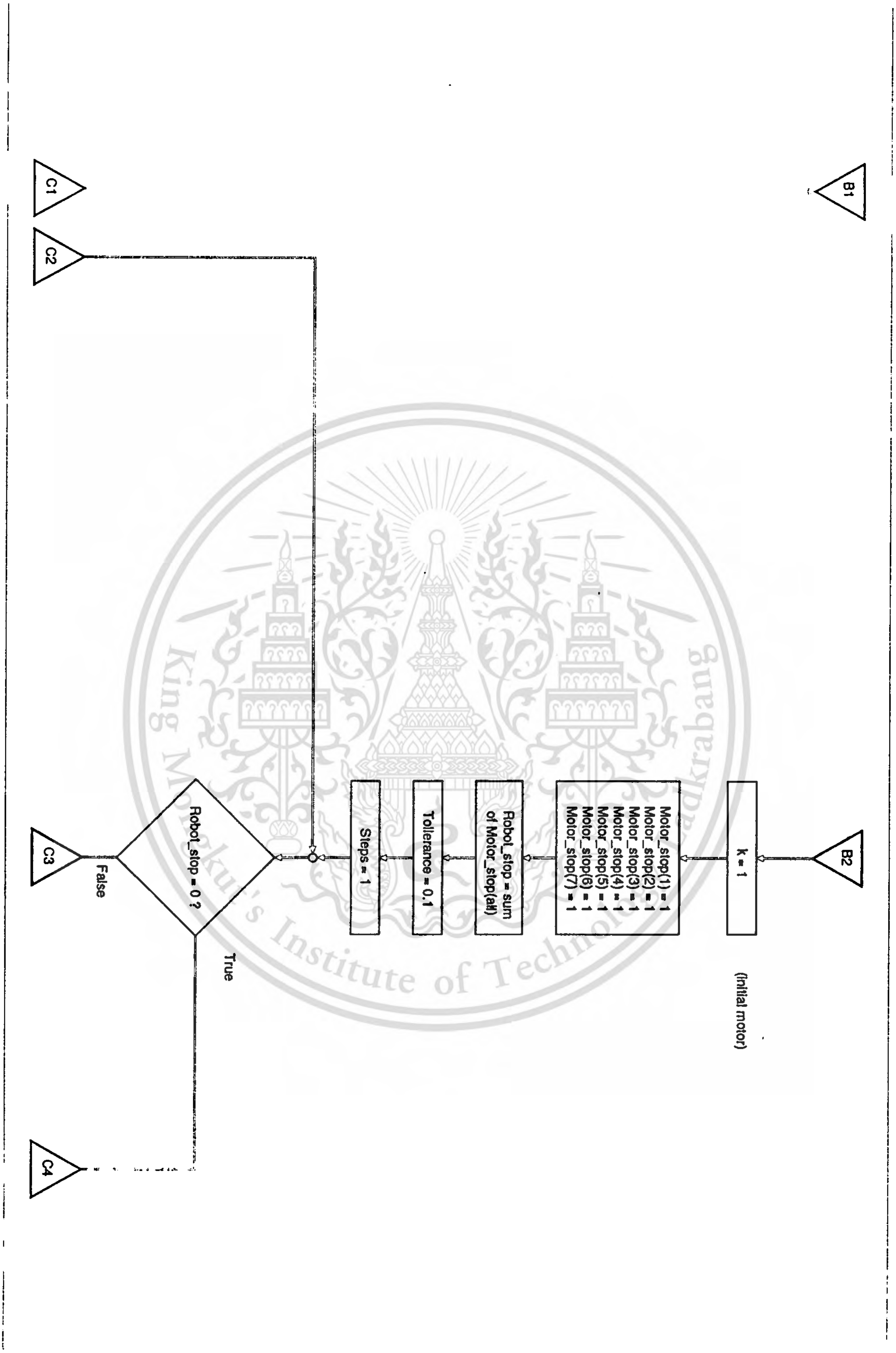


Figure B.3 Programming flow chat for 6-axes robot control (page 3)

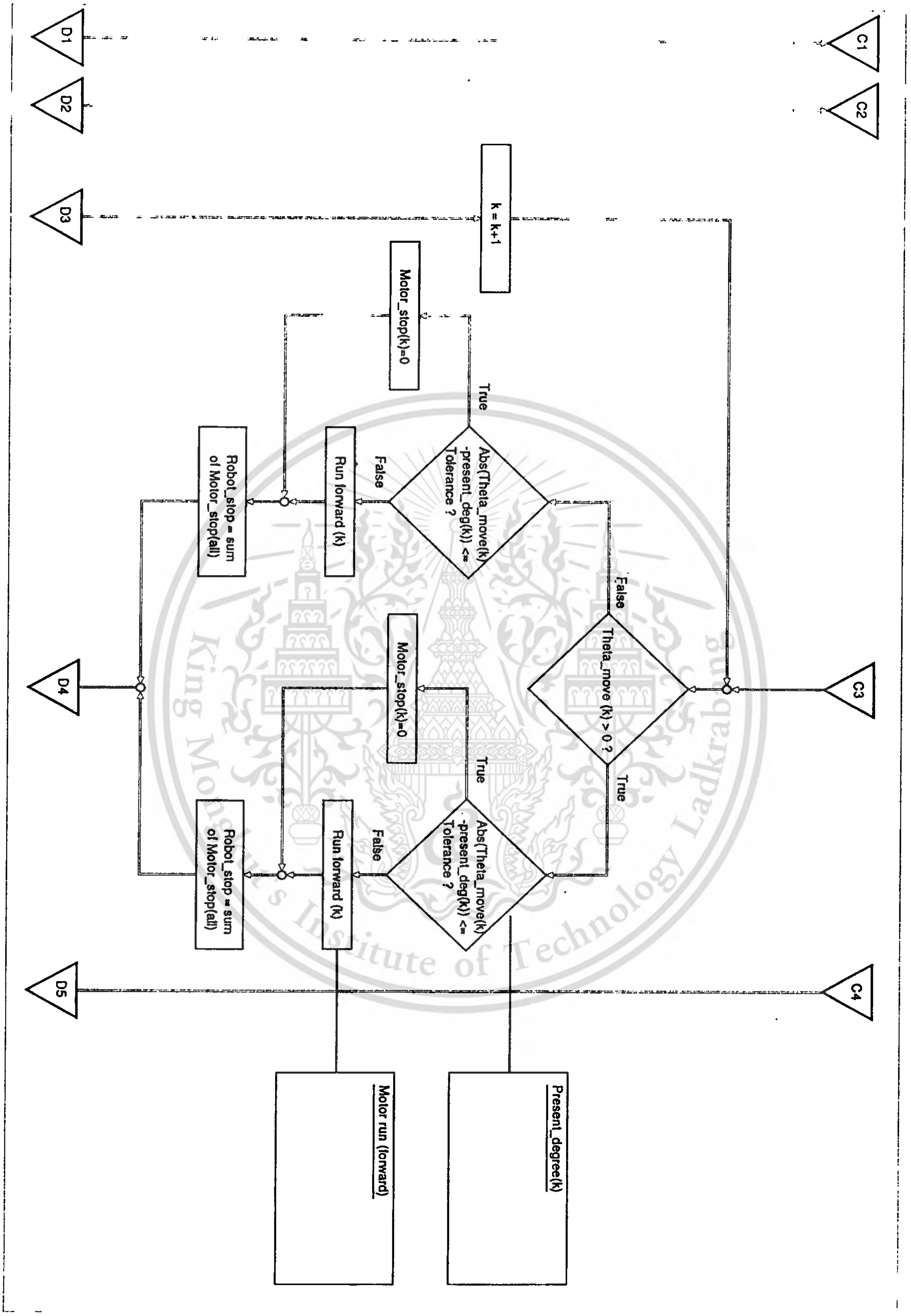


Figure B.4 Programming flow chat for 6-axes robot control (page 4)

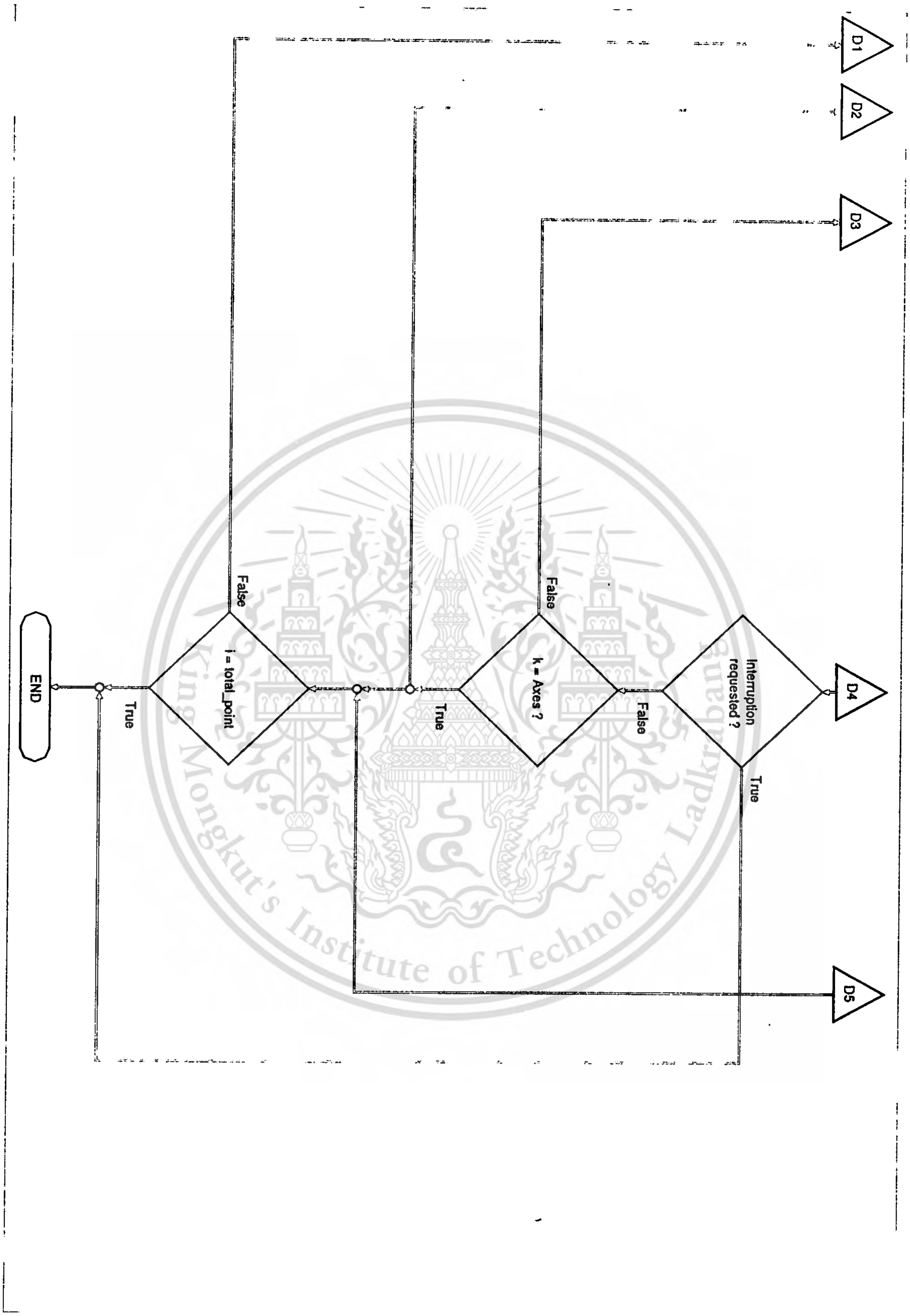
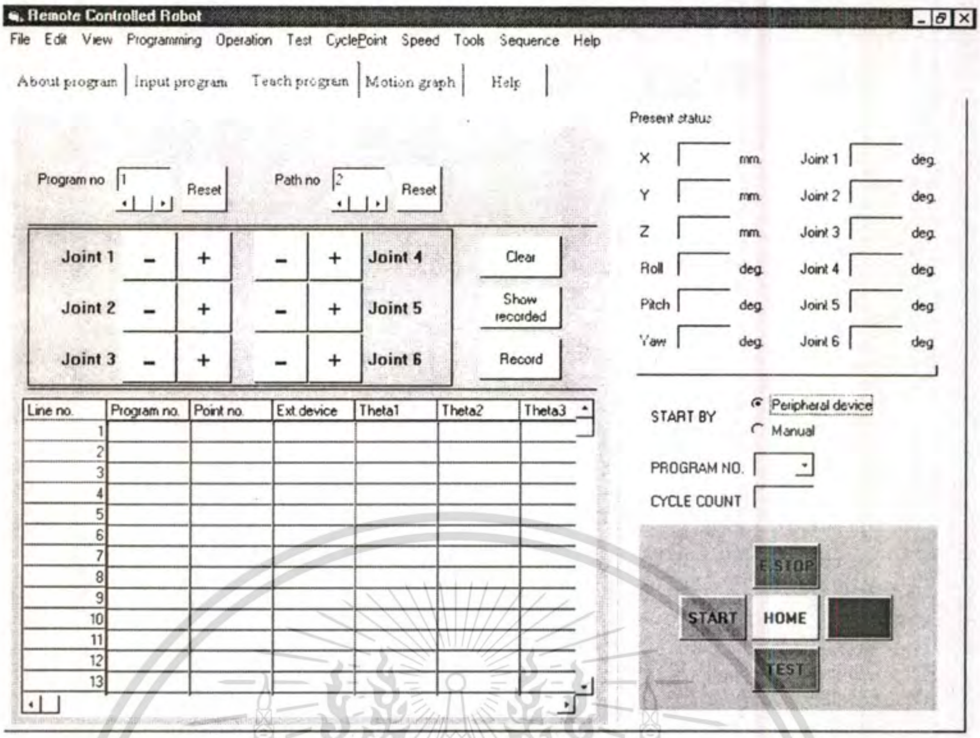


Figure B.5 Programming flow chat for 6-axes robot control (page 5)



Program no 1

Path no 2

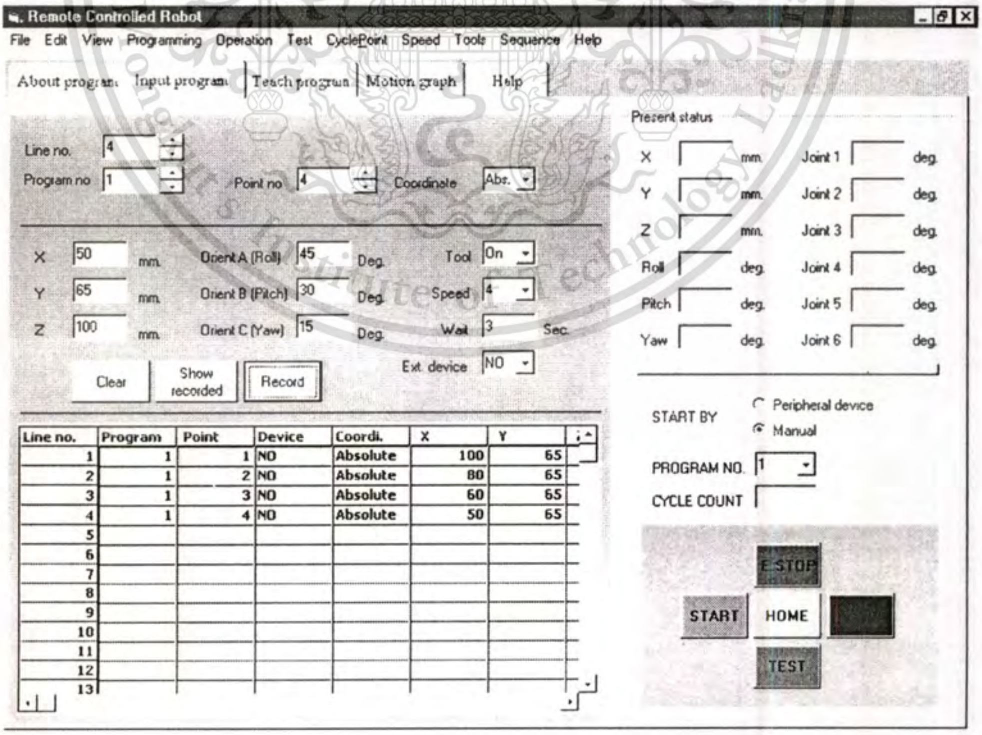
START BY ● Peripheral device ○ Manual

PROGRAM NO.

