A Study on Retrofitting Conventional Lathe with CNC Technology

Sova Dootraj[1], Dechen Tshomo[2], and Norden Wangchuk[3*]

[1-4]*Department of Mechanical Engineering, Jigme Namgyel Engineering College, Dewathang*
[*]*Corresponding author: nordenwangchuk.jnec@rub.edu.bt*

Published: December 2025

Abstract

The semi-automated conventional lathe machine is about to become obsolete as it does not meet the advance features of industry 4.0. Conventional lathe machine is widely used in educational institutes despite its limitations in precision and productivity. This project focuses on retrofitting conventional lathe machine with the features of CNC technology by reducing the cost rather than buying a new CNC lathe machine. The objective of the project is to evaluate the feasibility of retrofitting conventional lathe by examining the key components for retrofitting, designing their integrating parts and conducting a comprehensive cost analysis. The duration of the project evaluated by using value stream mapping and critical path method which is approximately 8 months. Further a case study was conducted to find out the retrofitting challenges. The result indicate that it is feasible to do the retrofitting of lathe with low cost by considering the initial cost, maintenance cost and set up cost.

Keywords— Retrofitting, CNC machine, industry 4.0, Conventional lathe machine, Automation, Low cost automation, value stream mapping

1 Introduction

Jigme Namgyel Engineering College, established in 1974, has grown steadily over the years with the introduction of various engineering programs, including Mechanical Engineering. As new courses were added, the college expanded its infrastructure, which eventually led to the establishment of machine shops. The installation of conventional lathe machines marked an important step toward modernizing the institutes manufacturing facilities. Starting with just one machine, the number gradually increased to nine lathes, which continue to support hands-on learning today.

Conventional lathes are among the oldest and most widely used machine tools in metalworking. They shape materials by removing chips as the work piece rotates in the chuck while the tool feeds onto it, enabling operations such as turning, drilling, facing, knurling, and deformation [1]. These machines offer reliable precision and accuracy, but with rapid technological advancements, automation has begun to dominate the manufacturing sector. CNC machines, known for their high precision, automation, and efficiency, have transformed modern machining [2]. However, their high cost makes it challenging for resource-constrained institutes to acquire them.

Retrofitting offers a practical solution by upgrading existing conventional machines with modern components to enhance performance and functionality [3]. This study focuses on retrofitting a conventional lathe to incorporate CNC capabilities by integrating servo motors, stepper motors, an auto-indexing tool post, a pneumatic chuck, and a ball screw mechanism.

The feasibility of retrofitting is assessed through detailed analysis, design, calculations, cost estimation, case studies, project duration, and maintenance requirements. Overall, this work serves as a comprehensive guide to evaluating the technical and economic viability of CNC retrofitting, highlighting its significant cost advantages and long-term benefits.

2 Literature Review

This literature review is a compilation of different papers related to retrofitting the conventional lathes. The source of the papers is goggle scholar, research gate, academia.edu, springer.com. With the advent of technologies and with new machines developed every day, it is quite challenging for the aging machines to sustain. As the automation dominating the manufacturing industry, the conventional machine tools are becoming inefficient. So as to overcome these challenges faced by the conventional machine tools, retrofitting is the efficient solution to reuse the aging machineries.

Retrofitting enables sustainability, Industry 4.0 connectivity, and improved usability emphasis on the importance of reusing the resources for environmental sustainability, resource conservation and cost savings[4]. With this basis importance the author delves into the insights as to how much raw materials are required its consequences to the environments while producing the raw materials [5]. The intention of the research is to minimize the production of new machine tools instead perform retrofitting that is reusing the old machines to make it a new one and meet the new advent technology [6]. So, our proposed improvement is to retain the existing mechanical structure of the lathe machine to avoid any cost escalation.

Retrofitting the aging machines also enables meeting the industry 4.0 and prevents the item to become obsolete. It also focuses on the PC- based CNC software implementation developed. LinuxCNC and its derivatives Mach4 and Machine Kit are the most common PC-based solutions for machine tool control. Mach4 is a commercial solution, while LinuxCNC and Machine Kit are open-source software [7]. It provides the feasibility study on retrofitting a CNC machine tool using LinuxCNC. The scope of this research paper provides the insights as to how to use the software like LinuxCNC and a detail study on the various components of CNC machine tools. It presents approach to retrofit machine tools, a feasibility study after long-term industrial use, methods to enable industry 4.0 connectivity for LinuxCNC. The drawback of It is there is limited data on its long-term industrial suitability [8].

The research on "Low-Cost Automation and Retrofitting of Conventional Lathe Machines" highlights that replacing outdated machinery with modern automation parts is a more affordable option than buying brand-new CNC equipment [9]. Low-cost automation, was first implemented in German industry which prove that it increases production efficiency. When comparing the purchasing price of new CNC lathe machinery, retrofitting can save costs by up to three times while increasing efficiency, lowering energy usage, and eliminating downtime[5]. The basic upgradation was did using servo motors for variable speed control, automating the four-jaw chuck, and switching from lead screws to ball screws are important improvements [10]. Retrofitting is a cost-effective and environmentally friendly way to update outdated machinery by converting traditional lathes into CNC-like devices [11]. The main draw backs from this research where there is no concrete analysis the showed the clear comparison of the retrofitting cost and the new price of CNC lathe machine. In contrast to their research paper this research paper will include detail cost analysis that will consider the initial cost set up cost and the maintenance cost. This comprehensive cost analysis will enable us to see the feasibility of retrofitting traditional lathe machine with CNC technology.

