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[ICAME-2018]

ISSN 2348 – 8034
Impact Factor- 5.070

GLOBAL JOURNAL OF ENGINEERING SCIENCE AND RESEARCHES

# COMPARATIVE PERFORMANCE EVALUATION OF STEPPED AND STEPLESS DRIVE IN TURNING

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## ABSTRACT

The primary function of a belt drive in lathe machine is to transmit power from a source to head stock spindle through a gear box. The conventional transmission allows for the selection of discrete speed ratios, thus limiting the machine to providing maximum power or efficiency for limited ranges of output with high chances of slip of belt. The present paper is to create such a device, that allows an infinitely variable ratio change within a finite range, thereby allowing the machine to continuously operate in its most efficient or highest performance range, while the transmission provides a continuously variable output to the load with the minimum chances of slip of belt, material removal rate, production rate, machining time and surface finish are compared with conventional lathe. The improvements in the aforementioned output identies are reported in this work.

## I. INTRODUCTION

Generally in a lathe head stock spindle is rotated with A.C electric motor. The head stock needs to rotated with different speeds in order to cater to needs of machining various materials for different operations. Due to number of gears in the gearbox few limited speeds are available at the head stock spindle. The machinist has to compromise to select the required speed due to limited speeds, which Leeds to increase the machining time, reduce the productivity and increase the production economics. A thorough search was made to define the problem, Johnjoshua, et al. [1] explained the effective approach based on the optimization of turning parameters with response to the surface roughness methodology (RSM). They majorly considered machining time and manufacturing cost. Stan Van Der Meulen, et al. [2] presented in push belt continuously variable transmission (CVT). CVT is stepless power transmission device, which is able to provide infinitely many transmission rations within a finite range they also compared the stepped power transmission and also discussed about power loss in CVT. Power loss is due to aviator and actuator system. C.Camposeco-Negrete, et al. [3]worked on optimization of cutting parameters in turning and minimizing cutting power. To optimize the cutting parameters in order to minimize the power consumed in the removal of material, robust design is used to analyze the effects of the depth of cut, feed rate and cutting speed on electric power consumed. Cheng Wang, et al. [4] described about stepless speed regulation actuation concept and simulation of the mini-car power split automatic. This includes performance of the power split automatic transmission for mini-car. CVT speed ratio and the clamping force are controlled by adjusting the hydraulic force on the movable discs of the drive pulley and driven one. The speed ratio is adjusted by regulating the cylinder pressure or flow of driver pulley through speed ratio control valve, which changes the axial position of drive pulley movable disc. Jing Chen, et al. [5] presented a new hydro-elctro-mechanical transmission system with Stepless speed regulation, This paper also includes The start-up electric current in high power motor have an impact to the motors and the electric networks. Andre-Michel Ferran, et al. [6] presented benefits of variable frequency drives on pumping systems in Enbridge liquids pipelines, this paper describes about variable frequency which can control motor speed by varying frequency and voltage supplied to motor, this paper highlighted the application of VFD in liquid pipeline it provides the operator with improved control over the critical parameters of the pump and in doing so increases pumpingefficiency while reducing energy cost. In this paper an attempt has been made to overcome all these difficulties to replace Brush Less Direct Current (BLDC) motor in place of A.C motor. These BLDC motor can operate infinite number of speeds by changing the frequencies of the current to achieve infinite number of speeds

