MATERIAL DEPOSITING ROBOT ARM FOR ARC WELDING: STRUCTURE & DRIVING MECHANISM

CHOONG WAI HENG
(PS04-008-014)

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Alamat:
430, Laluan Simee 9,
Simee,
31400 Ipoh,
Perak, Malaysia.

(Penyelia: Prof. Dr. Yeo Kiam Beng @ Abdul Noor)

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CHOONG WAI HENG
(PS04-008-014)

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Professor Dr. Yeo Kiam Beng @ Abdul Noor

(signature)

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ABSTRACT

MATERIAL DEPOSITING ROBOT ARM FOR ARC WELDING: STRUCTURE & DRIVING MECHANISM

This thesis presents the research work on the design and modeling of a 3-DoF robot arm as part of the 6-DoF arc welding robot called Robotums RA-01 developed at Centre of Materials & Minerals, Universiti Malaysia Sabah. A 3-DoF robot arm has been designed with the ability to interface with a forearm mechanism developed by Chua (2007) to form a complete 6-DoF arc-welding robot with a maximum reachable distance of 1,300mm and a handling payload of 6kg at the wrist center. As well as designing of the robot-arm mechanics and structure, and the driving system design fundamentals. The robot kinematics model has been developed to serve as the fundamental mechanics of the robot-arm system. Modified Denavit-Hartenberg frame assignment is introduced to resolve the complexity of the skeleton structure frame assignment with a final reference coordinate frame been fixed, which leads to the forward and inverse kinematics model formulation. Each joint of the designed robot arm is given a degree of freedom by attaching a joint driving system using servomotors and harmonics drive partnership. The joint driving systems are designed based on the criteria to meet acceleration and manipulation of the robot-arm structures and inertia masses achieving the 6kg payload at the wrist center point. Prediction of harmonic drive safety functional life span of the shortest period of 8 years is achieved at 1^{st} joint driving system before failure is anticipated. The robot arm 3-D virtual prototype linkage structures are designed through SolidWorks to meet the design requirement of a maximum deflection value of 0.257mm and an equivalent stiffness of 295717.5 N/mm for 6kg payload acting at the wrist center has also been achieved. The main linkage structures design involved the theoretical model, and the iteration or numerical via CAD with CAE verification has been introduced. For analyzing the theoretical dynamic behavior of the robot arm, a dynamic model of the arm has been developed based on the Lagrange approach. An ideal theoretical dynamic model, neglects on the frictional force terms are simulated in the development of inverse dynamic solutions of the joint torques. A close-to real life dynamic simulation or 3-D motion numerical analysis has also been performed through CosmosMotion CAE application tool for comparison and verification of the results with the theoretical model. The linear trajectory simulation of the GMAW robot-arm wrist center Cartesian position error range of 0.00mm to 0.35mm is achieved at 400 mm/min for standard gas metal welding operation, which permitted tolerance variation position between the arc and joint gap not to exceed more than $\pm$0.5 mm. Therefore, the designed GMAW robot-arm has successfully met the requirement of gas metal arc welding operation.