3 Methodology

3.1 Data Collection

It adopts a systematic approach to evaluate the feasibility of retrofitting of the traditional lathe machine with the CNC features. The first process starts with the extensive literature review referring various research paper and case study to gain the ideas on retrofitting of conventional lathe machine. This was followed by a field survey to collect relevant data on traditional lathes in use, including their specifications and operational limitations Focused on lathe machine which are kept unused due to its defective parts and the oldest lathe which its function is being deteriorating. Based on the findings, least frequently used lathe was identified and L1 (GK195) lathe selected for this retrofitting project. It has large working space which will support additional CNC components such as motors and integrating parts. The lathe has minimal wear on key parts like the bed, spindle, and carriage.

To retrofit the conventional lathe with CNC technology, it focusses on changing the five basic parts of lathe. To upgrade the parts of lathe machine at a lower cost by improving precision, productivity, and to make it fully programmable with automation capabilities, thereby extending the productive life of existing lathe machine without the need for expensive new CNC machines. The five parts are lead screw with ball screw, manually operated chuck with automated chuck, Gearbox with servo motor, saddle with stepper motor and tool post with auto-indexing tool post. The traditional lathe was then converted into a CNC-operated lathe through integration of the designed components. A case study analysis was conducted on the modified system to assess its performance and functionality. Further, a cost comparison between purchasing a new CNC lathe and retrofitting an existing one was carried out to determine the economic benefit. Finally, the overall feasibility of retrofitting was evaluated based on technical performance, cost efficiency, and practical implementation

3.2 Flow Chart

The methodology flow chart illustrates the project's progression from planning and research to implementation and monitoring. It provides a concise visual representation of the systematic approach used to accomplish the project's goals.

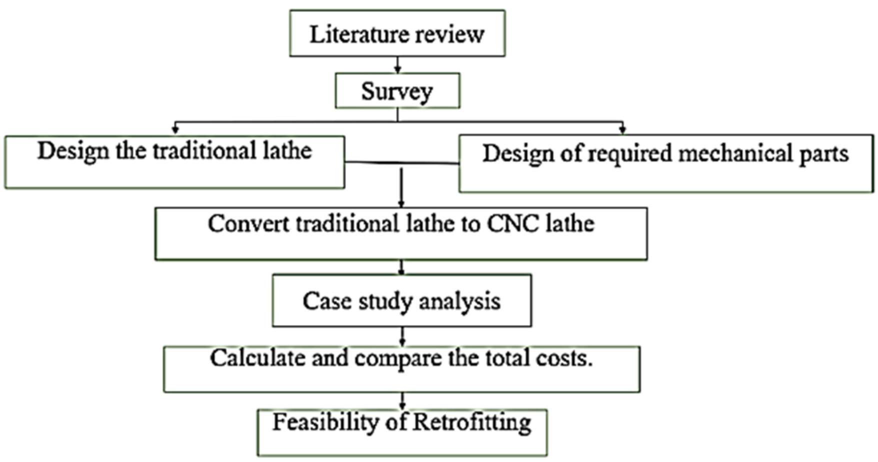

Figure 1: Methodology Flow Chart

3.3 Design calculations

To ensure proper retrofitting and component selection, a series of mechanical and design calculations evaluated. The torque of the existing lathe was calculated to determine appropriate specifications for selecting the stepper motor. Based on the motor and transmission requirements, the dimensions of the timing pulley, belt length, and belt width computed. Additionally, shaft diameters and mounting bracket dimensions for the auto-indexing tool post were determined. For the pneumatic chuck system, a circuit diagram developed and calculated the required gripping force and working pressure. Subsequently, the necessary mechanical components integration such as stepper motors, timing pulleys, belts, shafts, brackets, and pneumatic systems were designed to suit the retrofitting process.

1. Detail design for gearbox replaced with servo motor To replace the gearbox with servo motor, the bulky gear train should be eliminated, keeping the spindle shaft and chuck assembly untouched. To do so, the values of Torque, diameter of pulley, width and length of the belt and diameter of the shaft should be calculated.

   (a) Torque for servo motor To calculate the torque for servo and stepper motor using equation (1),

   $$P = \frac{2\pi NT}{60} \tag{1}$$

   Where, P = Power transmitted

   N = RPM

   T = Torque

   Taking the values of P=4500 W,N=1440, we get the value of torque (T) [12].

   T=29.8 Nm NEMA 42 size motor, offering a torque of approximately 30Nm meets the torque requirements and thus found appropriate.

   (b) Diameter of pulley The diameter of the pulley is calculated using equation (2),

   $$d = \frac{60\,v}{\pi N} \tag{2}$$

   However, the velocity of the pulley is also unknown. Thus, the velocity of the pulley is calculated using equation (3)

   $$v = \sqrt{\frac{\sigma_t}{\rho}} \tag{3}$$

   Taking the values of $\sigma_t = 4.5 \times 10^6\,\mathrm{N/m^2}$ and $\rho = 7200\,\mathrm{kg/m^3}$, we obtain the velocity, and by substituting it into equation (2), we determine the diameter of the motor pulley (d).

   d=*166.9mm*

   Determining the diameter of spindle pulley using equation (4),

   $$D = \frac{\text{Motor pulley diameter}}{\text{Pulley ratio}} \tag{4}$$

   Pulley ratio is calculated using equation (5),

   $$PR = \frac{\text{Motor rpm}}{\text{Spindle rpm}} \tag{5}$$

   Taking the values of motor rpm as 1440 and spindle rpm as 2000, we get pulley ratio as 0.72 and the diameter of spindle D,

$$\mathbf{D=231.88}\boldsymbol{mm}$$

The standard sizes of pulley diameters should be D=224mm and d=160mm [12]