## II. MECHANICAL DRIVES

The various drives in machine tool are belt drive, gear drive and hydraulic drive. Belt drive is the simplest drive which absorbs small vibrations, due to slip, difficulty to maintain constant speed. Gear drive is widely used to constant speed and most reliable and can easily change from one speed to another. Stepless speed drives may be mechanical, hydraulic, or electric. Selection of suitable drive depends on the purpose of the machine tool, power requirement, speed range ratio, mechanical characteristics of the machining operation, and the cost of the variable speed unit. In most of the stepless drives, positive torque transmission is possible. Their operation consists of friction and slip losses. However, they are more compact, less expensive, and quieter in operation than the stepped speed control elements. Infinitely variable speed (stepless) drives provides output speeds, forming infinitely variable ratios to the input ones. Such type of units is used for main and feed drives to provide the most suitable speed or feed for each job, thereby reducing the machining time. They also enable machining to be achieved at a constant cutting speed, which leads to increase in tool life and ensures uniform surface finish. Friction stepless drive, the drive shaft rotates at a constant speed $n_1$ with friction roller of diameter d. the output shaft rotates at variable speed $n_2$ that depends on the instantaneous diameterD. $n_1d=n_2D$ hence $n_2=n_1*d/D$ the diameter ratio d/D can be varied in infinitely small steps by the axial displacement of the friction roller. Due to small contact area a small amount of slip occurs which makes this arrangement to transmit small torque and it is also limited to reduction ratios not more than 1:4**.** Hydraulic stepless drivethe speed of the machine tool can be regulated hydraulically by controlling oil discharge circulated in hydraulic system consisting of a pump and hydraulic motor. This can be achieved by changing either eccentricity of the pump and eccentricity of hydraulic motor or by both.

**Electrical stepless speed drive**

Continuously variable transmission (CVT), is an automatic transmission that can change seamlessly through an infinite number of effective gear ratios between maximum and minimum values. Power is transmitted from source to main spindle without any intermitted steps. Here the source is an AC motor and a variable frequency drive is used to control speed by varying the input voltage to the motor. Variable Frequency Drive (VFD ) It works on the principle that is used to make an AC motor working in variable speed. A basic VFD system consists of AC motor, controller and operator interface. VFD for AC motors have been innovation that has bought the use of AC motors back into prominence.

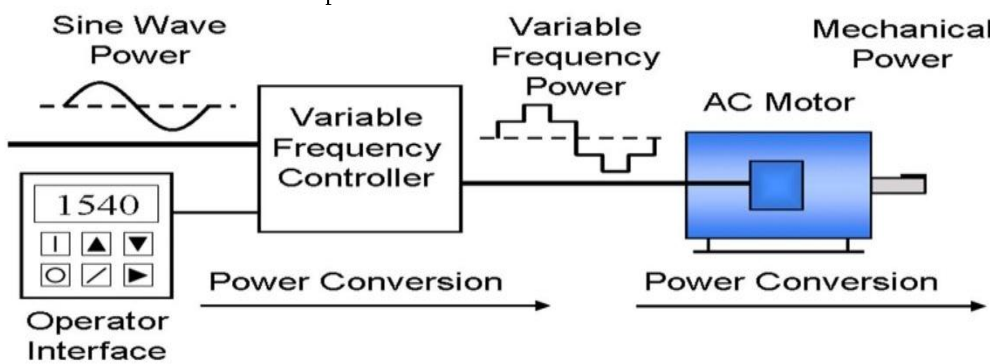


*Fig 1. Electrical stepless speed drive*

AC induction motor can have its speed changed by changing frequency of voltage. This means if the voltage applied to the AC motor is 50Hz, the motor works at its rated speed. If the frequency is increased above 50Hz the motor will run faster than its rated speed, and if the frequency is below 50Hz motor will run slower than its rated speed. If application does not require electric motor load. According to VFD working principle, its electronic controller which is designed to change frequency of voltage supplied to induction motor.

**Working of variable frequency drive**

First stage of variable frequency AC drive or VFD is the converter. The converter is composed of six diodes which are similar to check values used in plumbing systems. they allow current to flow in one direction only, and the direction shown by arrow in diode symbol. for example, whenever A-phase voltage is more than B- phase, then that diode will open and allow current to flow. When B-phase becomes more positive than A-phase then B diode will open and A diode will close. The same is true for 3 diodes on the negative side. Thus, we get six current pulses as each diode opens and closes. This is called "six-pulse VFD", which is standard configuration for current VFD.

