Design of Compliant Mechanism And PID controller

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Abstract*— Compliant mechanism is single-piece flexible structures that deliver the desired motion by undergoing elastic deformation as opposed to jointed rigid body motions of conventional mechanisms. Compliant Mechanism is not different but same to XY Flexure mechanism. Pro-E software is used for modeling of compliant mechanism and ANSYS is used for Static analysis and dynamic analysis. Deflection of motion is concluded by static analysis with force. Proportional Integral Derivative (PID) controller is designed using the concept of Cart Pole system (Inverted Pendulum). Inverted pendulum is a kind of typical platform for control theory verification This paper gives design of jointless mechanisms with distributed compliance and fabricated for MEMS application and the PID controller design. The paper also illustrates a Simulation of model in Matlab.

Index Terms— **Compliant Mechanism, MEMS, Flexure Mechanism, Cart Pole system, PID Controller,Simulation**

1. INTRODUCTION

Compliant Mechanism is a recent development in the field of MEMS designing. A compliant mechanism is a single-piece mechanism that transfers motion without any relative motion between joints or linkages, thus causing no friction or hysteresis loss.. The design of a mechanism having flexural bending at the linkages methods for modeling and designing compliant mechanisms has spurred their use in a variety of products, ranging from macro-scale products such as clutches, guides, and switches, to micro-electromechanical systems (MEMS). Compliant mechanisms offer a number of advantages, such as increased precision, reduced friction and wear, simple construction, and reduced assembly. In many ways compliant mechanisms have developed similar functionality to rigid mechanisms. Compliant mechanisms have the potential to completely eliminate relative motion between linkages, and thus eliminate friction.

` Inverted Pendulum, is a non-linear, strong-coupling and natural instable system, and has been widely concerned for a long time. Not only used as a teaching instrument, it is also studied in the spheres of theory and technology which are usually connected with precision instruments, robot control The Inverted Pendulum is an invaluable tool for the effective evaluation and comparison various control theories.

Traditionally, engineered artifacts are designed to be strong and stiff. Designs in nature, on the other hand, are strong but not necessarily stiff—they are compliant. Compliance in design leads to creation n of jointless, no-assembly,

Monolithic mechanical device. Nature has realized the pivotal role that compliance plays at the realm of microorganisms, the level at which MEMS fit.[1]

Mathematical modeling of several XY flexure mechanism having large range of motion and low parasitic error. The modeling of XY flexure mechanism is based on characteristics of building blocks used to build it. Comparison of linear and non-linear closed form analysis is presented in this paper. At last analytical results are compared with results of FEA and experiment.[2]

Kinematic design of large displacement precision X-Y positioning stage by using cross strip flexure joints and over constrained mechanism. For the design of a large displacement precision XY positioning stage, a cross strip flexure joints were used. [3]

The analysis and design of general platform type parallel mechanisms containing flexure joints. They considered static performance measures such as task space stiffness and manipulability. They established the key difference between flexure mechanism and parallel mechanism with conventional joints and is that kinematic stability is no longer a design consideration.[4]

Design and analysis of a compliant flexure-based totally decoupled XY micro positioning stage. Compliance and stiffness analysis based on matrix method, and analytical models for electromagnetic forces is done by using the kinematics and dynamic modelling of the mechanical system of the stage. Both mechanical structure and electromagnetic model are validated by finite element analysis (FEA) via ANSYS. [5]

Automatic Control is a growing field of study in the field of Mechanical Engineering. This covers the proportional, integral and derivative (PID) and state space control. The principal reasons for its popularity are its nonlinear and unstable characteristics. This report begins with an outline of the research into Inverted Pendulum system design and control along with mathematical modeling methods.[6]

2. Design of Compliant Mechanism

Based on the designs studied we found out that the all the compliant mechanisms were based on flexural motion. An elastic strip is made to bend or twist causing distortion in its original dimensions and producing the desired motion. After studying various existing mechanisms, we tried designing our own mechanism based on Flexural Force Transmission

To eliminate the mounting difficulties we decided to take Single piece mechanism in which whole mechanism is cut from the single block using Wire cut machining processes. It provides ease in mounting and avoids unnecessary displacement of the beams (strips), which provides good stability and accuracy. The stress developing in this design is maximum. It contains the angular motion of the beams because of its design and this mechanism provides linear motion.