(c) Width and length of the belt To Calculate the width of the belt, use equation (6)

$$T_1 = T - T_c \tag{6}$$

Where: T is the maximum tension of the belt, T_1 is the tension in the tight side of the belt, and T_c is the centrifugal tension of the belt.
In order to calculate the width of the belt following equation is used as follows,

$$T = \sigma bt \tag{7}$$

$$T_c = MV^2 \tag{8}$$

$$2.3 \log \frac{T_1}{T_2} = \mu\theta \tag{9}$$

$$P = (T_1 - T_2)V \tag{10}$$

Where:
p = Power transmitted,
θ = Angle of contact,
μ = Coefficient of friction,
T_2 = Tension in the slack side of the belt,
V = Velocity of the belt,
M = Mass of the belt,
t = Belt thickness,
σ = Stress, and
b = Width of the belt.
The width of the belt is **b=20** $\boldsymbol{mm}$
To Calculate the length of the belt, use equation (11),

$$L = 2C + \frac{\pi(D+d)}{2} + \frac{(D-d)^2}{4C} \tag{11}$$

The distance between two pulleys (C) is taken twice the diameter of the bigger pulley which is **160** $\boldsymbol{mm}$.
The length of the v-belt is approximately $\mathbf{L = 1000}\ \boldsymbol{mm} = \mathbf{1}\ \boldsymbol{m}$

(d) Shaft diameter
Using the equation (12), and taking the value of stress as 50MPa [12],

$$T = \frac{\pi}{16}\tau d^3 \tag{12}$$

Where:
T = Torque,
τ_S = Shear stress, and
d = Diameter.
The diameter of the shaft is 19 **mm** $\approx$ 20 **mm.**

(e) Bracket for servo motor

To integrate the motor with the lathe, key dimensions such as mounting space, hole locations, and shaft alignment were measured directly on the machine. Using these measurements, a custom mounting bracket designed to securely support the servo motor, maintain alignment, and withstand operational vibration and torque.

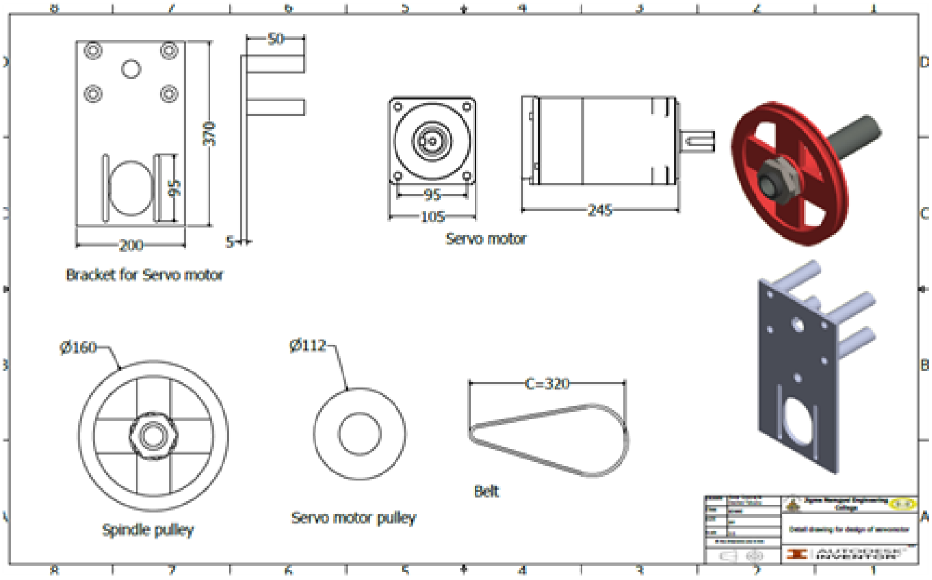

Figure 2: Bracket design for servo motor

3.4 Detail design for cross slide replaced with stepper motor

In addition, the cross slide is being retrofitted with a stepper motor using a timing pulley system. The following section presents the calculations for determining the appropriate timing pulley. The remaining parameters such as belt width, belt length, and shaft diameter are obtained using the same calculation procedures and equation numbering (Equations 6-12) described previously.

3.4.1 Timing pulley diameter

Taking the number of teeth 80T and pitch 5.08mm and belt type XL and equation (13) to calculate the timing pulley diameter [13].

$$D = PD + 2h \tag{13}$$

$$pd = \frac{zp}{\pi} \tag{14}$$

Where:
PD = Pitch diameter
z = no of teeth
P = pitch
h = tooth height of the belt
The diameter of the driven pulley is **D = 130** ***mm***

A reduction ratio of 1:2 selected for finding the diameter of driving pulley. The driving pulley is half the dimeter of the driven pulley. The driving pulley is approximately 65mm with a bore of 14mm.

The remaining parameters such as belt width, belt length, and shaft diameter are obtained using the same calculation procedures and equation numbering (Equations 6-12) described previously.

The calculated design parameters for the timing belt system are as follows: belt width (b) = 35 mm, belt length (L) = 0.5 m, and shaft diameter (d) = 14 mm. Based on these parameters and the overall calculation analysis, a NEMA 34 stepper motor with a 30 Nm torque rating was selected. Two identical NEMA 34 stepper motors will be used in this project, one for driving the cross slide and the other for the ball screw feed mechanism.

Similarly, for the stepper motor installation, the required dimensions including mounting clearance, hole positions, and alignment constraints were measured directly on the cross-slide assembly. Based on these measurements, a dedicated stepper-motor mounting bracket was designed, to ensure rigid support, accurate alignment with the ball screw, and stable operation under load and vibration.