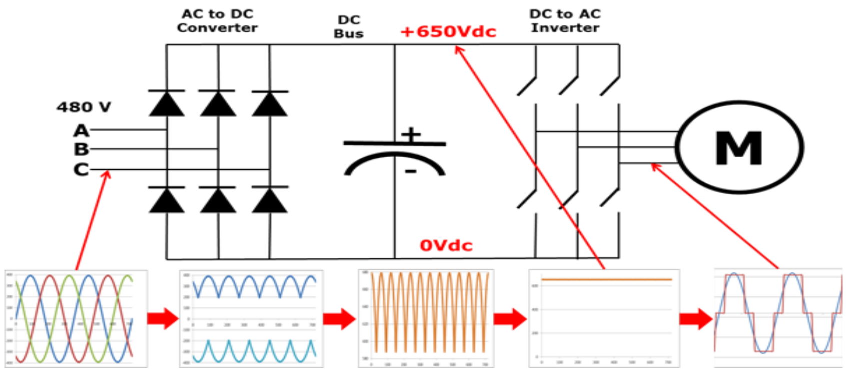

*Fig 2. Circuit diagram of VFD*

**Implimentation of VFD on lathe and use of VFD**

In any application that does not need to run at full speed, for reducing the energy costs by controlling the motor with a variable frequency drive, which is one of benefits of variable frequency drive. There is no other method of AC electric motor control that allow us to accomplish. Electric motor systems are responsible for more than 65% of power consumption in industry today. Optimizing motor control by installing a VFD can reduce energy consumption. Additionally, the use of VFD improves product quality and reduce production costs. Any equipment will last longer and will have less downtime due to maintenance when it is controlled by VFD ensuring optimal motor application speed. Because of VFD control it will offer motor better protection from electro thermal overloads, phase protection, under and over voltage. When the start of the VFD with a load will subject the motor to the instant shock of across the line starting, but can start smoothly, thereby eliminating belt, gear and bearing wear Optimum cutting speed for minimum cost $(V_o) = C/[(1-n/n)\ (K_1{*}T_c)+K_c)/K_1)]^n$ and Optimum cutting speed for maximum production rate $(V_{mxp}) = C/[(1-n)/n{*}\ T_C]^n$


*Fig 3. Experimental setup of stepless power transmission to the lathe*

The experimental set up is shown in fig 3 with a necessary modification to exiting heavy duty lathe. The main spindle of the lathe is extended beyond end of bed gearing and a pulley is keyed to it. A 3 phase motor with 2.25 kW power is used to drive the main spindle via belt. The original motor fitted at the base is disengaged. The VFD is attached to separate panel connected to the head stock.

ISSN 2348 – 8034
Impact Factor- 5.070

## III. EXPERIMENTAL RESULTS FOR AISI 1040 STEEL AND AA6060 ALUMINUM ALLOY CONVENTIONAL LATHE AND STEP LESS LATHE

The present work is mainly focused work materials like AISI 1040 steel and AA6060 Aluminum alloy using cutting tool materials HSS and Tungsten carbide tools.In normal conventional lathe, the speeds are limited 54, 90, 135, 125, 325, 500, 770 and 1200 RPM. Therefore, the speed which is nearer to the required speed is selected for experimenting on conventional lathe. MRR and machining time is calculated using fundamental equation and Surface finish is recorded by using Talysurf.

### Experimental results for AISI 1040 steel and AA6060 aluminum alloy for conventional lathe

The feed rate and depth of cut are kept constant at 0.3mm/rev and 0.5 mm respectively forAISI 1040 steel and 0.2 and 0.5 mm for AA6060 Aluminum alloy the same was reported in table 1 to 4.

*Table 1. Data for turning on AISI 1040 steelusing HSS on conventional Lathe*

| S. NO | DIAMETER (mm) | ACTUAL SPEED $N=V*1000/\pi D$ RPM | OPERATED SPEED (RPM) | SURFACE ROUGHNESS (µm) | MATERIAL REMOVAL RATE ($mm^3$/min) | MACHINING TIME (min) |
|---|---|---|---|---|---|---|
| 1. | 24 | 397.8 | 325 | 6.88 | 11716.17 | 2.309 |
| 2. | 21 | 454.72 | 325 | 5.89 | 15904.31 | 1.5 |
| 3. | 18 | 535.51 | 500 | 5.65 | 13783.73 | 1.5 |
| 4. | 15 | 636.61 | 500 | 5.49 | 11663.16 | 1.5 |
| 5. | 12 | 795.77 | 770 | 4.86 | 14697.5 | 0.975 |

