PROJECT : MILLING

Experiment: Perform milling on a soft material and validate the milling forces through theoretical calculations

CONTRIBUTIONS

Name	Roll No	Contribution
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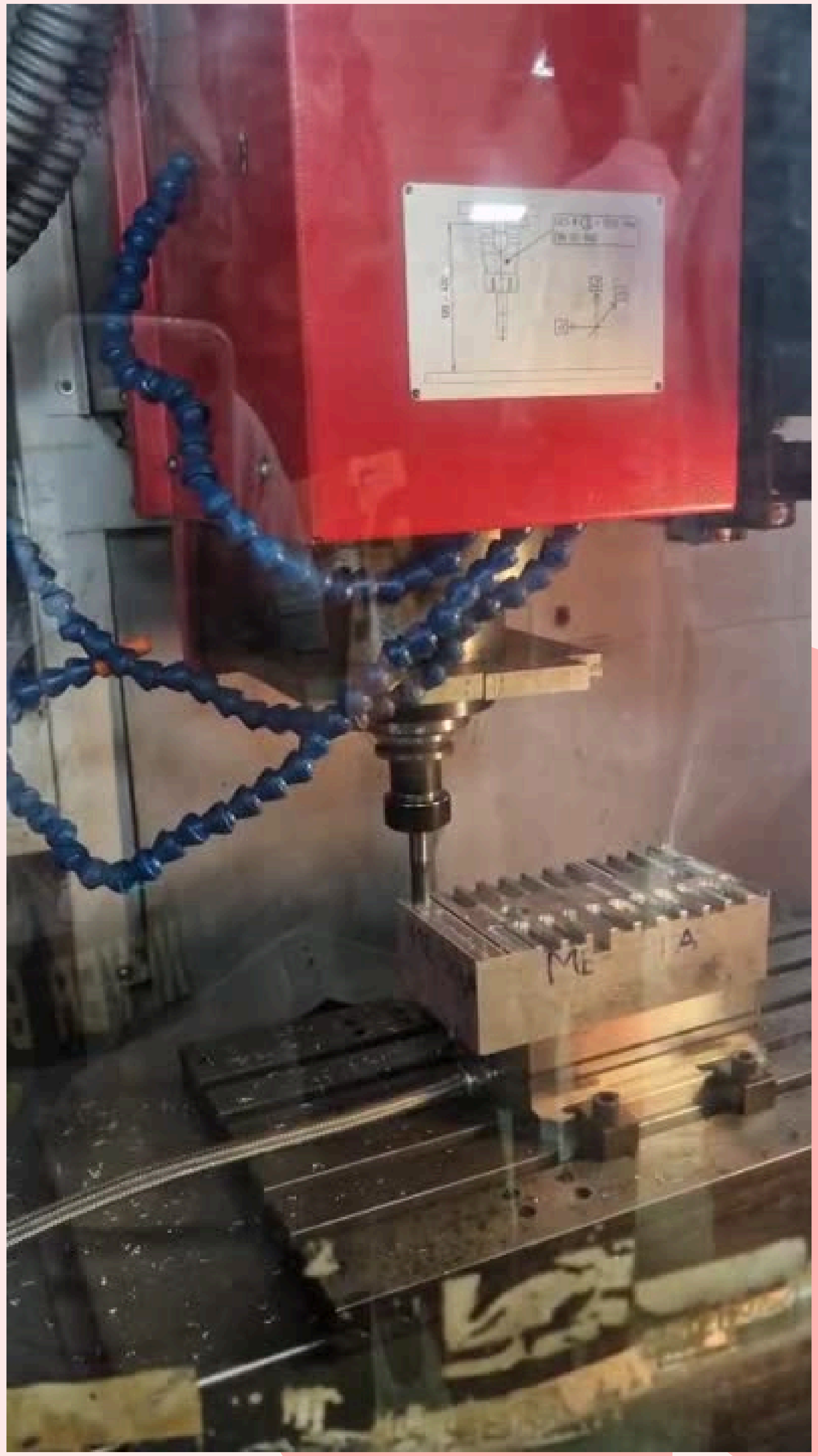
Mahak	220601	Introduction and Theoretical Overview
Mahesh	220603	Spindle Speed Selection
Manish	220615	Procedure and Methods
Mansi Patel	220626	Challenges faced in the project
Manoj Kumar	220625	Force Coefficients and Equations
Mayank Agrawal	220636	Validation and Error Analysis

WHAT IS MILLING?

