ADVANCE CONTROL OF AN ELECTROHYDAULIC AXIS & DESIGN OPTIMIZATION OF MECHATRONIC SYSTEM

PRESENTED BY:

M K PODDAR

M.Tech(Student)

Manufacturing Engg.

NIT Warangal, India

http://ajourneywithtime.weebly.com

CONTENTS

- INTRODUCTION
- PRINCILPE OF SERVO CONTROL
- CONVENTIONAL CONTROLLER
- CONTROL WITH FUZZY CONTROLLERS
- DESIGN OPTIMIZATION OF MS
- CASE STUDY
- CONCLUSION
- REFERENCES

Introduction

- An electrohydraulic axis consists of a servovalve and a hydraulic cylinder and has a nonlinear structure.
- The control system of one axis consists of:

1. the controller represented by a personal computer endowed with a process card;
2. the electrohydraulic converter;
3. the actuator (a linear hydraulic servomotor (LHM));
4. the mechanical process to be controlled, characterized by the slade position;
5. the position transducer.

- Electrohydraulic system is one of the axes of a robot.

Introduction contd…

- An electrohydraulic axis whose mathematical model (MM) is described large number of nonlinearities. Conventional controllers are becoming increasingly inappropriate to control the systems with an imprecise model where many nonlinearities are manifested.

- The three axes of ROBI_3 are identically controlled by the controlling software named TORCH, which runs in Windows.

