Dr. BABASAHEB AMBEDKAR TECHNOLOGICAL UNIVERSITY

MAHARASHTRA (INDIA)

A

In-plant Training Project Report

ON

"MODIFIED WIRE BENDING CNC"

Carried out at

"Sai Techno Springs Pvt. Ltd."

FOR THE B.Tech IN MECHANICAL ENGINEERING

SUBMITTED BY

ASHISH S. BHAVSAR

UNDER THE GUIDANCE OF

Prof. Vinay M. Chidri Sir

DEPARTMENT OF MECHANICAL ENGINEERING

MARATHWADA INSTITUTE OF TECHNOLOGY, AURANGABAD.

MAHARASHTRA STATE, INDIA

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Affiliated to Dr. Babasaheb Ambedkar Technological University, Lonere (MS) (For First to Third Year)
DTE Code – 2126/2160

This is to certify that Project Report Tilted

"Modified wire bending CNC"

Carried out at

"Sai Techno Springs Pvt. Ltd."

Has been submitted by the following student in Final Year Mechanical Engineering for the partial fulfillment of **"B.Tech in Mechanical Engineering"** of Dr. Babasaheb Ambedkar Technological University, Lonere record of his work carried out by him during the academic session 2021-2022

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CERTIFICATE

This is to certify that the In-plant Training project report entitled **"Modified Wire Bending CNC"** submitted by **Ashish Sunil Bhavsar (20212620181161210105)** to Marathwada Institute of Technology, Aurangabad, in partial fulfilment of the requirement for the award of the degree of **B. Tech** in **Mechanical Engineerin**g is a record of bonafide work carried out by him under my guidance. The project fulfils the requirements as per the regulations of this institute and in my opinion meets the necessary standards for submission. The contents of this report have not been submitted and will not be submitted either in part or in full, for the award of any other degree or diploma and the same is certified.

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ASHISH S. BHAVSAR
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INDEX

A List of Figures…… i

B List of Tables…… ii

C Abstract…… iii

1 Introduction…… 1

- 1.1 Introduction…… 1
- 1.2 Problem Statement…… 2
- 1.3 Solution…… 2
- 1.4 Objective…… 3

2 Literature Review…… 4

3 Bending…… 5

- 3.1 CNC Bending…… 5
- 3.2 Universal bending machines – modular construction…… 5
- 3.3 Bending Tools…… 5

4 Bending Terminology…… 8

- 4.1 Quasi-static bending of beams…… 8

5 Plastic Bending…… 15

6 System Design…… 17

- 6.1 Classification based on physical configurations…… 17
- 6.2 Technical features of the system…… 17
- 6.3 Difference between old and automated systems…… 18
- 6.4 Design Difference…… 18
- 6.5 Architecture…… 21

7 Ohm’s Law…… 22

- 7.1 Law…… 22
- 7.2 Circuit analysis…… 23
- 7.3 Temperature effects…… 24

8 Sensor Selection Criteria…… 26

- 8.1 At a high level, the selection criteria for sensors involve two steps…… 26
- 8.2 Selection criteria for sensors…… 26

9 Force-Sensing Resistor…… 28

- 9.1 Properties…… 28
- 9.2 Operation principle of FSR…… 28

10 Tactile Sensors…… 33

10.1 Uses……………………………………………………………………. 34
10.2 Working principle……………………………………………………... 34
10.3 Criteria for sensor design………………………………………………… 36
10.4 Pressure sensor arrays…………………………………………………. 37
10.5 Strain gauge rosettes……………………………………………………... 37
10.6 Tactile sensor setup……………………………………………………. 37
11 Conclusion………………………………………………………………… 39
11.1 Conclusion…………………………………………………………….. 39
11.2 Future scope……………………………………………………………… 39
References

LIST OF FIGURES

Fig 1.1	Wire Bending CNC Machine………………………………………………..	1
Fig 1.2	Wire Unwinding & Feeding Machine……………………………………	2
Fig 1.3	Different types of wire formation…………………………………………...	3
Fig 3.1	90' bending tool…………………………………………………………...	5
Fig 3.2	Graphical user interface of a bending machine……………………………..	7
Fig 4.1	Element of a bent beam: the fibers form concentric arcs, the top fibers are compressed and bottom fibers stretched…………………………………….	9
Fig 4.2	Bending moments in a beam……………………………………………...	10
Fig 4.3	Deflection of a beam deflected symmetrically and principle of superposition…………………………………………………………………...	11
Fig 4.4	Big bending asymptote stress…………………………………………….	12
Fig 4.5	Deformation of a Timoshenko beam. The normal rotates by an amount θ which is not equal to dw/dx………………………………………………..	13
Fig 5.1	Plastic Bending Stress Distribution………………………………………	15
Fig 6.1	Isometric Top View old design…………………………………………...	18
Fig 6.2	Isometric Bottom View old design……………………………………….	18
Fig 6.3	Isometric Top View new design………………………………………….	19
Fig 6.4	Isometric Bottom View new design………………………………………	20
Fig 6.5	Block diagram of feedback controlled wire bending CNC………………….	21
Fig 7.1	Ohm’s Law Circuit…………………………………………………….	22
Fig 7.2	Resistance………………………………………………………………	23
Fig 8.1	Sensor selection question’s flow diagram…………………………………...	26
Fig 9.1	Force-Sensing Resistor…………………………………………………...	28
Fig 9.2	Extraneous load factors on Force-Sensing Resistor………………………	29
Fig 9.3	Setup of Force-Sensing Resistor on Bending Pallet………………………...	32
Fig 10.1	Tactile Sensor……………………………………………………………..	33
Fig 10.2	Working of resistive touch sensor…………………………………………...	35
Fig 10.3	Experimental setup of tactile resistive touch sensor………………………...	37
Fig 10.4	Tactile Sensor with applied Load…………………………………………	38
Fig 10.5	Simultaneous operation of 12 sensor platform LSIs configured for resistive sensing mode…………………………………………………………………...	38

LIST OF TABLES

Table 6.1 Difference between old & automated system…………………………….. 18
Table 10.1 Design guidelines for tactile sensors in CNC wire bending machine…….. 36

ABSTRACT

The use of a wire bending machine acquired a high level of importance as a consequence of increasing the level of the industry. This project aims to modify and develop a feedback-controlled automated 2D wire bending machine. This bending machine has achieved brilliant output with decrease in downtime. This project focus on material wastage and tool breaking of machine which leads to machine failure. These two types of sensors are used to monitor forces with the horizontal axis. Most of the time the jaw or bending tool gets broken down due to this wire does not get its shape and un-uniform shaped wire comes out ad it leads to material wastage as the machine does not have any type of feedback control system which analyze or monitor the end product. In this the sensors help to solve this issue by placing them at the bending jaw and end point of the bending pallet and interfacing them with the controller's emergency switch or main power supply. So as the force exceeds sensor sends the signal to the controller and the controller stops the operation, if not then it will directly cut the power supply to prevent the machine from being damage. This technology is new and cheaper but complex in design. After implementing this technology the worker does not need to continuously monitor the machine. As if there is any problem machine automatically reports that problem. Along with that it reduces downtime, maintenance cost, and material wastage and increases the productivity.

1. INTRODUCTION

1.1 Introduction

CNC wire forming or wire bending is an advanced technique used to manipulate metal into standard or customized shapes for the manufacturing of products. Consisting of various shapes and sizes, wire forms are fabricated with machines through heat treatment, cutting, and bending. CNC wire forming machines operate by using standardized tooling to alter the shape of the wire in size and dimension to create complex two-dimensional and three-dimensional parts.

Wire forming in general is instrumental in several industries—automotive, aerospace, construction, military, commercial, and electrical sectors—to name a few. Wire forms are fabricated from a variety of materials, including steel, stainless steel, copper, aluminum, and several alloys. CNC wire forming offers benefits such as custom design, less setup time, reduced development time for introducing new or modified product parts into the market, and lower per-piece costs even in small to medium size production runs.

Fig 1.1: Wire Bending CNC Machine

Fig 1.2: Wire Unwinding & Feeding Machine

1.2 Problem Statement

In the production process, material wastage is a common problem in the various process industries. To reduce or remove this thing the changes are required. So, I have studied the process in detail. In that, after a particular period, the jaws of the bending machine get break down, and this thing varies with the material used for wire forming.

And when the jaw of the machine is get broken then the wire is unable to bend and cannot take the desired shape as required. Due to this on average 0.5 to 1-meter wire is gone waste as the machine does not contain any feedback system.

1.3 Solution

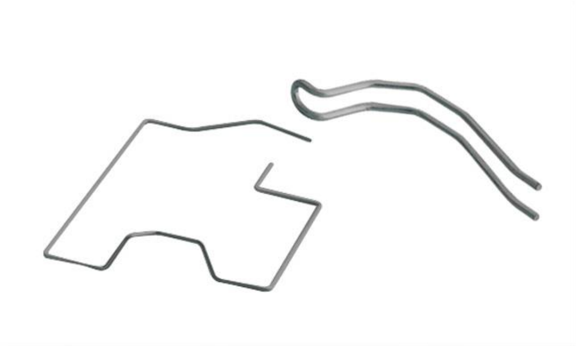
For changes to this problem or prevention of material wastage, I suggest an automation system for force detection during the process. So it can detect force during every single bending operation.

When the jaw of the machine gets broken then the sensor of the system gets activated due to force being applied to it and disconnects the power supply of the whole machine. So the wastage of material gets reduced.

1.4 Objectives

In industry-based projects, the main problem is the wastage of material during production.

a) To reduce wastage of material during process, or in production.
b) Increasing productivity of the industry.
c) Increasing the efficiency of the production process.
d) Reduce the efforts and extra time of workers during maintenance and reset of the machine.



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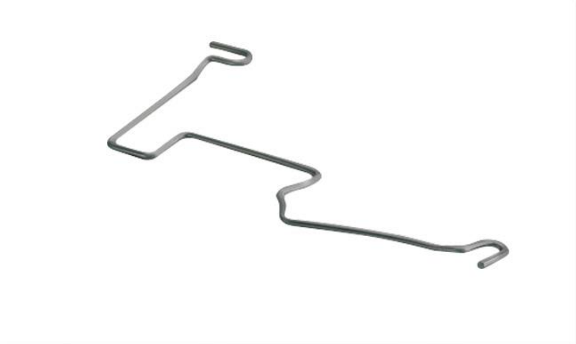

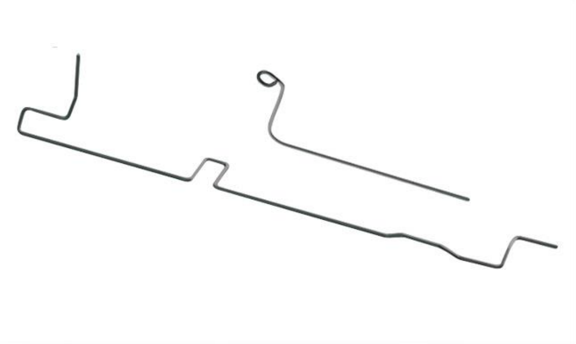

c) **d)**

Fig 1.3: Different types of wire formation

2. LITERATURE REVIEW

The need for a reliable feedback-controlled automated wire bending machine in the industrial sectors is still rising; it does not fulfill the industry automation standard for bending operations.

However, industries still use some traditional bending machines with no end feedback control system.

After reviewing more than 20 (pdf, blog and white papers) research papers, I observed that presently, researchers have paid attention to improving productivity, accuracy, and on PID sub-controller. Some researchers are developing bending machines using cheaper but reliable hardware like Arduino, and Rasberry-Pi for the small use case.