- **Definition**: Milling is a machining process that involves the removal of material from a workpiece using rotary cutters.
- **Purpose**: Primarily used to create precise shapes, surfaces, and dimensions on a variety of materials, milling is essential for producing parts in manufacturing, especially in metalworking.

HOW MILLING WORKS?

- In milling, a rotating tool with multiple cutting edges removes material by advancing into the workpiece.
- The material is removed in the form of chips, which are generated due to the tool's interaction with the workpiece surface.



Machine, Tool and Workpiece specifications

Machine Specifications:

•Model/Make: EMCO Concept Mill 250

•Max Speed: 10,000 RPM, Power 7KW

•ATC with 20 tool

•20 Station Tool Drum with directional logic

Controller: SIEMENS

Tool Specifications:

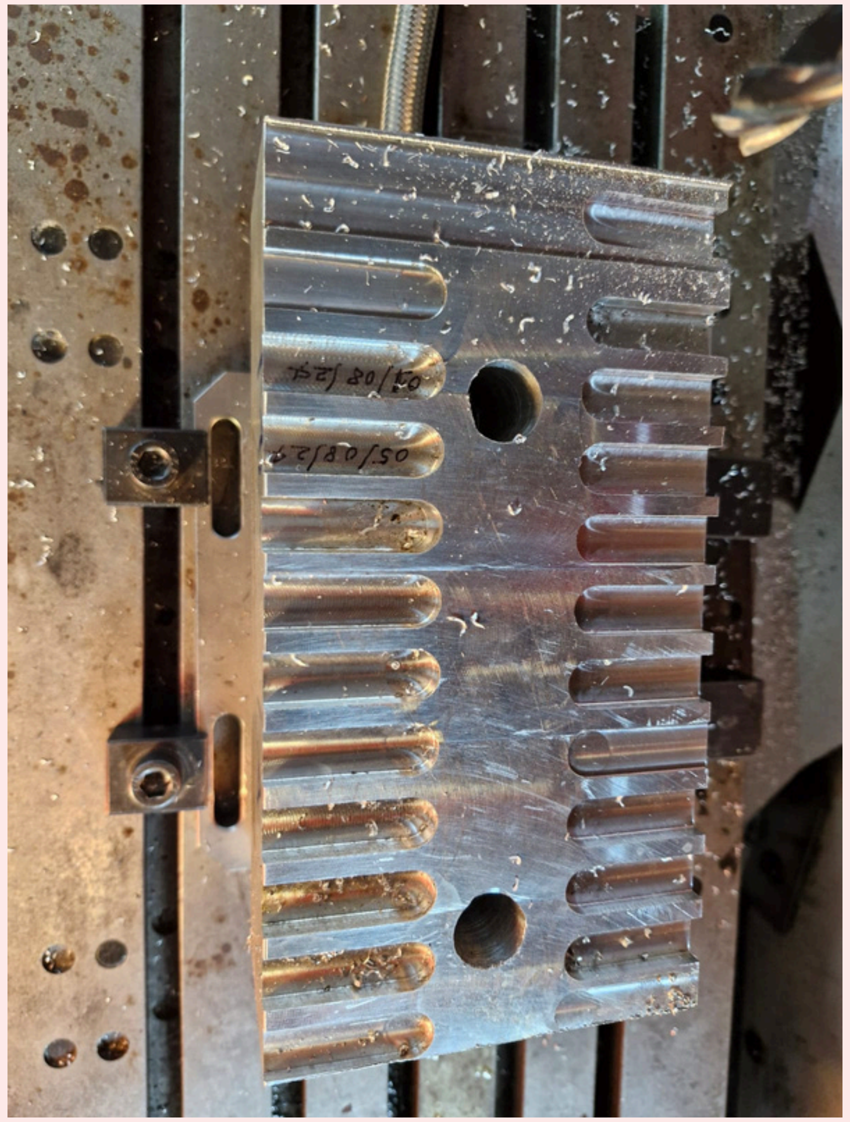
End mill cutter : Solid Carbide

Tool diameter : 12 mm

No. of teeth on tool : 4

Workpiece Specifications:

Aluminum



Procedure and Methods

Milling is a versatile machining process used to remove material from a workpiece, shaping it into the desired form. When working with aluminum, a soft and malleable metal, milling is a popular choice due to its efficiency and precision. Here's a general procedure for milling aluminum:

1. Calibrate the dynamometer for measuring forces in three directions. Plot the calibration curve. (Calibration values are provided)

2. Set-up the experiment and let the instruments warm up for 15 minutes.

3. Measure cutting forces for different values of feed rate (mm/tooth).

4. Measure forces for at least 10 full revolutions of the cutter.

5. Calculate the average measured forces in x, y and z over two or more revolutions.

Aluminum is widely used in milling processes due to several advantageous properties :

- Lightweight and Malleable
- High Machinability
- Excellent Surface Finish
- Good Heat Dissipation
- Cost-Effective and Widely Available
- Corrosion Resistance

Using fruit peels as a holding device in milling processes isn't practical for several reasons:

- **Lack of Rigidity**: Fruit peels are soft, flexible, and lack the necessary rigidity to hold materials in place securely.
- **Inconsistent Thickness:** Fruit peels have varying thicknesses and textures, which makes them unreliable as holding materials.
- **Slippery Surface:** The natural oils and moisture in fruit peels make them slippery, reducing friction.
- **Contamination:** Organic materials like fruit peels decompose over time and can introduce contaminants (like moisture and sugars) that may corrode or damage the milling machine and tools.
- **Incompatibility with Coolants:** Milling processes often require coolant to reduce heat, which could further weaken the peel's structure, making it even less effective as a holding device.

Challenges in Milling Soft Materials

1. **Material-Specific Challenges:**
   - **Plastics:** Prone to melting, deformation, and chip sticking on tools.
   - **Wood:** Grain direction affects quality; cutting against grain risks tear-out and splintering.
   - **Foams:** Lightweight; can crumble or produce dust that clogs machinery.
   - **Brass & Copper:** Abrasive; can cause tool wear and chip adhesion.
   - **Waxes:** Prone to melting and smearing, challenging sharp edge precision.
2. **Anisotropy Challenges:**
   - **Wood:** Grain direction affects finish; tear-out risk if not cut with the grain.
   - **Composites:** Layered structure leads to fiber pull-out and delamination.
   - **Metals:** Rolled metals may exhibit varying wear and surface finish issues.

Specification of Cutting Force Coefficients and Machine Calibration

Cutting Force Coefficients

Cutting force coefficients describe the relationship between machining forces and process parameters, such as tool geometry and material properties. Tangential, radial, and axial coefficients are used to predict forces in various directions, which helps optimize machining for tool life, accuracy, and surface finish.

Machine Calibration for Force Measurement

To ensure accurate force measurement in x, y, and z directions, the Kistler Type 9123C Dynamometer, equipped with piezoelectric sensors, was calibrated

Calibration Process:

Dynamometer Setup: Align sensors and connect to the data system.

Force Application: Apply known forces in each axis to verify response.

Verification:

Compare initial readings against expected values to confirm accuracy, ensuring reliable force data for coefficient calculation.

Calculation of Coefficients

Method: Use linear regression on force data to derive accurate cutting force coefficients.

Application: Enables fine-tuning of speed and feed rate for efficient and precise milling operations.

Model Selection

- For selection of model to relate feed rate with the forces, we searched through many resources and research papers.
- Most of these papers had stated a linear relation between feed rate and all 3 force components.
- In these linear models **'ft'** is the feed rate in mm/tooth, **'Nt'** is the number of teeth on milling tool which is 4 in our case, and **'b'** is the axial depth of cut in mm.
- Other coefficients - **Knc** (radial cutting coeff.), **Kne** (radial edge coeff.), **Ktc** (tangential cutting coeff.), **Kte** (tangential edge coeff.), **Kac** (axial cutting coeff.) and **Kae** (axial edge coeff.) are all determined experimentally after data analysis.

$$\bar{F}_x = \frac{N_t b k_{nc}}{4} f_t + \frac{N_t b k_{ne}}{\pi}$$

$$\bar{F}_y = \frac{N_t b k_{tc}}{4} f_t + \frac{N_t b k_{te}}{\pi}$$

$$\bar{F}_z = -\frac{N_t b k_{ac}}{\pi} f_t - \frac{N_t b k_{ae}}{2}$$

source - click here

Spindle Speed Selection for Model Accuracy

Objective :

Select an optimal spindle speed to provide consistent, reliable data for developing a linear regression model that accurately predicts milling forces in aluminum.