CYCLE COUNT

Line no.	Program no.	Point no.	Ext device	Theta1	Theta2	Theta3
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						

Figure B.6 Window of developed program (joint control window)



Line no. 4

Program no 1

Point no 4

Coordinate Abs.

X 50 mm.

Y 65 mm.

Z 100 mm.

Orient A (Roll) 45 Deg.

Orient B (Pitch) 30 Deg.

Orient C (Yaw) 15 Deg.

Tool On

Speed 4

Wait 3 Sec.

Ext. device NO

START BY ○ Peripheral device ● Manual

PROGRAM NO. 1

CYCLE COUNT

Line no.	Program	Point	Device	Coordi.	X	Y
1	1	1	NO	Absolute	100	65
2	1	2	NO	Absolute	80	65
3	1	3	NO	Absolute	60	65
4	1	4	NO	Absolute	50	65
5						
6						
7						
8						
9						
10						
11						
12						
13						

Figure B.7 Window of developed program (point control window)

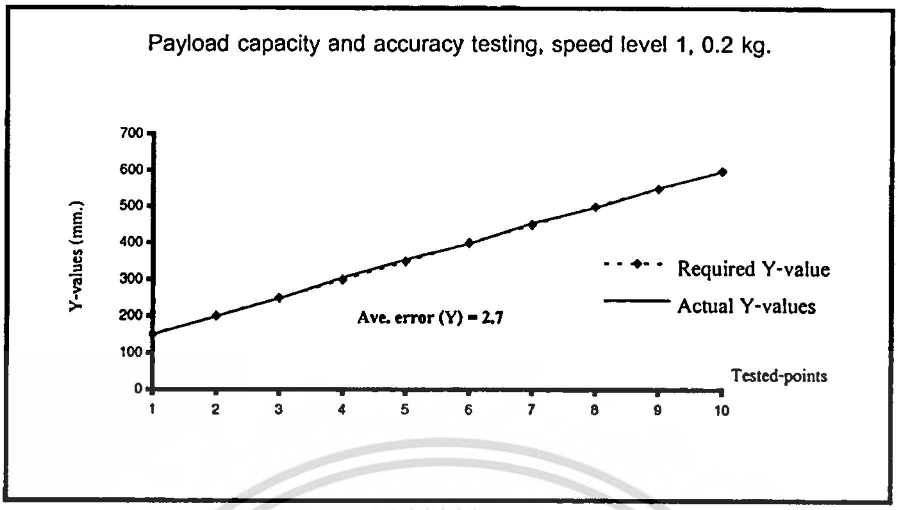
APPENDIX C

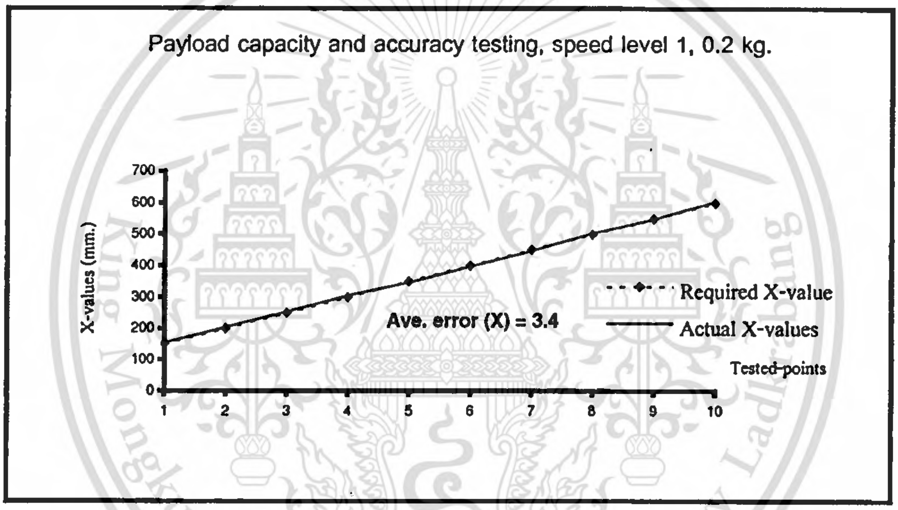
Experimental data

Graphs of payload capacity and accuracy testing

Payload capability and accuracy testing are experimented by change speeds and loads as following.

1. Speed on level 1 (5 degree/sec.) with load 0.2 kg.
2. Speed on level 1 (5 degree/sec.) with load 0.3 kg.
3. Speed on level 1 (5 degree/sec.) with load 0.4 kg.
4. Speed on level 1 (5 degree/sec.) with load 0.5 kg.
5. Speed on level 2 (10 degree/sec.) with load 0.2 kg.
6. Speed on level 2 (10 degree/sec.) with load 0.3 kg.
7. Speed on level 2 (10 degree/sec.) with load 0.4 kg.
8. Speed on level 2 (10 degree/sec.) with load 0.5 kg.
9. Speed on level 3 (15 degree/sec.) with load 0.2 kg.
10. Speed on level 3 (15 degree/sec.) with load 0.3 kg.
11. Speed on level 3 (15 degree/sec.) with load 0.4 kg.
12. Speed on level 3 (15 degree/sec.) with load 0.5 kg.





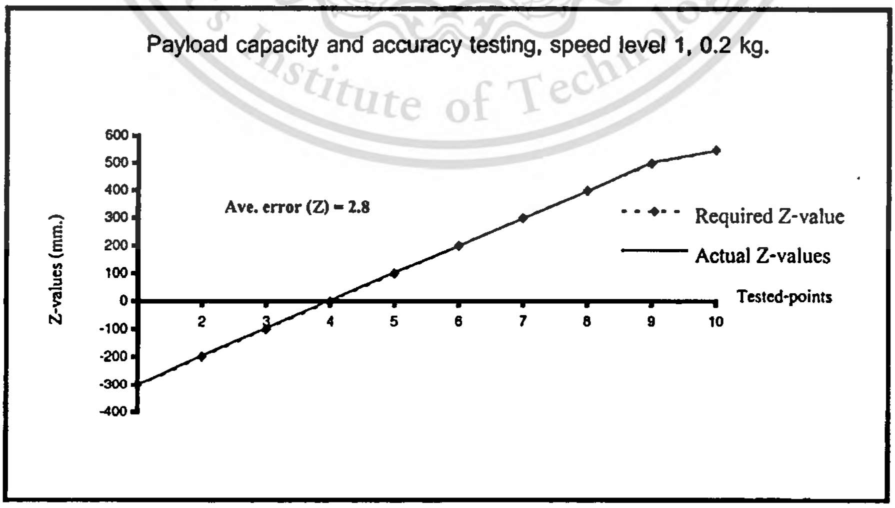


Figure C.1 Payload capacity and accuracy testing, speed level 1, 0.2 kg.

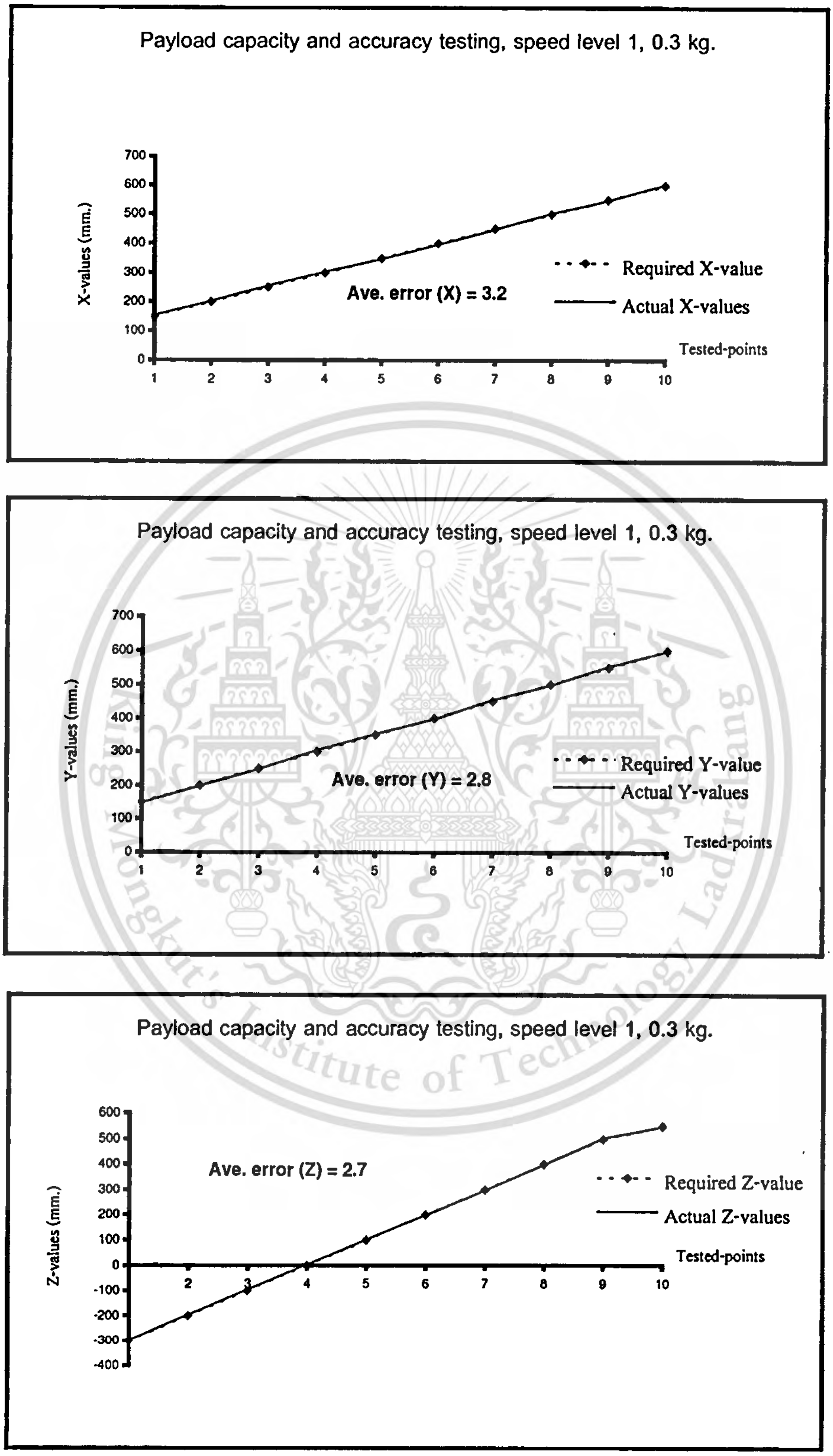


Figure C.2 Payload capacity and accuracy testing, speed level 1, 0.3 kg.