But the end effector remains untouchable at some point as there are non-uniform technologies used which do not give desired results.

So this project is fulfilling this gap with new technology.

This is the first project which focuses on the end effector controlling associated with 2D wire bending Technology.

3. BENDING

A bending machine is a forming machine tool (DIN 8586). Its purpose is to assemble a bend on a workpiece. A bend is manufactured by using a bending tool during a linear or rotating move. The detailed classification can be done with the help of the kinematics.

3.1 CNC Bending

CNC bending machines are developed for high flexibility and low setup times. Those machines are able to bend single pieces as well as small batches with the same precision and efficiency as series-produced parts in an economical way.

3.2 Universal bending machines – modular construction

Universal bending machines consists of a basic machine that can be adjusted with little effort and used for a variety of bends. A simple plug-in system supports quick and easy exchange of tools.

The basic machine consists of a CNC-operated side stop, a work bench, and software for programming and operating. Its modular construction offers an affordable entry into the bending technology, because after an initial investment the machine can be customized and extended later without any conversion. That means the basic machine delivers a bending stroke, and the tool determines the kind of bending.

3.3 Bending tools

In the case of bending tools they are classified by the kind of generated bends. They can be constructed to adjust the bending angle by reference, stroke measurement or angle measurement.

CNC machines usually abstain from a reference part. They grant a high bending accuracy starting with the first work piece.

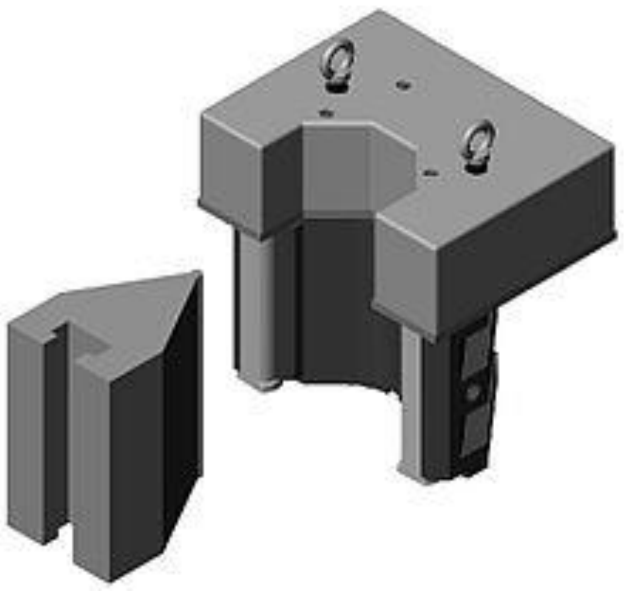

Fig 3.1: 90' bending tool

3.3.1 Standard bends

All bends without an extraordinary geometry belong to standard bends. The distance between a bend and the material end is quite high providing an adequate bearing area. The same with one bend to the next.

Typical tools are a so-called bending former combined with a prisms with electronic angular measurement or an ordinary prism.

3.3.2 U-bending

For U-bends where tight and narrow bends are necessary, the bending former is replaced by a bending mandrel. A bending mandrel has a narrow geometry.

3.3.3 Offset Bending

Offset bending tools are used to assemble two bends with a small distance between in one step

3.3.4 Edgewise bending

Edge bending tools are used if the bending axis is placed parallel to the tight side of the work piece. Tools for bending on edge may include electronic angular measurement allowing a high bending accuracy.

3.3.5 Torsion bending

Torsion tools are able to rotate the workpiece on the longitudinal axis. Alternatives are complex assembly groups with standard bends.

3.3.6 Angular measurement and spring back compensation

For producing single pieces as well as small batches with the same precision and efficiency as series-produced parts, a spring back compensation is helpful. A bending accuracy of +/- 0.2° starting from the first work piece is achieved due to calculated spring back compensation and the use of electronic tools.

3.3.7 Operating mode angular measurement

Bending prisms with electronic angular measurement technology are equipped with two flattened bending bolds. That bold rotate while bending giving a signal to the angle measurement. The measuring accuracy is about 0.1º. The computer then calculates the required final stroke and spring back of every bend is compensated regardless of material type. A high angle accuracy of +/- 0.2º is achieved instantly with the first workpiece without adjustments. Compared to adjustment by reference, material waste amounts are decreased, because even inconsistencies within a single piece of material are automatically adjusted.

3.3.8 Operating mode stroke measurement

Wherever bending prisms with electronic angular measurement are not suitable, a small distance between the bends might be a reason, bending prisms without electronic angle measurement are applied. In that case the control unit can be switched from angular measurement to stroke measurement. This method allows the pre-selection of the stroke of the bending ram in mm and therefore the immersion depth of the punch into the prism. Setting accuracy is +/- 0.1 mm. A final stroke is usually not required. Further development of the stroke system enables the user to specify an angle from which the stroke is calculated by using stored stroke functions. Bending accuracy in that case is dependent on material properties such as thickness, hardness, etc. which may differ from one work piece to another.

3.3.9 Programming and principle of operation

Programming is done on a PC equipped with dedicated software, which is part of the machine or connected to an external workstation. For generating a new program engineering data can be imported or pasted per mouse and keyboard. Through a graphic and menu-driven user interface previous CNC programming skills are not required. The software asks for all necessary values and checks all figures. Inputs can be corrected at any time and minimum distances are checked instantly to guard against improper inputs. The software automatically calculates the flat length of each part being bent and determines the exact position of the side stop. The part is shown on a screen.

Ideally each program is stored in one database, so it is easy to recover them by search and sort functions.

Fig 3.2: Graphical user interface of a bending machine

4. Bending Terminology

In applied mechanics, bending (also known as flexure) characterizes the behaviour of a slender structural element subjected to an external load applied perpendicularly to a longitudinal axis of the element.

The structural element is assumed to be such that at least one of its dimensions is a small fraction, typically 1/10 or less, of the other two. When the length is considerably longer than the width and the thickness, the element is called a beam. For example, a closet rod sagging under the weight of clothes on clothes hangers is an example of a beam experiencing bending. On the other hand, a shell is a structure of any geometric form where the length and the width are of the same order of magnitude but the thickness of the structure (known as the 'wall') is considerably smaller. A large diameter, but thin-walled, short tube supported at its ends and loaded laterally is an example of a shell experiencing bending.

In the absence of a qualifier, the term bending is ambiguous because bending can occur locally in all objects. Therefore, to make the usage of the term more precise, engineers refer to a specific object such as; the bending of rods, the bending of beams, the bending of plates, the bending of shells and so on.

4.1 Quasi-static bending of beams

A beam deforms and stresses develop inside it when a transverse load is applied on it. In the quasi-static case, the amount of bending deflection and the stresses that develop are assumed not to change over time. In a horizontal beam supported at the ends and loaded downwards in the middle, the material at the over-side of the beam is compressed while the material at the underside is stretched. There are two forms of internal stresses caused by lateral loads:

- Shear stress parallel to the lateral loading plus complementary shear stress on planes perpendicular to the load direction;
- Direct compressive stress in the upper region of the beam, and direct tensile stress in the lower region of the beam.

These last two forces form a couple or moment as they are equal in magnitude and opposite in direction. This bending moment resists the sagging deformation characteristic of a beam experiencing bending. The stress distribution in a beam can be predicted quite accurately when some simplifying assumptions are used.

4.1.1 Euler–Bernoulli bending theory

In the Euler–Bernoulli theory of slender beams, a major assumption is that 'plane sections remain plane'. In other words, any deformation due to shear across the section is not accounted for (no shear deformation). Also, this linear distribution is only applicable if the maximum stress is less than the yield stress of the material. For stresses that exceed yield, refer to article plastic bending. At yield, the maximum stress experienced in the section (at the furthest points from the neutral axis of the beam) is defined as the flexural strength.

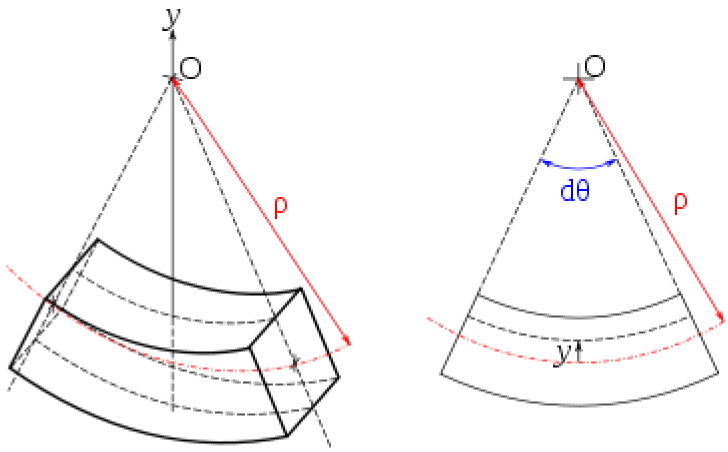

Fig 4.1: Element of a bent beam: the fibers form concentric arcs, the top fibers are compressed and bottom fibers stretched.

Consider beams where the following are true:

The beam is originally straight and slender, and any taper is slight

The material is isotropic (or orthotropic), linear elastic, and homogeneous across any cross section (but not necessarily along its length)

Only small deflections are considered

In this case, the equation describing beam deflection (ω) can be approximated as:

$$\frac{d^2w(x)}{dx^2} = \frac{M(x)}{E(x)I(x)}$$

Where the second derivative of its deflected shape with respect to x is interpreted as its curvature, E is the Young's modulus I is the area moment of inertia of the cross-section, and M is the internal bending moment in the beam.

If, in addition, the beam is homogeneous along its length as well, and not tapered (i.e. constant cross section), and deflects under an applied transverse load $q(x)$, it can be shown that:

$$EI\frac{d^4w(x)}{dx^4} = q(x)$$

This is the Euler–Bernoulli equation for beam bending.

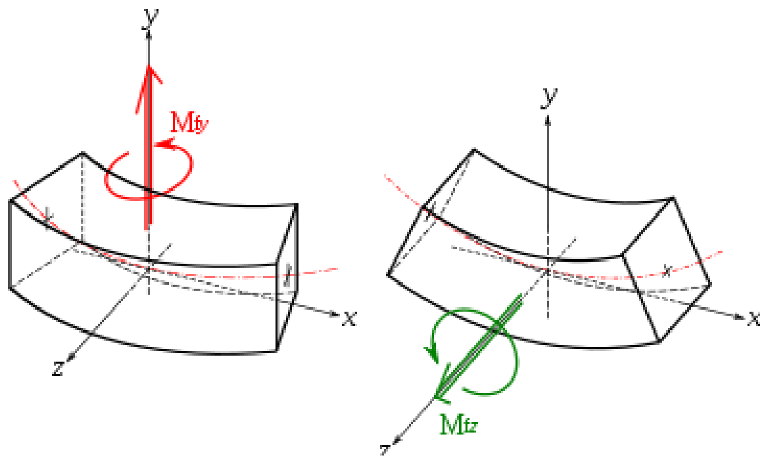

Fig 4.2: Bending moments in a beam

After a solution for the displacement of the beam has been obtained, the bending moment (M) and shear force (Q) in the beam can be calculated using the relations

$$M(x) = -EI\frac{d^2w}{dx^2}; Q(x) = \frac{dM}{dx}$$

Simple beam bending is often analysed with the Euler–Bernoulli beam equation. The conditions for using simple bending theory are:

- The beam is subject to pure bending. This means that the shear force is zero, and that no torsional or axial loads are present.
- The material is isotropic (or orthotropic) and homogeneous.
- The material obeys Hooke's law (it is linearly elastic and will not deform plastically).
- The beam is initially straight with a cross section that is constant throughout the beam length.
- The beam has an axis of symmetry in the plane of bending.
- The proportions of the beam are such that it would fail by bending rather than by crushing, wrinkling or sideways buckling.
- Cross-sections of the beam remain plane during bending.