Why 4500 RPM?

- **Optimal Cutting Speed:** 4500 RPM aligns with the ideal cutting speed for efficient material removal.
- **Efficiency & Tool Life:** Balances fast cutting with minimal tool wear.
- **Low Heat Generation:** Aluminum’s properties allow for higher speeds without excess heat.
- **Improved Performance:** Higher speeds result in smoother cuts and better surface finish.

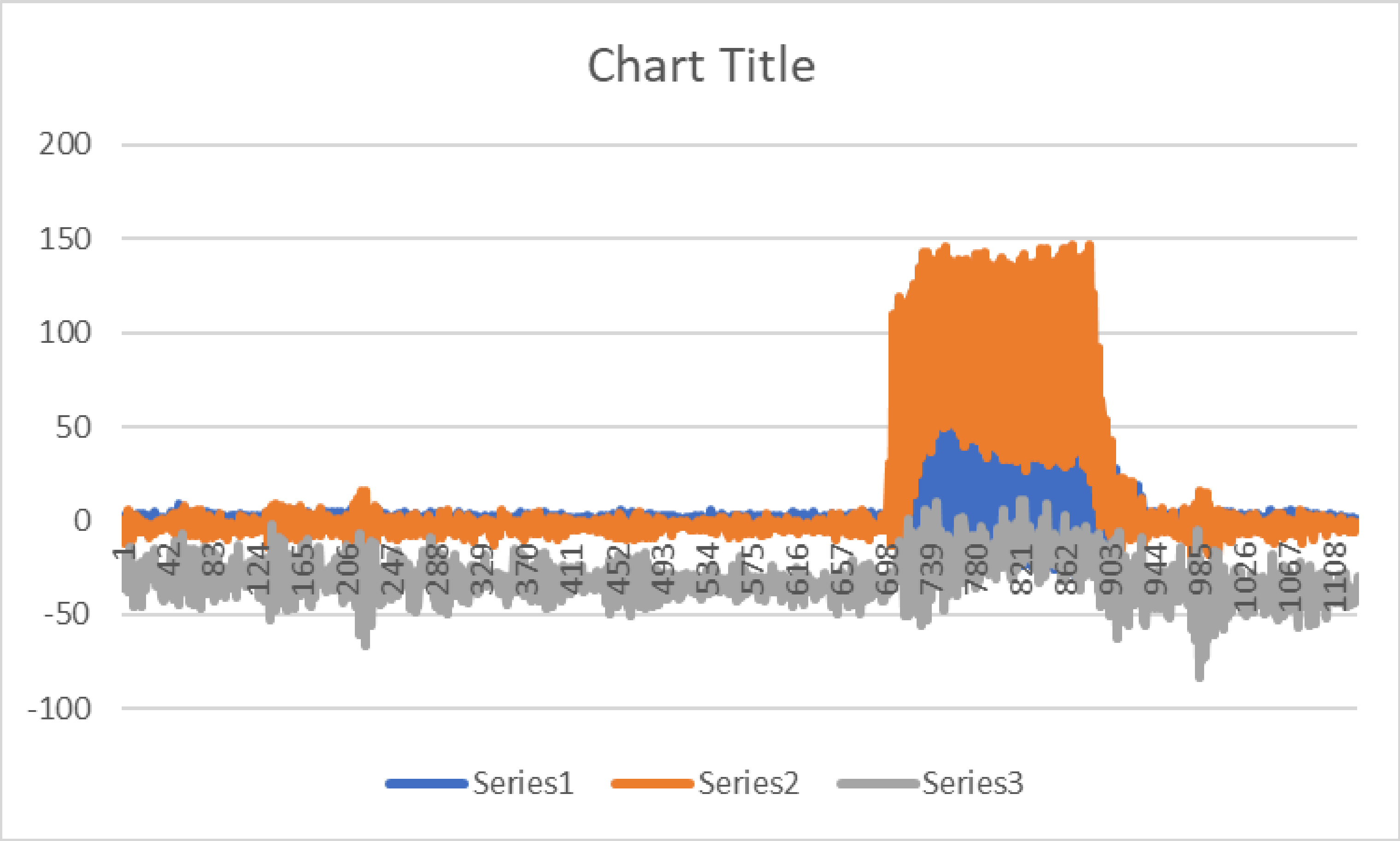
Benefits of High Spindle Speed

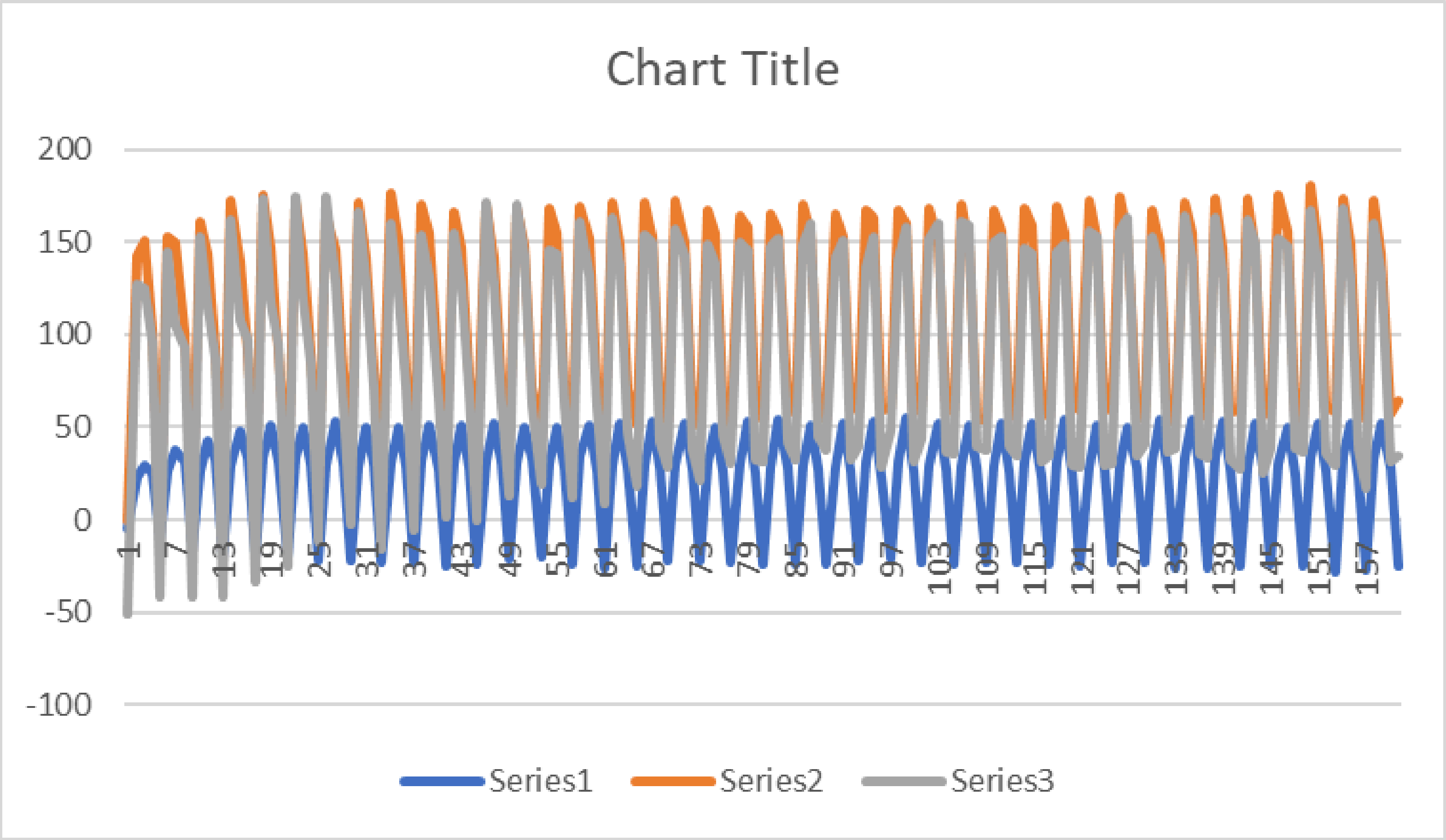
- High spindle speeds increase cutting speeds, enhancing material removal rates and preventing built-up edge formation.