The Geometrical Modeling of the Compliant Amplifier is essential for numerical analysis and graphical representation of the model. This is done on a CAD software which in this case is Pro-E Wildfire 5.0.

Part Dimensions of Individual Components of the model is shown in table below.

Sr. No.	Part	Dimensions
1.	Base plate	258.3 X 228.3 X 10 mm
2.	Flexure beam(strips)	100 X 10 X 0.85 mm

Table 1:Part Dimensions of Individual Components of model

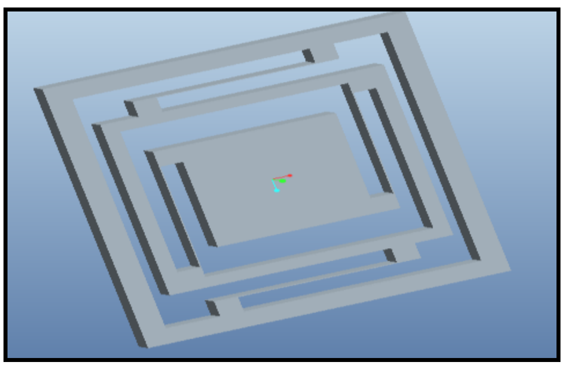


Fig.1: CAD Model of the Compliant Mechanism on Pro-E Wildfire 5.0

3. FEA Analysis of Mechanism

Meshing is the process of discretization of a part into finite number of small elements. Usually the element is chosen based upon the shape and form of the part. In this case all the parts are be easily meshed by using triangular and cubical element.

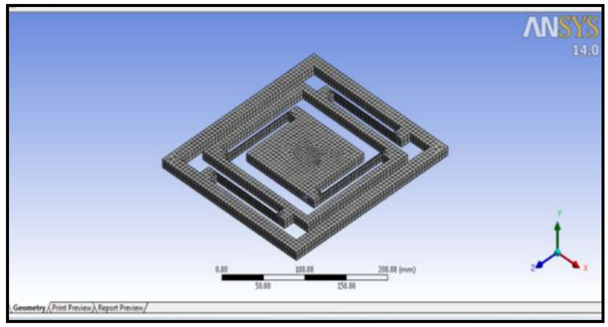


Fig.2: Fine Meshing of Model

When we apply the force of 20N in X-direction and in Y-direction in Ansys software then we get the maximum deformation in X and Y didrection also the maximum stresses occures in X and Y directon