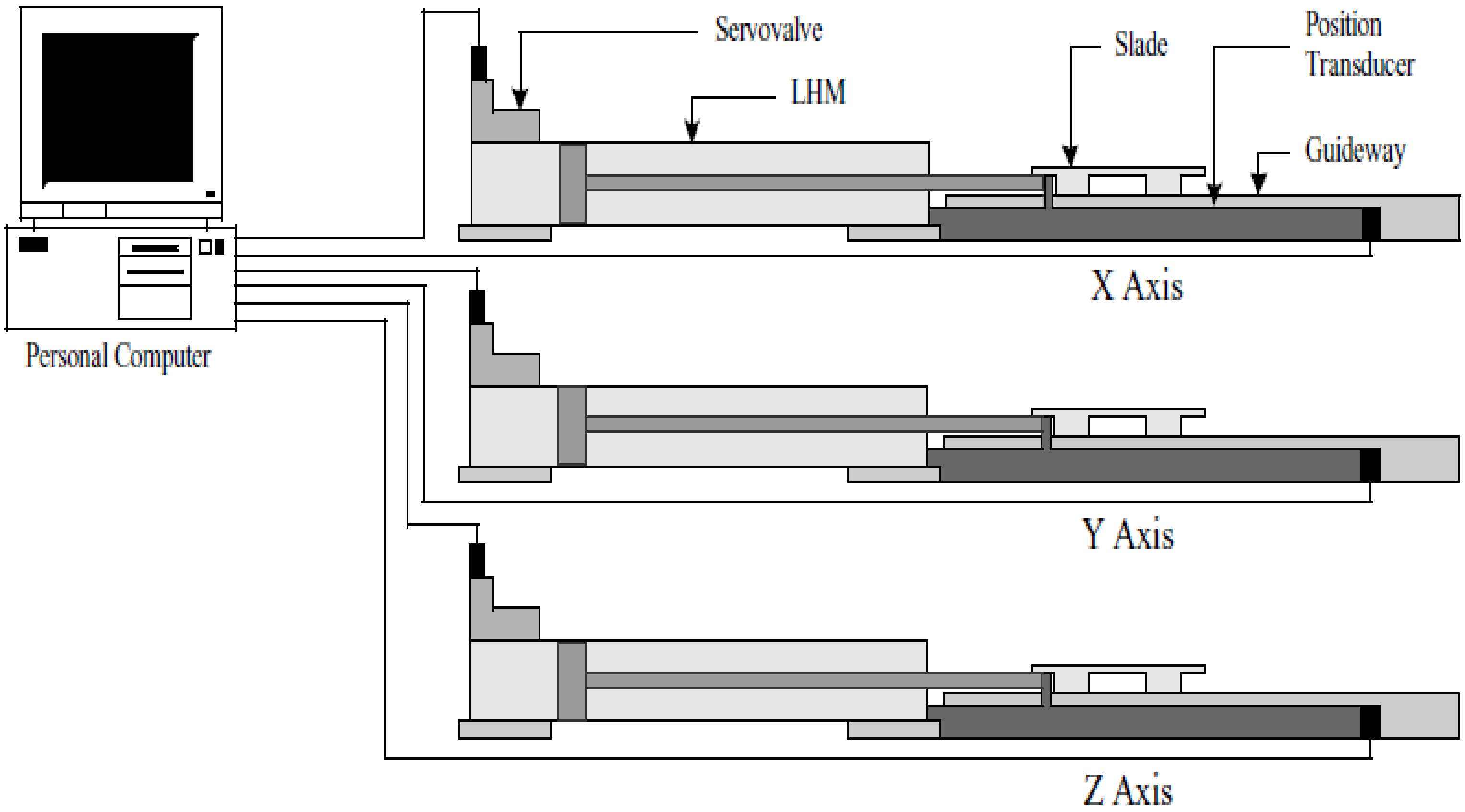


Fig 2. The control system of the robot

PRINCIPLE OF SERVO CONTROL

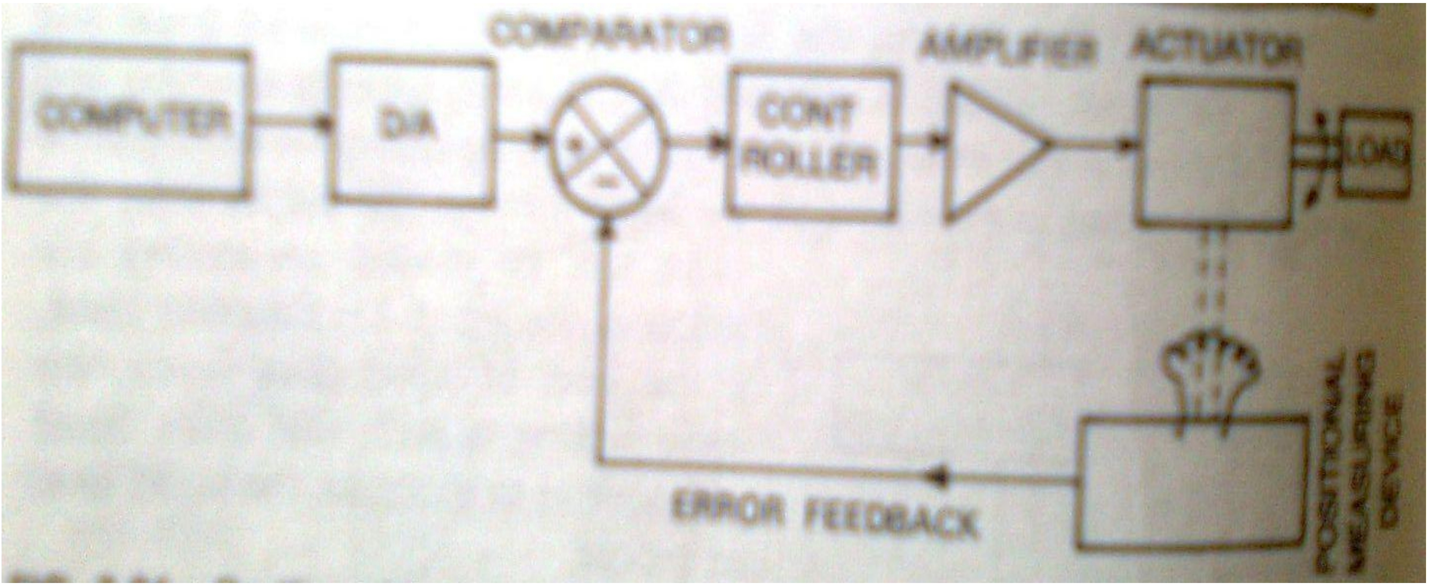
- Close loop servo control systems are activated by the error signal
- The desired position of the robot arm is given through a computer that sends a digital signal. Finally the robot's arm is sifted to a new position by a servo motor fitted to arm.
- The digital signal from computer is converted to an analog signal by a digital to analog (D/A) converter. This analog voltage is fed to the positive input of a comparator. The output of the comparator is fed to the controller which in turn, send its output of the actuator through a variable gain power amplifier.

