Design Principles for Precision Mechanism 1

Project Design Report

Group 18

Miguel Cacarin Cumbal	s2074311
David Carrera Robles	s2074222

UNIVERSITY OF TWENTE.

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1 Introduction

This report will be based on the development of a mechanism that has 3 degrees of freedom, being one of this already defined, the mechanism will be used to pick up and place electronic components inside a printed circuit (PCB). The mechanism is provided with a device that creates a vacuum to pick up the pieces and place them in their corresponding place.
To carry out this project, several assumptions will be analyzed and backed up with calculations and also graphics based on Spacar that will give the certainty that the mechanism could work in a possible work environment.

2 Mechanism Pick and Place

In order to design a mechanism that is capable of pick electronic components and place them into a PCB a list of requirements have to be meet such that an accuracy of 10 μm , it should fit in a space of $100 \cdot 75 \cdot 120mm$ and be able to reach an area of $25 \cdot 25mm$ [1] .
The idea of this mechanism is based in Leaf Springs, because 2 Leaf Springs allows 1 DoFs 1 translation, Therefore we use 2 pairs of leaf springs, 1 pair connected to the other. In figure 1 you can see how this mechanism is mounted.
The vertical displacement, Z direction, is considered the large stroke movement which is already defined. the 2 other translations are performed by leaf springs, the goal is to obtain a mechanism with high accuracy by avoiding Shortening effect, because Z direction is already defined, the deflection in this axis can be calculated and compensated with this movement already defined. For that reason the forces applied are in the center of compliance, For the first pair of leaf springs, figure (1), (yellow), the center of compliance is the grey square body that is in the half way of the yellow leaf springs
For the second leaf springs the center of compliance is the grey body that was extended to the half way of these leaf springs, all of these to avoid most of the problems.

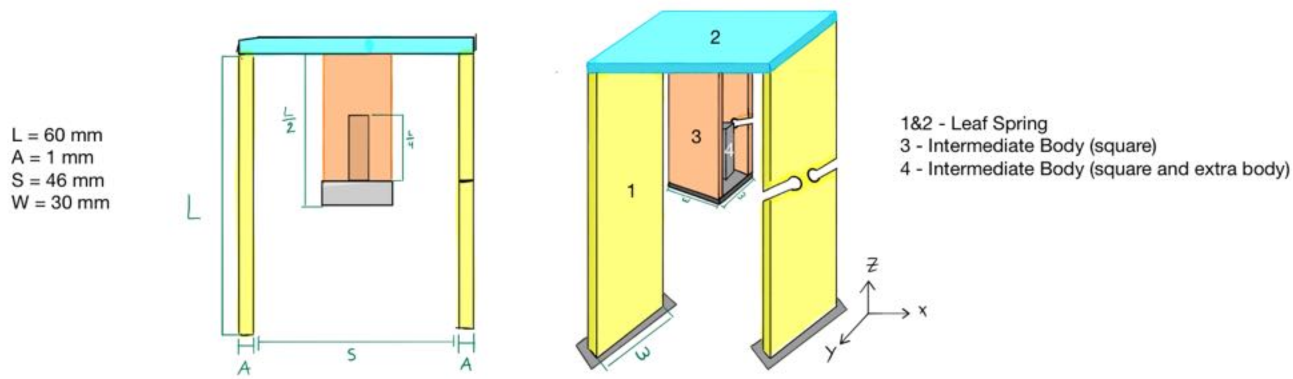

Figure 1: Pick and Place Mechanism

2.1 Advantages

- This mechanism is based on simple movements which makes the work more simple and is able to reach the Area of 25· 25 mm.
- By acting a force through the center of compliance and along one of the principal axis will cause deflection co-linear with the force.
- Very easy to produce and few changes can be made, combination of notched leaf spring and simple leaf spring is better option to avoid over constraints.

2.2 Disadvantages

- Shortening effect can happen in this mechanism nevertheless, this effect was considered during dimensions.
- The use of notch flexure will cause a stress acumulation in the center part .

3 Calculations

3.1 Dimensions and Manual Calculation

Some calculation can be manual determined such as: Stiffness of the leaf spring, Moment of Inertia, Transverse deflection and the maximum stress. With our design we are able to make calculation using the center of compliance and the center of gravity of the figure. In order to do the calculations some assumption about the dimensions were done. The assumption were based of the actual size of the electronic components that are mounted in the PCB which are not larger than 10 mm [2] in that way there are not inference with the height of the mechanism and the components at the moment of picking them of the feeder.