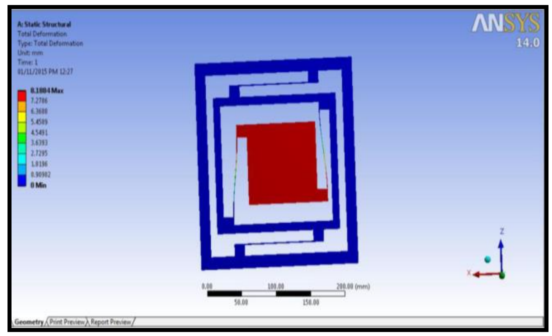


Fig.3: Deformation in X-Axis

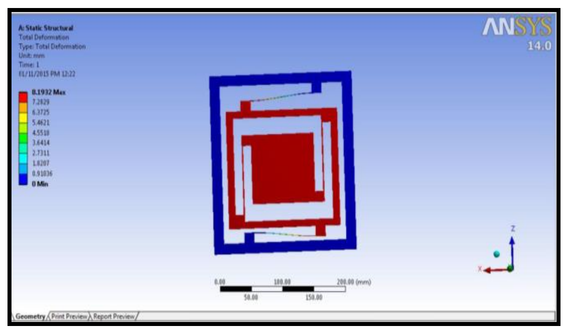


Fig.4: Deformation in Y-Axis

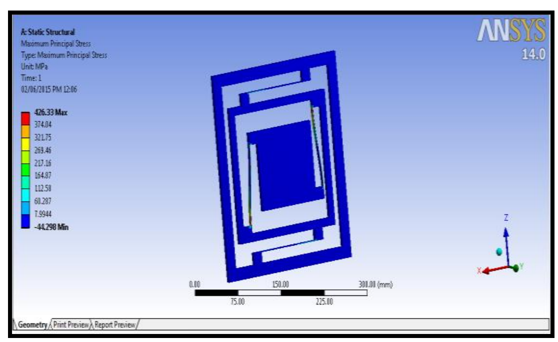


Fig.5: Stresses in X-Axis

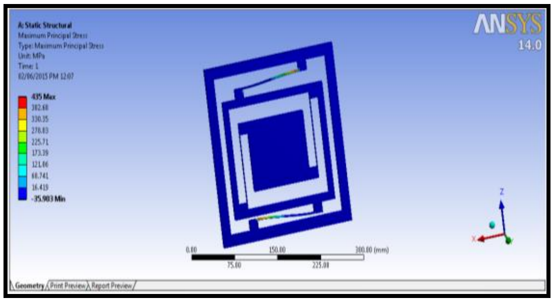


Fig.6: Stresses in Y-Axis

As it is seen from the figure, the maximum stress created at the Flexure strip is 426MPa in X direction and 435MPa in Y direction. The material used for Flexure strip is Mild Steel. The Tensile Yield Strength of Mild Steel is 490MPa. Thus the maximum stress generated at the Flexure strip is within the permissible limit. So the design is safe.

4. PID Controller

The Inverted Pendulum is a classical control theory problem. It involves developing a system to balance an Inverted pendulum. For visualization purposes, this is similar to trying to balance a broomstick on a finger. There are three main subsystems that compose this design including the mechanical system, the feedback network and a controller. The most fundamental case is when a pendulum is mounted on a cart which can move back and forth in one linear direction. The pendulum is then balanced in upright position by controlling the movement of the cart.

Now we are using the cart pole system for the further process.

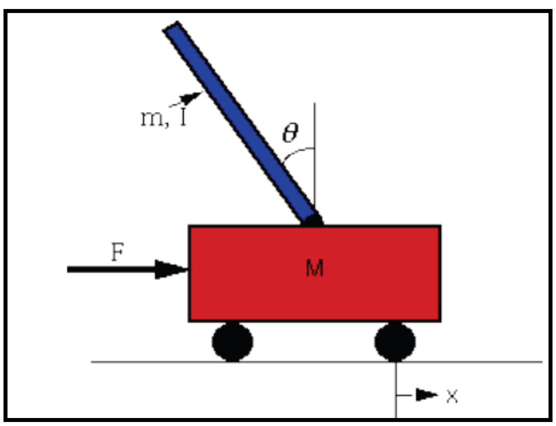
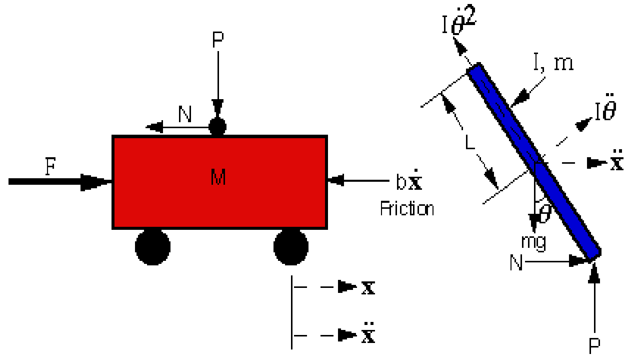