*Table 2 Data for turning on AA6060 Aluminum alloy using HSS for conventional lathe*

| S. NO | DIAMETER (mm) | ACTUAL SPEED $N=V*1000/\pi D$ RPM | OPERATED SPEED (rpm) | SURFACE ROUGHNESS (µm) | MATERIAL REMOVAL RATE ($mm^3$/min) | MACHINING TIME (min) |
|---|---|---|---|---|---|---|
| 1. | 24 | 530.51 | 500 | 6.09 | 12016.59 | 2.25 |
| 2. | 21 | 606.3 | 500 | 5.62 | 10602.87 | 2.25 |
| 3. | 18 | 707.3 | 770 | 5.01 | 14151.30 | 1.461 |
| 4. | 15 | 848.8 | 770 | 4.76 | 11974.18 | 1.461 |
| 5. | 12 | 1061.03 | 1200 | 3.57 | 15268.14 | 0.937 |

*Table 3. Data for turning on AISI 1040 steel using carbide tool on conventional lathe*

| S. NO | DIAMETER (mm) | ACTUAL SPEED $N=V*1000/\pi D$ RPM | OPERATED SPEED (rpm) | SURFACE ROUGHNESS (µm) | MATERIAL REMOVAL RATE ($mm^3$/min) | MACHINING TIME (min) |
|---|---|---|---|---|---|---|
| 1. | 24 | 397.8 | 325 | 6.52 | 11716.17 | 2.3076 |
| 2. | 21 | 454.72 | 500 | 5.79 | 15904.31 | 1.5 |
| 3. | 18 | 535.51 | 500 | 5.38 | 13783.73 | 1.5 |
| 4. | 15 | 636.61 | 500 | 5.05 | 11663.16 | 1.5 |
| 5. | 12 | 759.77 | 770 | 4.51 | 14697.5 | 0.97 |

*Table 4. Data for AA6060 Aluminum alloyJob Using Carbide Tool on Conventional Lathe*

| S.NO | DIAMETER (MM) | ACTUAL SPEED N=V*1000/*πD* RPM | OPERATED SPEED (RPM) | SURFACE ROUGHNESS (μM) | MATERIAL REMOVAL RATE ($MM^3$/MIN) | MACHINING TIME (MIN) |
|---|---|---|---|---|---|---|
| 1. | 24 | 530.51 | 500 | 5.33 | 12016.59 | 2.25 |
| 2. | 21 | 630.3 | 500 | 4.89 | 10602.87 | 2.25 |
| 3. | 18 | 707.3 | 770 | 3.97 | 14151.30 | 1.46 |
| 4. | 15 | 848.8 | 770 | 3.33 | 11974.18 | 1.46 |
| 5. | 12 | 1061.03 | 1200 | 2.65 | 15268.14 | 0.937 |

**Experimental results for AISI 1040 steel and AA 6060 Aluminum alloy for step less lathe**

The feed rate and depth of cut are kept constant at 0.3mm/rev and 0.5 mm respectively for AISI 1040 steel and 0.2 and 0.5 mm for AA 6060 Aluminum alloy the same was reported in table 5 to 8

.

*Table 5. AISI 1040 steelJob Using HSS Tool on Stepless lathe*

| S.NO | DIAMETER (MM) | ACTUAL SPEED N=V*1000/*πD* (RPM) | OPERATED SPEED (RPM) | SURFACE ROUGHNESS (μm ) | MATERIAL REMOVAL RATE ($mm^3$/min) | MACHINING TIME (min) |
|---|---|---|---|---|---|---|
| 1. | 24 | 397.82 | 325 | 5.64 | 14341.32 | 1.885 |
| 2. | 21 | 454.72 | 325 | 4.917 | 14464.01 | 1.65 |
| 3. | 18 | 535.71 | 500 | 4.35 | 14630.33 | 1.413 |
| 4. | 15 | 636.61 | 500 | 3.66 | 14852.10 | 1.178 |
| 5. | 12 | 797.77 | 770 | 3.18 | 15225.58 | 0.94 |