Compressive and tensile forces develop in the direction of the beam axis under bending loads. These forces induce stresses on the beam. The maximum compressive stress is found at the uppermost edge of the beam while the maximum tensile stress is located at the lower edge of the beam. Since the stresses between these two opposing maxima vary linearly, there therefore exists a point on the linear path between them where there is no bending stress. The locus of these points is the neutral axis. Because of this area with no stress and the adjacent areas with low stress, using uniform cross section beams in bending is not a particularly efficient means of supporting a load as it does not use the full capacity of the beam until it is on the brink of collapse. Wide-flange beams (I-beams) and truss girders effectively address this inefficiency as they minimize the amount of material in this under-stressed region.

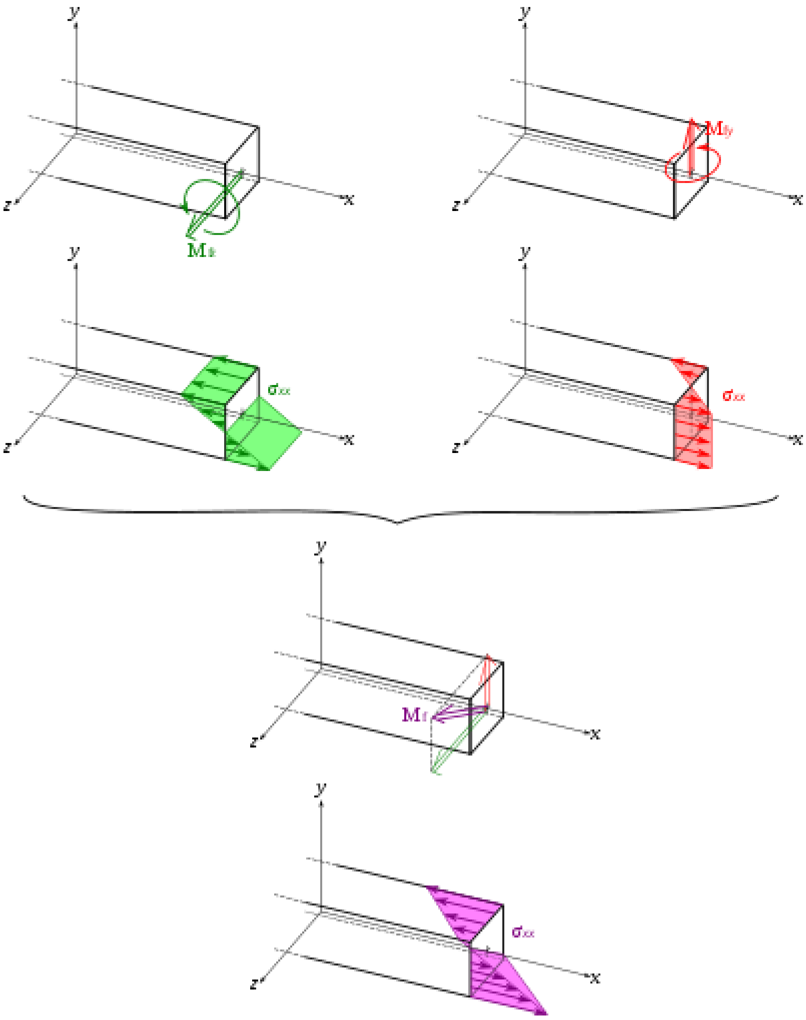

Fig 4.3: Deflection of a beam deflected symmetrically and principle of superposition

The classic formula for determining the bending stress in a beam under simple bending is:

$$\sigma_x = \frac{M_z y}{I_z} = \frac{M_z}{W_z}$$

Where

σ_x = bending Stress

Mx = the moment about the neutral axis

y = the perpendicular distance to the neutral axis

I_z = the second moment of area about the neutral axis z.

W_z = the Resistance Moment about the neutral axis z. $W_z = I_z/y$

1.2 Extensions of Euler-Bernoulli beam bending theory

1.2.1 Plastic bending

The equation $\sigma = \frac{M_y}{I_x}$ is valid only when the stress at the extreme fiber (i.e., the portion of the beam farthest from the neutral axis) is below the yield stress of the material from which it is constructed. At higher loadings the stress distribution becomes non-linear, and ductile materials will eventually enter a plastic hinge state where the magnitude of the stress is equal to the yield stress everywhere in the beam, with a discontinuity at the neutral axis where the stress changes from tensile to compressive. This plastic hinge state is typically used as a limit state in the design of steel structures.

4.1.2.2 Complex or asymmetrical bending

The equation above is only valid if the cross-section is symmetrical. For homogeneous beams with asymmetrical sections, the maximum bending stress in the beam is given by

$$\sigma_x(y,z) = -\frac{M_z I_y + M_y I_{yz}}{I_y I_z - I_{yz}^2} y + \frac{M_z I_y + M_y I_{yz}}{I_y I_z - I_{yz}^2} z$$

Where *y*,*z* are the coordinates of a point on the cross section at which the stress is to be determined as shown to the right, M_y and M_z are the bending moments about the y and z centroid axes, I_y and I_z are the second moments of area (distinct from moments of inertia) about the y and z axes, and I_{yz} is the product of moments of area. Using this equation it is possible to calculate the bending stress at any point on the beam cross section regardless of moment orientation or cross-sectional shape. Note that M_y M_z, I_y, I_z, I_{yz} do not change from one point to another on the cross section.

4.1.2.3 Large bending deformation

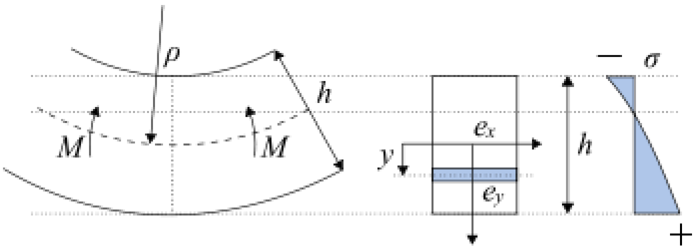

Fig 4.4: Big bending asymptote stress

For large deformations of the body, the stress in the cross-section is calculated using an extended version of this formula. First the following assumptions must be made:

1. Assumption of flat sections – before and after deformation the considered section of body remains flat (i.e., is not swirled).
2. Shear and normal stresses in this section that are perpendicular to the normal vector of cross section have no influence on normal stresses that are parallel to this section.

Large bending considerations should be implemented when the bending radius ρ is smaller than ten section heights h:

$$\rho < 10h$$

With those assumptions the stress in large bending is calculated as:

$$\sigma = \frac{F}{A} + \frac{M}{\rho A} + \frac{M}{I_x'} y \frac{\rho}{\rho + y}$$

Where

F = the normal force

A = the section area

M = the bending moment

ρ = the local bending radius (the radius of bending at the current section)

I'_y = the area moment of inertia along the x-axis, at the y place

y = the position along y-axis on the section area in which the stress σ is calculated.

When bending radius ρ approaches infinity and $y \ll \rho$, the original formula is back:

$$\sigma = \frac{F}{A} \pm \frac{My}{I}$$

4.1.3 Timoshenko bending theory

In 1921, Timoshenko improved upon the Euler–Bernoulli theory of beams by adding the effect of shear into the beam equation. The kinematic assumptions of the Timoshenko theory are:

- normals to the axis of the beam remain straight after deformation
- there is no change in beam thickness after deformation

However, normals to the axis are not required to remain perpendicular to the axis after deformation.

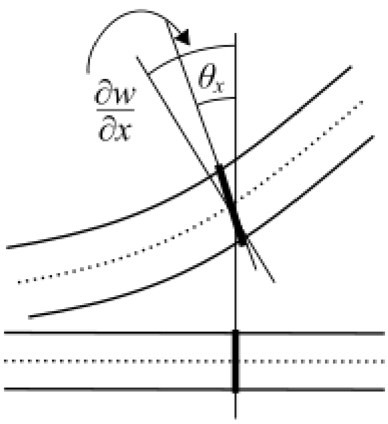

Fig 4.5: Deformation of a Timoshenko beam. The normal rotates by an amount θ which is not equal to dw/dx

The equation for the quasistatic bending of a linear elastic, isotropic, homogeneous beam of constant cross-section beam under these assumptions is

$$EI\frac{d^4w}{dx^4} = q(x) - \frac{EI}{kAG}\frac{d^2q}{dx^2}$$

Where I is the area moment of inertia of the cross-section, A is the cross-sectional area, G is the shear modulus k is a shear correction factor, and $q(x)$ is an applied transverse load. For materials with Poisson's ratios (ν) close to 0.3, the shear correction factor for a rectangular cross-section is approximately

$$k = \frac{5 + 5\nu}{6 + 5\nu}$$

The rotation ($\varphi(x)$) of the normal is described by the equation

$$\frac{d\varphi}{dx} = -\frac{d^2\omega}{dx^2} - \frac{q(x)}{kAG}$$

The bending moment *(M)* and the shear force *(Q)* are given by

$$M(x) = -EI\frac{d\varphi}{dx}; Q(x) = kAG\left(\frac{d\omega}{dx} - \varphi\right) = -EI\frac{d^2\varphi}{dx^2} = \frac{dM}{dx}$$

5. PLASTIC BENDING

Plastic bending is a nonlinear behavior particular to members made of ductile materials that frequently achieve much greater ultimate bending strength than indicated by a linear elastic bending analysis. In both the plastic and elastic bending analyses of a straight beam, it is assumed that the strain distribution is linear about the neutral axis (plane sections remain plane). In an elastic analysis, this assumption leads to a linear stress distribution but in a plastic analysis, the resulting stress distribution is nonlinear and is dependent on the beam’s material.

The limiting plastic bending strength M_r can generally be thought of as an upper limit to a beam’s load–carrying capability as it only represents the strength at a particular cross-section and not the load-carrying capability of the overall beam. A beam may fail due to global or local instability before M_r is reached at any point on its length. Therefore, beams should also be checked for local buckling, local crippling, and global lateral-torsional buckling modes of failure.

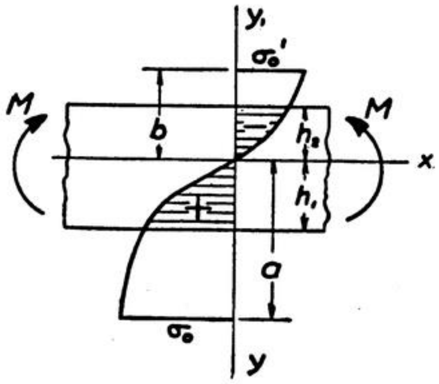

Fig 5.1: Plastic Bending Stress Distribution

Note that the deflections necessary to develop the stresses indicated in a plastic analysis are generally excessive, frequently to the point of incompatibility with the function of the structure. Therefore, a separate analysis may be required to ensure design deflection limits are not exceeded. Also, since working materials into the plastic range can lead to permanent deformation of the structure, additional analyses may be required at a limited load to ensure no detrimental permanent deformations occur. The large deflections and stiffness changes usually associated with plastic bending can significantly change the internal load distribution, particularly in statically indeterminate beams. The internal load distribution associated with the deformed shape and stiffness should be used for calculations.

