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# GEARBOX DESIGN FOR CNC LATHE

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**Abstract -** *Gearboxes are used to obtain variable speed and torque to the headstock spindle in lathes according to the work done. Usually the gearbox is placed inside the headstock. This causes various problems such as structural vibration which affects the accuracy of the work done, causes inconveniences during maintenance and also increases difficulties in case any replacements are required.*

*In complex works the accuracy plays a major role and hence the above problems should be eliminated. The project aims to design a gearbox which can be placed outside the headstock.*

***Key Words***: **Gears, Gearbox, CNC, Lathe, Direct Drive, Power Transmission**

## 1. INTRODUCTION

Gearboxes provide for a wide range of cutting speeds and torque from a constant speed power input enabling proper cutting speeds or torque to be obtained at the spindles as required in the case of cutting drives and desired feed rates in the case of feed drives. The design of gearbox is intimately linked with the whole structure of the spindle drives. The gearbox can be built integral into the spindle head housing. This type of arrangement promotes more compact spindle drives, higher localization of controls, fewer housing and less assembly work involving in the fitting of joining surfaces.

Main drawback is the possibility of transmitting vibration from the gearbox to the spindle, heating of the spindle head by the heat generated in the gearbox.

The gear box can also be arranged in separate housing and linked to the spindle head through belt transmission. This type of arrangement has advantage that neither the heat generated by neither frictional losses nor vibrations developed in the gearbox are transmitted to the spindle head.

### 1.1 Indirect Drive

Design of gearbox mainly depends upon the tool work piece combinations used. Here we are using aluminium whose cutting speed varies from 250 rpm to 4000 rpm. Motor is selected which is working under a speed range equal to 1500 rpm to 6000rpm. While selecting motor power rating should be kept to minimum value in order to maintain low economy of lathe. From SIEMENS motor catalogue, motor selected is "SIEMENS" squirrel cage induction standard three phase motor" – 1PH8087. Its specifications are given below

- Rated power – 3.7 KW
- Rated speed - 1500 rpm
- Rated current - 10 A
- Rated voltage – 400 V

Since we are designing two speed gear box it is possible for obtaining two different rpms from an input motor rpm. Designing a ray diagram is necessary for finding out speed ratios between rotor shaft of motor and driver shaft of gear box, driver shaft and driven shaft, driven shaft and output shaft. Procedure for drawing ray diagram is given in the next section.

### 1.2 Disadvantages of Existing System

The indirect drive involved power transmission through gears throughout the entire speed range of the motor. This results in power loss in the form of frictional losses in the gears. When the speed requirement for cutting comes in the constant power range of the motor power transmission can be directly to the spindle thereby transmission loss through gears can be avoided in these speed ranges. Hence a new gearbox design was developed incorporating a clutch which bypasses transmission through gears for the constant power speed range of the motor.

## 2. DESIGN OF INDIRECT DRIVE (Using Gears)

### 2.1 Ray Diagram

The speed chart or ray diagram is a graphical representation of the drive arrangement in the general form. In other words the ray diagram is a graphical representation of the structural formula.

A ray diagram can be used to easily explain the speed reduction stages. Motor – gear box stage is the first V-belt stage. V belt- pulley assembly is used to provide a speed ratio of 1:2. Second stage is gear box stage. Here two gear ratios are provided to give the required speed range. The last stage is another V belt stage with a speed ratio 1:1.5. All these

stages helps to get a speed range between 250 RPM to 4000 RPM with a constant power from the induction motor. The diametrical changes of the pulley initiate the first speed reduction. The next speed reduction in the gears depends upon the gear ratio. The gear ratios are fixed to attain the required rpm in the lathe. Thus by these three reduction stages we could get a lower rpm of 150 to a higher rpm of 4000 with the maximum torque/ power.