PRINCIPLE OF SERVO CONTROL CONTD…

- A measuring device is fitted on the output shaft. The measuring device produces an electrical signal indicating the current position of the robot arm.

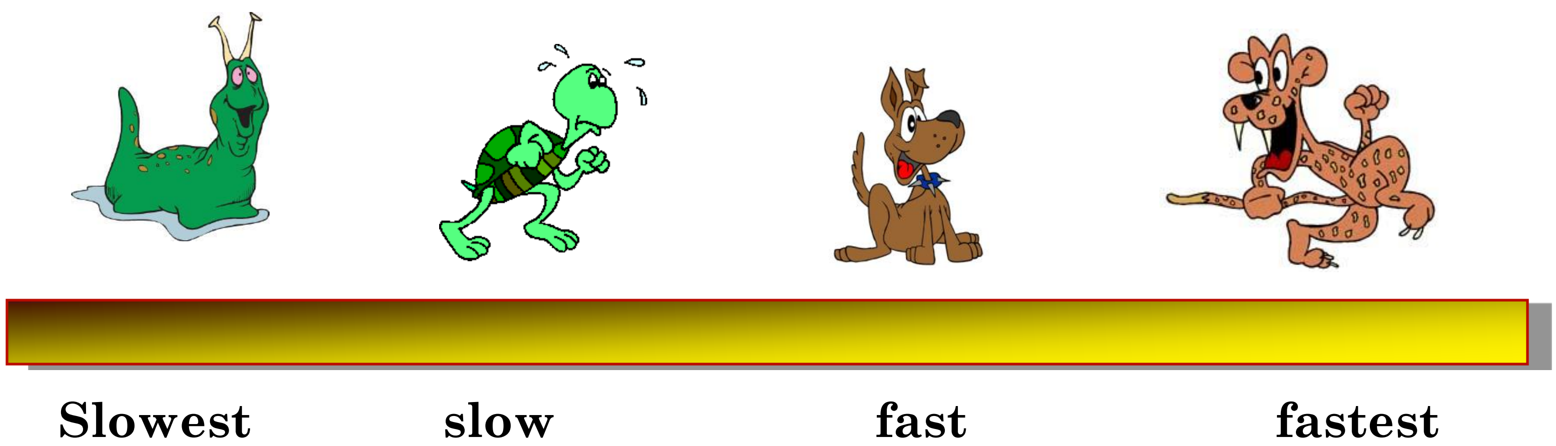
- the signal of the current positional information is fed back to the negative input of the comparator. The comparator compares the desired input signal and the actual output signal obtained through measuring device.

- Their difference(error signal) is amplified and fed to the actuator. When comparator output is zero, the robot arm stop moving as it has reached the desired position.


COMPUTER
D/A
COMPARATOR
CONT ROLLER
AMPLIFIER
ACTUATOR
LOAD
ERROR FEEDBACK
POSITIONAL MEASURING DEVICE

CONTROL WITH FUZZY CONTROLLERS

- Fuzzy logic is based on the theory of fuzzy sets.
- Fuzzy logic uses the whole interval of real numbers between zero (*False*) and one (*True*) to develop a logic as a basis for rules of inference.
- Fuzzy controller is the approach for nonlinear mapping of one set of variables into another set of variables.