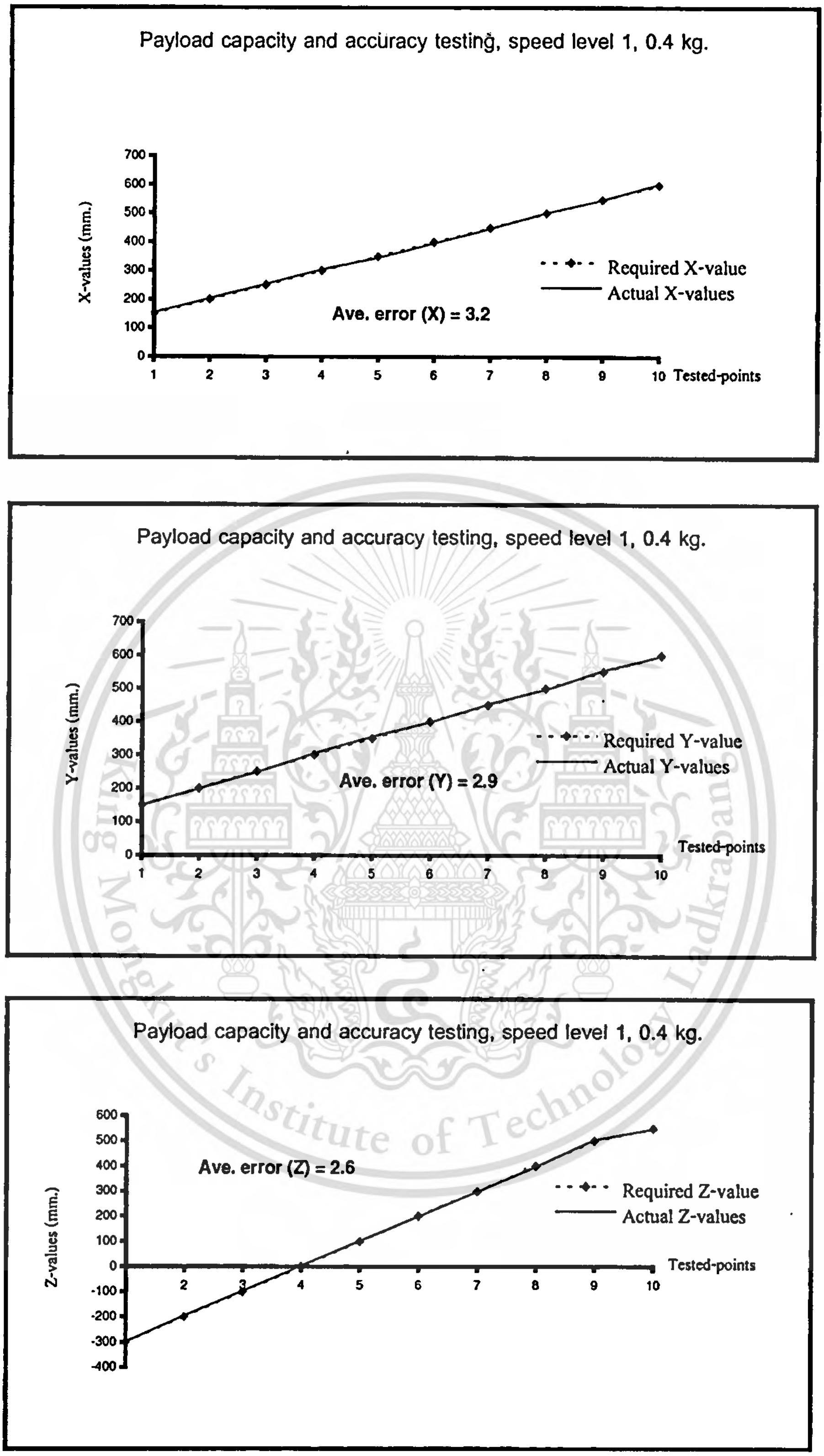


Figure C.3 Payload capacity and accuracy testing, speed level 1, 0.4 kg.

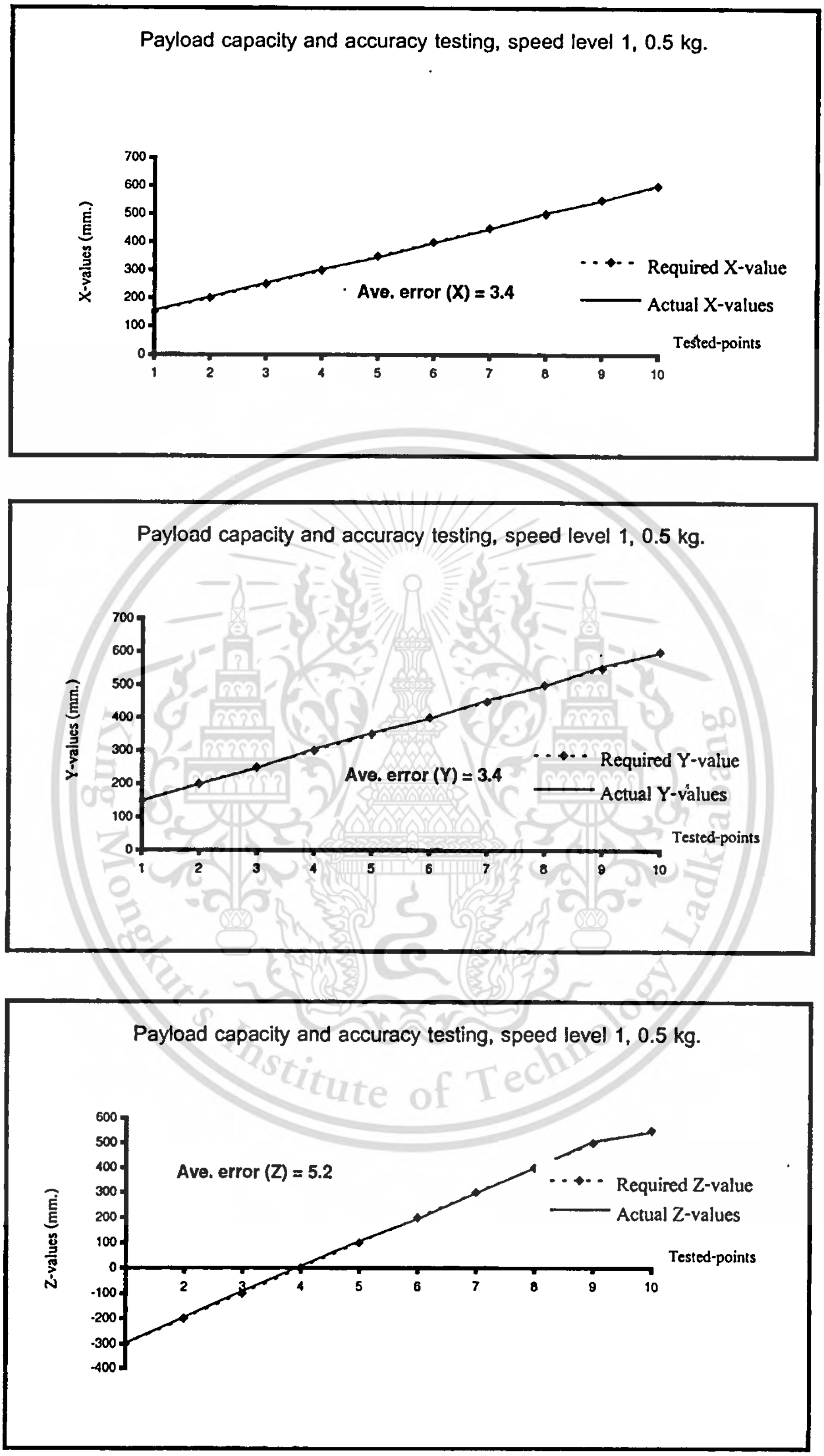


Figure C.4 Payload capacity and accuracy testing, speed level 1, 0.5 kg.

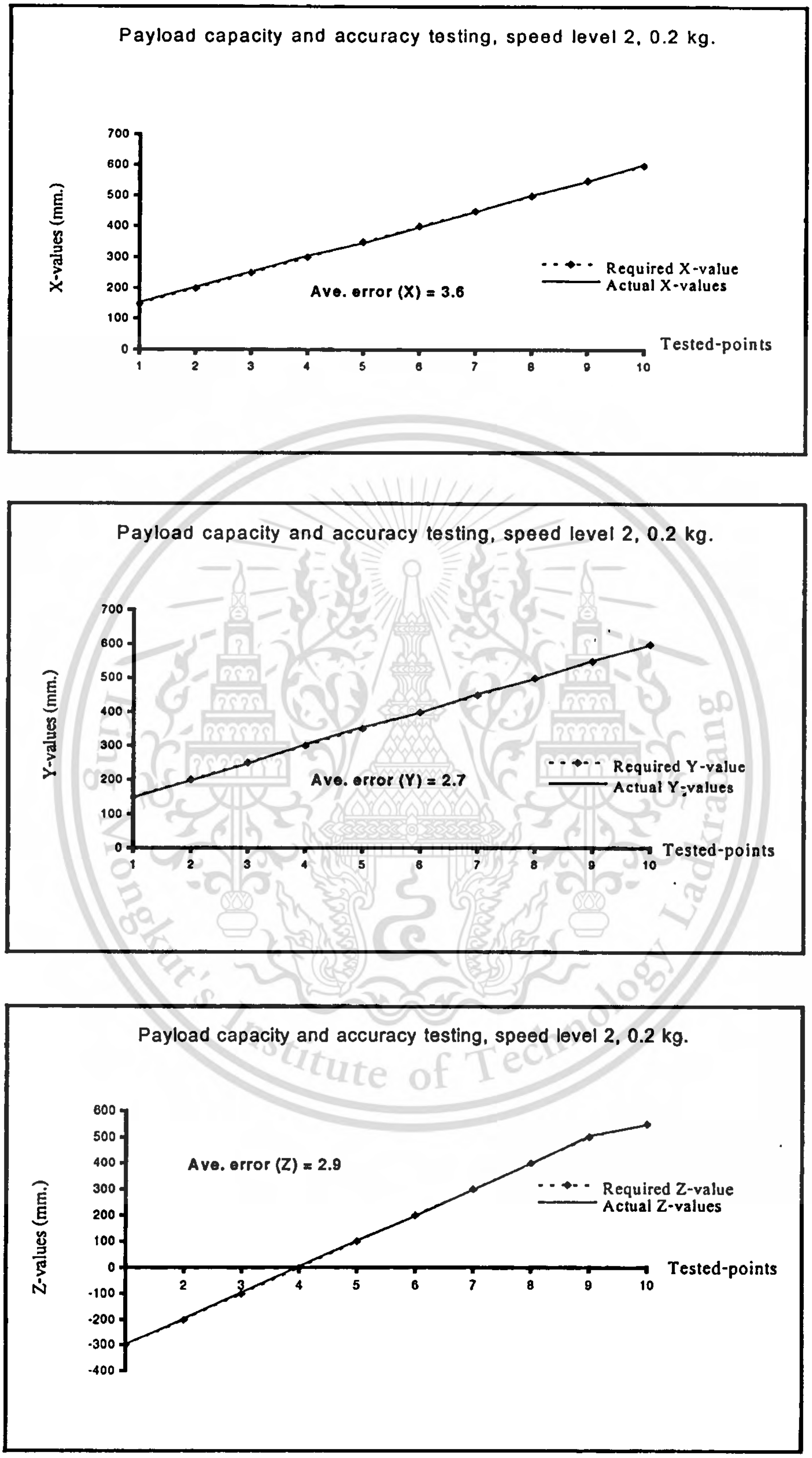
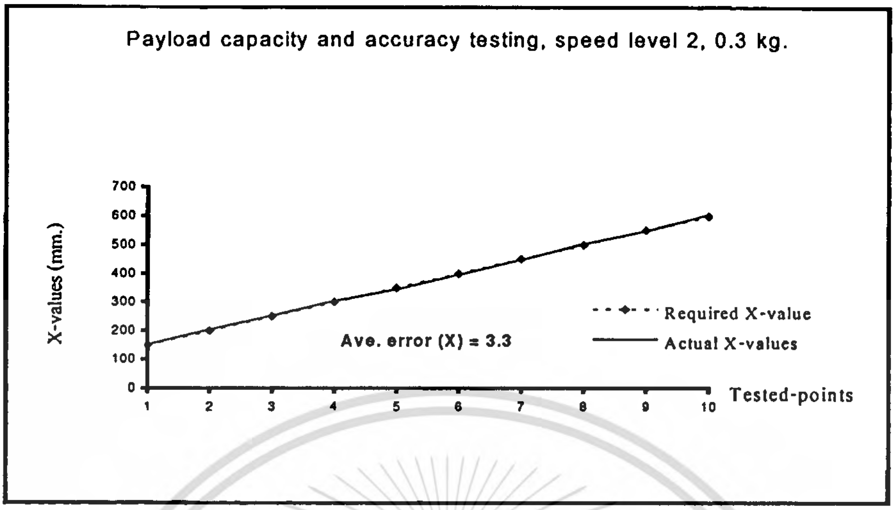
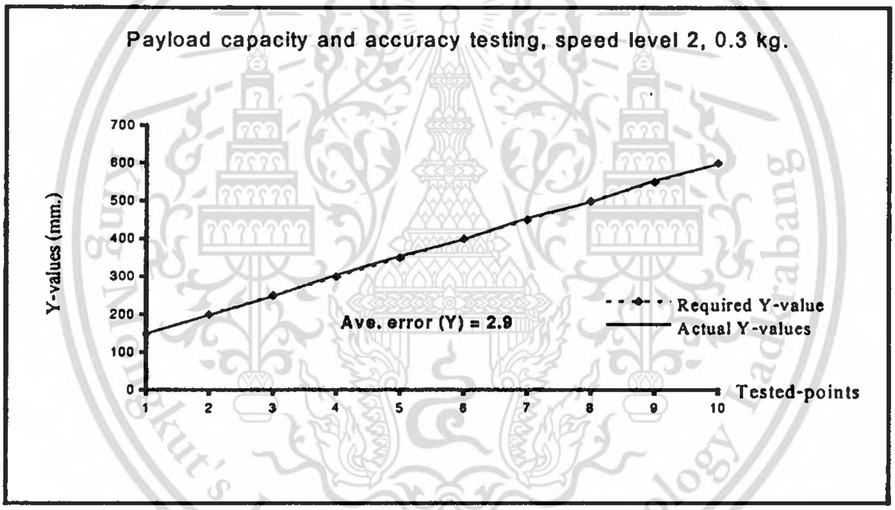


Figure C.5 Payload capacity and accuracy testing, speed level 2, 0.2 kg.