Properties	**Leaf Springs**	**Rigid Bodies**
Material	Low Carbon Steel	Acrylonitrile Butadiene Styrene (ABS)
Length (mm)	60 , 30	57
Thickness (mm)	0.2 , 0.3	5
Density ($\frac{Kg}{m^2}$)	7800	1030
E-modulus (GPa)	200	2.08
G-Modulus (GPa)	80	0.75
Width (mm)	30	30

3.1.1 Force Required

For transverse displacement we basically use the deflection formulas and the relation with the Internal moment and lateral displacement v(x).

$$v(l) = \frac{Fl^3}{3EI} \tag{1}$$

$$M(x) = \frac{EId^2v}{dx^2} \rightarrow F(l-x) + M = \frac{EId^2v}{dx^2} \tag{2}$$

- First pair of Leaf Springs. Here we can find the Transverse displacement $v(l) = \frac{FL^3}{24EI}$ with a force of 4 N,a moment of inertia of 6.75e-14 with these values we got a transverse movement of 12.5 mm which is enough to cover 25 mm of total length. Now we can calculate the stiffness by using $\kappa = \frac{F}{v}$, the stiffness for the first leaf Spring is 320Pa.
- Second pair of leaf Springs. For these Leaf Spring we use a material with Young Modulus of 200 Mpa and has a thickness is 0.2 mm instead of 0.3 mm. with these changes we apply the same formula $v(l) = \frac{FL^3}{24EI}$ and we get 12.5 mm of transverse movement but we need a force of 4.3 N because the length and the thickness is different of previous leaf Spring.

3.1.2 Maximum stress

Maximum stresses of a Leaf Spring happen in $\sigma(0)$ and $\sigma(l)$, .

$$\sigma(x) = \frac{M(x)Y}{I} \tag{3}$$

Then we just analyze $\sigma(l)$ with a force of 4 N and a moment of Inertia of $I = 6.75e - 14$, with all this information we get 222.2 MPa for the first pair of Leaf Springs.

4 Spacar Analysis

The purpose of Spacar is Modeled a system in which the components will be treated as flexure in order to understand the values of the graphics an have a clear idea about how the mechanism will work during real situations .
The idea that was develop before with beams, now will be modeled using leaf spring and solid bodies .
There are two types of elements in the design , two pairs of leaf springs with different thickness and the solid body that support the device that pick and located the components on the PCB with a mass of 45 g. The properties and dimensions of the parts were chosen based on the assumptions .The graph of the final design will find in the appendix.
The basic idea of the mechanism is 4 leaf spring located in different orientation and as result of the leaf springs combination, we could obtain 2 degrees of freedom. The stresses calculation will divide in 2 parts for each movement in the translation direction.

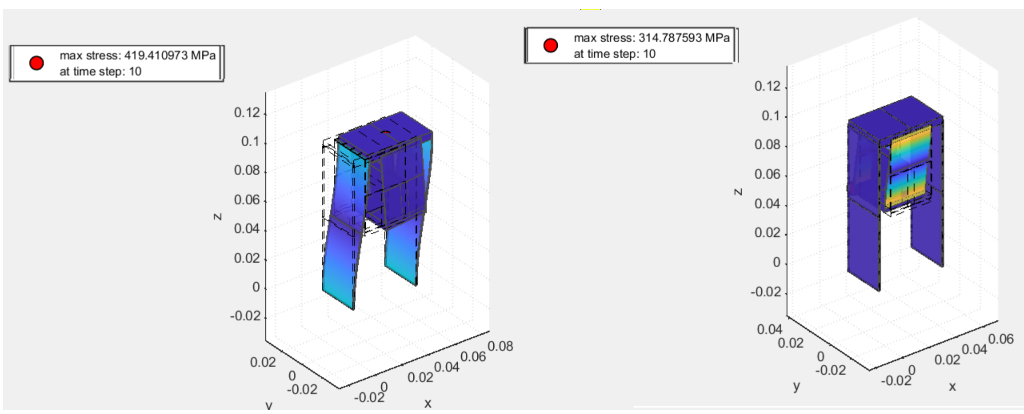

Figure 2: Spacar Stress

The maximum stress that the mechanism will support are:

- $\sigma_{max_1} = 419.41 MPa$
- $\sigma_{max_2} = 314.78 MPa$

.
It is clearly visible that the maximum stresses will occurs in the outer parts of the leaf spring it means at the top and the bottom. The displacement result in spacar are 0.0125 mm in x,y direction with a force of 4 N in x-direction and 4.65 y-direction. The Result of the force is the same as the hand made calculations.