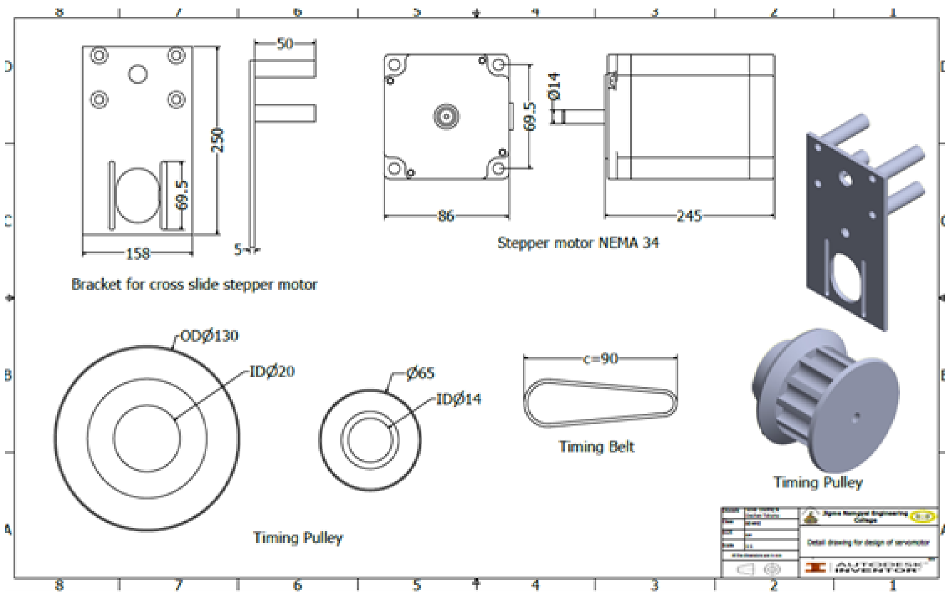

Figure 3: Bracket design for stepper motor for cross slide

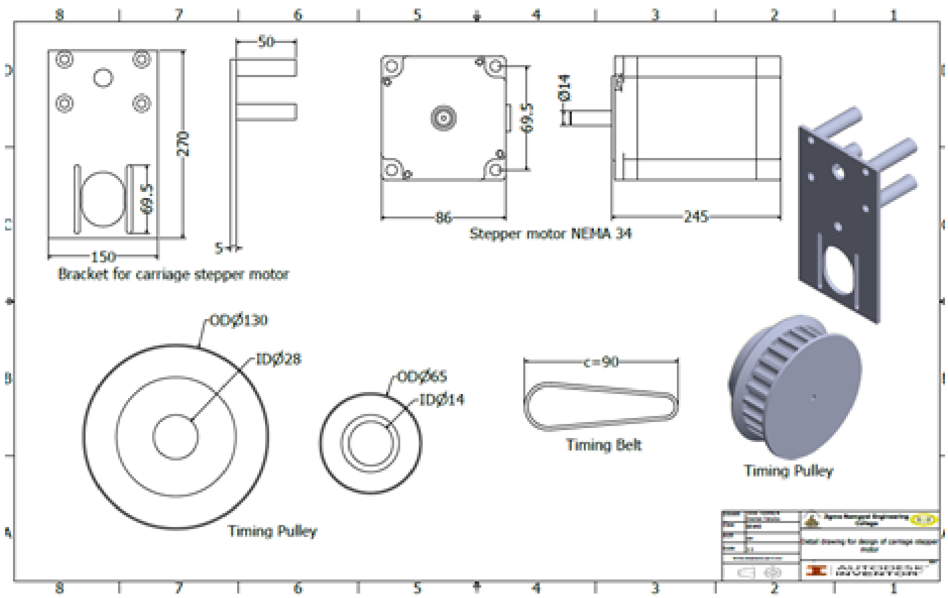

Figure 4: Bracket design for stepper motor for ball screw

3.5 Detail design for tool post replaced with auto indexing tool post

The adaptor was carefully designed to ensure proper alignment between the auto-indexing tool post and the compound slide of the GK 195 lathe. Although a standard adaptor exists, it could not be used because the compound slide of the GK 195 has a smaller width than the standard specification. Therefore, a custom adaptor was designed using mild steel to suit the machines dimensions.

According to the GK 195 manual, the compound slide specifications are:

Top slide length: 230 mm

Top slide width: 110 mm

Maximum top slide travel: 120 mm

The design of the adaptor, as developed for the GK 195 lathe, is presented in Figure 5.

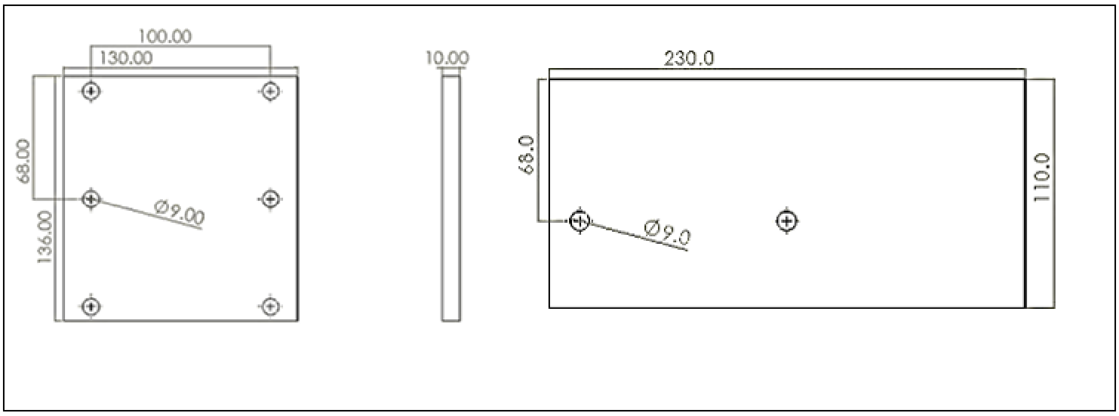

Figure 5: Adapter plate and compound slide

3.6 Detail design for chuck replaced with pneumatic chuck

The aim of this paper is to develop a self-centering, pneumatically powered three-jaw chuck for traditional lathe machines. The design incorporates a built-in air cylinder and receiver, eliminating the need for external pneumatic accessories and making it suitable for most conventional lathe operations.