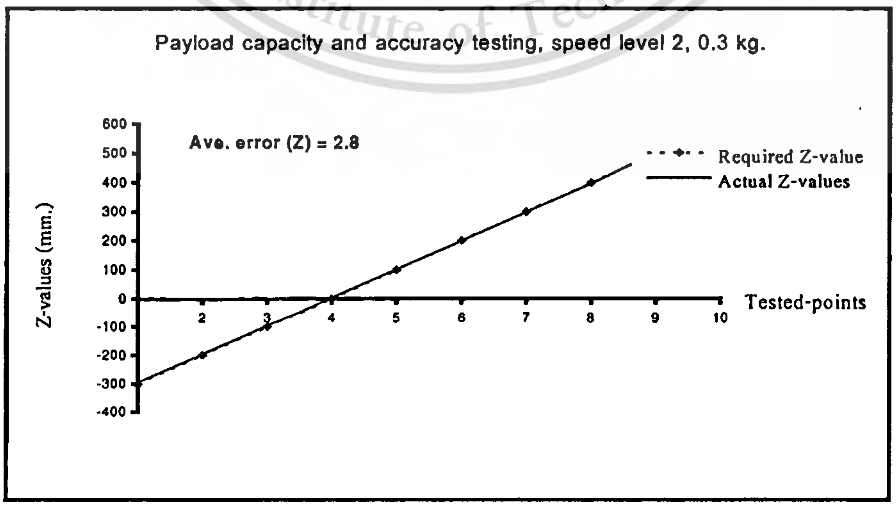
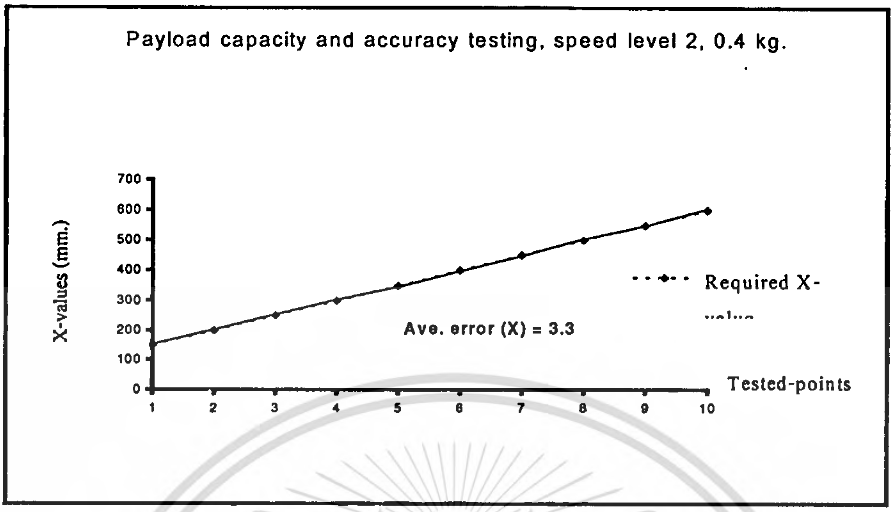
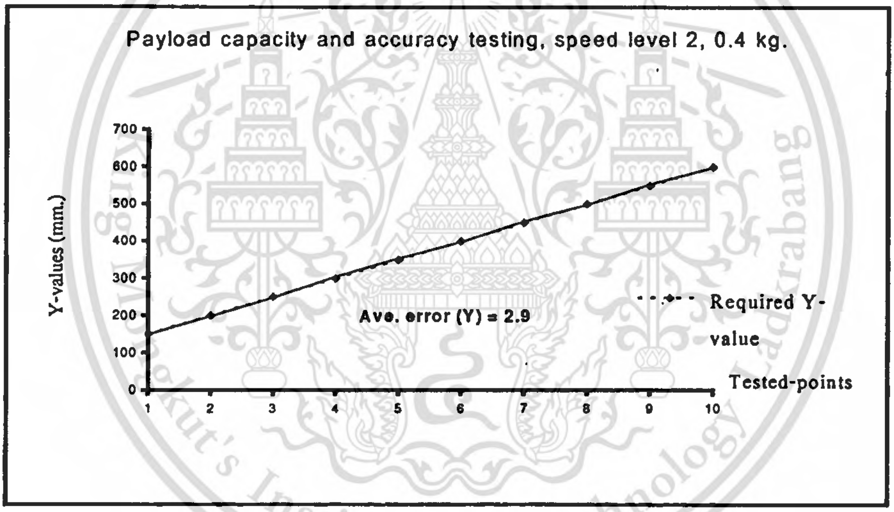


Figure C.6 Payload capacity and accuracy testing, speed level 2, 0.3 kg.





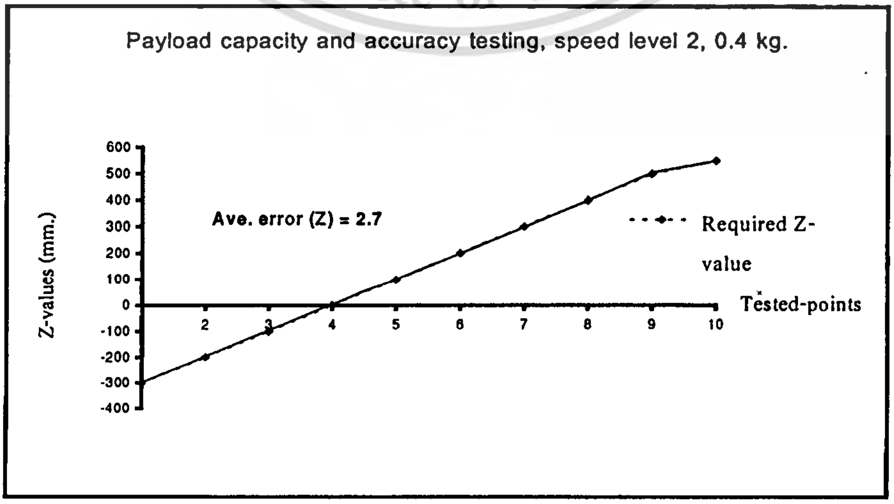


Figure C.7 Payload capacity and accuracy testing, speed level 2, 0.4 kg.

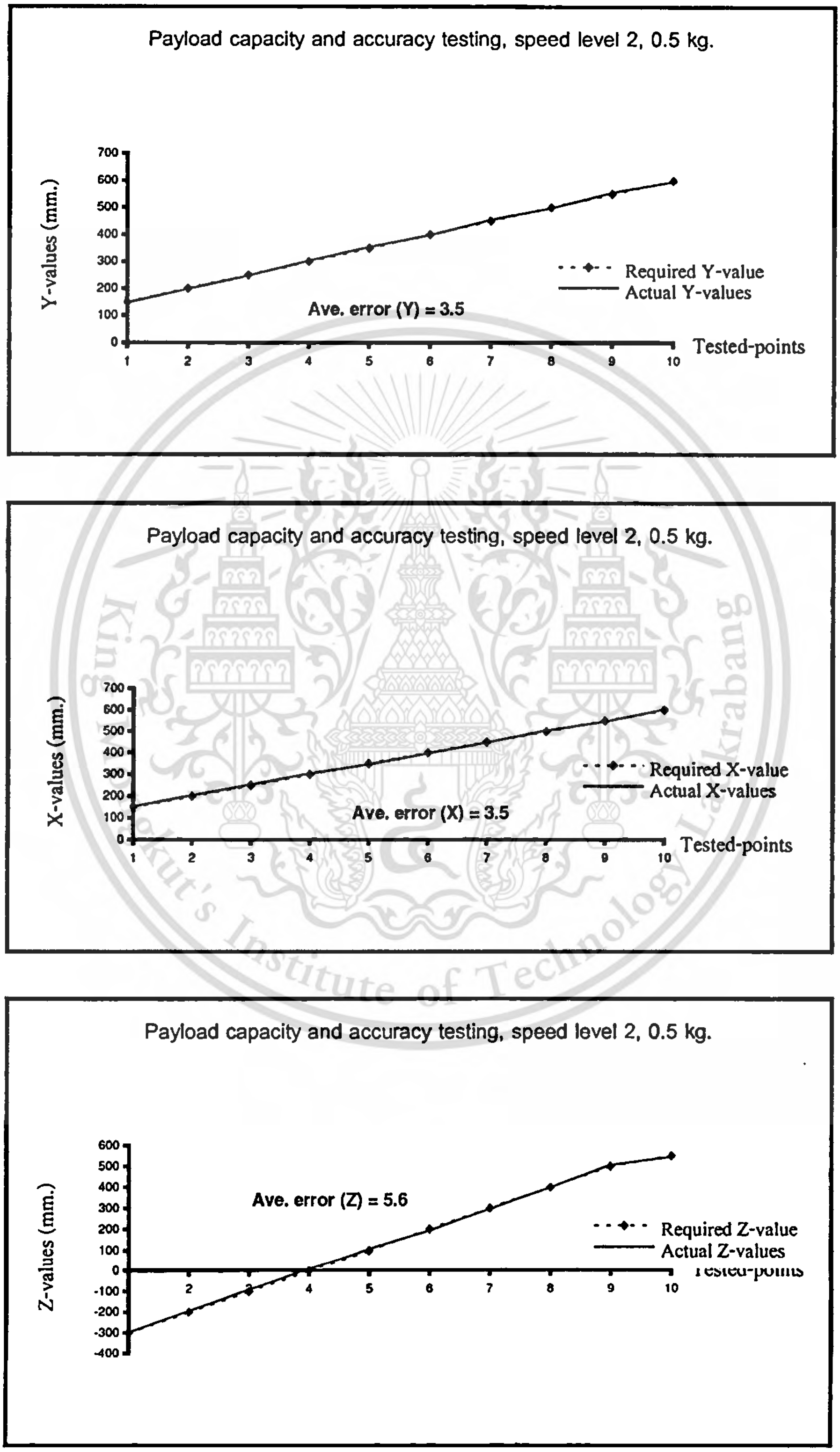
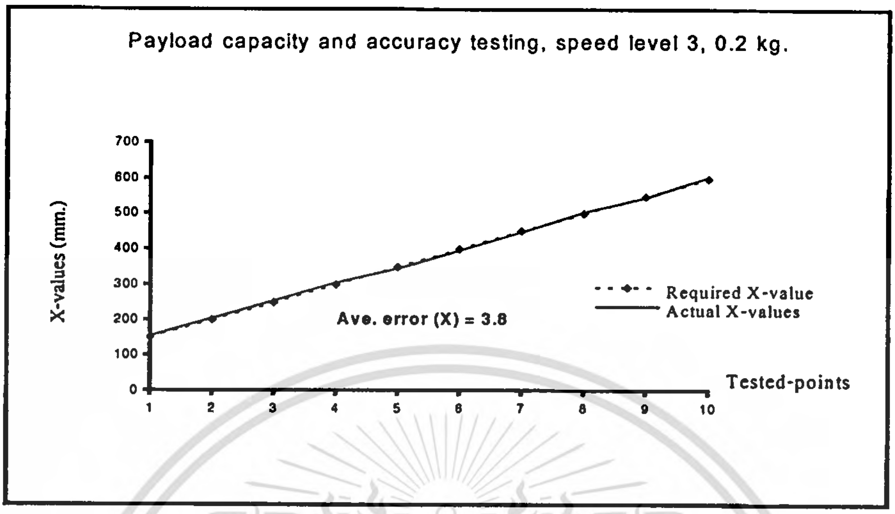
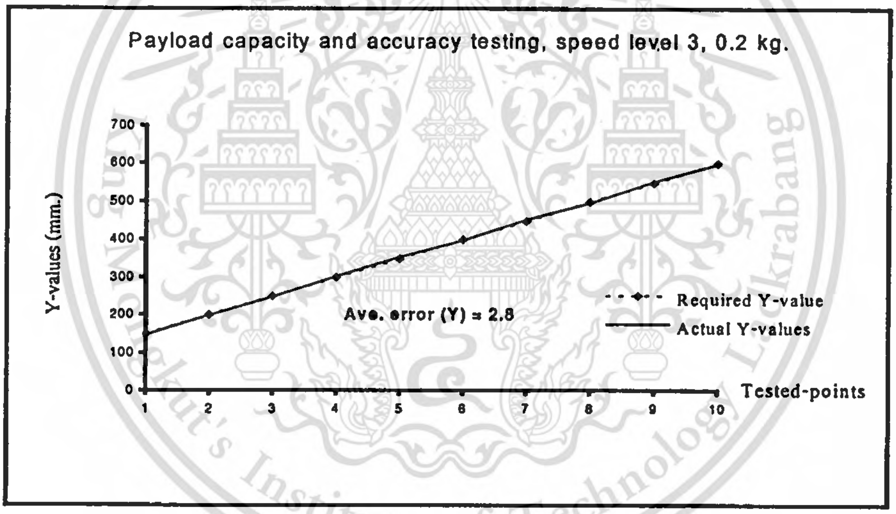


Figure C.8 Payload capacity and accuracy testing, speed level 2, 0.5 kg.





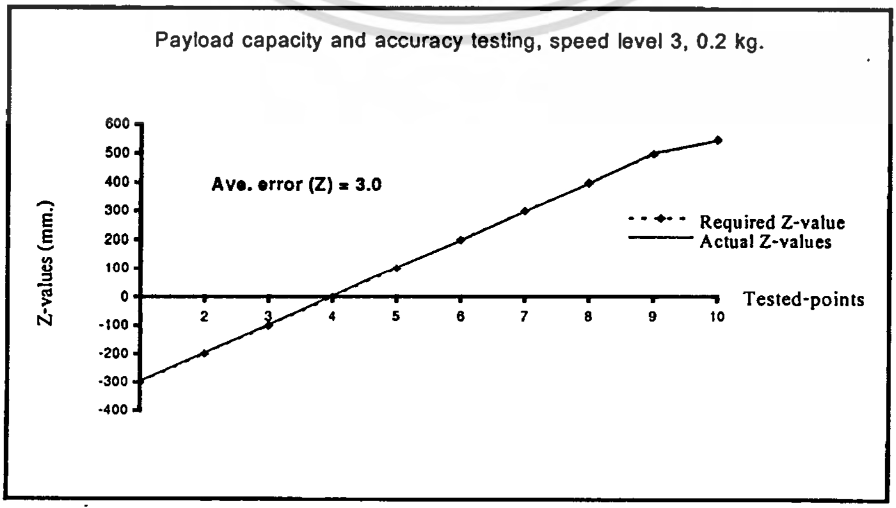


Figure C.9 Payload capacity and accuracy testing, speed level 3, 0.2 kg.