Plastic bending begins when an applied moment causes the outside fibers of a cross-section to exceed the material's yield strength. Loaded only by a moment, the peak bending stroccuroccurs at the outside fibers of a cross-section. The cross-section will not yield linearly through the section. Rather, outside regions will yield first, redistributing stress and delaying failure beyond what would be predicted by elastic analytical methods. The stress distribution from the neutral axis is the same as the shape of the stress-strain curve of the material (this assumes a non-composite cross-section). After a cross-section reaches a sufficiently high condition of plastic bending, it acts as a Plastic hinge.

Elementary Elastic Bending theory requires that the bending stress varies linearly with distance from the neutral axis, but plastic bending shows a more accurate and complex stress distribution. The yielded areas of the cross-section will vary somewhere between the yield and ultimate strength of the material. In the elastic region of the cross-section, the stress distribution varies linearly from the neutral axis to the beginning of the yielded area. Predicted failure occurs when the stress distribution approximates the material's stress-strain curve. The largest value is that of the ultimate strength. Not every area of the cross-section will have exceeded the yield strength.

As in the basic Elastic Bending theory, the moment at any section is equal to an area integral of tonding stress across the cross-section. From this and the above additional assumptions, predictions of deflections and failure strength are made.

6. SYSTEM DESIGN

Industrial wire-bending CNC comes in a variety of shapes and sizes. In addition to new features, they are capable of continuous bend the wire as per the program.

6.1 Classification based on physical configurations

The following basic configurations are identified with most of the commercially available industrial wire-bending CNC machines.

a) Horizontal configuration

A system that is constructed around this configuration consists of an orthogonal working bed. The bed is parallel to the body of the machine. By appropriate movement of the working bed, the system is capable of moving in within the dimensional workspace.

b) Vertical rotary configuration

In this configuration, the tool (jaw) is vertically rotated by a prime mover such as a motor. This system permits the tool to rotate at different angles.

c) Cartesian configuration

A system that is constructed around this configuration consists of both orthogonal tool and work bed as shown in the figure, both tool and work bed are moved along the X and Z axis of the Cartesian coordinate system. By appropriate movements of these two-component, the system is capable of moving at any position with a two-dimensional rectangular workspace.

6.2 Technical features of the system

The technical features of the system determine its efficiency and effectiveness in performing a given task. The following are some of the most important among these technical features

a) Degree of freedom (D.O.F.)

Each joint in the degree of freedom. DOF can be a slider and rotary type. The system has two degrees of freedom. One of them is allowed to in a horizontal direction, and the other rotates in a vertical direction.

b) Work Volume/ Workspace

The work-bed tends to have a fixed and limited geometry. The work envelope is the boundary of position in a space where the system can be rich. For a horizontal, the workspace might be a rectangle, for wire bending.

6.3 Difference between old and automated screen systems

Table 6.1: Difference between old & automated system

Parameters	Old system	Automated System
Production Volume	In this system, the production volume is less.	In this system the production volume is high.
Efficiency	The efficiency of this system is less, compared to the automated system	The efficiency of this system is more, compared to the old system
Monitoring	In this system, continuous monitoring is required	In this system, continuous monitoring is not required
Material Wastage	In this system wastage of material is more.	In this system wastage of material is less.

6.4 Design Difference

6.4.1 Old Design

Fig 6.1: Isometric Top View old design

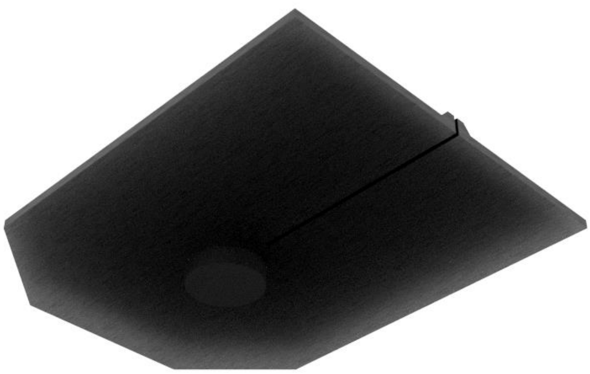

Fig 6.2: Isometric Bottom View old design

6.4.2 New Design

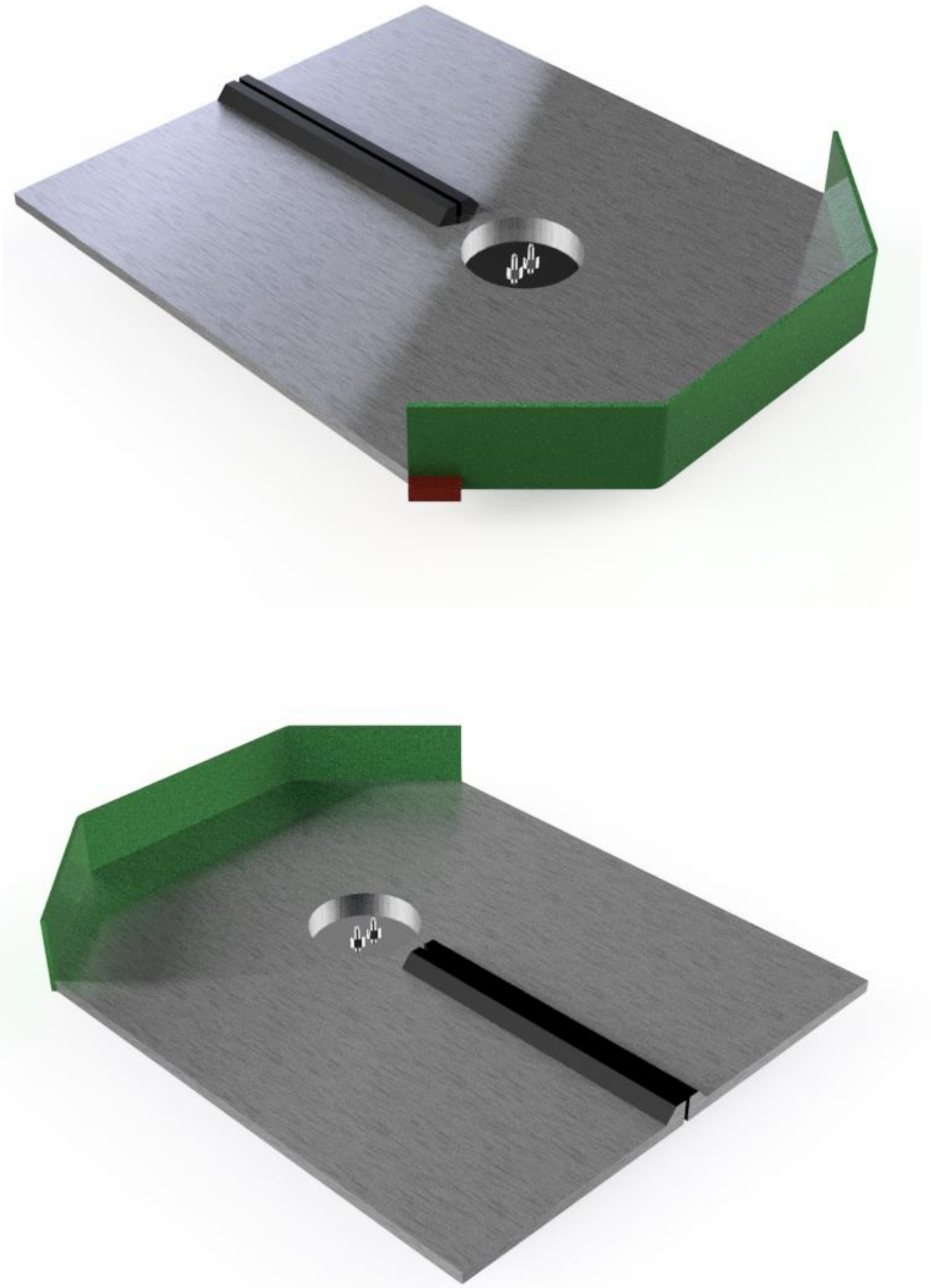

Fig 6.3: Isometric Top View new design

Fig 6.4: Isometric Bottom View new design

6.5 Architecture

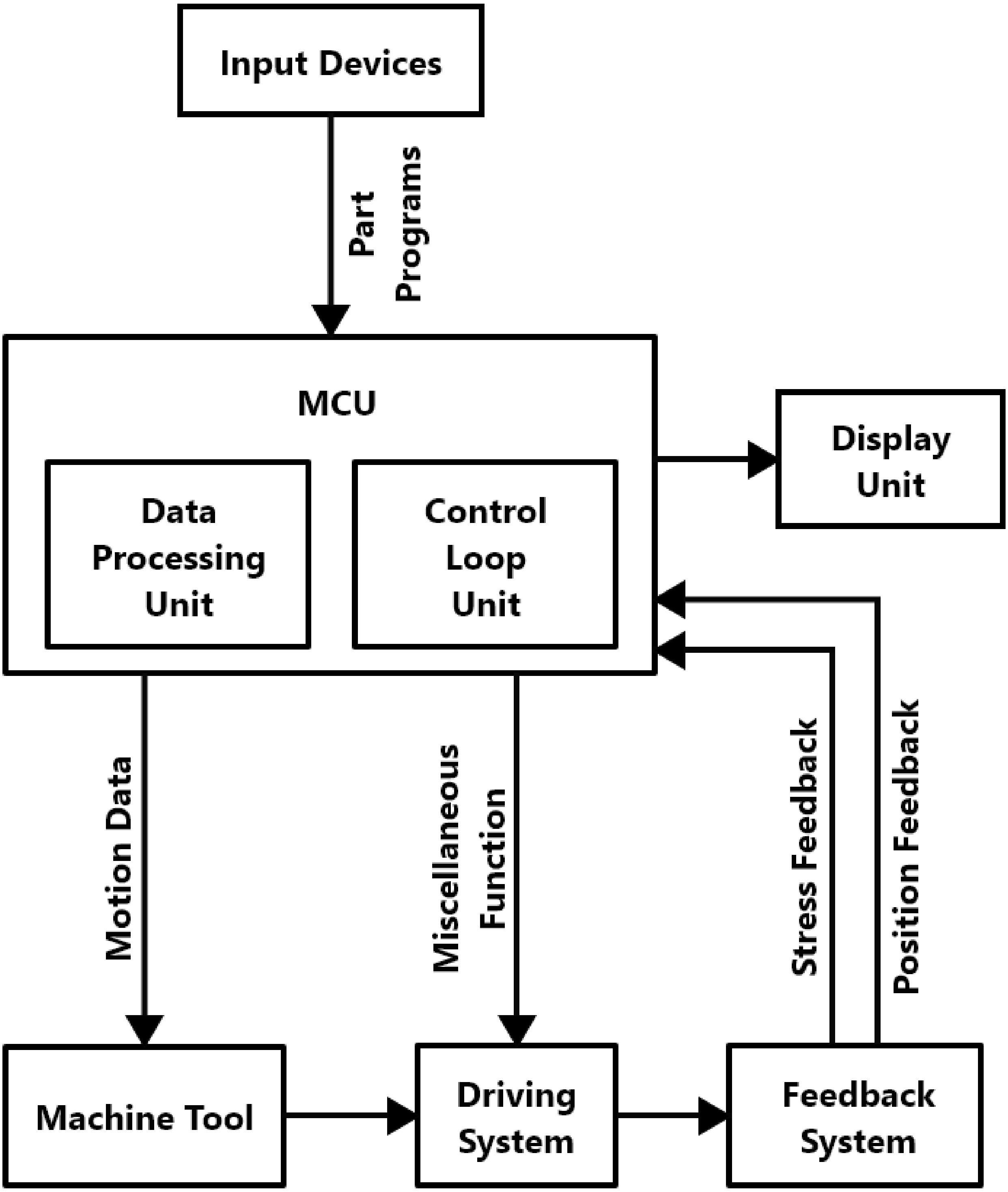

Fig 6.5: Block diagram of feedback controlled wire bending CNC

7. OHM'S LAW

7.1 Law

Ohm's law states that the current through a conductor between two points is directly proportional to the voltage across the two points. Introducing the constant of proportionality, the resistance, one arrives at the usual mathematical equation that describes this relationship:

$$I = \frac{V}{R},$$

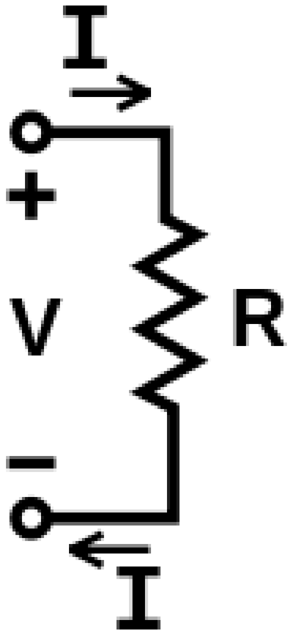

Fig 7.1: Ohm's Law Circuit

Where I is the current through the conductor in units of amperes, V is the voltage measured across the conductor in units of volts, and R is the resistance of the conductor in units of ohms. More specifically, Ohm's law states that the R in this relation is constant, independent of the current. If the resistance is not constant, the previous equation cannot be called Ohm's law, but it can still be used as a definition of static/DC resistance. Ohm's law is an empirical relation which accurately describes the conductivity of the vast majority of electrically conductive materials over many orders of magnitude of current. However some materials do not obey Ohm's law; these are called non-ohmic.