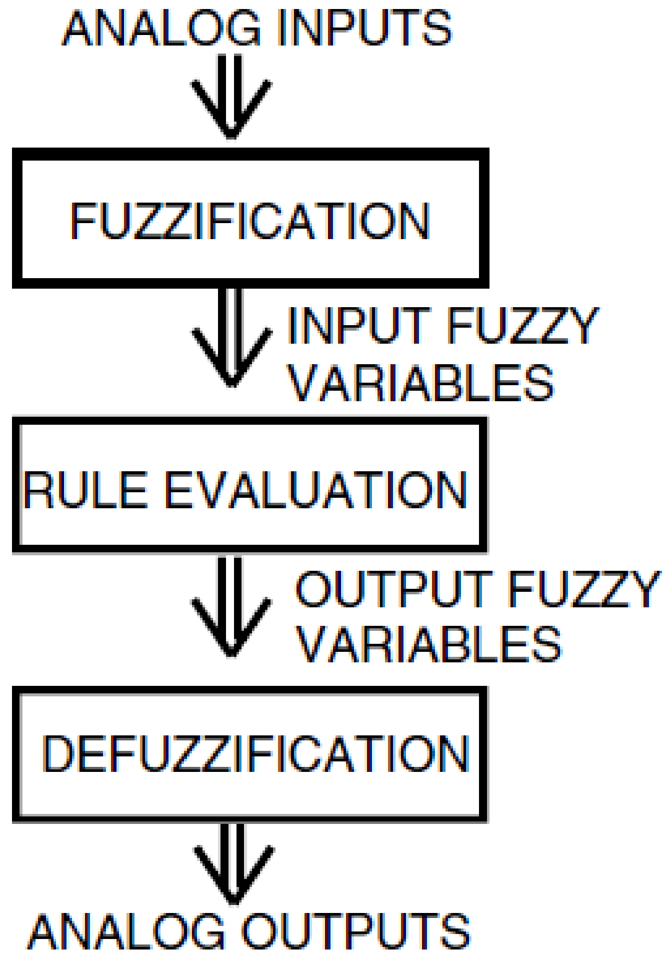


FUZZY CONTROLLERS CONTD….

Fuzzification-> The purpose of fuzzification is to convert an analog variable input into a set of fuzzy variables

```
float speed;
get the speed
if ((speed >= 0.0)&&(speed < 0.25)) {
//  speed is slowest
}
else if ((speed >= 0.25)&&(speed <
0.5))
{
//  speed is slow
}
else if ((speed >= 0.5)&&(speed <
0.75))
{
//  speed is fast
}
else // speed >= 0.75 && speed < 1.0
{
//  speed is fastest
}
```

The block diagram of a fuzzy controller



FUZZY CONTROLLERS CONTD….

Rule evaluation: In fuzzy logic all variables may have any values between zero and one. The fuzzy logic consists of the same basic: —AND, -OR, and NOT operators:

Defuzzification-> As a result of fuzzy rule evaluation, each analog output variable is represented by several fuzzy variables. The purpose of defuzzification is to obtain analog outputs.

DESIGN OPTIMIZATION OF MECHATRONIC SYSTEMS:

- Electromechanical systems form an integral part of mechanical and mechatronic systems. Their optimization is a necessary condition for a product to be competitive.
- In engineering practice, a large number of optimization and identification problems exist , the aim of an optimization process is to optimize several properties that simulteneously , affect the system.
- So we obtain a multi-criteria objective function.

DESIGN OPTIMIZATION CONTD….

- **To solve the problem of optimizing the selected properties of a system, the following has to be done:**
- A mathematical description has to be formulated,
- It has to be analyzed at the starting point,
- The desired form of the objective function ψ has to be specified,
- The optimization variables have to be selected,
- The desired form of the constraining functions *qj* has to be specified,
- A suitable optimization method has to be selected,
- The resulting mathematically formulated optimization problem has to be solved

CASE STUDY:

- A multi-objective genetic algorithm optimization of a motor-driven four-bar system:
  - A genetic algorithm based method to design a mechatronic system. First, we present the sequential approach where we optimize the geometry of the mechanism, for a given path, and then solve the dynamic problem where we take into account the characteristics of the motor along with the inertia of the different links of the mechanism.
- Several types of objective functions are tested but this sequential method does not yield acceptable results for the dynamic behavior due to the fact that the geometry is assumed fixed when optimizing the dynamics.

CASE STUDY CONTD….

- This led us to formulate a global optimization problem where all the parameters of the mechanism are considered simultaneously. The problem is then presented as a multi-objective optimization one where the geometry and the dynamics are considered simultaneously. The obtained solutions form what is called a “Pareto front” and they are analyzed for several different design conditions.

Case study contd….