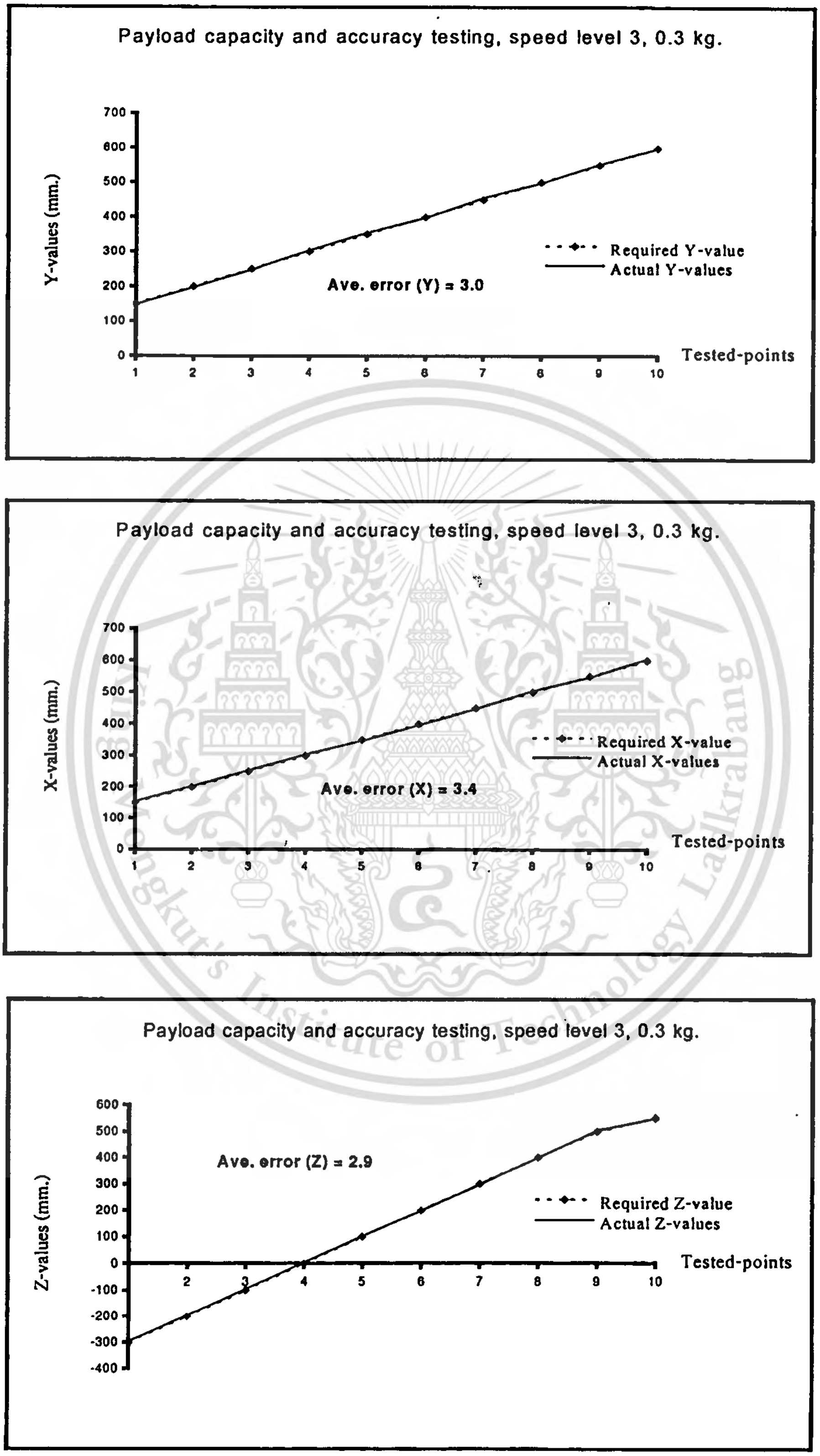
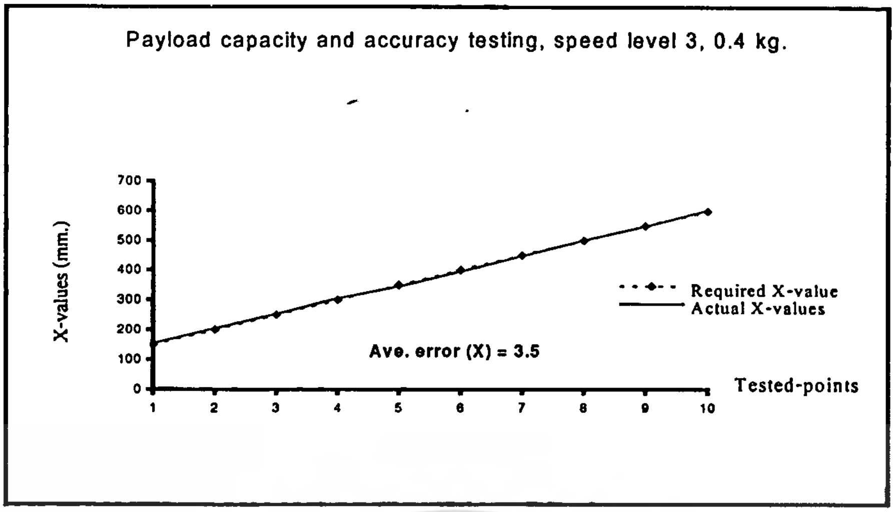
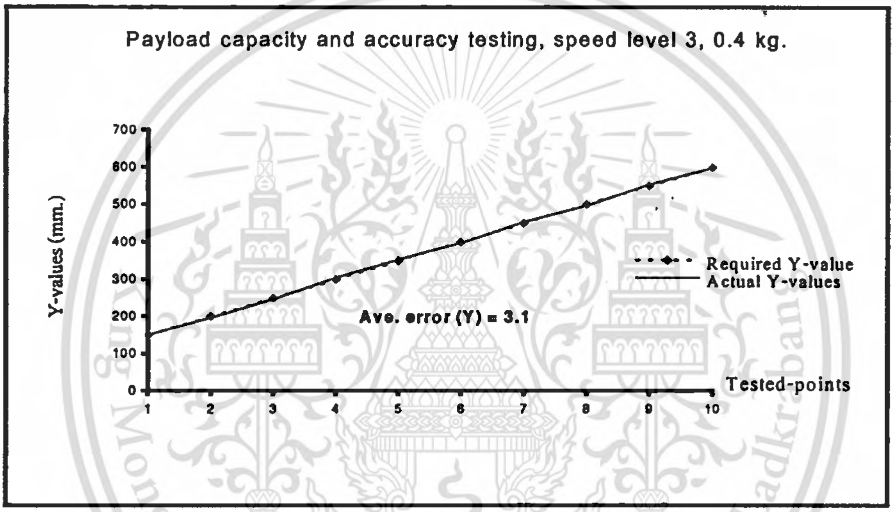


Figure C.10 Payload capacity and accuracy testing, speed level 3, 0.3 kg.


Payload capacity and accuracy testing, speed level 3, 0.4 kg.


Payload capacity and accuracy testing, speed level 3, 0.4 kg.

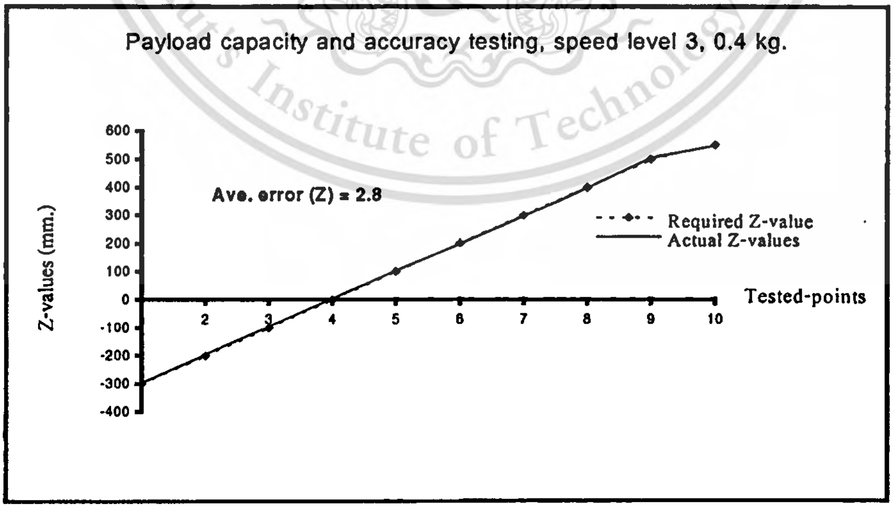

Payload capacity and accuracy testing, speed level 3, 0.4 kg.

Figure C.11 Payload capacity and accuracy testing, speed level 3, 0.4 kg.

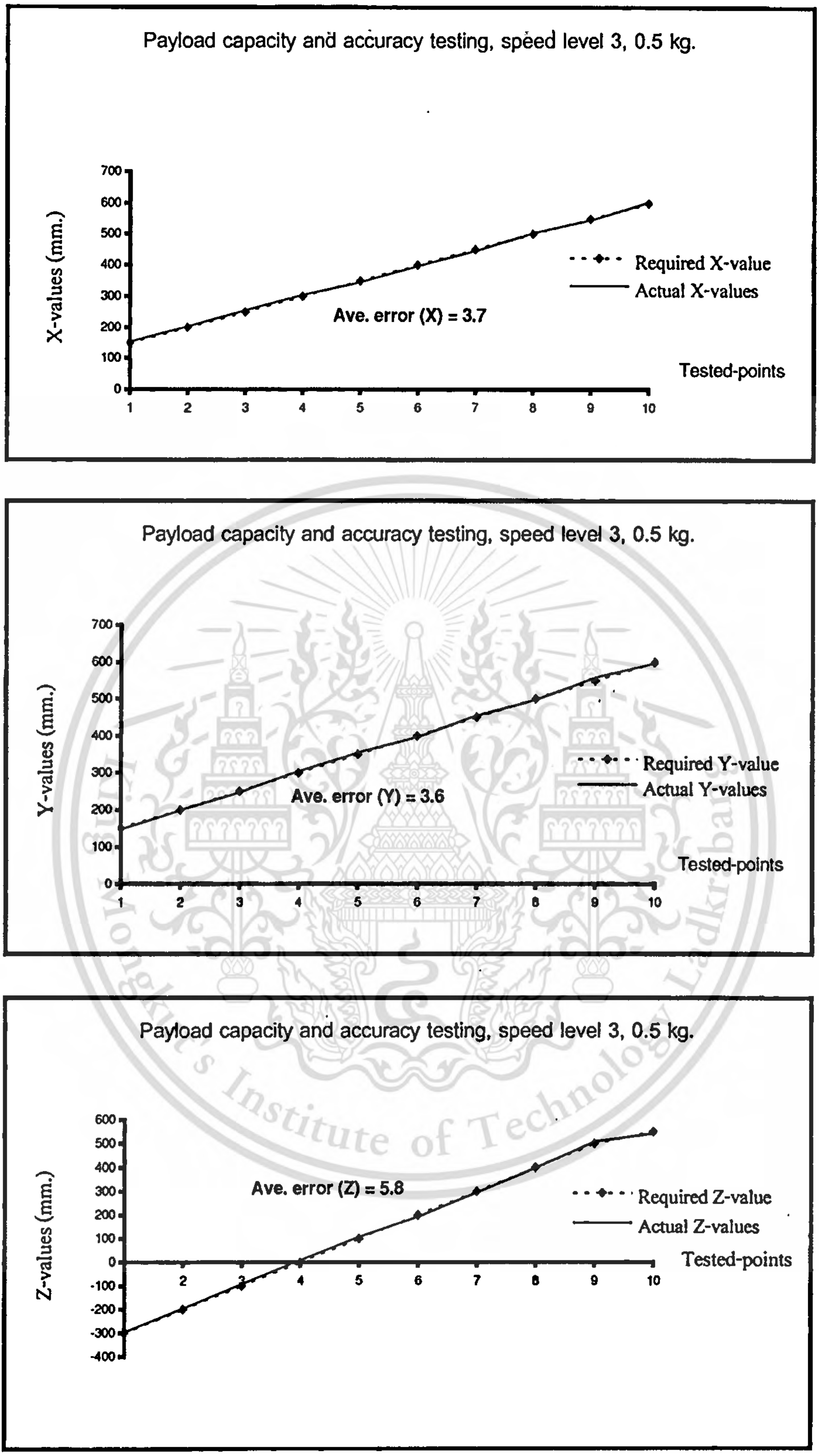


Figure C.12 Payload capacity and accuracy testing, speed level 3, 0.5 kg.

Graphs of repeatability testing

1. Speed on level 1 (5 degree/sec.) without load, test 10 times on the same point.
2. Speed on level 2 (10 degree/sec.) without load, test 10 times on the same point.
3. Speed on level 3 (15 degree/sec.) without load, test 10 times on the same point.
4. Speed on level 1 (5 degree/sec.) with maximum load, test 10 times on the same point.
5. Speed on level 2 (10 degree/sec.) with maximum load, test 10 times on the same point.
6. Speed on level 3 (15 degree/sec.) with maximum load, test 10 times on the same point.