Fig 7: The cart with an inverted pendulum

Free Body Diagrams of the above system is given as



From above F.B.D, Cart and the pendulum have one degree of freedom. We will then model Newton's equation for these two degrees of freedom

$$\frac{d^2x}{dt^2} = \frac{1}{M}\sum_{cart} F_x = \frac{1}{M}\left(F - N - b\frac{dx}{dt}\right)$$
$$\frac{d^2\theta}{dt^2} = \frac{1}{I}\sum_{pend} \tau = \frac{1}{I}\left(NL\cos(\theta) + PL\sin(\theta)\right)$$

we will model the additional x and y equations for the pendulum

$$\begin{aligned}
m\frac{d^2x_p}{dt^2} = \sum_{pend} F_x &= N \\
\Longrightarrow N &= m\frac{d^2x_p}{dt^2} \\
m\frac{d^2y_p}{dt^2} = \sum_{pend} F_y &= P - mg \\
\Longrightarrow P &= m\left(\frac{d^2y_p}{dt^2} + g\right)
\end{aligned}$$

xp and yp are exact functions of theta. So, we can represent their derivatives in terms of the derivatives of theta

$$\begin{aligned}
x_p &= x - L\sin(\theta) \\
\frac{dx_p}{dt} &= \frac{dx}{dt} - L\cos\theta\frac{d\theta}{dt} \\
\frac{d^2x_p}{dt^2} &= \frac{d^2x}{dt^2} + L\sin\theta\left(\frac{d\theta}{dt}\right)^2 - L\cos\theta\frac{d^2\theta}{dt^2}
\end{aligned}$$

$$\begin{aligned}
y_p &= L\cos(\theta) \\
\frac{dy_p}{dt} &= -L\sin\theta\frac{d\theta}{dt} \\
\frac{d^2y_p}{dt^2} &= -L\cos\theta\left(\frac{d\theta}{dt}\right)^2 - L\sin\theta\frac{d^2\theta}{dt^2}
\end{aligned}$$

These expressions can then be substituted into the expressions for N and P. Rather than continuing with algebra here, we will simply represent these equations in Simulink. Simulink can work directly with nonlinear equations, so it is unnecessary to linearize these equations.

By using the above equations we build up a simulation file in Matlab software.

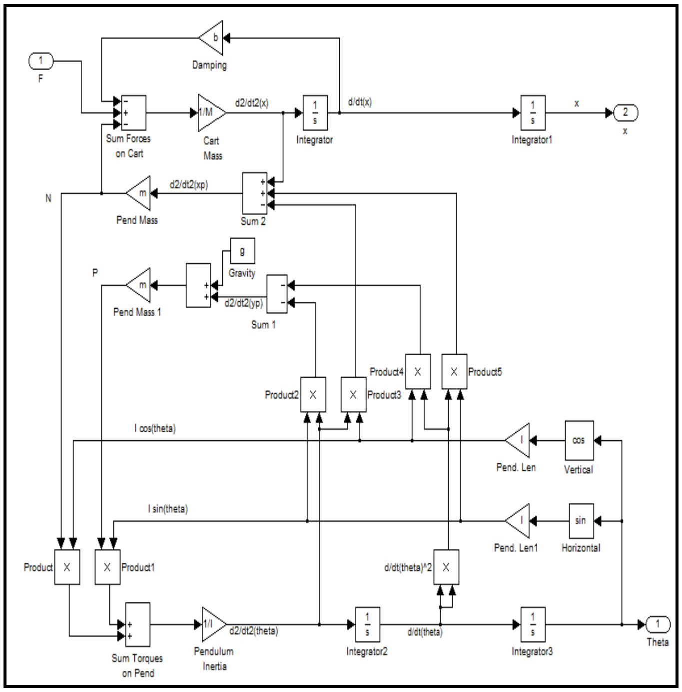


Fig 8: Simulation diagram

To generate the open-loop response, it is necessary to contain this model in a subsystem block.