The law was named after the German physicist Georg Ohm, who, in a treatise published in 1827, described measurements of applied voltage and current through simple electrical circuits containing various lengths of wire. Ohm explained his experimental results by a slightly more complex equation than the modern form above.

In physics, the term Ohm's law is also used to refer to various generalizations of the law; for example the vector form of the law used in electromagnetics and material science:

$$J = \sigma E,$$

Where J is the current density at a given location in a resistive material, E is the electric field at that location, and σ (sigma) is a material-dependent parameter called the conductivity.

7.2 Circuit analysis

In circuit analysis, three equivalent expressions of Ohm's law are used interchangeably:

$$I = \frac{V}{R} \;\; or \;\; V = IR \;\; or \;\; R\frac{V}{I}$$

Each equation is quoted by some sources as the defining relationship of Ohm's law, or all three are quoted, or derived from a proportional form, or even just the two that do not correspond to Ohm's original statement may sometimes be given.

The interchangeability of the equation may be represented by a triangle, where V (voltage) is placed on the top section, the I (current) is placed to the left section, and the R (resistance) is placed to the right. The divider between the top and bottom sections indicates division (hence the division bar).

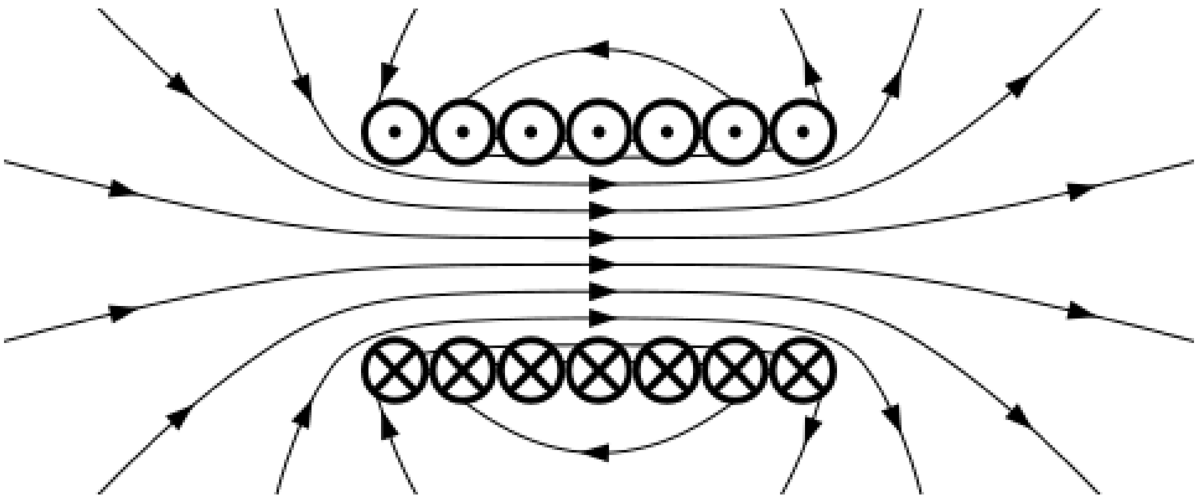

Fig 7.2: Resistance

7.2.1 Resistive circuits

Resistors are circuit elements that impede the passage of electric charge in agreement with Ohm's law, and are designed to have a specific resistance value R. In schematic diagrams, a resistor is shown as a long rectangle or zig-zag symbol. An element (resistor or conductor) that behaves according to Ohm's law over some operating range is referred to as an ohmic device (or an ohmic resistor) because Ohm's law and a single value for the resistance suffice to describe the behavior of the device over that range.

Ohm's law holds for circuits containing only resistive elements (no capacitances or inductances) for all forms of driving voltage or current, regardless of whether the driving voltage or current is constant (DC) or time-varying such as AC. At any instant of time Ohm's law is valid for such circuits.

Resistors which are in series or in parallel may be grouped together into a single "equivalent resistance" in order to apply Ohm's law in analysing the circuit.

7.2.2 Reactive circuits with time-varying signals

When reactive elements such as capacitors, inductors, or transmission lines are involved in a circuit to which AC or time-varying voltage or current is applied, the relationship between voltage and current becomes the solution to a differential equation, so Ohm's law (as defined above) does not directly apply since that form contains only resistances having value R, not complex impedances which may contain capacitance (C) or inductance (L).

Equations for time-invariant AC circuits take the same form as Ohm's law. However, the variables are generalized to complex numbers and the current and voltage waveforms are complex exponentials.

In this approach, a voltage or current waveform takes the form Aest, where t is time, s is a complex parameter, and A is a complex scalar. In any linear time-invariant system, all of the currents and voltages can be expressed with the same s parameter as the input to the system, allowing the time-varying complex exponential term to be cancelled out and the system described algebraically in terms of the complex scalars in the current and voltage waveforms.

The complex generalization of resistance is impedance, usually denoted Z; it can be shown that for an inductor,

$$Z = sL$$

and for a capacitor,

$$Z = \frac{1}{sC}$$

We can now write,

$$V = ZI$$

Where V and I are the complex scalars in the voltage and current respectively and Z is the complex impedance.

This form of Ohm's law, with Z taking the place of R, generalizes the simpler form. When Z is complex, only the real part is responsible for dissipating heat.

In a general AC circuit, Z varies strongly with the frequency parameter s, and so also will the relationship between voltage and current.

For the common case of a steady sinusoid, the s parameter is taken to be $j\omega$, corresponding to a complex sinusoid $Ae^{j\omega t}$. The real parts of such complex current and voltage waveforms describe the actual sinusoidal currents and voltages in a circuit, which can be in different phases due to the different complex scalars.

7.3 Temperature effects

Ohm's law has sometimes been stated as, "for a conductor in a given state, the electromotive force is proportional to the current produced." That is, that the resistance, the ratio of the applied electromotive force (or voltage) to the current, "does not vary with the current strength." The qualifier "in a given state" is usually interpreted as meaning "at a constant temperature," since the resistivity of materials is usually temperature dependent.

Because the conduction of current is related to Joule heating of the conducting body, according to Joule's first law, the temperature of a conducting body may change when it carries a current. The dependence of resistance on temperature therefore makes resistance depend upon the current in a typical experimental setup, making the law in this form difficult to directly verify. Maxwell and others worked out several methods to test the law experimentally in 1876, controlling for heating effects.

8. SENSOR SELECTION CRITERIA

A sensor is usually not good or bad on it's own. It totally depends on the application. To give you an idea, a sensor with 10-bit resolution could be a good fit for an application whereas another one with 16-bit resolution could be overkill.

8.1 At a high level, the selection criteria for sensors involve two steps:

8.1.1 Suitable Candidates:

Narrowing down the search list of sensors (typically to 2-3). In this step, you consider all parameter and select a few sensors that suit your requirements.

8.1.2 Testing the shortlisted sensors

Testing the sensors in an environment similar to the application setup, so that we can analyze the sensors accordingly.

8.2 Selection criteria for sensors

So while comparing the Sensor, consider the following parameters:

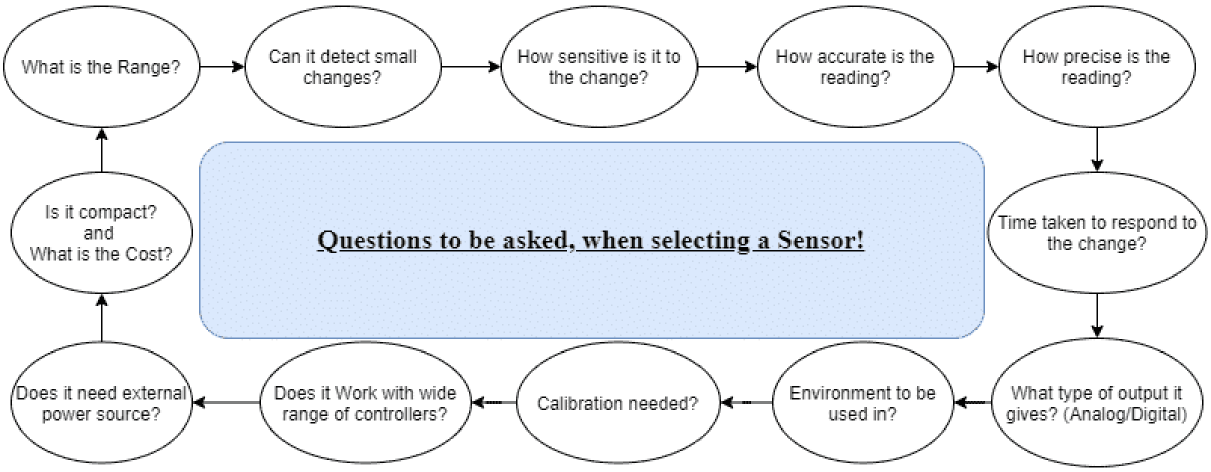

Fig 8.1: sensor selection question's flow diagram

a) Range:

Difference between Maximum and Minimum value which can be sensed by the sensor. What is the minimum value you need to sense? What is the maximum value you need to sense?

b) Resolution:

The smallest change which can be sensed by the sensor. High is good but not always. If it is too high, it would pickup even very minute fluctuations which would then require additional processing.

c) Sensitivity:

Ratio of change in output to a unit change in the input. Again, high is good, but too high could be a problem. Also, higher the sensitivity, more will be the cost in most cases.

d) Error:

Difference between the Measured Value and True Value. You want this value to be low. All sensors have a margin of error. Does you application allow you to have that margin of error?

e) Accuracy:

It is inversely proportional to Error, i.e. How close the sensor reading is to the True Value. (Should be high).

f) Precision:

Ability to give/reproduce accurate value repeatedly. If a sensor is giving different values for the same physical conditions, it is not a good choice.

g) Response Time:

Time lag between the Input and Output. (Should be Minimum)

h) Signal-to-noise Ratio:

Ratio between the magnitude of the signal and the noise at the output.

i) Calibration:

As sensors need frequent calibration, so it should be easy to calibrate.

j) Cost:

It shouldn't be expensive.

k) Nature of Output:

Do we need Analog output or Digital output, it should be clear.

l) Environment:

It is one of the most important parameters because not all sensors can work in extreme conditions. Sensors can get affected due to the non-ideal conditions(like temperature, humidity, etc.) which may affect the output of the sensor.

m) Flexibility:

We check whether the sensor can adapt to changes in the product with a simple OTA.

n) Interfacing:

It should be compatible to use with a wide range of instruments. Some sensors need an external power source to produce an output, so it important to provide the power source, so that additional errors aren't introduced.

o) Size and Weight:

Sensors should be compact and lightweight

9 FORCE-SENSING RESISTOR

A force-sensing resistor is a material whose resistance changes when a force, pressure or mechanical stress is applied. They are also known as force-sensitive resistor and are sometimes referred to by the FSR.