Validation at 5000 RPM Using Linear Regression

- It ensures higher efficiency, optimal material removal, and stable milling with tool durability at faster speeds.
- It confirms the model's ability to predict milling forces at 4500 RPM across feed rates of 1200 to 1800 mm/min.

Data Analysis



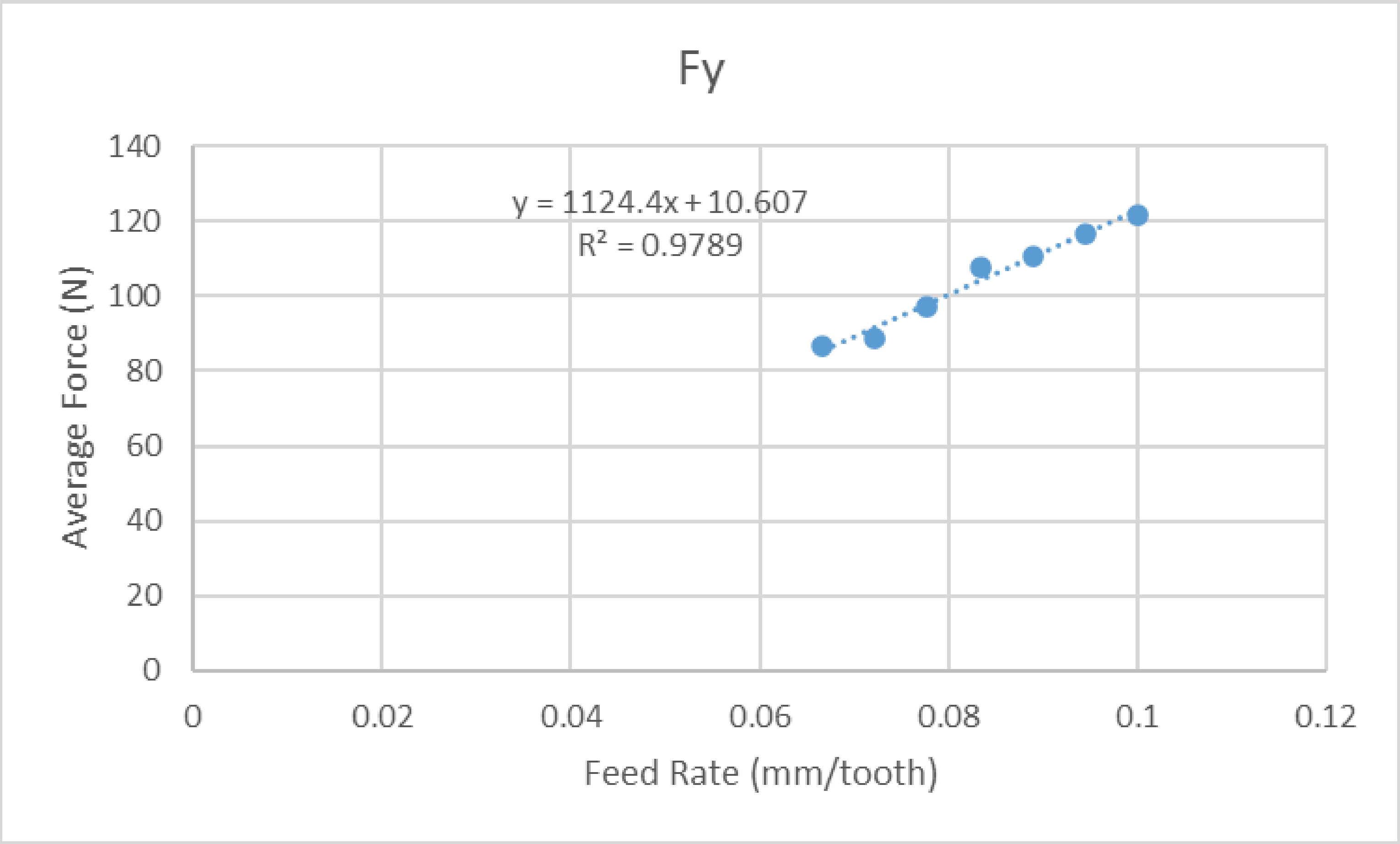


First step was to filter out the data points that were useful for analysis. These were selected approximately around where the forces started showing deviation. After filtering, average forces were calculated for each feed rate over these data points only to minimize inconsistency in data.