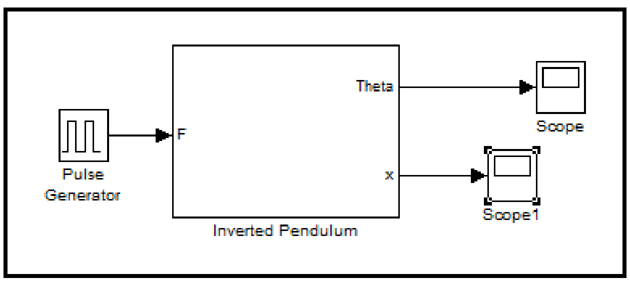


Fig 9:Sub system of Inverted Pendulum

Implementing PID control

A PID controller was designed with proportional, integral, and derivative gains. To implement this, we will add in both a control input and the disturbance impulse input to the above model.

The equation of PID controller is given as-

$$P = K_P.e_P + K_P.K_I \int_0^t e_p dt + K_P.K_D.\frac{d}{dt} e_P(t) + P_I(0)$$

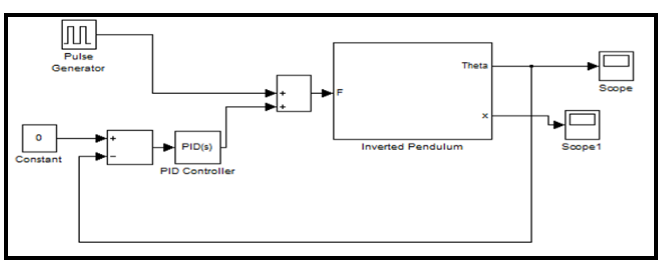
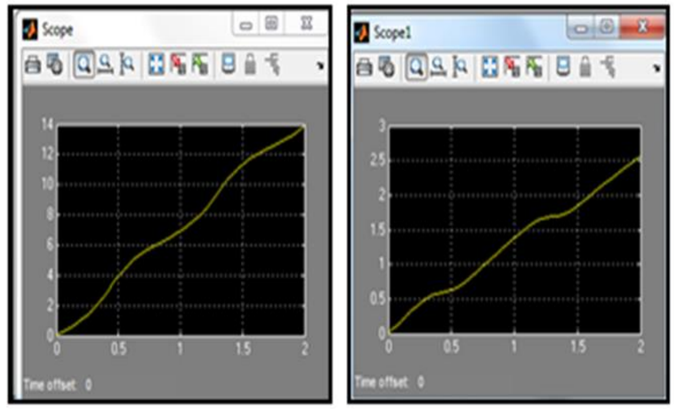


Fig 10: Sub system with PID controller

5. Result and Disscussion

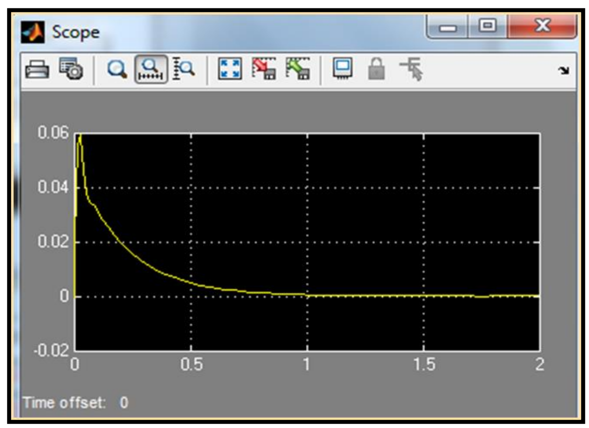
When we run the above Inverted Pendulum simulink files in Matlab software. We get,



Graph 1:Sub system of Inverted Pendulum

From above graph, it is notice that the pendulum swings all the way around due to the impact, and the cart travels along with a jerky motion due to the pendulum.

When we run the Simulink file of Inverted Pendulum sub system with PID controller, we get,



Graph 2: Sub system of Inverted Pendulum with PID Controller

From above graph, it is clear that PID controller handles the linear and nonlinear system very well with very small angle and dimensions.

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