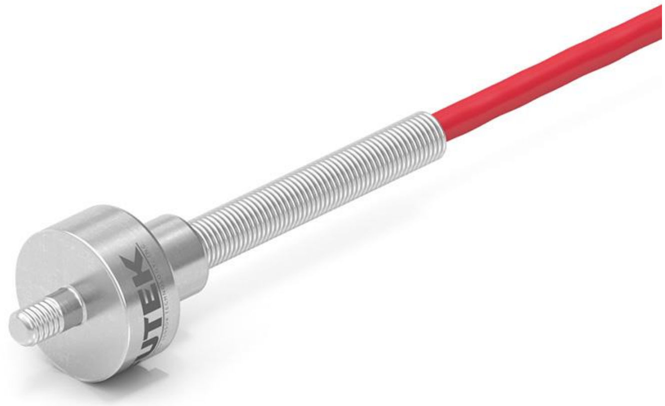

Fig 9.1: Force-Sensing Resistor

9.1 Properties

Force-sensing resistors consist of a conductive polymer, which changes resistance in a predictable manner following application of force to its surface. They are normally supplied as a polymer sheet or ink that can be applied by screen printing. The sensing film consists of both electrically conducting and non-conducting particles suspended in matrix. The particles are sub-micrometre sizes, and are formulated to reduce the temperature dependence, improve mechanical properties and increase surface durability. Applying a force to the surface of the sensing film causes particles to touch the conducting electrodes, changing the resistance of the film. As with all resistive based sensors, force-sensing resistors require a relatively simple interface and can operate satisfactorily in moderately hostile environments. Compared to other force sensors, the advantages of FSRs are their size (thickness typically less than 0.5 mm), low cost and good shock resistance. A disadvantage is their low precision: measurement results may differ 10% and more. Force-sensing capacitors offer superior sensitivity and long term stability, but require more complicated drive electronics.

9.2 Operation principle of FSRs

There are two major operation principles in force-sensing resistors: percolation and quantum tunneling. Although both phenomena actually occur simultaneously in the conductive polymer, one phenomenon dominates over the other depending on particle concentration. Particle concentration is also referred in literature as the filler volume fraction ϕ. More recently, new mechanistic explanations have been established to explain the performance of force-sensing resistors; these are based on the property of contact resistance R_C occurring between the sensor electrodes and the conductive polymer. Specifically the force induced transition from Sharvin contacts to conventional Holm contacts. The contact resistance, R_C, plays an important role in the current conduction of force-sensing resistors in a twofold manner. First, for a given applied stress σ, or force F, a plastic deformation occurs between the sensor electrodes and the polymer particles thus reducing the contact resistance. Second, the uneven polymer surface is flattened when subjected to incremental forces, and therefore, more contact paths are created; this causes an increment in the effective Area for current conduction A. At a macroscopic scale, the polymer surface is smooth. However, under a scanning electron microscope, the conductive polymer is irregular due to agglomerations of the polymeric binder.

Up to date, there is not a comprehensive model capable of predicting all the non-linearities observed in force-sensing resistors. The multiple phenomena occurring in the conductive polymer turn out to be too complex such to embrace them all simultaneously; this condition is typical of systems encompassed within condensed matter physics. However, in most cases, the experimental behavior of force-sensing resistors can be grossly approximated to either the percolation theory or to the equations governing quantum tunneling through a rectangular potential barrier.

Fig 9.2: Extraneous load factors on Force-Sensing Resistor

9.2.1 Percolation in FSRs

The percolation phenomenon dominates in the conductive polymer when the particle concentration is above the percolation threshold $\emptyset_c$. A force-sensing resistor operating on the basis of percolation exhibits a positive coefficient of pressure, and therefore, an increment in the applied pressure causes an increment in the electrical resistance R For a given applied stress σ, the electrical resistivity ρ of the conductive polymer can be computed from:

$$\rho = \rho_0(\emptyset - \emptyset_c)^{-x}$$

Where ρ_0 matches for a prefactor depending on the transport properties of the conductive polymer and x is the critical conductivity exponent. Under percolation regime, the particles are separated from each other when mechanical stress is applied, this causes a net increment in the device's resistance.

9.2.2 Quantum tunneling in FSRs

Quantum tunneling is the most common operation mode of force-sensing resistors. A conductive polymer operating on the basis of quantum tunneling exhibits a resistance decrement for incremental values of stress σ. Commercial FSRs such as the FlexiForce, Interlink and Peratech sensors operate on the basis of quantum tunneling. The Peratech sensors are also referred to in the literature as quantum tunnelling composite.

The quantum tunneling operation implies that the average inter-particle separation s is reduced when the conductive polymer is subjected to mechanical stress, such a reduction in s causes a probability increment for particle transmission according to the equations for a rectangular potential barrier. Similarly, the contact resistance R_C is reduced amid larger applied forces. In order to operate on the basis of quantum tunneling, particle concentration in the conductive polymer must be held below the percolation threshold $\emptyset_c$.

Several authors have developed theoretical models for the quantum tunneling conduction of FSRs, some of the models rely upon the equations for particle transmission across a rectangular potential barrier. However, the practical usage of such equations is limited because they are stated in terms of electron energy,E, that follows a Fermi Dirac probability distribution, i.e. electron energy is not a priori determined or cannot be set by the final user. The analytical derivation of the equations for a rectangular potential barrier including the Fermi Dirac distribution was found in the 60`s by Simmons. Such equations relate the current density J with the external applied voltage across the sensor U. However, J is not straightforward measurable in practice, so the transformation $I = JA$ is usually applied in literature when dealing with FSRs.

Just as the in the equations for a rectangular potential barrier, the Simmons' equations are piecewise in regard to the magnitude of U, i.e. different expressions are stated depending on U and on the height of the rectangular potential barrier $V_\propto$. The simplest Simmons' equation relates I with U, s when $U \approx 0$ as next:

$$I(U,s) = \frac{3A\sqrt{2mV_\propto}}{2s}\left(\frac{e}{h}\right)^2 Uexp\left(-\frac{4\pi s}{h}\sqrt{2mV_\alpha}\right)$$

where $V_\propto$ is in units of electron volt, m, e are the electron's mass and charge respectively, and h is the Planck constant. The low voltage equation of the Simmons' model is fundamental for modeling the current conduction of FSRs. In fact, the most widely accepted model for tunneling conduction has been proposed by Zhang et al. on the basis of such equation. By re-arranging the aforesaid equation, it is possible to obtain an expression for the conductive polymer resistance R_{Pol}, where R_{Pol} is given by the quotient U/I according to the Ohm's law:

$$R_{Pol} = \frac{s}{A\sqrt{2mV_a}}\left(\frac{h}{e}\right)^2 exp\left(\frac{4\pi s}{h}\sqrt{2mV_a}\right)$$

When the conductive polymer is fully unloaded, the following relationship can be stated between the inter-particle separation at rest state s_0,the filler volume fraction ϕ and particle diameter D:

$$s_0 = D\left[\left(\frac{\pi}{6\emptyset}\right)^{\frac{1}{3}} - 1\right]$$

Similarly, the following relationship can be stated between the inter-particle separation s and stress σ

$$s = s_0\left(1 - \frac{\sigma}{M}\right)$$

where M is the Young's modulus of the conductive polymer. Finally, by combining all the aforementioned equations, the Zhang's model is obtained as next:

$$R_{Pol} = \frac{D\left[\left(\frac{\pi}{6\emptyset}\right)^{\frac{1}{3}} - 1\right]\left(1 - \frac{\sigma}{M}\right)}{A\sqrt{2mV_a}} \left(\frac{h}{e}\right)^2 exp\left(\frac{4\pi D}{h}\left[\left(\frac{\pi}{6\emptyset}\right)^{\frac{1}{3}} - 1\right]\left(1 - \frac{\sigma}{M}\right)\sqrt{2mV_a}\right)$$

Although the model from Zhang et al. has been widely accepted by many authors, it has been unable to predict some experimental observations reported in force-sensing resistors. Probably, the most challenging phenomenon to predict is sensitivity degradation. When subjected to dynamic loading, some force-sensing resistors exhibit degradation in sensitivity. Up to date, a physical explanation for such a phenomenon has not been provided, but experimental observations and more complex modeling from some authors have demonstrated that sensitivity degradation is a voltage-related phenomenon that can be avoided by choosing an appropriate driving voltage in the experimental set-up.

The model proposed by Paredes-Madrid et al. uses the entire set of Simmons' equations and embraces the contact resistance within the model; this implies that the external applied voltage to the sensor V_{FRS} is split between the tunneling voltage V_{bulk} and the voltage drop across the contact resistance V_{Rc} as next:

$$V_{FRS} = 2V_{RC} + V_{bulk}$$

By replacing sensor current I in the above expression, V_{bulk} can be stated as a function of the contact resistance R_C and I as next:

$$V_{bulk} = V_{FRS} - 2RcI$$

And the contact resistance R_C is given by:

$$R_C = R_{par} + \frac{R_C^0}{\sigma^k}$$

Where R_{par} is the resistance of the conductive nano-particles and R_C^0, k are experimentally determined factors that depend on the interface material between the conductive polymer and the electrode. Finally the expressions relating sensor current I with V_{FSR} are piecewise functions just as the Simmons equations are:

When $V_{bulk} \approx 0$

$$R_{bulk} = \frac{s_0\left(1 - \frac{\sigma}{M}\right)}{(A_0 + A_1\sigma^{A_2})\sqrt{2mV_a}} \left(\frac{h}{e}\right)^2 exp\left(\frac{4\pi s_0\left(1 - \frac{\sigma}{M}\right)}{h}\sqrt{2mV_a}\right)$$

When $V_{bulk} < V_a/e$

$$I = \frac{(A_0 + A_1\sigma^{A_2})e}{2\pi h s_0^2 \left(1 - \frac{\sigma}{M}\right)^2} \left\{ \left(V_a - \frac{V_{bulk}}{2}\right) exp\left[-\frac{4\pi}{h} s_0 \left(1 - \frac{\sigma}{M}\right) \sqrt{2m\left(V_a - \frac{eV_{bulk}}{2}\right)}\right] - \left(V_a + \frac{V_{bulk}}{2}\right) exp\left[-\frac{4\pi}{h} s_0 \left(1 - \frac{\sigma}{M}\right) \sqrt{2m\left(V_a + \frac{eV_{bulk}}{2}\right)}\right] \right\}$$

When $V_{bulk} > V_a/e$

$$I = \frac{2.2e^3 V_{bulk}^2 (A_0 + A_1\sigma^{A_2})}{8\pi h V_a s_0^2 \left(1 - \frac{\sigma}{M}\right)^2} \left\{ exp\left[-\frac{8\pi s_0 \left(1 - \frac{\sigma}{M}\right)}{2.96heV_{bulk}^2} \sqrt{2mV_a^3}\right] - \left(1 + \frac{2eV_{bulk}}{V_a}\right) exp\left[-\frac{8\pi s_0 \left(1 - \frac{\sigma}{M}\right)}{2.96heV_{bulk}^2} \sqrt{2mV_a^3\left(1 + \frac{2eV_{bulk}}{V_a}\right)}\right] \right\}$$