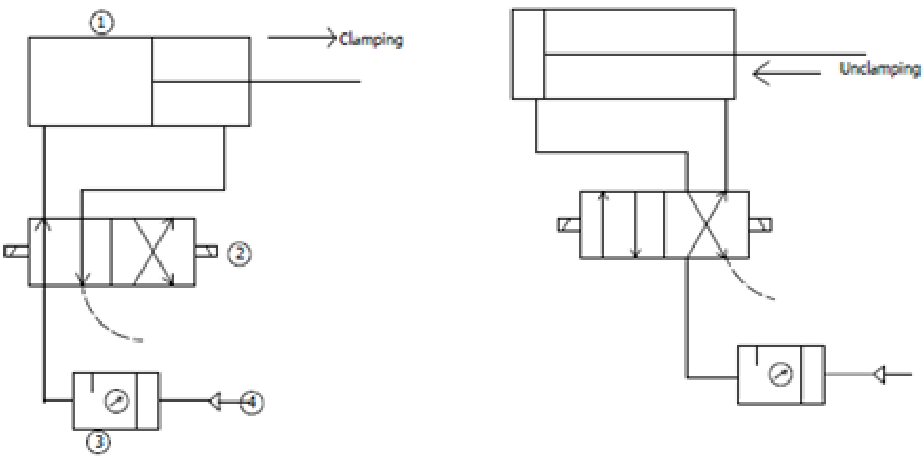

Figure 6: Circuit diagram of pneumatic chuck

The chuck diameter is 200 mm per the manual. Compressed air actuates the piston, whose linear motion is converted into the radial movement of the jaws via a wedge system, enabling clamping and unclamping of the work piece[14]. The circuit diagram is illustrated.

The list of components used:
1-Pneumatic chuck
2-Solenoid operated 4/2 DC valve
3-FRL (Filter Regulator Lubricator) unit
4- Air compressor

3.6.1 Griping force of chuck

The main forces generated in power chuck during its running are gripping force/clamping force, centrifugal forces and frictional forces between contact surfaces[14]. As a clamping device, the design of a pneumatic chuck mainly involves the magnitude of clamping or gripping force. The pneumatic chuck must withstand all forces acting against it, the amount of gripping force is a feature of the various component forces acting against the chuck's top jaws[15]. Feed, depth of cut, and tool rake angle with corresponding friction angle are used to estimate working and turning associated forces. Shear deformation of the work material to form a chip is the most common cutting operation in machining, when the chip is removed, a new surface is uncovered. The shear stress is the amount of force needed to complete the machining process. As a result, under the conditions of cutting, this tension is equal to the work material's shear strength. The chuck must be capable of effectively absorbing and transmitting the forces and moments produced during the machining process. This is done mainly through the chuck generating a gripping force.

Rake angle is the angle between the face of the cutting tool and the normal to the surface being cut and Friction angle is the angle whose tangent is the coefficient of friction (μ) between the tool and the chip[14].

Determining the shear angle using the equation (14),

$$\phi = \tan^{-1}\left(\frac{r_c \cos\alpha}{1 - r_c \sin\alpha}\right) \tag{15}$$

Where:
r_c = Chip thickness ratio,
α = Rake angle.
Taking the values for a high-speed steel tool with a rake angle $\alpha = 15°$ and a chip thickness ratio $r_c = 0.58$ (**?**).
The value of ϕ is $\phi = 33.69°$.
Determining the shear force using the equation (15),

$$F_s = \tau A_s \tag{16}$$

Where:
F_s = Shear force,
τ = Shear stress (unit: Pa or N/m^2), and
A_s = Shear area.
To calculate the shear area, the equation is (16), Where: t_1 = Uncut chip thickness, ω = Width of cut.

Taking the values of uncut chip thickness as $t_1 = 0.2\,\text{mm}$, width of cut as $\omega = 1.5\,\text{mm}$, and shear stress as $\tau = 180\,\text{MPa}$, the value of the shear force is $F_s = 97.2\,\text{N}$.

$$A_s = \frac{t_1\,\omega}{\sin\phi} \tag{17}$$

Determining the Gripping force using equation (17),

$$F_G = \frac{F_c\, S_z}{\mu_{sp}} \cdot \frac{X d_z}{d_{sp}} \tag{18}$$

Where:
F_G = Gripping force,
d_z = Machining diameter, and
d_{sp} = Chucking diameter.
μ_{sp} = Chucking coefficient,
S_z = Safety factor.

Taking the values of chucking coefficient $\mu_{sp} = 0.95$, safety factor $S_z = 4.0$, machining diameter $d_z = 6000$, and chucking diameter $d_{sp} = 200$ from the design data book, the value of gripping force is $F_G = 2301.4\,\mathrm{N/rev}$.

3.6.2 Working pressure of the chuck

Working pressure of the chuck determined by the equation (18),

$$P = \frac{F_G}{A_b} \tag{19}$$

Where:
F_G = Gripping force,
A_b = Bearing area.

The bearing area is calculated using the equation (19),

$$A_b = \pi(r_1 - r_2)^2 \tag{20}$$

Where:
r_1 = Outer radius of the contact surface,
r_2 = Inner radius of the contact surface.