*Table 6. AA6060 Aluminum alloy Job Using HSS Tool on Stepless lathe*

| S.NO | DIAMETER (MM) | ACTUAL SPEED N=V*1000/*πD* RPM | OPERATED SPEED (RPM) | SURFACE ROUGHNESS (μm ) | MATERIAL REMOVAL RATE ($mm^3$/min) | MACHINING TIME (min) |
|---|---|---|---|---|---|---|
| 1. | 24 | 530.51 | 500 | 5.085 | 12749.84 | 2.12 |
| 2. | 21 | 606.61 | 500 | 4.382 | 12863.62 | 1.85 |
| 3. | 18 | 707.3 | 770 | 3.681 | 12998.98 | 1.59 |
| 4. | 15 | 848.8 | 770 | 3.08 | 13199.59 | 1.325 |
| 5. | 12 | 1061.03 | 1200 | 2.14 | 13499.96 | 1.06 |

*Table 7. AISI 1040 steelJob Using Carbide Tool on Stepless lathe*

| S.NO | DIAMETER (MM) | ACTUAL SPEED N=V*1000/*πD* RPM | OPERATED SPEED (RPM) | SURFACE ROUGHNESS (μm ) | MATERIAL REMOVAL RATE ($mm^3$/min) | MACHINING TIME (min) |
|---|---|---|---|---|---|---|
| 1. | 24 | 397.82 | 325 | 5.332 | 14341.32 | 1.885 |
| 2. | 21 | 454.72 | 325 | 3.984 | 14464.01 | 1.65 |
| 3. | 18 | 530.71 | 500 | 3.34 | 14630.33 | 1.413 |

ISSN 2348 – 8034
Impact Factor- 5.070

| | | | | | | |
|---|---|---|---|---|---|---|
| 4. | 15 | 636.61 | 500 | 2.88 | 14852.10 | 1.178 |
| 5. | 12 | 795.77 | 770 | 2.18 | 15225.58 | 0.94 |

*Table 8.AA6060 Aluminum alloyJob Using Carbide Tool on Stepless lathe*

| S. N O | DIAM ETER (MM) | ACTUAL SPEED N=V*1000/$\pi D$ RPM | OPERA TED SPEED (RPM) | SURFAC E ROUGH NESS (µm ) | MATERIAL REMOVAL RATE ($mm^3$/min) | MACHI NING TIME (min) |
|---|---|---|---|---|---|---|
| 1. | 24 | 530.51 | 500 | 1.59 | 12749.84 | 2.12 |
| 2. | 21 | 606.3 | 500 | 1.29 | 12863.62 | 1.854 |
| 3. | 18 | 707.3 | 770 | 0.94 | 12998.98 | 1.59 |
| 4. | 15 | 848.8 | 770 | 0.80 | 13199.59 | 1.325 |
| 5. | 12 | 1061.03 | 1200 | 0.70 | 13499.96 | 1.06 |

## IV. RESULTS AND DISCUSSIONS

The variable frequency drive BLDC motor is perfect alternative in place of AC motor because of operational flexibility. Thus by choosing the above objective features of the stepless power transmission, the problems mentioned in conventional lathe can be avoided.

**Surface Roughness**

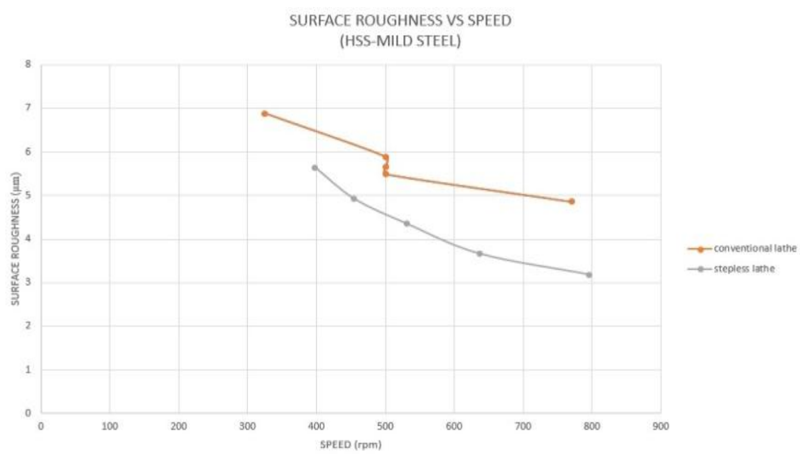


*Fig 4. Variation of surface roughness with speed (AISI 1040 Steel – HSS)*

From shown in fig. 4 as speed increases surface roughness decreases. The maximum and minimum value of surface roughness of AISI1040 steel using HSS on conventional lathe are 6.88µm and 4.86µm. and on stepless lathe are 5.64µm and 3.18µm. The speed is kept constant at 500RPM on conventional lathe because, obtained speeds for different diameters are not available, so the nearer value 500RPM is chosen.