In the aforesaid equations, the effective area for tunneling conduction A is stated as an increasing function dependent on the applied stress σ, and on coefficients A_0, A_1, A_2 to be experimentally determined. This formulation accounts for the increment in the number of conduction paths with stress:

$$A = A_0 + A_1\sigma^{A_2}$$

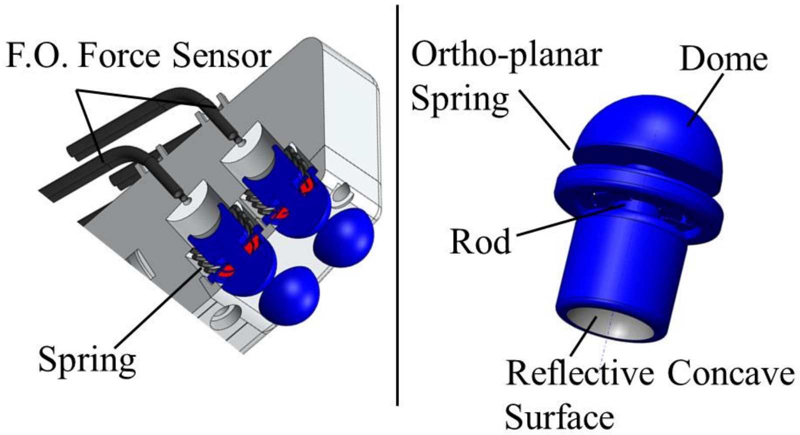

Fig 9.3: Setup of Force-Sensing Resistor on Bending Pallet

10. TACTILE SENSORS

Tactile sensors are data acquisition devices, or transducers, that are designed to sense a diversity of properties via direct physical contact. Tactile sensor designs are based around a range of different technologies some of which are directly inspired by research on biological touch. The growth of robotic applications in healthcare, agriculture, social assistance, autonomous systems and unstructured environments has created a pressing need for effective tactile sensors. Their deployment plays an important role permitting the detection, measurement and conversion of information, acquired by physical interaction with objects, into an appropriate form to be processed and analysed by higher level modules within an intelligent system. Although, in recent decades, tactile sensor technology has shown great advances in design and capability, tactile sensing systems are still relatively undeveloped compared to the sophisticated technology accomplished in vision. The relatively slow development attained thus far is possibly related to the inherent complexity of the sense of touch. Another limiting factor is that, by their very nature, tactile sensors require direct contact to be made surfaces and objects, and are therefore subject to wear and risk of damage than some other sensor types.

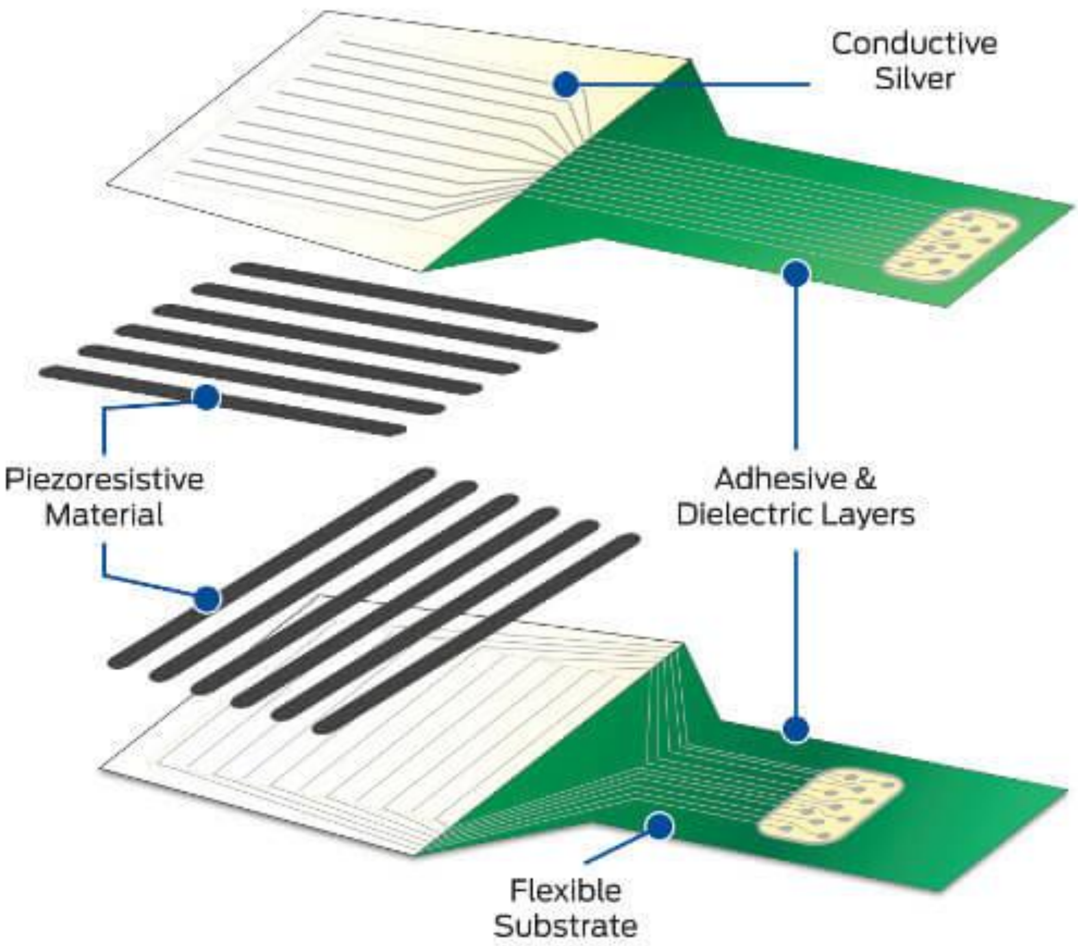

Fig 10.1: Tactile Sensor

10.1 Uses

Tactile sensors appear in everyday life such as elevator buttons and lamps which dim or brighten by touching the base. There are also innumerable other applications for tactile sensors of which most people are never aware.

Sensors that measure very small changes must have very high sensitivities. Sensors need to be designed to have a small effect on what is measured; making the sensor smaller often improves this and may introduce other advantages. Tactile sensors can be used to test the performance of all types of applications. For example, these sensors have been used in the manufacturing of automobiles (brakes, clutches, door seals, gasket), battery lamination, bolted joints, fuel cells etc.

Tactile imaging, as a medical imaging modality, translating the sense of touch into a digital image is based on the tactile sensors. Tactile imaging closely mimics manual palpation, since the probe of the device with a pressure sensor array mounted on its face acts similar to human fingers during clinical examination, deforming soft tissue by the probe and detecting resulting changes in the pressure pattern.

Robots designed to interact with objects requiring handling involving precision, dexterity, or interaction with unusual objects, need sensory apparatus which is functionally equivalent to a human's tactile ability. Tactile sensors have been developed for use with robots. Tactile sensors can complement visual systems by providing added information when the robot begins to grip an object. At this time vision is no longer sufficient, as the mechanical properties of the object cannot be determined by vision alone. Determining weight, texture, stiffness, center of mass, coefficient of friction, and thermal conductivity require object interaction and some sort of tactile sensing.

Several classes of tactile sensors are used in robots of different kinds, for tasks spanning collision avoidance and manipulation. Some methods for simultaneous localization and mapping are based on tactile sensors.

10.2 Working Principle

The resistive touch sensor does not depend on the electrical properties such as the conductivity of the metallic plates.

The resistive sensor works by sensing the pressure when applied on the surface.

Since there is no need to measure the difference in the capacitance the resistive touch sensor can operate on non-conductive materials such as pen, stick, or finger inside the gloves.

The resistive touch sensor consists of the two conductive layers which are separated by a very small distance or dots. The two layers (i.e the top as well as the bottom layer) are made up of a film. The films are generally coated by the Indium Tin Oxide which is a good conductor of electricity and is also transparent in nature as well.

A constant voltage is applied across the surface of two films. When the pressure is applied with the help of the finger or a stick on the top film, the sensor is activated and senses the touch.

The sensor operates when enough pressure is applied, the top film touches the bottom film. When the two film touches each other they create the potential drop. The point of contact of the two films creates the voltage divider at that particular coordinate on the X-Y plane assumed at the film.

The change in the voltage hereby detected by a controller circuit and the location (coordinate) at which the voltage divider created is calculated.

The coordinate of the voltage divider interns of the X and Y axis created as the position of touch at which pressure is applied.

Below circuit illustrates that how the resistive touch sensor works.

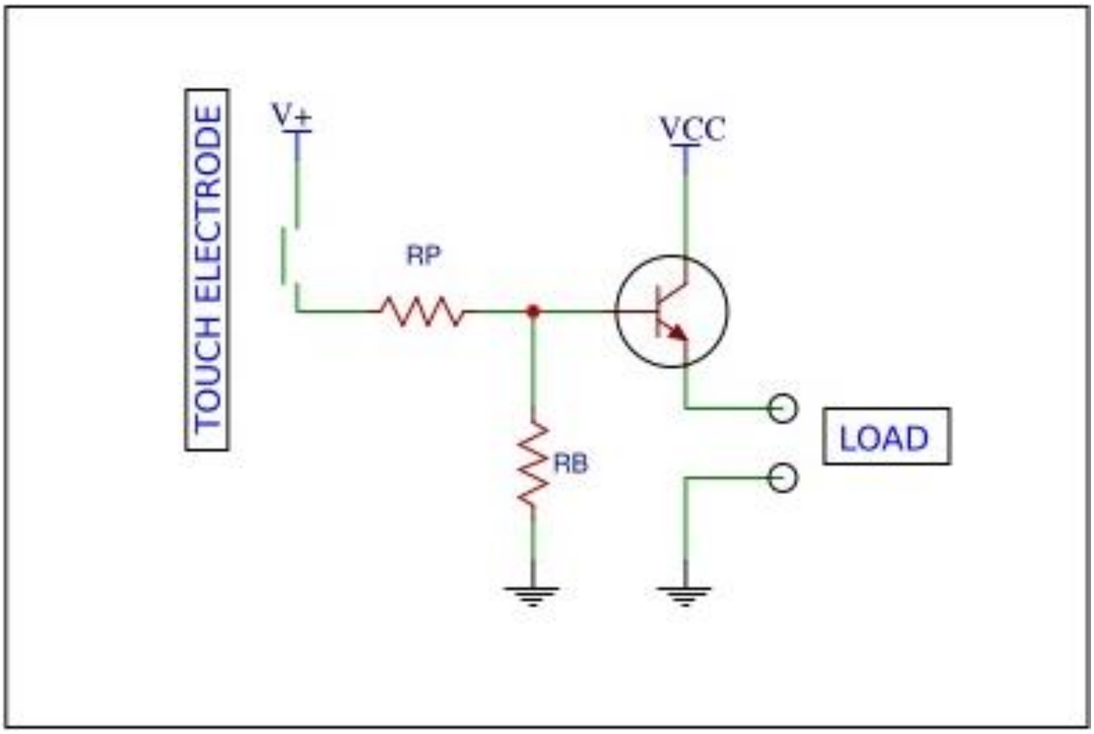

Fig 10.2: Working of resistive touch sensor

The above circuit shows the basic working of the touch sensor which consists of the touch electrode or the surface.