ABSTRAK

Tesis ini mempersembahkan hasil penyelidikan dan reka bentuk sebuah robot lengan yang mempunyai tiga darjah kebebasan (3-DoF) yang merupakan sebahagian daripada robot kimpalan arka, Robotums Ra-01 yang dihasilkan daripada Pusat Bahan dan Galian, Universiti Malaysia Sabah. Robot lengan ini direka untuk pengabungkan sebuah mekanisma lengan hasil ciptaan Chua (2007) supaya sebuah robot enam darjah kebebasan dihasilkan dengan menpunyai kemampuan meliputi 1300mm jarak jangkauan dan mengangkat berat muatan sebanyak 6kg di pusat pergelangan. Kerja-kerja penyelidikan dan reka bentuk robot lengan ini adalah merangkumi asasi-asasi seperti robot lengan mekanik, reka bentuk struktur badan dan sistem pemacuan. Kinamatik model langsungan dan songsangan yang merupakan asasi kepada sistem mekanik robot lengan dibentuk dengan berpandukan konsep Denavit-Hartenberg dalam penetapan kedudukan koordinat rangka yang telah diubahsuai dengan kesesuaian rekabentuk rangka robot lengan. Setiap sendi atau penyambungan dikurniakan satu darjah kebebasan dengan kehadiran sistem pemacuan yang terdiri dari gabungan motor servo dan gear harmonik dan ia direka dengan berpandukan ciri-ciri asas motor servo dan gear harmonik membolehkan struktur robot lengan dapat digerakkan dengan kelajuan yang ditetapkan dengan kehadairan berat muatan 6kg di pusat pergelangan. Setiap sistem pemacuan sendi dijangkakan mempunyai 8 tahun hayat berfungsi dengan jangkaan kerosakan awal berlaku ke atas sistem pemacuan sendi pertama. Model robot lengan dalam bentuk 3-D maya yang dihasilkan dengan penggunaan SolidWorks telah memenuhi syarat reka bentuk, di mana pembiasan maksima adalah 0.257mm bersama kekakuan kesamaan sebanyak 295717.5N/mm dengan kehadiran berat muatan 6kg di pusat pergelangan. Kelakuan robot lengan ini dikaji secara dinamik dengan pembangunan model teori dinamik yang berasaskan konsep Lagrange's mengabaikan sebarangan kuasa yang disebabkan oleh geseran disimulasikan secara songsangan model dinamik untuk pencarian tork sendi. Simulasi nyata dalam bentuk 3-D maya dilakukan untuk tujuan pemerhatian gerakan robot lengan secara kaedah berangka. Hasil penyelidikan secara kaedah berangka dan teori dibanding dan dibincangkan. Pergerakan lurus kimpalan arka dengan kelajuan 4000mm/min telah disimulasikan dan menunjukkan ketepatan (kedudukan) pusat pergelangan robot lengan adalah antara 0.00mm ke 0.35mm yang berada dalam had yang dibenarkan (±0.5mm) dalam piawaian kimpalan arka. Dengan ini, robot lengan yang dicipta telah berjaya mencapai keperluan kimpalan arka.

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LIST OF ABBREVIATIONS

2-D	Two dimensional
3-D	Three dimensional
AC	Alternating current
ARM	Articulated/anthropomorphic robot-arm
CAD	Computer aided design
CAE	Computer aided engineering
CAM	Computer aided manufacturing
CIM	Computer integrated manufacturing
CNC	Computer numerical control
CSF	Cup type harmonic drive
DC	Direct current
D-H	Denavit Hartenberg
DoF	Degree of freedom
E-L	Euler Lagrange's
FEA	Finite element approach
JETRO	Japan External Trade Organization
MIG	Metal inert gas welding
mm	millimeter
m	meter
N-E	Newton-Euler
NC	Numerical control
OICA	International Organization of Motor Vehicle Manufacturers
PTP	Point to point
PAM	Pneumatic artificial muscle

RISC	Reduced instruction set computer
SCARA	Selective compliance adaptive robot arm
SHG	Silk hat type harmonic drive

LIST OF SYMBOLS

k	Structure stiffness
g	Gravity acceleration
n	Gear ratio
t	Cross-section thickness
C	Correlation factor
D	Dimensional coefficient
E	Material modulus of elasticity
F	System generalized forces causes by motion
G	Number of grounded link
I	Structure moment inertia computed about the neutral axis
J	Inertia
L	Structure overall length
M	Internal structure moment acting at x distance
P	Load
$\dot{Q}$	Robot-arm joint rate
R	Gearing reduction
T	Rotational torque
V	Structure volume
$\mathbf{K}$	System kinetic energy
$\mathbf{L}$	Lagrangaian terms
$\mathbf{P}$	System potential energy
δ	Deflection due to pure bending
$\delta_{\max}$	Maximum deflection
ρ	Material density
v	Velocity
α	Angular acceleration
ϖ	Angular velocity
$\varpi_{l\,p}$	Application peak speed
$\varpi_{m\max}$	Motor maximum speed
$\mathbf{v}_{ci}$	Linear velocity of the center of mass of i-th link

ϖ_{ci}	Angular velocity of the center of mass of i-th link
α_i	Twist angle of i-th joint
θ_i	Joint angle of i-th joint
$\dot{\theta}_i$	Joint rate or angular velocity of i-th joint
$\ddot{\theta}_i$	Angular acceleration of i-th joint
η_g	Power transmission unit efficiency / Efficiency rated torque of the drive
$\eta_{effective}$	Harmonic drive effective efficiency
τ	Generalized forces reflected of the system
τ_{ext}	External torques
F_{ext}	External forces
F_i	Force is exerted to link i
H_{n-1}^{n}	Transformation matrix of n coordinate frame to respect to n-1 coordinate frame
J_l^{ci}	Jacobian matrices for linear velocity of the center of mass of i-th link
J_a^{ci}	Jacobian matrices for angular velocity of the center of mass of i-th link
K_e	Harmonic drive compensation coefficient
L_h	Harmonic drive life span
N_i	Torque generated by force is exerted to link i
R_0^l	Rotation matrix of l-th linkage respect to base frame (0)
S_f	Safety factor
T_{RMS}	Root-mean square torque
T_c	Motor continuous torque rating
T_{lp}	Application required peak torque
T_p	Motor peak torque
$u_{xyz}, v_{xyz}, w_{xyz}$	Euler angle
P_x, P_y, P_z	Position of the wrist center
$G(\theta)$	Gravitational force