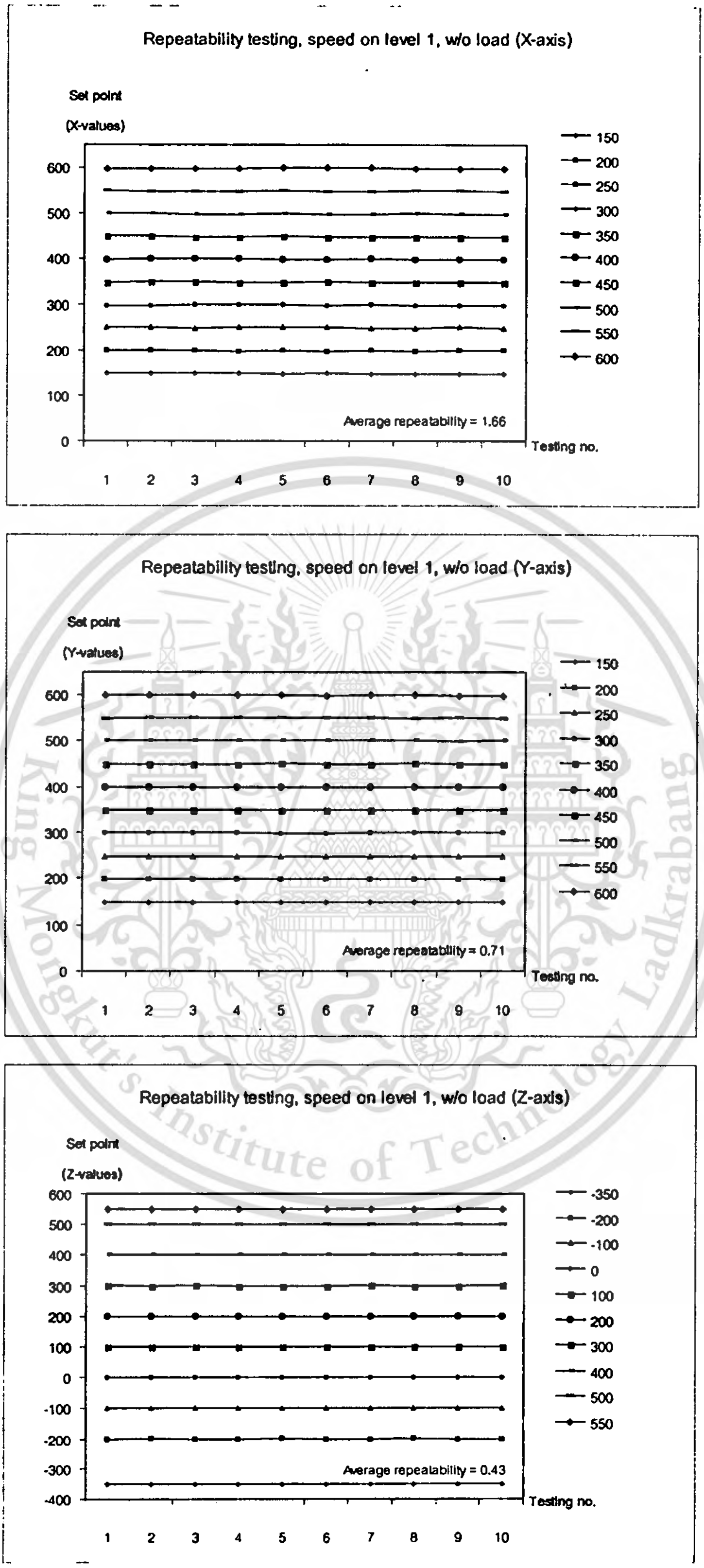


Figure C.13 Repeatability testing, speed level 1, without load

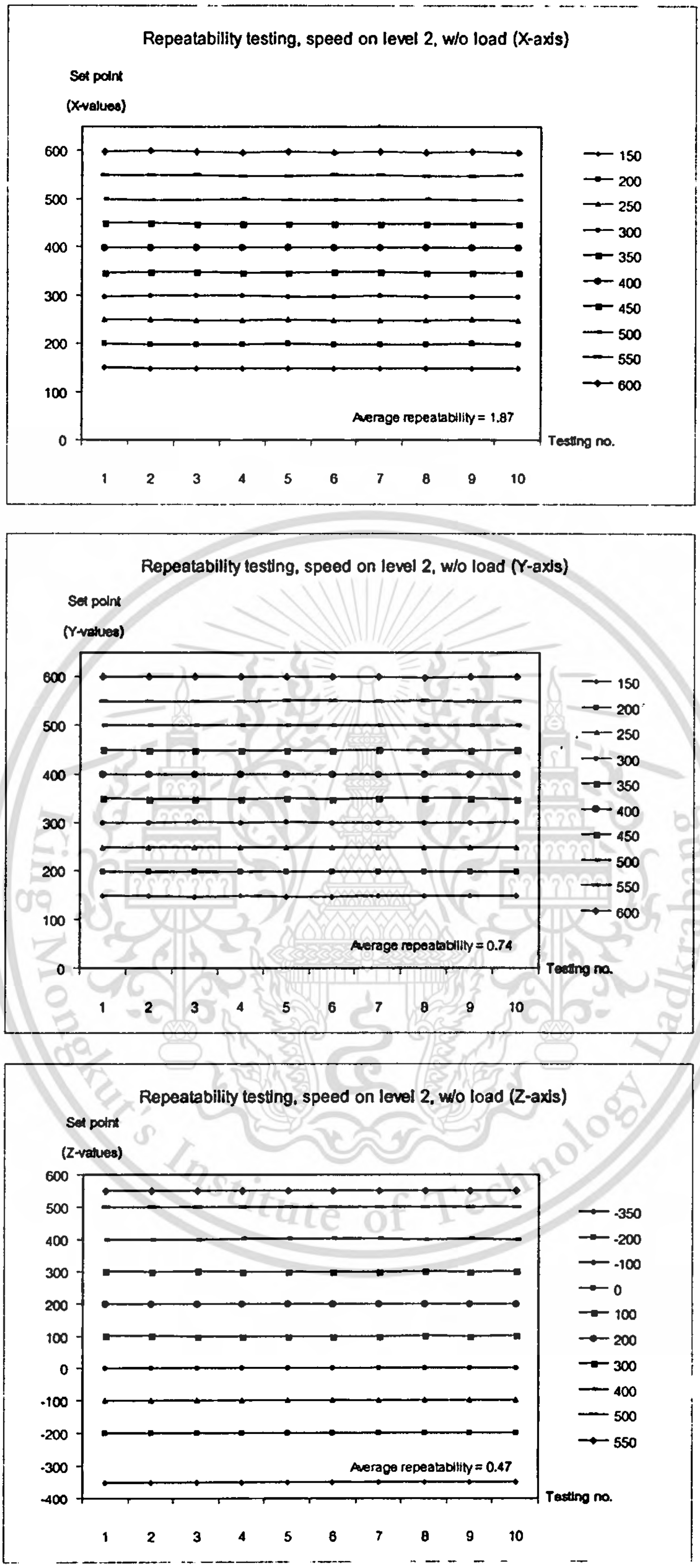
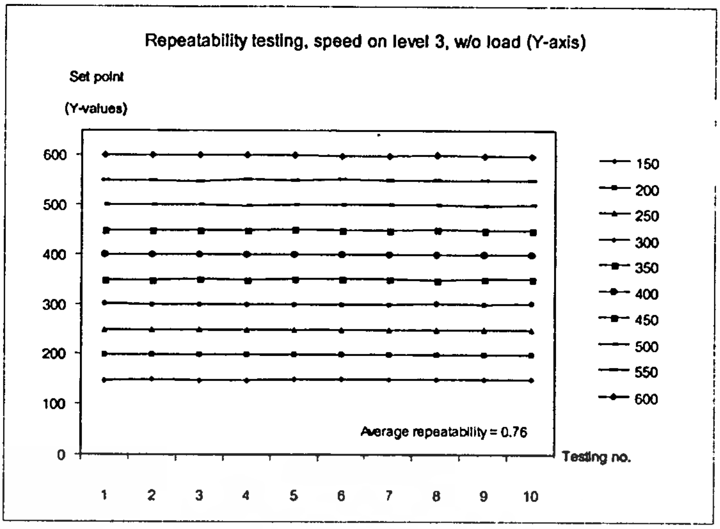
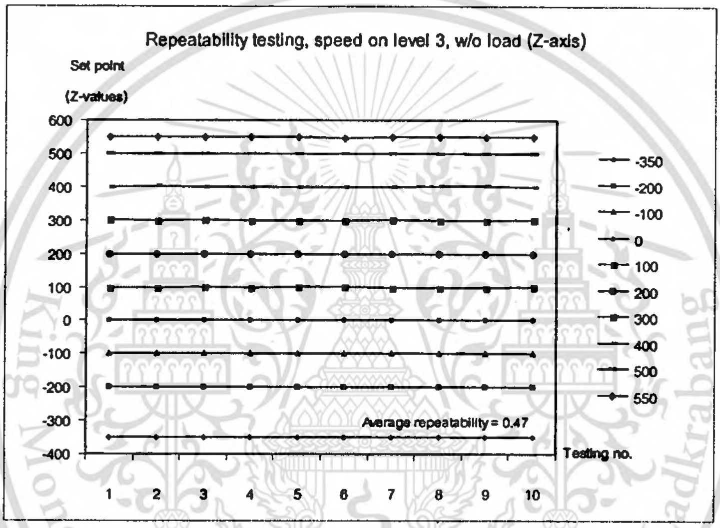


Figure C.14 Repeatability testing, speed level 2, without load





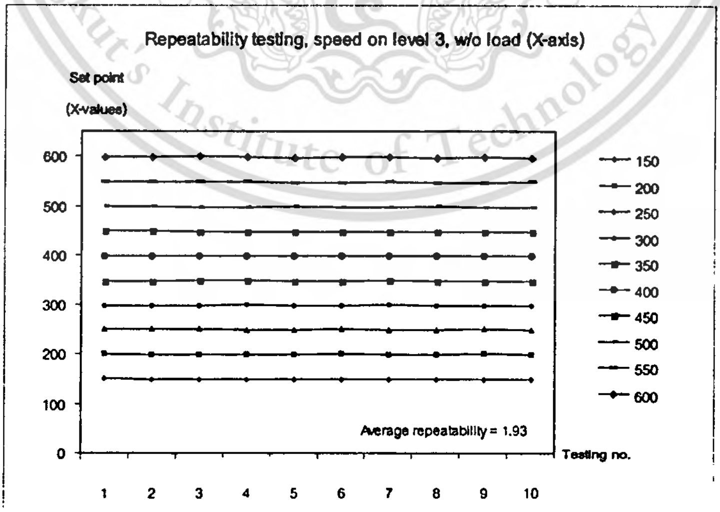


Figure C.15 Repeatability testing, speed level 3, without load

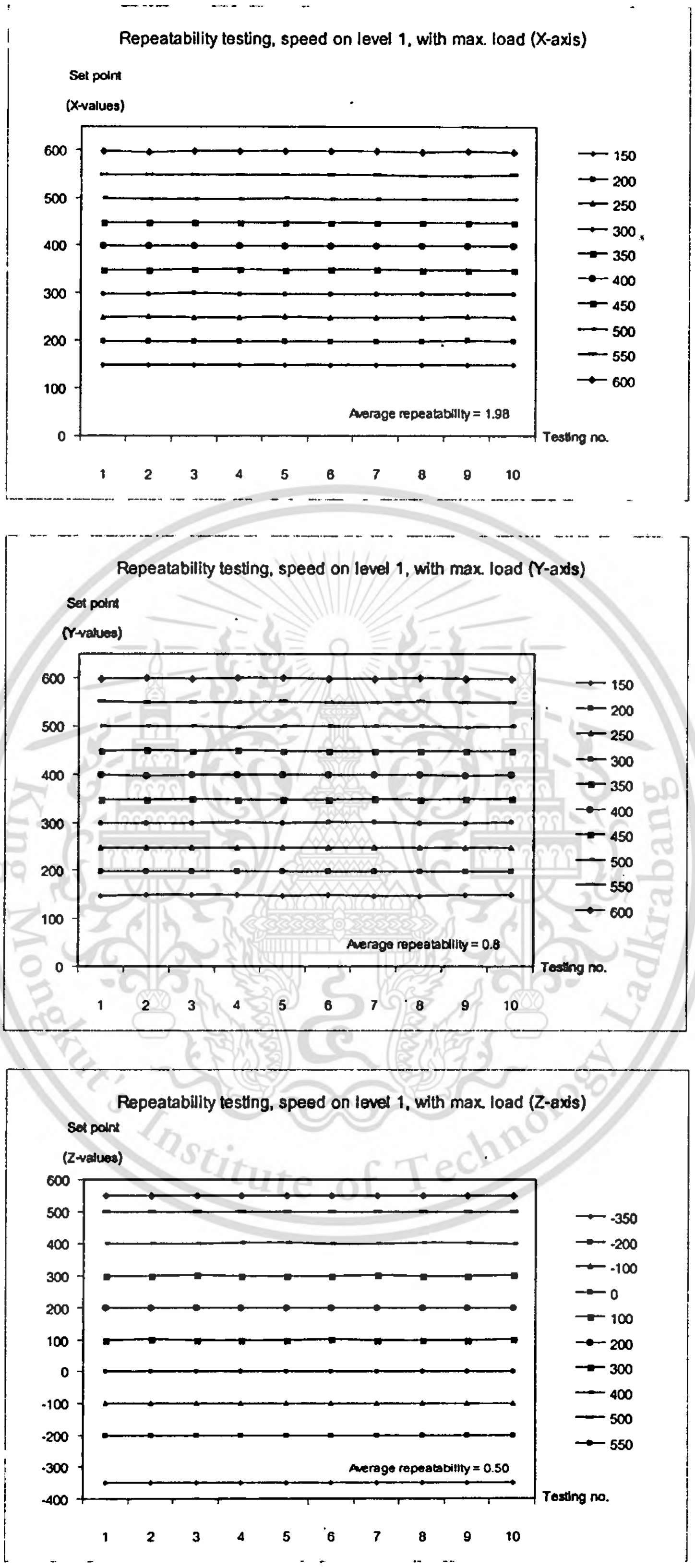
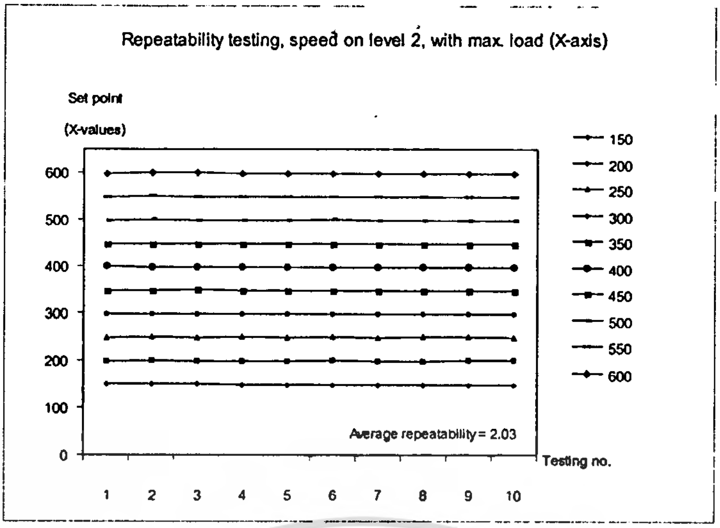
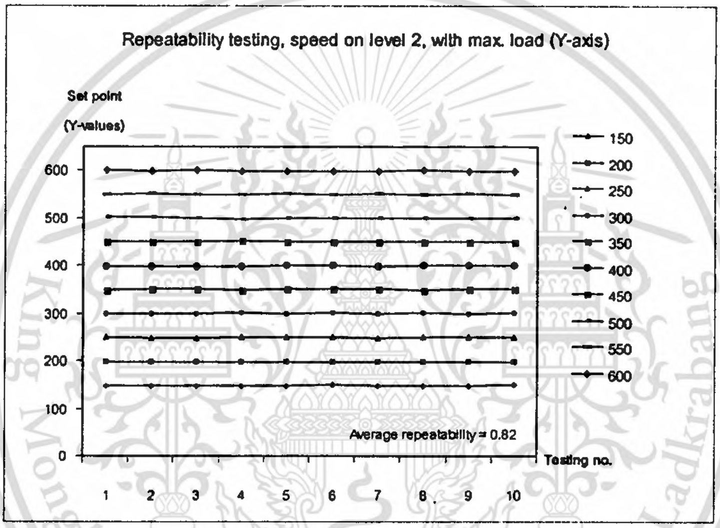