The resistive touch sensor operates when an object with some resistivity such as an object touches the surface. Touch of the object with a little resistance forms a close circuit which allows a small amount of current to flow.

In the above circuit the touch causes a very little current to flow.

- The transistor amplifies the voltage to some significant value.
- Resistance Rp is used to protect the transistor from the high current. It is useful In case if there is a fault occurs in the electrodes.
- Resistance Rb is used to keep the base of the transistor grounded. There is no current when there is an open circuit or if there is no pressure applied.

When the little pressure is applied to the electrode. There is a small flow of current through the base of the transistor. The current enables the resistive touch sensor and the current flows through the load.

10.3 Criteria for sensor design

The wire bending CNC has wide range of sensor types that support several different forms of touch. Whilst it would be desirable to create a robotic device with similar sensing capability, to do so would involve addressing a large list of design specifications. The first design criteria for tactile sensors were proposed by Harmon (1982) and were motivated by the design requirements for industrial robots in the 1980s. As the technology has evolved so have the criteria. A key target for contemporary systems is humanoid robotics and the capacity to emulate human in-hand manipulation. To achieve this goal, Yousef et al. (2011) proposed the following list of functional requirements:

- Contact detection and release of an object.
- Lifting and replacement of an object.
- Detection of shape and force distribution for object recognition.
- Detection of dynamic and static forces.
- Tracking of contact points during manipulation.
- Estimation and detection of grip forces for manipulation.
- Detection of motion and direction during manipulation.
- Detection of tangential forces to prevent slip.

Beginning with the desirable features for in-shaping object manipulation, a set of general design guidelines for tactile sensors was presented by (Dargahi and Najarian, 2004), considering also the limitations and possibilities of sensors. The suggested guidelines, shown in Table10.1, are draw inspiration from the sensing capacities of the specific object used (Dahiya et al., 2010).

Table 10.1: Design guidelines for tactile sensors in CNC Wire Bending Machine

Parameter	Guidelines
Force direction	Normal and tangential
Temporal variation	Dynamic and static
Time response	1ms
Force sensitivity	0.01-10N
Linearity/Hysteresis	Stable, repeatable and monotonic with low hysteresis
Robustness	Resistant to the application and the environment
Tactile cross-talk	Minimal cross-talk
Shielding	Electronic and/or magnetic shielding
Integration and fabrication	Simple mechanical integration. Minimal wiring with low power consumption and cost

Beyond the guidelines presented in Table 10.1, temperature tolerance, size, weight, power consumption and durability are some additional important criteria.

Multi-purpose sensors that address all of the above criteria remain a significant technological challenge. For this reason, a more limited set of constraints will be identified when designing sensors for specific applications, reducing cost and complexity.

10.4 Pressure sensor arrays

Pressure sensor arrays are large grids of tactels. A "tactel" is a 'tactile element'. Each tactel is capable of detecting normal forces. Tactel-based sensors provide a high resolution 'image' of the contact surface. Alongside spatial resolution and force sensitivity, systems-integration questions such as wiring and signal routing are important. Pressure sensor arrays are available in thin-film form. They are primarily used as analytical tools used in the manufacturing and R&D processes by engineers and technicians, and have been adapted for use in robots. Examples of such sensors available to consumers include arrays built from conductive rubber, lead zirconate titanate (PZT), polyvinylidene fluoride(PVDF), PVDF-TrFE, FET, and metallic capacitive sensing elements.

10.5 Strain gauge rosettes

Strain gauges rosettes are constructed from multiple strain gauges, with each gauge detecting the force in a particular direction. When the information from each strain gauge is combined, the information allows determination of a pattern of forces or torques.

10.6 Tactile Sensor Setup

10.6.1 Experimental Setup

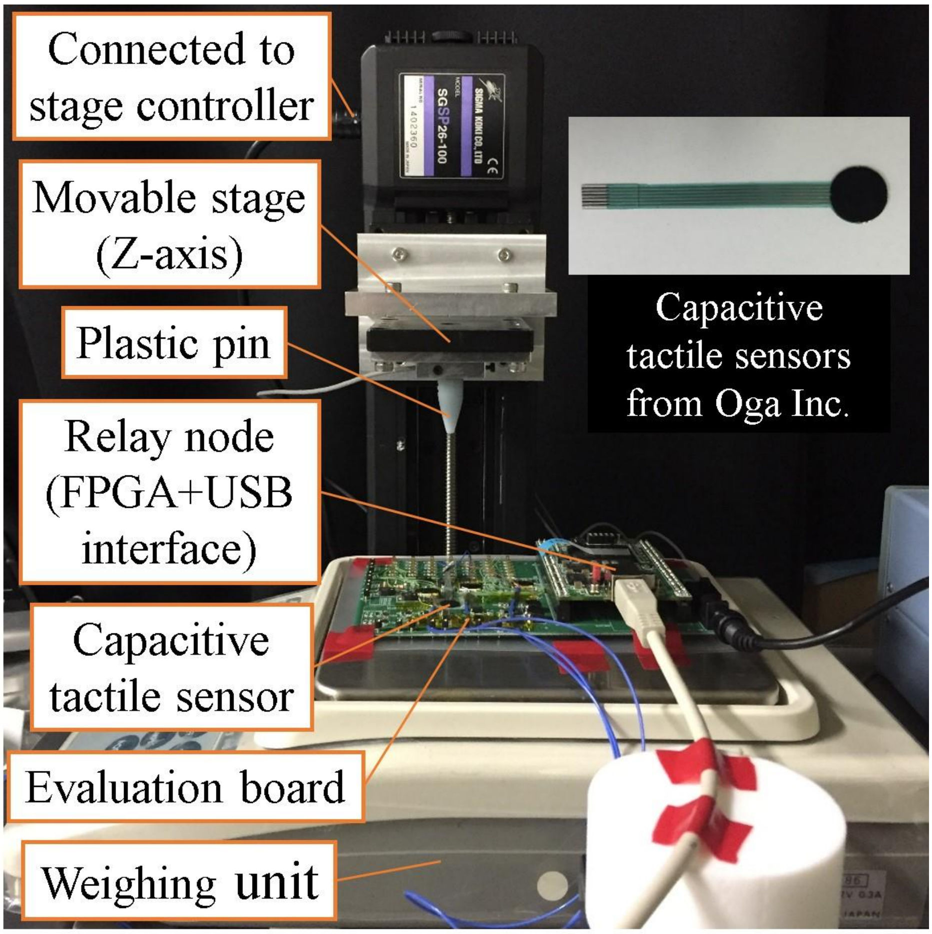

Fig 10.3: Experimental setup of tactile resistive touch sensor

Figure 10.3 shows relationships between external forces and decoded sensor outputs of the resistive sensor. The digital value of each point was the average of more than 1000 measurement values. Hysteresis loops of external forces from 0N to 6N were confirmed. In the case of Figure 10.3 2mm thick, around 6mm diameter PDMS cover was put on the sensor. The adding of the PDMS cover resulted in a more moderate resistance change along with force change. However, the same as the capacitive sensor case, using the PDMS cover leads to a larger hysteresis.

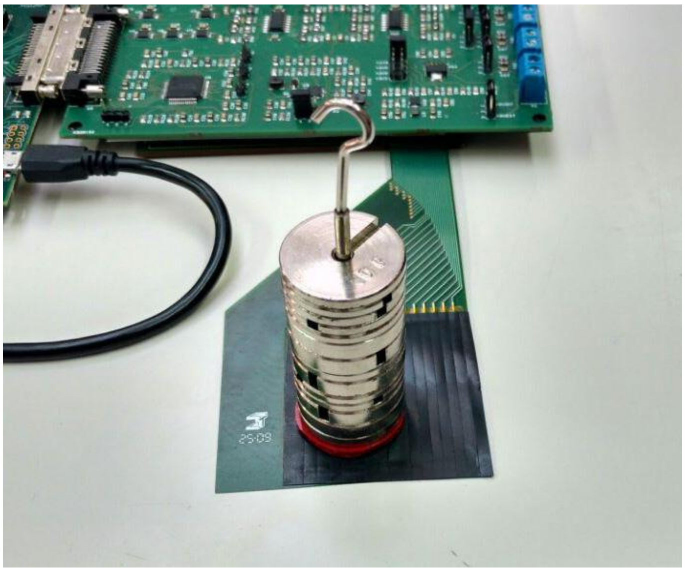

Fig 10.4: Tactile Sensor with applied Load

10.6.1 On-Board Setup

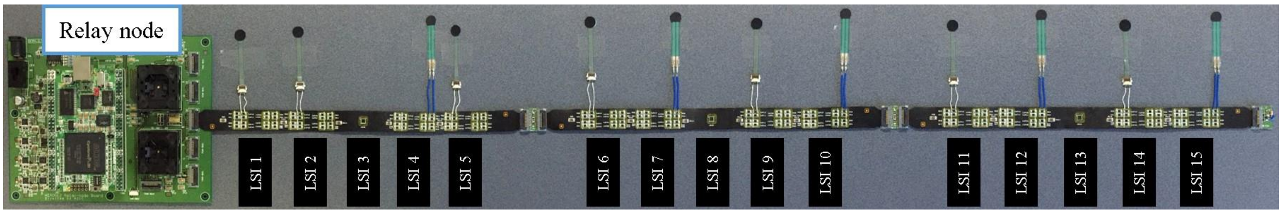

Fig 10.5: Simultaneous operation of 12 sensor platform LSIs configured for resistive sensing mode

Figure 10.4 shows a multi-sensor system demonstration setup with 12 sensor platform LSIs. In this demonstration, three FPC cables were connected in series to a relay node. Among these sensor platform LSIs, seven were configured for capacitive sensing mode, and each of them connected one z-axis capacitive tactile sensor. Another five sensor platform LSIs were configured for resistive sensing mode, and each of them connected one z-axis resistive tactile sensor. Although each sensor platform LSI can connect eight resistive z-axis tactile sensors, we only connected one tactile sensor to show the LSI's operation on one bus line. For the sensor platform LSI at the middle position of each cable, since there are only small sized capacitive MEMS sensor connection pads, we touched these exposed pads by fingers to check whether they were operating. Fingers have several hundreds of picofarads capacitances, so the three middle sensor platform LSIs were configured for resistive sensing mode.

11. CONCLUSION

11.1 Conclusion

From the above discussion, it can be concluded that an Automation system integrated with feedback control can help to improve the efficiency or productivity of the process. This system can help to decrease the rate of material wastage during working. In this project, two types of sensors are used Tactile Sensor & Force Resisting Sensor. These sensors sense the excess amount of force and as force exceeds the set limit they automatically stop the machine and save it from damage. By using this system efficiency of production of brackets is increased and decrease the downtime as well as decrease in the cost of maintenance along with that after implementing this system it is no need to continuous monitoring on the machine or to check whether all component mounted on bending pallet are working correctly or not as if a single part facing an issue the controller automatically stop the machine and report it. This level of consistency is hard to achieve by any other method or technology.

11.2 Future Scope

Automation is a technology with a future, and is a technology for the future. If present trends continue, and if some of the laboratory research currently underway is ultimately converted into practicable technology. Getting from the present future will require much work in mechanical engineering, electrical engineering, industrial engineering, Automation technology, material technology, manufacturing system engineering, and other engineering fields. A combination of economic and technical factors will determine how the future applications will be introduced. Although there is significant development in the science of automation, still its usage is limited due to high cost of production, less availability of resources. If we can overcome these limitations, more benefits can be gained from automation.

We can theorize a likely profile of the future automation based on the various research activities that are currently being performed. The features and capability of the future robot.

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