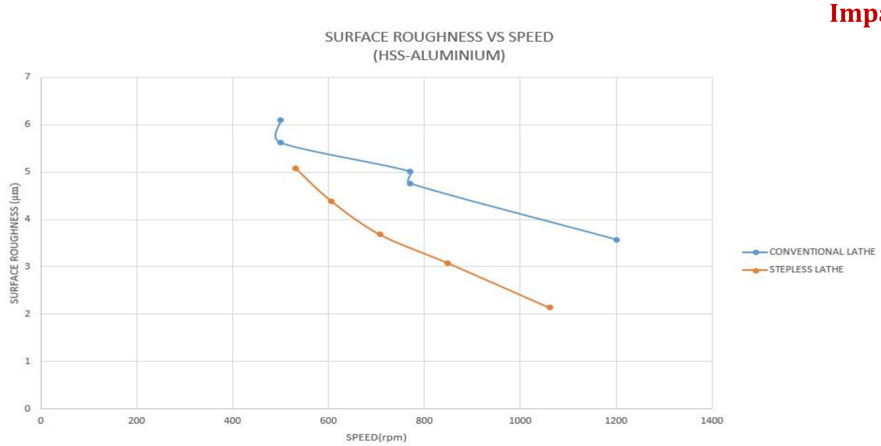


***Fig 5. Variation of surface roughness with Speed ( AL 6060 Aluminum alloy-HSS)***

From shown in fig.5 as speed increases surface roughness decreases. The maximum and minimum value of surface roughness of Aluminum using HSS on conventional lathe are 6.09µm and 3.57µm and on stepless lathe are 5.085µm and 2.14µm.The speed is kept constant at 770rpm on conventional lathe because obtained speeds for different diameters are not available, so the nearer value 770rpm is chosen.

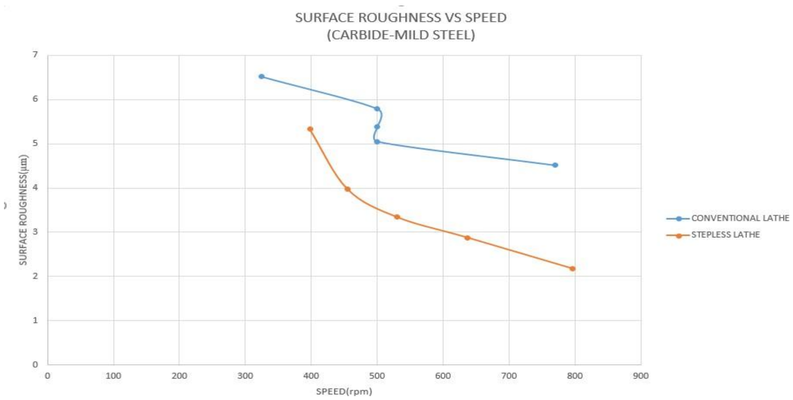


***Fig.6. Variation of surface roughness with Speed AISI 1040 Steel-Carbide)***

From shown in fig6 as speed increases surface roughness decreases. The maximum and minimum value of surface roughness of mild steel using carbide on conventional lathe are 6.52µm and 4.51µm. and on stepless lathe are 5.33µm and 2.18µm.The speed is kept constant at 500rpm on conventional lathe because obtained speeds for different diameters are not available so the nearer value 500rpm is chosen.