Figure C.16 Repeatability testing, speed level 1 with maximum load





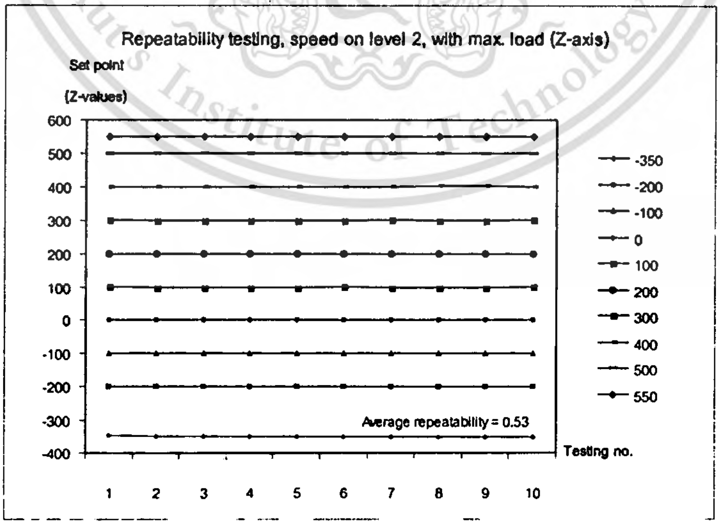


Figure C.17 Repeatability testing, speed leve2 with maximum load

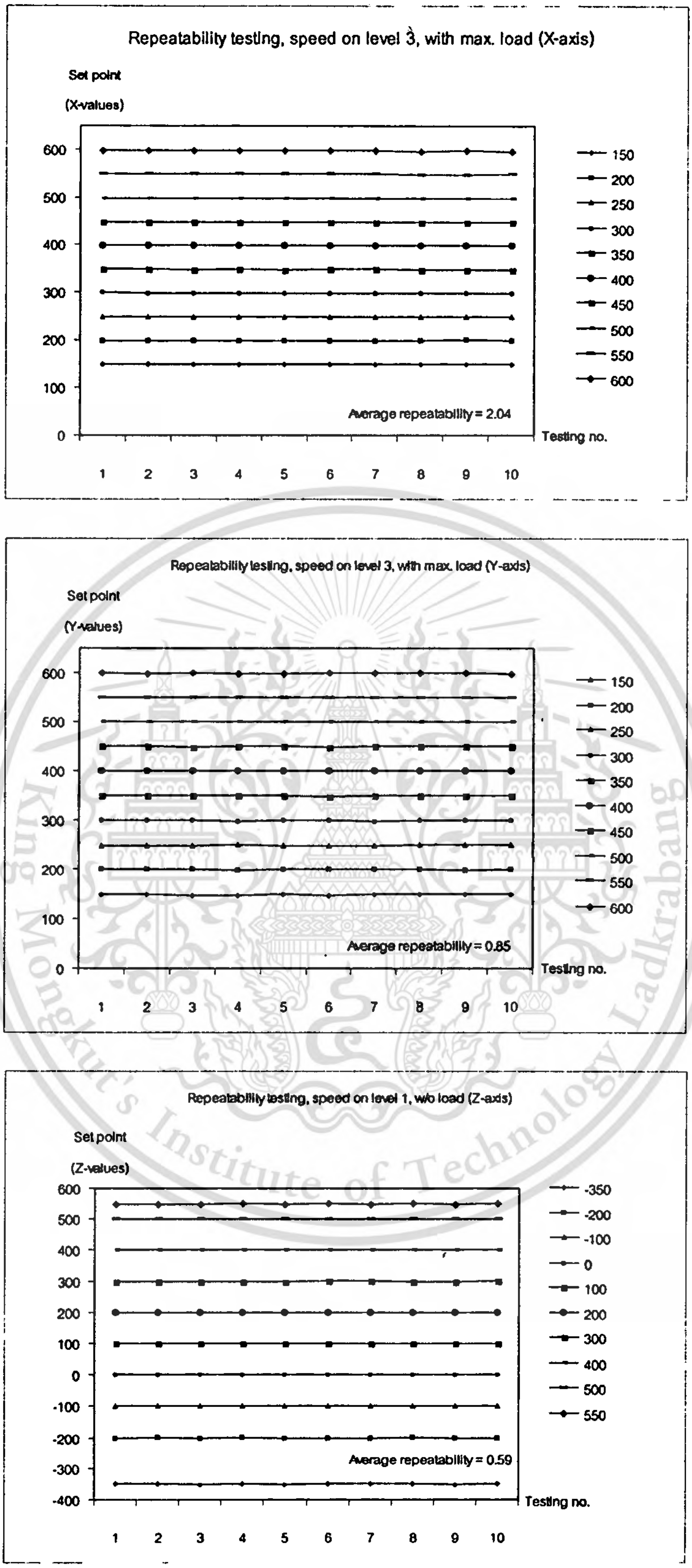


Figure C.18 Repeatability testing, speed leve3 with maximum load

Graphs of joint interaction testing

1. Move only joint 1, measure effected angle on other joints.
2. Move only joint 2, measure effected angle on other joints.
3. Move only joint 3, measure effected angle on other joints.
4. Move only joint 4, measure effected angle on other joints.
5. Move only joint 5, measure effected angle on other joints.
6. Move only joint 6, measure effected angle on other joints.

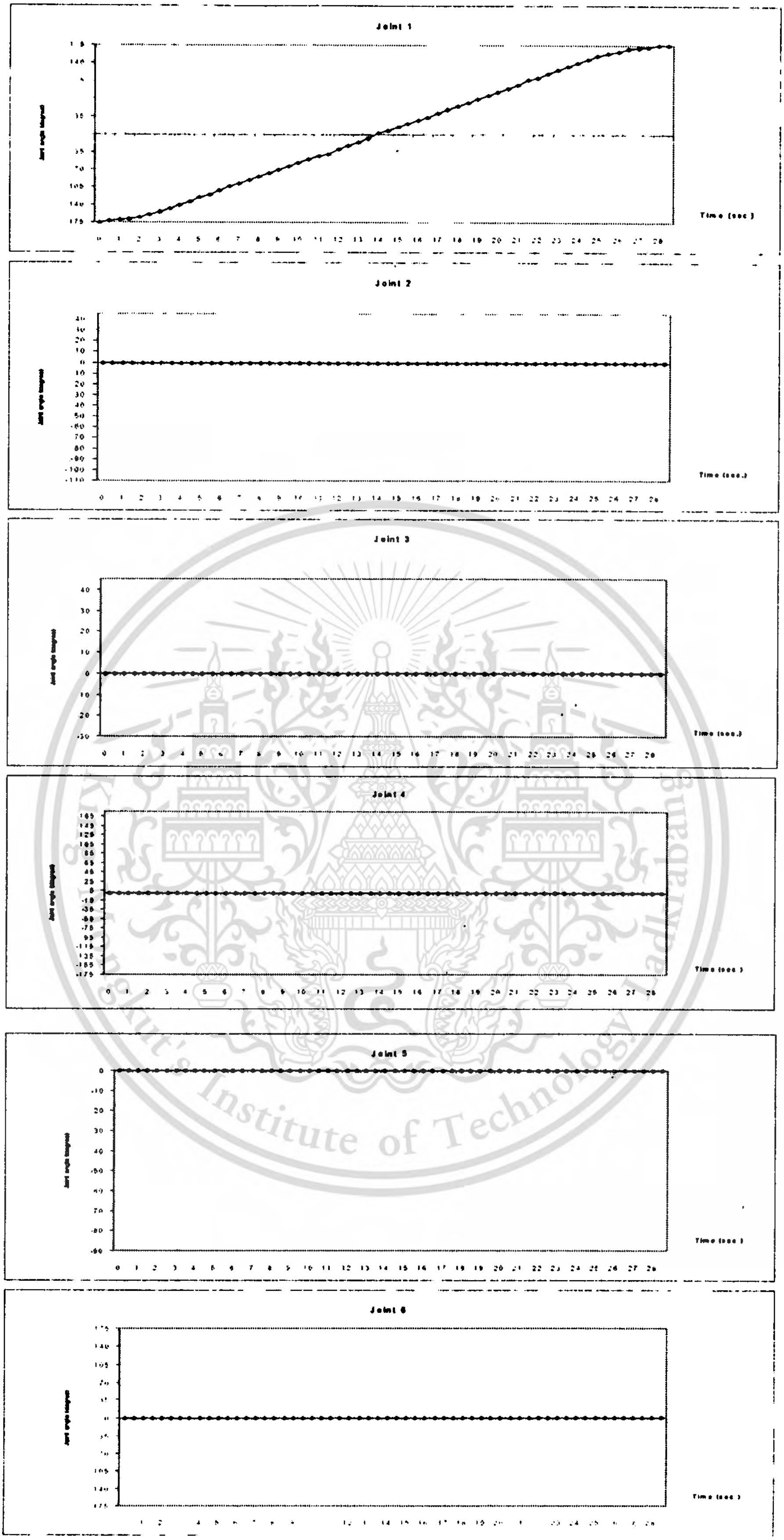


Figure C.19 Joint-interaction testing (move joint 1, others are in home position)

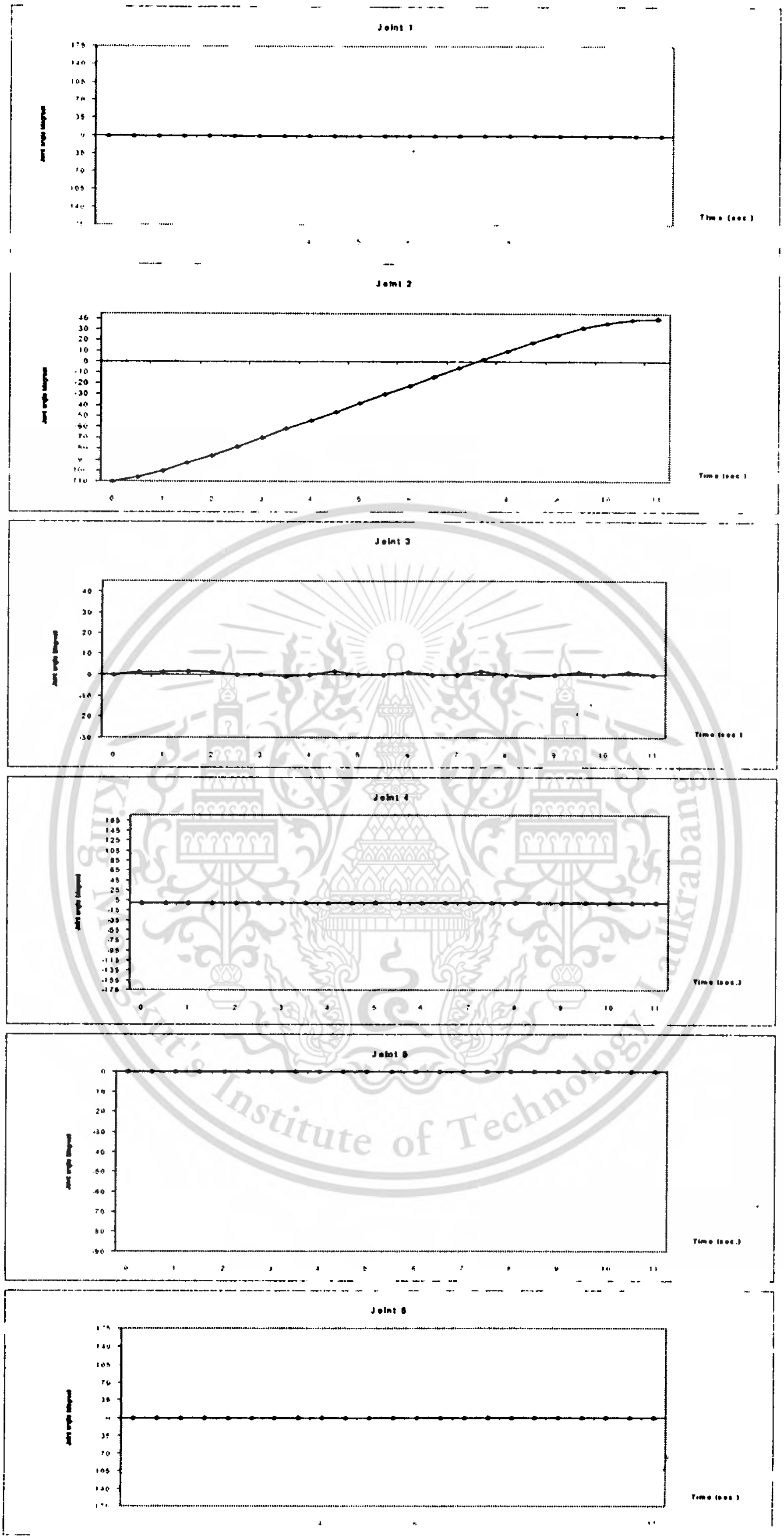


Figure C.20 Joint-interaction testing (move joint 2, others are in home position)