4.1 Spacar and Manual Calculations

Transverse displacements were almost the same values between Spacar and manual calculations, but Maximum Stresses are different in manual calculation the maximum stress is 222.2 MPa and Spacar has a maximum stress of 419 Mpa. Overall Spacar has 1.887 times bigger than manual calculations.

5 System Analysis

5.1 Ideal Physical Model (IPM)

The Ideal Physical model of the mechanism will focus at the bottom part ,which is composed by two leaf spring and damper,the mass will be the sum of the body 1 + body 2 and the mass of devices that pick the components.

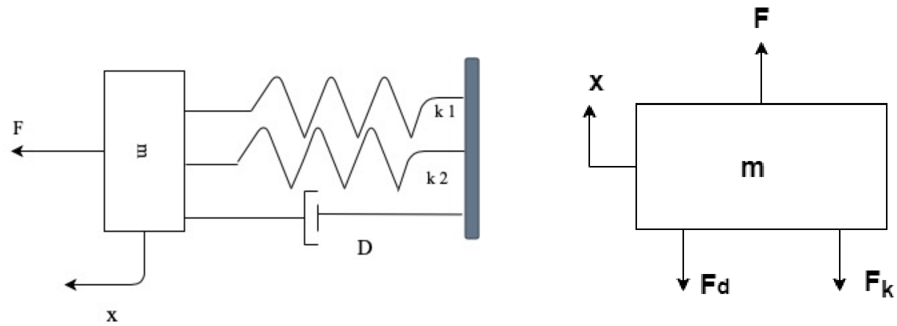

Figure 3: (a) Ideal Physical Model. (b) Free Body Diagram.

In figure 4 it is clear that spring forces are in the same direction, they will added to get one force $F_k = (k_1 + k_2) \cdot x$, but damper force is also present in this mechanism $F_d = d \cdot \dot{x}$, with these values it is possible to calculate the eigenfrecuency.
In order to find the eigenfrequency ,the differential equation of the motion should be found from the FBD of Figure 3b.
The equation of motion is the equation.

$$\dot{v} = \frac{1}{m} \sum_i F_i \tag{1}$$

$$F - d \cdot \dot{x} - k_{keq} \cdot x = m\ddot{x} \tag{2}$$

$$\ddot{x} + \frac{d}{m}\dot{x} + \frac{k_{keq}}{m}x = F \tag{3}$$

$$\ddot{x} + 2\zeta\omega_n\dot{x} + {\omega_n}^2 = 0 \tag{4}$$

The equation 2 is the analysis of forces of the FBD , rewrite it and divide by m the equation 3 is obtained.The basic equation of motion is equation 4 , and finally the eigenfrequency is found.

$$\omega_n = \sqrt{\frac{k_{keq}}{m}} \tag{5}$$

To calculate the eigenfrequency the stiffness value is needed, It is calculated using the force (4 N) and the displacement done(0.0125 mm).which result in $k_{keq} = \frac{2 \cdot 4}{0.0125} \rightarrow k_{keq} = 640\frac{N}{m}$, and with the mass of 59 g take in account the mass of the bodies 1 ,2 and the device. Finally the eigenfrequency is $\omega_n = 104.15\frac{rad}{s}$ in terms of Hertz will be $f_n = \frac{\omega_n}{2\pi} \rightarrow f_n = 16.56$ Hz.

5.2 Transfer Function

In order to find the Transfer Function we make use of Laplace transformation to differential equation. Laplace transformation of the differential equation is expressed as.

$$m \cdot s^2 \cdot x(s) + s \cdot d \cdot x(s) + k \cdot x(s) = F(s) \tag{6}$$

Transfer function follows

$$G(s) = \frac{output}{input} \rightarrow G(s) = \frac{1}{m \cdot s^2 + d \cdot s + k} \rightarrow G(s) = \frac{1}{0.059 \cdot s^2 + 0.03 \cdot 2\sqrt{0.059 \cdot 640}s + 640} \tag{7}$$

There are not zeros , because the numerator is a constant and does not contain any s , and 2 Poles because the highest power of s in the denominator is 2. Poles are the solution for the equation $m \cdot s^2 + d \cdot s + k$. The solutions are $s_{1\&2} = -\frac{369}{118} \pm 104.15i$ as the real is negative , the system is stable , with imaginary part far from the axis can be concluded as fast system. The eigefrequency could obtain from the Transfer function assuming a damper as 0. therefore the imaginary part of the poles will be the eigenfrequency $\omega_n = 104.15\frac{rad}{s}$. It is the same value as the previous calculated.