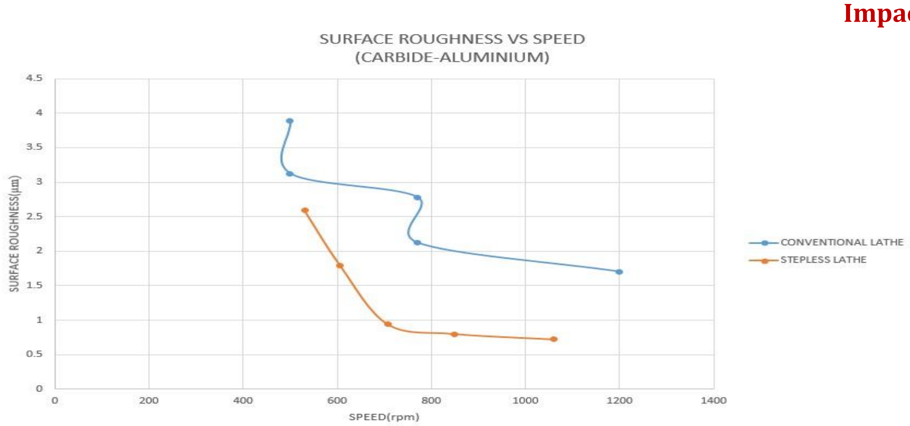


*Fig 7. Variation of surface roughness with Speed ( Al 6060 Aluminum alloy -Carbide)*

From shown in fig.7 as speed increases surface roughness decreases. The maximum and minimum value of surface roughness of Aluminium using Carbide on conventional lathe are 5.33µm and 2.65µm. and on stepless lathe are 1.59µm and 0.7µm.The speed is kept constant at 770rpm on conventional lathe because obtained speeds for different diameters are not available so the nearer value 770rpm is chosen.

**Material removal rate**


*Fig 8. Variation of material removal rate with Speed (AISI 1040 Steel Job)*

From shown in fig.8 as speed increases MRR increases. The speed is kept constant at 500rpm on conventional lathe because obtained speeds for different diameters are not available so the nearer value 500rpm is chosen.

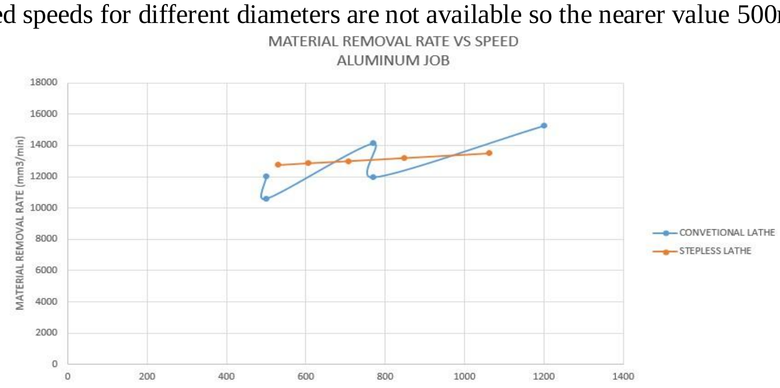


*Fig 9. Variation of material removal rate with Speed (Al 6060 Aluminum alloy Job)*

From shown in fig.9 it is observed that MRR of Aluminum material obtained on stepless lathe is more compared to the conventional lathe because as speed increases MRR increases. The speed is kept constant at 770rpm on conventional lathe because obtained speeds for different diameters are not available so the nearer value 770rpm is chosen.

**Machining time**

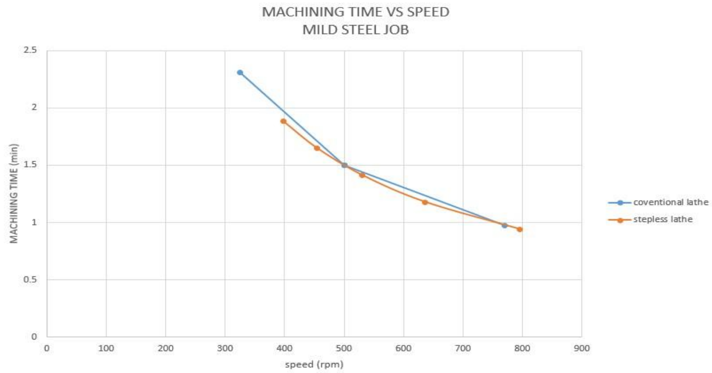


*Fig 10. Variation of machining time with Speed ( AISI 1040 Steel Job)*

From in thefig10, machining time of mild steel material on stepless lathe is less compared to conventional lathe because of the speed change.


*Fig 11. Variation of Machining Time with Speed ( AL 6060 Aluminum alloy Job)*

From in the fig11, machining time of aluminum material on stepless lathe is less compared to conventional lathe because of the speed change.