Taking the Diameter as 200mm and 51mm from the manual book, the working pressure of the chuck is **P = 1.311bar**.

3.7 Detail design for control panel

Fanuc controller is widely used in Bhutan. It is quite cheaper than the simens and are not widely supported in our region. Fanuc controller are commercially available as a complete unit. Fanuc controller has advanced features like closed loop servo control, precision, operator safety, and repeatability.

3.8 Final design overview

The isometric projection which offers a realistic 3D visualization of the final design of the retrofitted lathe. It depicts the relationship and orientation of each retrofitted part. The positioning of the servo motor, stepper motor, pneumatic chuck, auto indexing tool and control panel is clearly visible making it easier to understand assembly. It displays the stepper motors driving the ball screws interface with the machine bed.

The orthographic view of the final design. The servo motor is placed beneath the headstock. It replaces the traditional gearbox driven motor. The servo motor connected to the spindle via pulley and it provides precise control of spindle speed and torque. The manual chuck replaced with the pneumatic chuck which uses air pressure for automatic clamping of work pieces allowing for faster and more reliable part changes. The stepper motor drives X and Z axis via ball screw fitted under the carriage and cross slide. It provides accurate positioning and controlled feed rates.

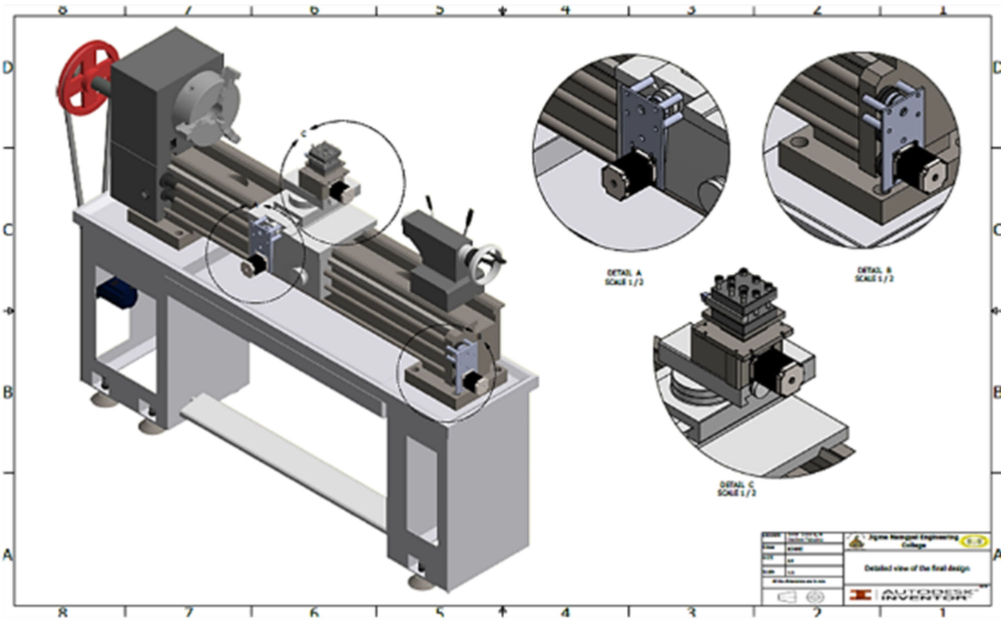

Figure 7: Complete retrofitted lathe assembly

The lead screw replaced with the ball screw mounted along the length of the bed under the carriage. The ball screw coupled via pulley with motors for CNC axis control. The auto indexing tool post mounted centrally on the carriage which is capable of holding multiple tools. It automatically rotates to change tools without manual intervention. Control panel positioned at the right end of the machine provides CNC interface for G-code input, machine status and axis control.

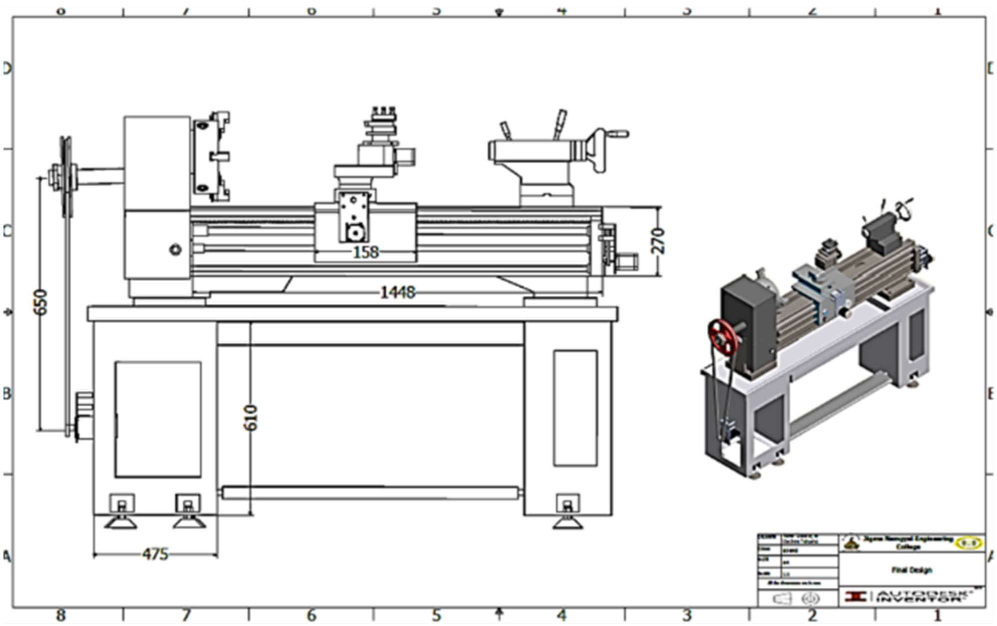

Figure 8: Comprehensive final design of the retrofitted lathe components

3.9 Project duration analysis

3.9.1 Critical path method

Table 1: Duration and Predecessor

Activity	Predecessor
Initial Assessment	N/A
Planning and Design	1
Procurement	2
Disassembly	1
Install CNC Components	3, 4
Wiring	5
Calibration and Testing	6