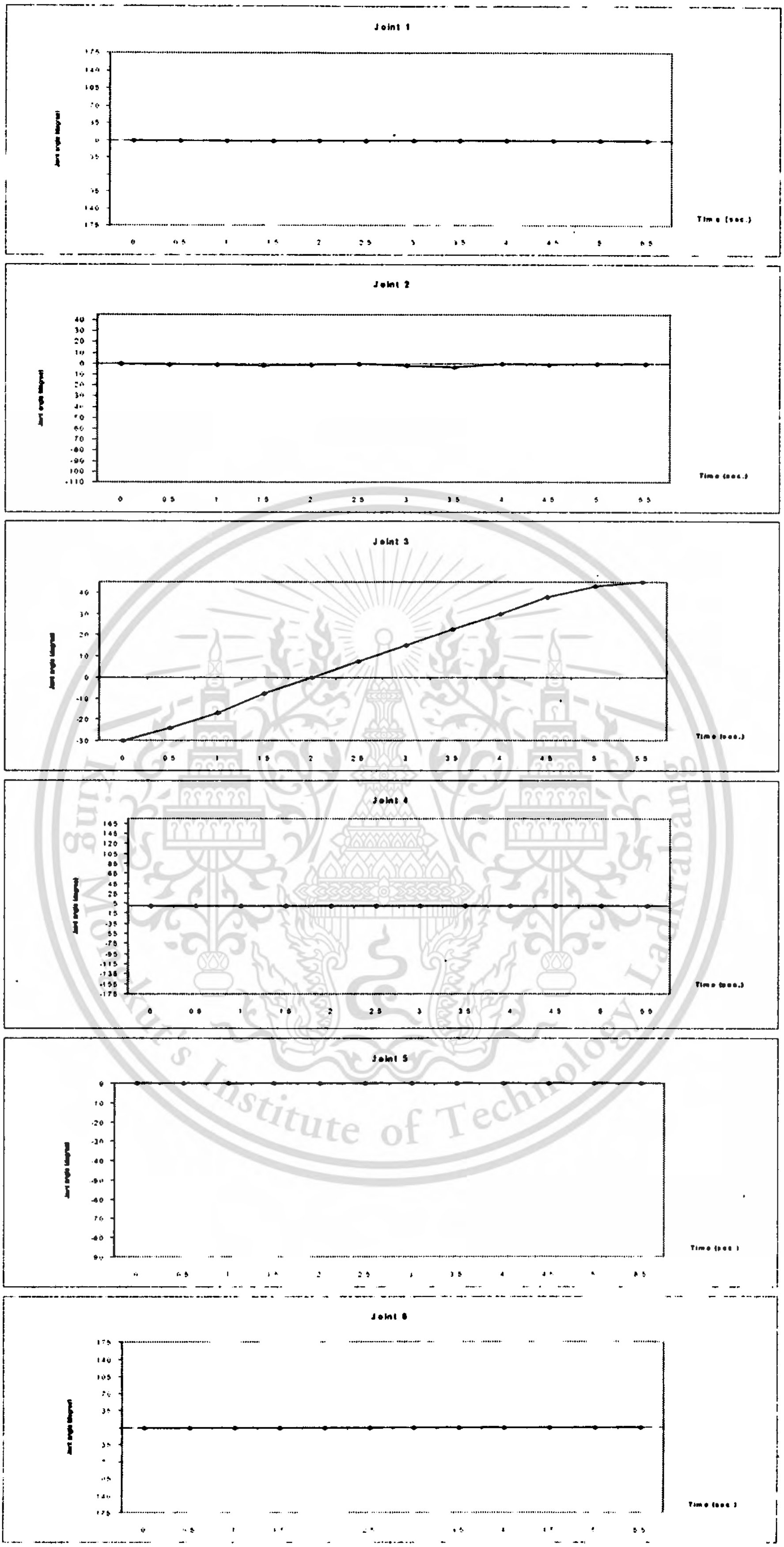


Figure C.21 Joint-interaction testing (move joint 3, others are in home position)

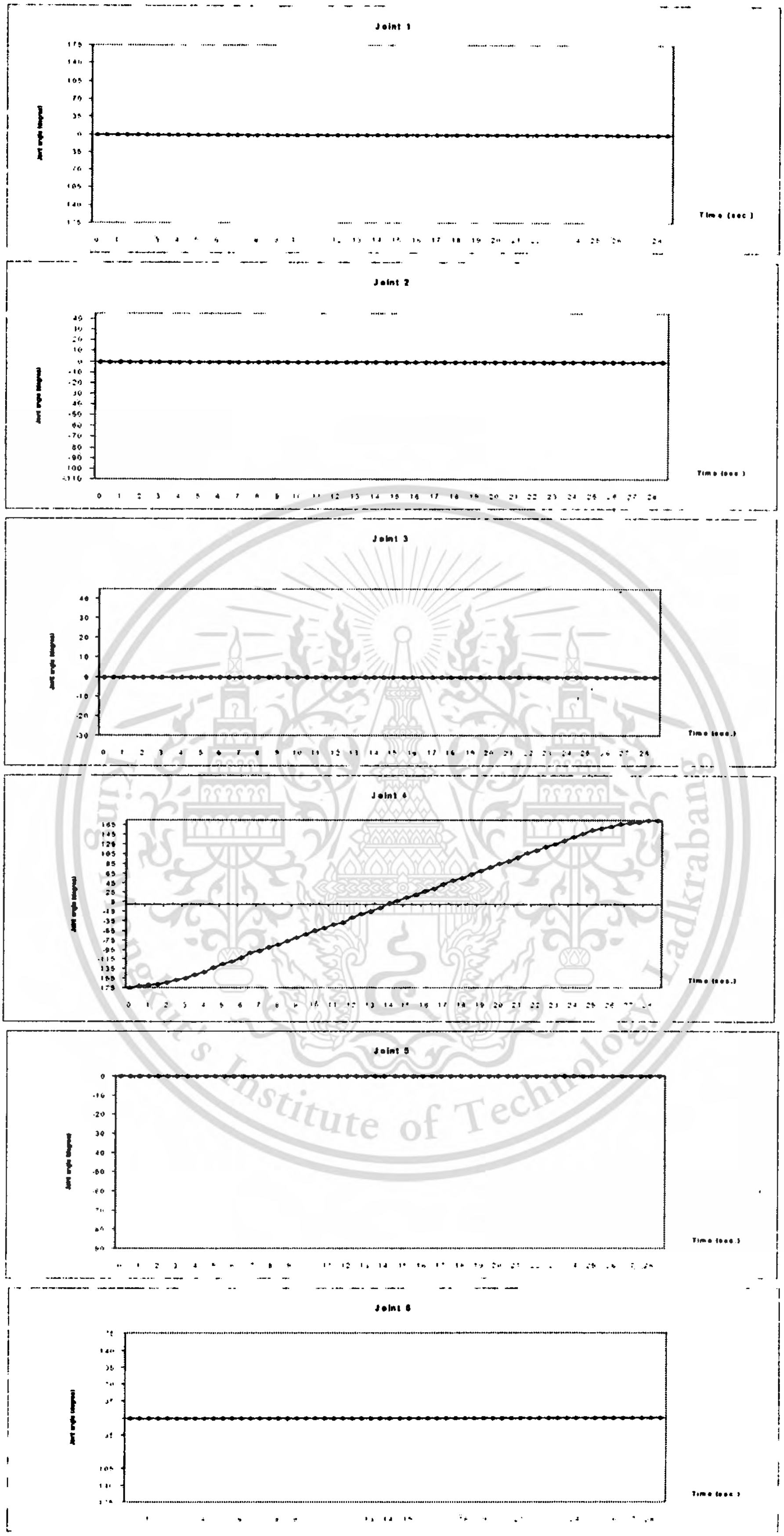


Figure C.22 Joint-interaction testing (move joint 4, others are in home position)

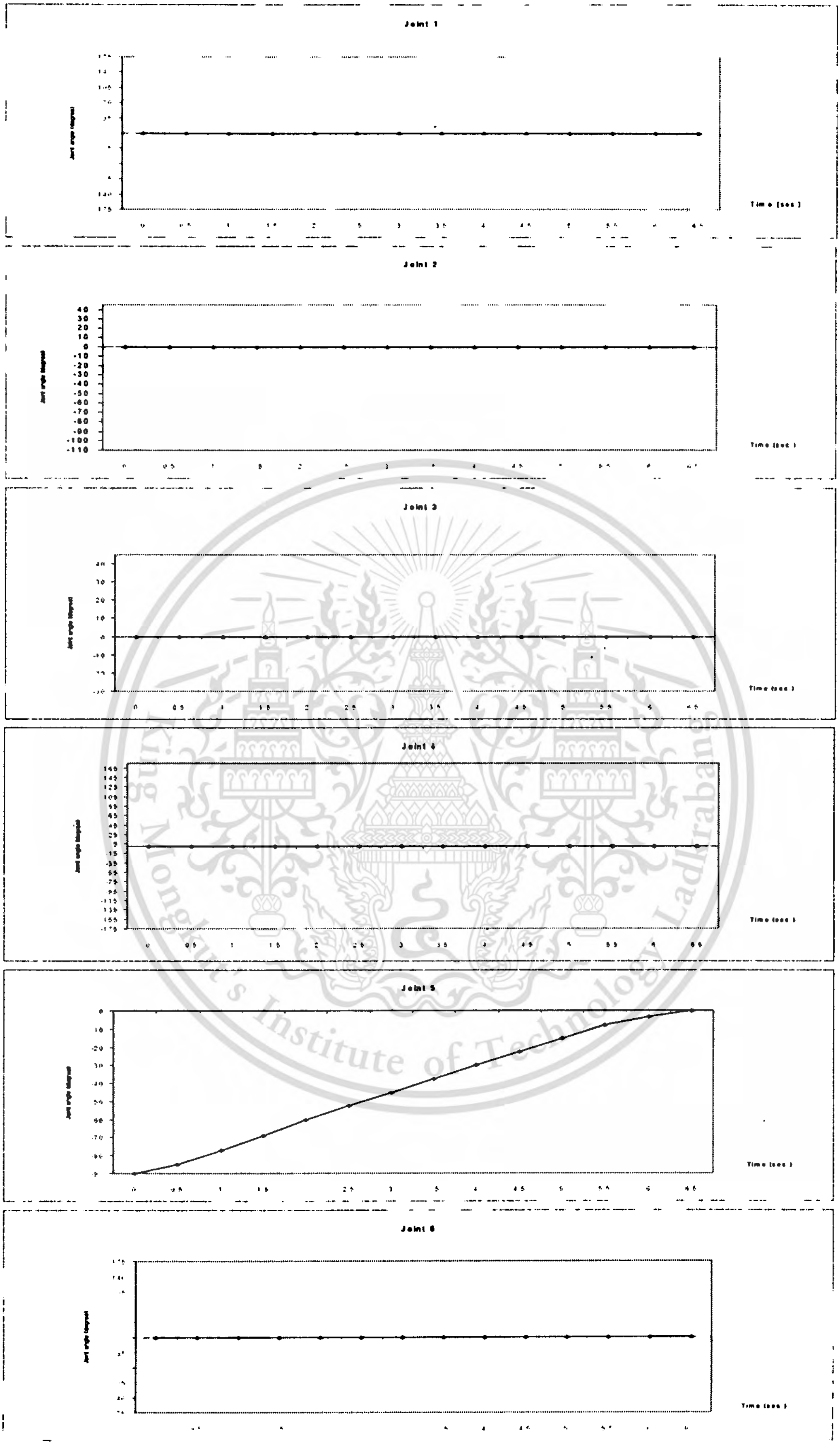


Figure C.23 Joint-interaction testing (move joint 5, others are in home position)

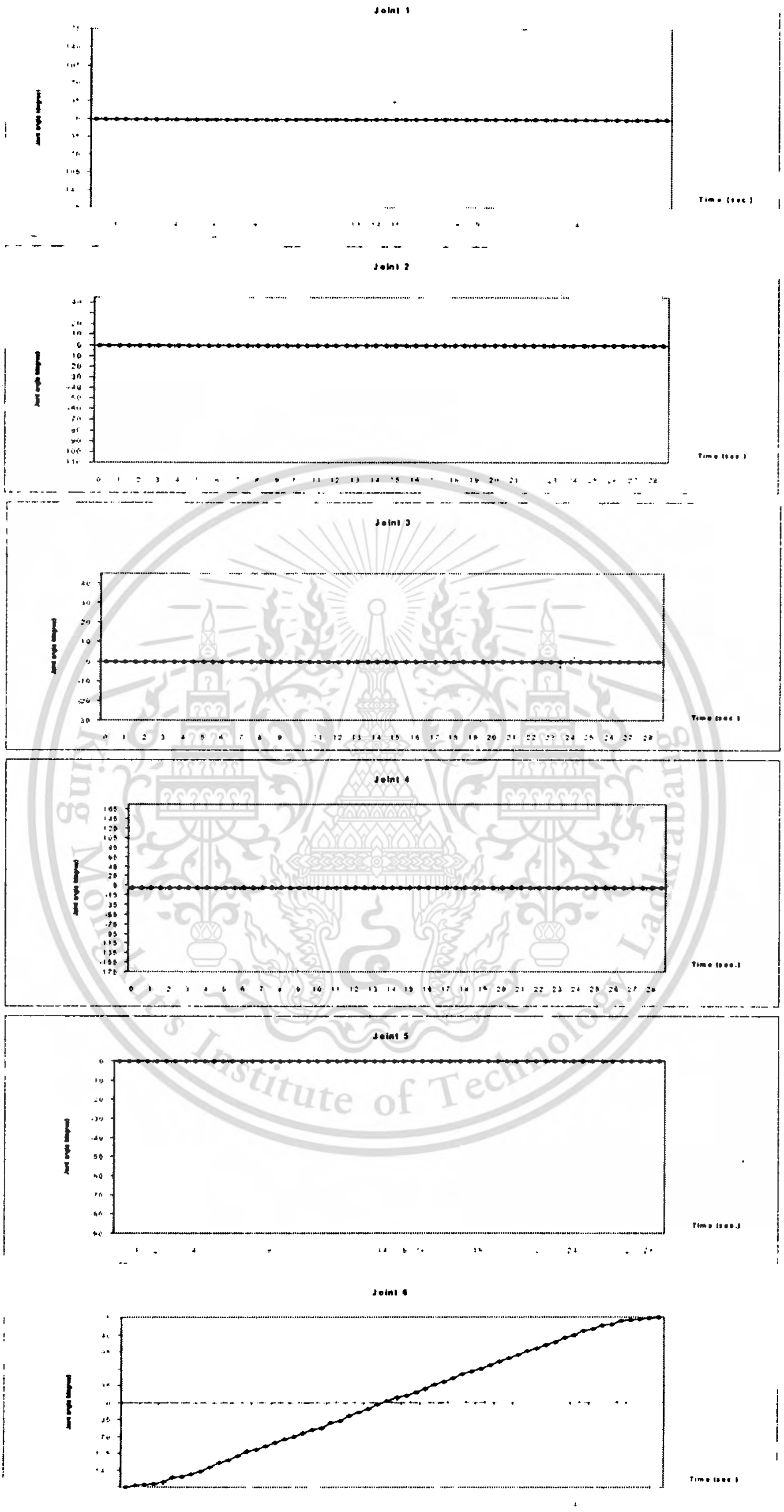


Figure C.24 Joint-interaction testing (move joint 6, others are in home position)

BIOGRAPHY

Mr. Anan Kongyoo graduated from Burapha University with a bachelor's degree in Industrial engineering. His research is primarily in fundamental areas of robotics dexterity, design for manufacturing, automatic control, assembly process and programming. He have work in elevator design at Mitsubishi elevator Asia co., ltd. His works concern with mechanical design and automation system. Furthermore, he interested in the intelligent algorithm such as Artificial Neural Networks (ANNs), Genetic Algorithms (GAs). He applied these algorithms for improvement the automation system.

In the other side, he develops equipment for entertainment system such as lighting controller.