- STEPS DURING DESIGN OPTIMIZATION
- problem formulation in the general case
- describes the dimensional synthesis of the four-bar mechanism for a specified path
- The mathematical model of the motor-driven mechanism system
- the results of the different optimization problems are presented along with the multi-objective optimization, which takes into account all the objective functions simultaneously.
- concluding remarks

Case study contd…

- Formulation of the problem

Min: $f_j(X)$, $J = 1,2,3\ldots\ldots m$

subject to: $g_k(X) \leq 0$, $k=1,2\ldots\ldots n$

x_i € [x_i min, x_i max]; x_i € X

where:

fj is the objective function,

gk is the constraint applied to the system,

X is a design vector of the mechatronic system, which contains all the independent design variables,

xi min and xi max define the limits of each design variable xi.

Case study contd…

- dimensional synthesis of the four-bar mechanism for a specified path

The objective function to be minimized is given by

$$f_1 : \min \left(\left(\sum_{i=1}^{N} [(C_{xd}^i - C_{xr}^i)^2 + (C_{yd}^i - C_{yr}^i)^2] \right)^{\frac{1}{2}} + M_1 h_1(X) + M_2 h_2(X) + M_3 h_3(X) \right)$$

Case study contd….

- **Mechatronic system model**

1. **Mechanism dynamic model**

the equation of motion as:

$$T = \frac{\mathrm{d}}{\mathrm{d}t}\left(\frac{\partial K}{\partial \dot{\Phi}_2}\right) - \frac{\partial K}{\partial \Phi_2} + \frac{\partial P}{\partial \Phi_2} + \frac{\partial D}{\partial \dot{\Phi}_2}$$

$$T = A\ddot{\Phi}_2 + \frac{1}{2}\frac{\mathrm{d}A}{\mathrm{d}\Phi_2}\dot{\Phi}_2^2 + k_p(\Phi_2) + c\gamma_4^2\dot{\Phi}_2$$

Case study contd…..

- **2. driving motor model**

Eqs for motor torque

$$\frac{\mathrm{d}i(t)}{\mathrm{d}t} = \frac{1}{L}(V - Ri(t) + nK_g\dot{\Phi}_2)$$

And

$$T = nK_{\mathrm{m}}i(t) - nT_L - n^2B\dot{\Phi}_2 - n^2J\ddot{\Phi}_2$$

Case study contd…

For a mechatronic system, the torque produced by the motor should be equal to the torque needed for the mechanical system.

$$nK_{\mathrm{m}}i(t) - nT_L - n^2B\dot{\Phi}_2 - n^2J\ddot{\Phi}_2 = A\ddot{\Phi}_2 + \frac{1}{2}\frac{\mathrm{d}A}{\mathrm{d}\Phi_2}\dot{\Phi}_2^2 + k_p(\Phi_2) + c\gamma_4^2\dot{\Phi}_2$$

Therefore, solving for i(t),

$$i(t) = \frac{1}{nK_{\mathrm{m}}}\left(\frac{1}{2}\frac{\mathrm{d}A}{\mathrm{d}\Phi_2}\dot{\Phi}_2^2 + k_p(\Phi_2) + c\gamma_4^2\dot{\Phi}_2 + nT_L + n^2B\dot{\Phi}_2\right)$$

This equation gives the current required to maintain a constant crank speed at a steady state. This is the second objective function that should be minimized.

CASE STUDY CONTD….

The third objective function is the current variation:

$\Delta I = \min (i_{max} - i_{min})$

Where i max and i min are the lower and the upper current values during a cycle of motion of the mechanisms.

Another objective function to minimize is the current fluctuation during a cycle

$$\frac{\mathrm{d}i(t)}{\mathrm{d}t} = \frac{1}{nK_\mathrm{m}} \left\{ \frac{1}{2} \dot{\Phi}_2^2 \frac{\mathrm{d}}{\mathrm{d}t} \left(\frac{\mathrm{d}A}{\mathrm{d}\Phi_2} \right) + k\dot{\gamma}_4 (\Phi_4 - \Phi_{4,0}) + k\gamma_4 \dot{\Phi}_4 + 2c\gamma_4 \dot{\gamma}_4 \dot{\Phi}_2 \right\}$$

If forces on the mechanism are zero, i.e., k = 0 and c =0

$$\left| \frac{\mathrm{d}i(t)}{\mathrm{d}t} \right|_{\max} = \left| \frac{1}{2nK_\mathrm{m}} \dot{\Phi}_2^2 \frac{\mathrm{d}}{\mathrm{d}t} \left(\frac{\mathrm{d}A}{\mathrm{d}\Phi_2} \right) \right|_{\max}$$

Case study contd….