Data Analysis

- After getting average forces for each feed rate, we plot Average Force (y) vs Feed Rate (x) for all 3 components.
- After that we use linear regression to make best fit lines for all 3 components to determine the experimental coefficients required for our model.
- To determine the coefficients, For example in the case of **Fy** we got the equation as:

$$y = 1124.4x + 10.607$$



Now we can equate and calculate:

Nt*b*Ktc/4 = 1124.4 & **Nt*b*Kte/π = 10.607**

Obtained Force Coefficients & Equations

We got the linear equations for the force calculation through linear regression, which gives us the corresponding force coefficients.

Knc	Kne	Ktc	Kte	Kac	Kae
346.1	16.919	2248.8	16.661	1129.575	-29.877

$$\bar{F}_x = 173.05 \times f_t + 10.77$$

$$\bar{F}_y = 1124.4 \times f_t + 10.607$$

$$\bar{F}_z = -719.11 \times f_t + 29.87$$

Validation of Linear Equations

- Dimensions of workpiece
  - Width 110.1 mm
  - Length 201.2 mm
  - Height 60mm

- We took 7 readings for a spindle speed of 4500rpm ranging from 1200 feed rate to 1800 feed rate, and 3 readings at a spindle speed of 5000 rpm and verified the coefficients of forces obtained

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	A	B	C	D	E	F	G
1	Feed (mm/min)	spindle speed(RPM)	Cutting speed	Feed/tooth(mm/tooth)	Avg Fx	Avg Fy	Avg Fz
2	1500	5000	188.4955592	0.075	22.07073	99.85053	-55.5476
3	1800	5000	188.4955592	0.09	22.80479	116.2793	-56.1173
4	2100	5000	188.4955592	0.105	23.09778	127.9763	-58.193

Error analysis: Validation of Linear Equations

Avg Fx	Avg Fy	Avg Fz	Theoretical Fx	Theoretical Fy	Theoretical Fz
22.07073	99.85053	-55.5476	23.74975	94.937	-24.0563
22.80479	116.2793	-56.1173	26.3455	111.803	-34.8429
23.09778	127.9763	-58.193	28.94125	128.669	-45.6296

- These are the Experimental forces obtained by dynamometer and the theoretical forces obtained using the linear model

Feed rate	%error in Fx	%error in Fy	%error in Fz
1500	7.069625	5.175568	130.9071
1800	13.43953	4.003695	61.05805
2100	20.19801	0.538343	27.53356

- Final Results

Avg error in Fx	Avg error in Fy	Avg error in Fz
13.56%	3.23%	73.16%

Conclusions from validation

Avg error in Fx	Avg error in Fy	Avg error in Fz
13.56%	3.23%	73.16%

- We can see that this linear model is valid for different spindle speeds and gives an error in a permissible range
- It especially predicts the Fx and Fy with high accuracy

Possible Sources of Error & Justification

- Improper calibration and the Dynamometer not working correctly will give us wrong force values. We got almost 2 readings lying out of the region of linearity which leads to the uneven calculation of force coefficients, leading to wrong theoretically calculated forces.

- Less number of data points will not provide us with a better regression line. Leading to the high amount of errors in the theoretical validation of forces at different cutting speed and spindle speed.

Conclusion

In this project, we successfully conducted milling on aluminum, a soft material, and validated the milling forces using theoretical calculations. Through meticulous calibration and data analysis, we identified the linear relationships between feed rate and cutting forces, verifying the model's accuracy within a permissible error range. Our findings confirmed that the selected linear model effectively predicts forces, particularly in the Fx and Fy components, at various spindle speeds.

Thank you