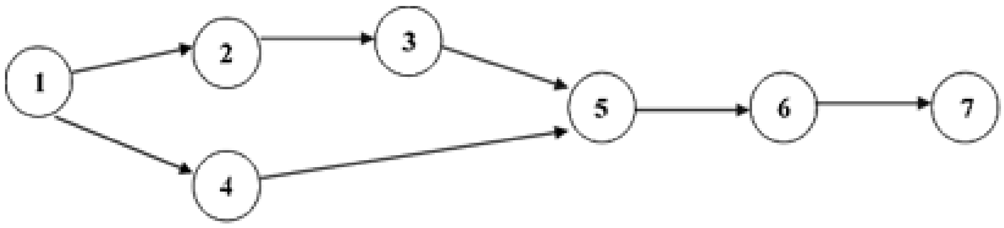

Figure 9: Comprehensive final design of the retrofitted lathe components

The activities with total float = 0 are 1, 2, 3, 5, 6 and 7. Which is critical path or critical activities.
Project completion time = 236 days

4 Results and Discussions

From this cost analysis the total expenses in retrofitting the conventional lathe with CNC components is lower than purchasing a new CNC lathe machine. The retrofitted system ensures to fulfill all the functions required for automatic and precise operation at a fraction of cost.

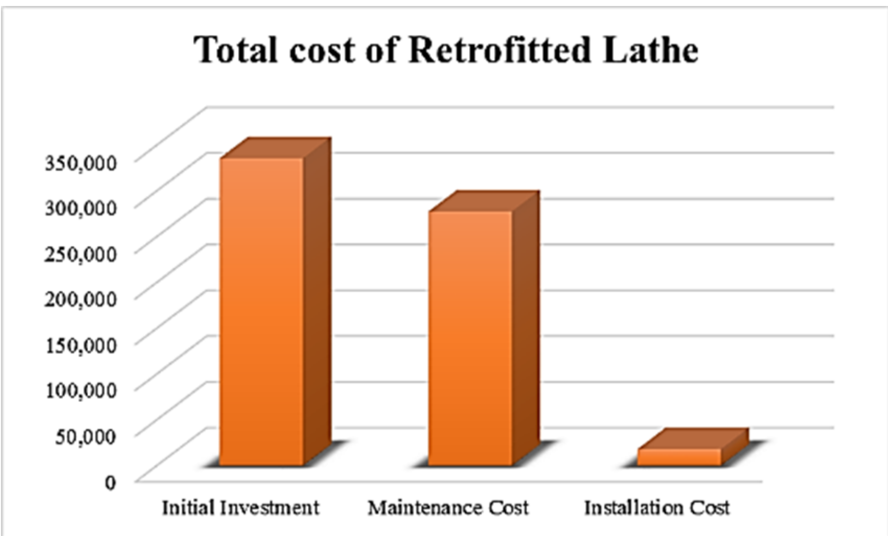

Figure 10: Comprehensive final design of the retrofitted lathe components

Initial investment is the highest cost component whereas maintenance cost is the second highest slightly lower than the initial investment. Installation cost is much lower compared to the other two. The majority of the cost for retrofitting comes from the initial investment and ongoing maintenance. Significant resources must be allocated for long term maintenance.