- **Optimization of the mechatronic system**

Optimization dimentional sysnthesis of the mechanism :

the final error of the optimized mechanical system is e = 4.43 mm, where e is given by

$$e = \left(\sum_{i=1}^{N} [(C^i_{xd} - C^i_{xr})^2 + (C^i_{yd} - C^i_{yr})^2] \right)^{\frac{1}{2}}$$

A total of 16 points (N = 16) on the desired curve are specified. The bounding intervals for eachone of the variables are given between zero and 500 mm

Table 1
Dimensions of the optimal mechanism (m)

L_1	L_2	L_3	L_4	r_{cx}	r_{cy}
0.246	0.111	0.295	0.186	0.145	0.152

CASE STUDY CONTD…

- **Geometry optimization (case: 1)**

 In this section, we will assume that the mass of each link is uniformly distributed. Therefore, the location of the center of mass and the moment of inertia of each link are given, respectively, by L/2 and mL2/12, where m its mass and L its length.

Table 3
The optimized design vector of the non-optimized mechatronic system

r_3 (m)	r_4 (m)	θ_3 (°)	θ_4 (°)	m_3 (kg)	m_4 (kg)	j_3 (kg m^2)	j_4 (kg m^2)
0.148	0.093	0	0	5.54	3.6	0.0133	0.0086

Case study contd…

- **minimization of the maximum current: (case : 2)**

The characteristics of the motor used in this work are given:

Table 2
Motor parameters

R (Ω)	L (H)	K_m (N m/a)	K_g (V s)	J (kg m^2)	T_L (N m)	B (N ms)
0.4	0.05	0.678	0.678	0.056	0.0	0.226

for the given dimensions, of the mechanism that minimize the maximum current of the mechatronic system

$$f_2 : \min(i(t)_{\max})$$

Subject to:

$$\begin{cases} g_1 : \dot{\Phi}_2 = \text{constant} \\ g_2(X) : x_i \in [x_{i\,\min}, x_{i\,\min}], \quad x_i \in X \end{cases}$$

The design vector to be optimized is

$$X = [r_3, r_4, \theta_3, \theta_4, m_3, m_4, j_3, j_4]$$

This is reduce the maximum current by a factor of 2.5 compared to previous one

Case study contd…

- **minimization of the current variation (case:3)**

$$f_3 : \min(\Delta i)$$

where

$$\Delta i = i_{\max} - i_{\min}$$

The constraints and the design vector are the same as the above case

minimization of the current fluctuation (case: 4)

$$f_4 : \min\left(\left|\frac{\mathrm{d}i(t)}{\mathrm{d}t}\right|_{\max}\right)$$

current fluctuation criterion can be a better one than current variation

Case study contd…

Table 4

Optimized design vector that minimizes the maximum current

r_3 (m)	r_4 (m)	θ_3 (°)	θ_4 (°)	M_3 (kg)	m_4 (kg)	j_3 (kg m^2)	j_4 (kg m^2)
0.057	0.050	353.7	191.4	2.49	1.20	0.0133	0.0086

Table 5

Optimized design vector that minimizes the current variation

r_3 (m)	r_4 (m)	θ_3 (°)	θ_4 (°)	m_3 (kg)	m_4 (kg)	j_3 (kg m^2)	j_4 (kg m^2)
0.0253	0	360	0	4.47	3.59	0.0133	0.0086

Table 6

Optimized design vector that minimizes the current fluctuation

r_3 (m)	r_4 (m)	θ_3 (°)	θ_4 (°)	m_3 (kg)	m_4 (kg)	j_3 (kg m^2)	j_4 (kg m^2)
0.034	0	343.9	215.3	2.17	1.20	0.0133	0.0086

Case study contd...