**4.4 Speed loss:**

*Table 9. Speed Loss Working On Mild Steel*

| S. NO | DIAMETER (mm) | ACTUAL SPEED $N_{act}$(RPM) | OPERT $N_{op}$ (RPM) | (%) of SPEED LOSS Ls=((Nact-Nop)/Nact) *100 |
|---|---|---|---|---|
| **1.** | 24 | 397.82 | 325 | 18.3 |
| **2.** | 21 | 454.72 | 500 | 9.95 |

| | | | | |
|---|---|---|---|---|
| **3.** | 18 | 530.71 | 500 | 5.78 |
| **4.** | 15 | 636.61 | 770 | 21.45 |
| **5.** | 12 | 795.77 | 770 | 3.23 |

*Table 10. Speed Loss Working on Al 6060 Aluminum alloy*

| S.NO | DIAMETER (mm) | ACTUAL SPEED $N_{act}$(RPM) | OPERAT $N_{op}$ (RPM) | (%) of SPEED LOSS Ls=((Nact-Nop)/Nact) *100 |
|---|---|---|---|---|
| | | | | |
| **1.** | 24 | 530.51 | 500 | 5.75 |
| **2.** | 21 | 606.3 | 500 | 17.53 |
| **3.** | 18 | 707.3 | 770 | 8.86 |
| **4.** | 15 | 848.8 | 770 | 9.283 |
| **5.** | 12 | 1061.03 | 1200 | 13.09 |

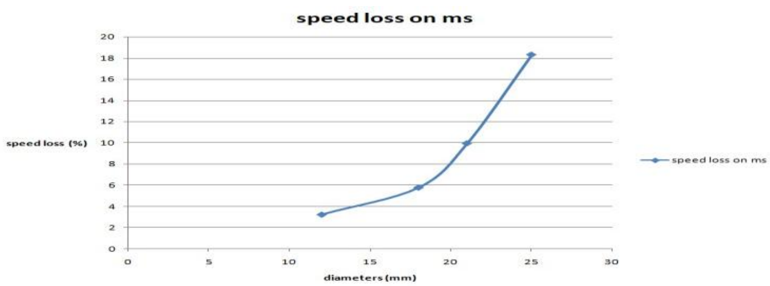


*Fig 12. speed Loss on AISI 1040 Steel Work Piece*

From the above fig 12, speed loss occurs on conventional lathe because of limited speeds and in stepless lathe zero speed loss occurs. Maximum speed loss is 21.45% and Minimum is 3.23% for mild steel material.

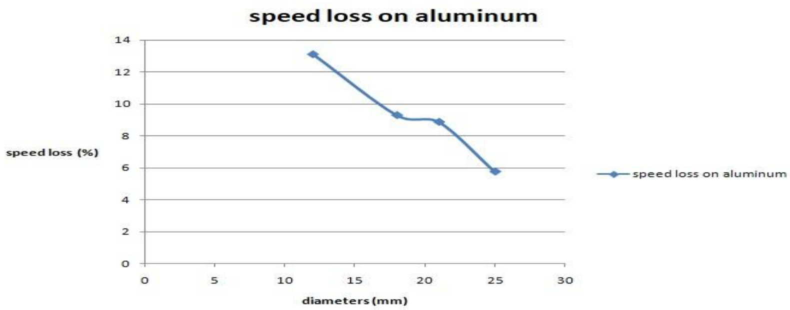


*Fig 13. Speed Loss on AL 6060 Aluminum alloy Work Piece*

From the above fig 13, speed loss occurs on conventional lathe because of limited speeds and in stepless lathe zero speed loss occurs. Maximum speed loss is 17.53% and minimum speed loss is 5.75% for aluminum.

## V. CONCLUSION

- Infinite range of speeds obtained to operate the machine at different speed by using variable frequency drive.
- Surface roughness values obtained by performing on stepless lathe is less than the conventional lathe

- Material removal rate at different speeds and different diameters are calculated. MRR on stepless lathe is more than conventional lathe
- Machining times obtained on stepless lathe is less compared to conventional lathe.
- Speed loss zer in stepless lathe.
- Optimum cutting parameters calculated based on minimum cost criteria and maximum production criteria

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