5.2.1 Block Diagram

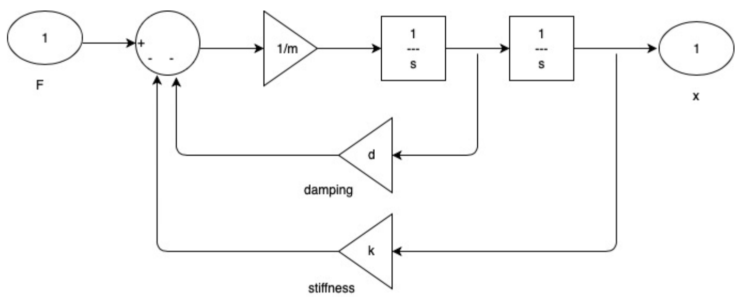

Figure 4: Block Diagram

5.2.2 Bode Diagram

With the mass of 59 g , the damper constant d = 0.369 find it from the derivation of the Equation of motion $d = 2 \cdot \zeta \cdot \sqrt{m\kappa}$ and the stiffnes of the materials $\kappa = 640\frac{N}{m}$, and the help of Matlab ,the below bode diagram is found.

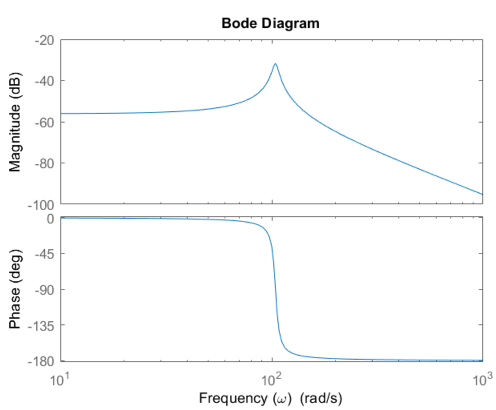

Figure 5: Bode Diagram

6 Appendices

Free Bodies Diagram of the manual calculations to find Deflection in the mechanism.

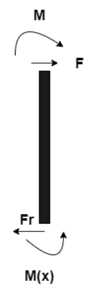

Figure 1: FBD

Figure 2: FBD 2

The Final modeled of the mechanism is present in the below figure , where gray part and green part are leaf spring with different properties and the blue parts are the solid bodies.

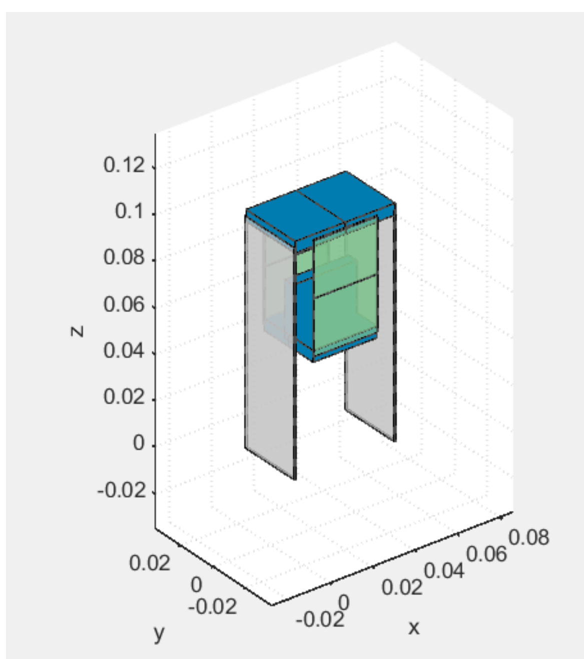

Figure 3: Spacar Model

7 Bibliography

References

[1] University of Twente, “Project Description, Design Principles for Precision Mechanism , 2019-2020”, October 2019

[2] TLJ Series , ”Tantalum Solid Electrolytic Chip Capacitors High CV Consumer Series”,PDF,2015