$M(\theta)\ddot{\theta}$	Inertia tensor matrix
$V(\theta,\dot{\theta})\dot{\theta}$	Coriolis and centrifugal force (velocity coupling terms)
DoF	Degree of freedom
a_i	Link length of i-th joint
d_i	Joint osset of i-th joint
k_{ci}	Unit of vector of i -th joint axis
k_{eq}	Equivalent stiffness
m_l	Mass properties of i-th link
$m_{payload}$	Payload
n_l	Number of link
n_j	Number of joint
x_i	x-axis of i-th joint
y_i	y-axis of i-th joint
z_i	z-axis of i-th joint

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Implementation of robotics is the main key to modern manufacturing systems and it will continue to evolve and succeed. Automobile productions are examples of successful modern manufacturing system, which are steadily increasing year by year and in year 2006 alone the world car production is over 69 millions units (OICA, 2006). Robotics has played a great role in the automobile industries to achieve these production volumes, where almost each automobile production processes can be robotized. These facts have become an encouragement of this research project in developing a material deposition automation with emphasize on gas metal arc welding (GMAW) robot structure and driving mechanism. Through this development, it will become a motivation for Malaysia manufacturing industries to adopt local robot technology rather than a total dependent on foreign technology. The challenges, objectives, scope, methodology, and thesis organization are summarized through a review on material deposition robot.

1.2 MATERIAL DEPOSITION

Material deposition can be defined as a process of delivering of a matter onto a base material. The matter is a material that may be of the same or different material properties as the base material. The common material deposition process includes metal joining, surface coating, electronic circuit board printing, and other processes.

1.2.1 Welding – Gas Metal Arc Welding (GMAW)

Welding is a material deposition process where two materials are united together by adding a filler material. According to British Standard – Welding Terms and Symbols, welding is defined as, "An operation in which two or more parts are united, by means of heat or pressure or both, in such a way that there is continuity in the nature of the metal between these parts. A filler metal, the melting temperature of which is of the same order as that of the parent metal, may or may not be used."

Welding processes are divided into two types of welding principles, which are welding with pressure and fusion welding. Welding with pressure is a joining process by applying pressure and heat. Resistance welding, cold pressure welding, diffusion bonding, and explosion welding are examples of welding by pressure. In fusion welding, a heat source is utilized to create a weldment between two materials or filler material such as consumable electrode or wire. As the weldment solidifies, the two materials are joined together. Fusion welding includes those of arc welding, gas welding, aluminothermic welding, electron beam welding, electro-slag welding and light radiation welding (Norish, 1992).

Gas metal arc welding (GMAW) or formerly known as metal inert gas welding (MIG) is a semi or fully-automatic fusion welding process for both ferrous and non-ferrous metals. The GMAW process produces a weldment between the work pieces and continuously fed the consumable filler electrode wire by heating them with an electric arc. Deoxidizers are presented in the electrode itself and also as addition to prevent oxidation from supplies of inert gas such as argon; helium; mixtures of argon and helium for non ferrous metals; and oxygen or carbon dioxide can be utilized for ferrous metals. During the process, shielding gas forms arc plasma to stabilize the arc on the metal being welded. It also shields the arc and molten weld pool from oxidization and allows smooth transfer of metal from the weld wire to the molten weld pool. Figure 1.1 illustrates the GMAW process and its elements. The applications of GMAW generally use a constant voltage and direct current polarity to the electrode. This welding process has been developed since 1950s, which utilizes a large diameter of steel electrode shielded by carbon dioxide gas. Improvement and development of welding power source technology and introduction of gas mixtures acting as shielded gas has enhanced the GMAW process such that thinner base material can be permitted for welding, providing opportunity for all-position welding, almost spatter free with excellent fusion at low heat input, and excellent weld bead appearance. In GMAW, magnitude of the current and voltage along types of shielding gas and diameter of electrode has been applied to affect the type of metal transfer mode. There are four metal transfer modes such as globular, short-circuiting, spray, and pulsed-spray each method has their own distinct properties and advantages. GMAW processes are commonly found in automotive, furniture, ship building, building construction and other industries. (Norish, 1992; Cary, 1995; Helzer, 2005).

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