- **Global synthesis of the mechatronic system**

minimizes all the previous objective functions simultaneously. This objective can be reached by using the multi-objective optimization. The following objective functions are selected to be minimized simultaneously.

$$f_1 : \min \left(\sum_{i=1}^{N} \left[(C_{xd}^i - C_x^i)^2 + (C_{yd}^i - C_y^i)^2 \right]. \right.$$

$$\left. + M_1 h_1(X) + M_2 h_2(X) + M_3 h_3(X) \right)$$

$$f_2 : \min(i(t)_{\max})$$

$$f_4 : \min \left(\left| \frac{\mathrm{d}i(t)}{\mathrm{d}t} \right|_{\max} \right)$$

Case study contd…

Subject to:

$$g_1 : \dot{\Phi}_2 = \text{constant}$$
$$g_2 : x_i \in [x_{i\,\text{min}}, x_{i\,\text{min}}], \quad x_i \in X$$
$$g_3(X) : \Phi_{2,i} - \Phi_{2,i+1} < 0$$
$$g_4(X) : L_1 + L_2 < L_3 + L_4; \quad L_2 < L_3 < L_4 < L_1$$

The design vector to be optimized is

$$X = [L_i, \Phi_{2k}, r_{cx}, r_{cy}, r_3, r_4, \theta_3, \theta_4, m_3, m_4, j_3, j_4]$$
$$(k = 1, \ldots, 16)$$

Case study contd...

Design vectors of the different cases

Design vector	Case 1	Case 2	Case 4	Case 5
L_1 (m)	0.246	0.246	0.246	0.250
L_2 (m)	0.111	0.111	0.111	0.080
L_3 (m)	0.295	0.295	0.295	0.290
L_4 (m)	0.186	0.186	0.186	0.190
r_{cx} (m)	0.145	0.145	0.145	0.155
r_{cy} (m)	0.152	0.152	0.152	0.155
r_3 (m)	0.150	0.057	0.034	0.0200
r_4 (m)	0.099	0.05	0	0
θ_3 (°)	0	353.7	343.9	344.82
θ_4 (°)	0	191.4	215.3	360.18
m_3 (kg)	5.54	2.49	2.17	2.95
m_4 (kg)	3.60	1.20	1.20	3.53
j_3 (kg m^{-2})	0.0133	0.0133	0.0133	0.0133
j_4 (kg m^{-2})	0.0086	0.0086	0.0086	0.0086
Objective functions				
Path error (mm)	4.43	4.43	4.43	21.84
Current (A)	5.42	2.14	2.20	1.77
Current fluctuation $\|di/dt\|$ (A/s)	67.90	38.47	25.00	15.76

CONCLUSION

- This work dealt with the problem of optimizing the geometry and the dynamic behavior of a four-bar mechatronic system.
- First, we presented the sequential approach where we optimized sequentially the geometry of the mechanism, for a given path, and then solved the dynamic problem where we take into account the characteristics of the motor along with the inertia of the different links of the mechanism.
- Several types of objective functions were tested: the maximum current used by the motor, its maximum variation, and finally its fluctuation.
- A global optimization problem was then formulated where all the parameters of the mechanism were considered simultaneously.
- The obtained solutions are then analyzed for several different design conditions.

RERERENCES

- Junpeng Shao, Lihua Chen, Zhibin Sun, “The Application of Fuzzy Control Strategy inElectro-hydraulic Servo System” Mechatronics and Automation, 2005 IEEE International Conference Volume 4, July 29-Aug. 1 pp. 2010 – 2016 , 2005
- Zouhaier Affi , Badreddine EL-Kribi , Lotfi Romdhane, Advanced mechatronic design using a multi-objective genetic algorithm optimization of a motor-driven four-bar system Mechatronics 17 (2007) 489–500
- Junpeng Shao, Lihua Chen, Zhibin Sun, “The Application of Fuzzy Control Strategy in Electro-hydraulic Servo System” Mechatronics and Automation, 2005 IEEE International Conference Volume 4, July 29-Aug. 1 pp. 2010 – 2016 , 2005
- THE MECHATRONICS H A N D B O O K

  By: Robert H. Bishop

  The University of Texas at Austin

  Austin, Texas
- Robotics by prof. S R DEV

  Jadavpur University

THANK U