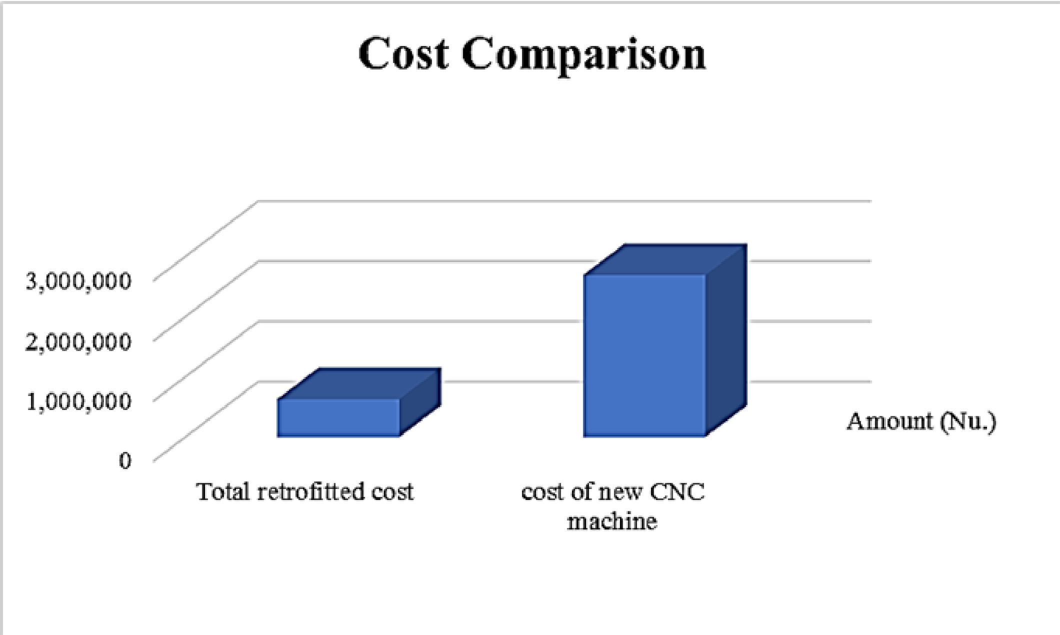

Figure 11: Comprehensive final design of the retrofitted lathe components

5 Conclusion

This study provides a detailed understanding of retrofitting a conventional lathe with CNC technology, with specific focus on the GK 195 model. The research examines the integration of advanced CNC components, cost comparison with new CNC machines, and insights from industrial practices within and outside Bhutan. Although limited to the GK 195 lathe and Bhutanese market pricing, and without performance evaluation of the retrofitted system, the analytical design and cost assessment offer meaningful conclusions. The findings indicate that retrofitting is both technically and economically feasible. The estimated cost of the retrofitted lathe is Nu. 631,169, compared to Nu. 2,693,577 for a new CNC machinemaking retrofitting approximately four times more economical. Overall, the results demonstrate that retrofitting provides a viable and cost-effective pathway for enhancing traditional lathes with CNC capabilities, with opportunities for future work to assess performance, accuracy, and operational efficiency.

6 Recommendation

This study provides a comprehensive approach as to evaluate CNC Retrofit Feasibility and the benefit in terms of price. However, there is limited exposure in the industries of Bhutan on to retrofitting concept. Retrofitting should be encouraged in industries and institutes of Bhutan who have limited budgets. There is need of training to be provided for students and operators on the troubleshooting, usage and various components of retrofitted lathe. Further research can focus on retrofitting the other machine tools like milling machine and shaper machines which are very old, rarely used and about to be obsolete.

This report provides a detail design, component selection and cost estimates specifically tailored for GK 195 lathe model. The same approach can be directly applied to retrofit the GK 195 lathe currently available in the JNEC workshop or similar setups.

7 Acknowledgement

We deeply appreciate the invaluable support of the Department of Mechanical Engineering at Jigme Namgyel Engineering College who played the base foundation of this research.

We owe a huge debt of gratitude to our guide, Lecturer Norden Wangchuk. His encouragement, insightful discussions, valuable feedback, and unwavering support were driving force behind the success of this project. We especially appreciate his constant availability and commitment to keeping us on the right course.

We'd also like to acknowledge the amazing faculty of the Department of Mechanical Engineering. Their observations during project review helped us with thoughtful feedbacks and suggestions. Their constructive criticism significantly enhanced our project which strived us to work harder to achieve the final outcome.

Finally, our heartfelt thanks go to everyone who contributed in any way big or small, in bringing this project to succession.

References

[1] M. Minhat, S. B. Mohamed, M. S. Kasim, M. J. Kadhim, and R. Besar, *Retrofitting a Conventional Lathe To a Digital*, Proceedings of the International Conference on Artificial Intelligence and Computer Science (AICS 2014), 2014.

[2] P. N. Parmar, N. C. Mehta, and M. V. Trivedi, *Investigation on Automation of Lathe Machine*, International Journal of Emerging Technology and Advanced Engineering, 2015.

[3] A. Koulwar, S. Chakrawar, A. Pawale, G. Thakur, and P. R. Singh, *Retrofitting of Traditional Lathe Machine*, International Journal of Innovative Research in Electrical, Electronics, Instrumentation and Control Engineering, vol. 10, no. 5, pp. 233239, 2022.

[4] Z. T. Abdullah, E. A. Abdulrazaq, and S. S. Ghazi, *Sustainability Modeling Approach on Remanufacturing Conventional Lathe into CNC Machine Tool*, Current Journal of Applied Science and Technology, 2020.

[5] V. D. Nichit, N. S. Dixit, and M. V. Bhadak, *Retrofitting for Lathe Machines*, International Journal of Scientific Research in Engineering and Management, vol. 6, no. 1, pp. 36, 2022.

[6] P. N. Parmar, V. R. Gondalia, and N. C. Mehta, *Review on Advance Automation of Conventional Lathe Machine*, International Journal of Engineering Development and Research, vol. 2, no. 2, 2014.

[7] T. Kaarlela, T. Niemi, T. Pitkäaho, and J. Harjula, *Retrofitting enables sustainability, Industry 4.0 connectivity, and improved usability*, Advanced Industrial Manufacturing Engineering, vol. 9, 2024.

[8] P. S. Koradiya, A. H. Kania, H. S. Vankhede, and P. A. Patel, *Conversion of a Conventional Bench Lathe to CNC Machine*, International Journal of Engineering and Technology Research, vol. 8, no. 12, pp. 1923, 2018.

[9] P. D. Bhatt, *Conversion of a Conventional Lathe Machine into a Semi-Automatic CNC Machine*, 2020.

[10] J. Miranda and A. Molina, *International Conference on Management of Technology (IAMOT 2013) Proceedings*, 2013.

[11] M. Bevilacqua, F. E. Ciarapica, and G. Giacchetta, *Value Stream Mapping in Project Management: A Case Study*, Project Management Journal, vol. 39, no. 3, pp. 110124, 2008.

[12] R. S. Khurmi and J. K. Gupta, *A Textbook of Machine Design*, 2005.

[13] S. Önnered, *Automatic Belt Tension Device*, Masters Thesis, Lund University, 2020.

[14] V. K. Sankaramoorthi, M. M. Yelak, P. Paramasivam, M. Venkatesh Kumar, and S. Nagarajan, *Design and Construction of Conventional Lathe Pneumatic Chuck System*, 2022.

[15] S. Gaikwad, A. M. Shaikh, and P. R. Kubade, *Finite Element Analysis of Lathe Machine Chuck for Vibration Stability*, Journal of Physics: Conference Series, 2024.