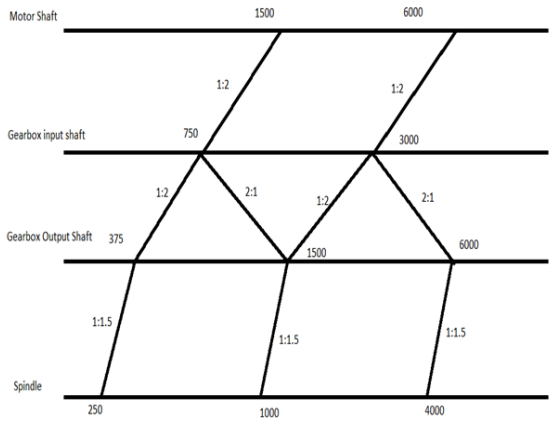


Fig.2.1.1 Ray Diagram

## 2.2 Motor selection for spindle drive

Table 4- 35 SINAMICS, 3-ph. 400 VAC, Active Line Module, (ALM), 1PH8087-□□F□□

| $n_{rated}$ [rpm] | $P_{rated}$ [kW] | $M_{rated}$ [Nm] | $I_{rated}$ [A] | $n_{max1}$ [rpm] | $n_{max2}$ [rpm] | $n_{max3}$ [rpm] | $n_{max, Br}$ [rpm] | $n_2$ [rpm] | $M_{max}$ [Nm] | $I_{max}$ [A] | $M_0$ [Nm] | $I_0$ [A] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1750 | 4.3 | 23 | 10.0 | 10000 | 14000 | - | 5000 | 5850 | 49 | 20 | 27 | 11 |
| 1500 | 3.7 | 24 | 10.0 | | | | | 6750 | | | | |

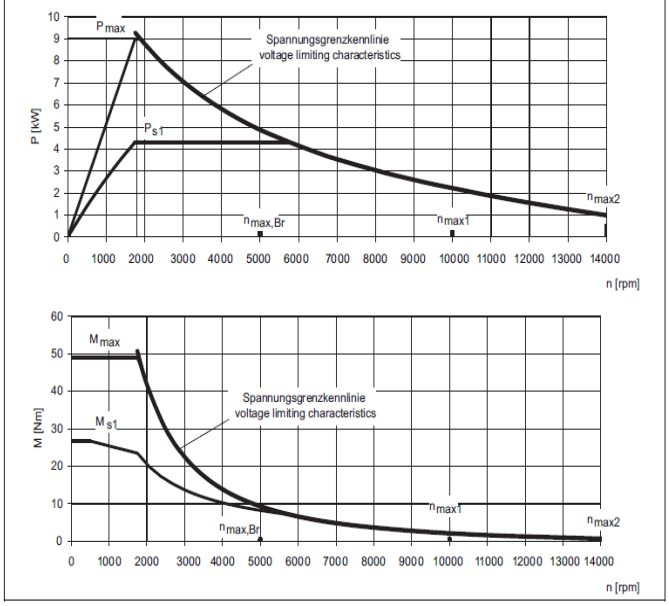


Fig.2.2.1 Torque Characteristics of Motor.

The characteristic between power and speed in rpm of the given input motor is shown above

## 2.3 Design of indirect drive system (Using gears)

The whole assembly design of the gearbox consists of the gear pairs, input and output shaft, shaft bearings. Also the design of the V-belt drive should be done to complete the full driving mechanism from motor to lathe spindle.

A 3D model of gear pairs, belt-pulley system and gearbox created using modeling software Solidworks is presented in figures given below.

Fig.2.3.1 3D model of gearbox

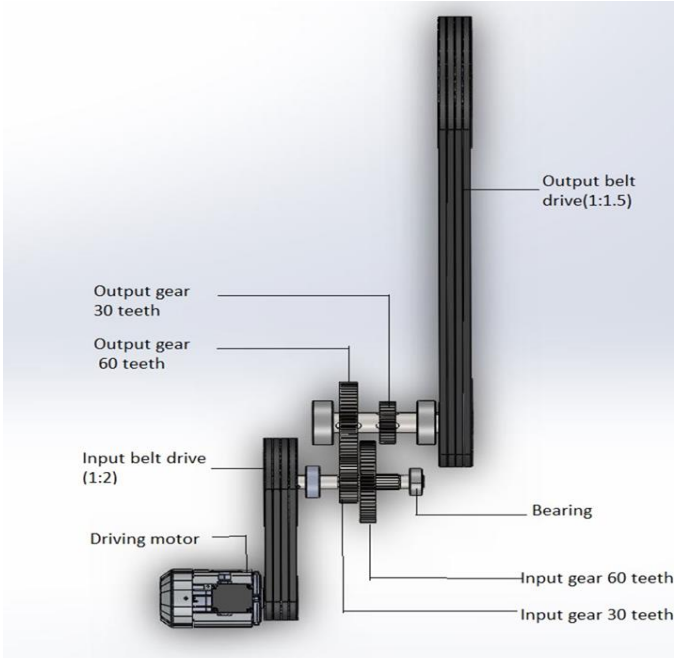


Fig.2.3.2 Top View of Gearbox.

### 2.4 Static analysis of indirect drive components (Using gears)

The safety of the design is a great factor. The modern powerful analysis software help us to make detailed analysis on our design. The objective is to analysis the stress concentrated points in the gear mesh, shaft and keys. The results of the stress analysis is provided in figures.

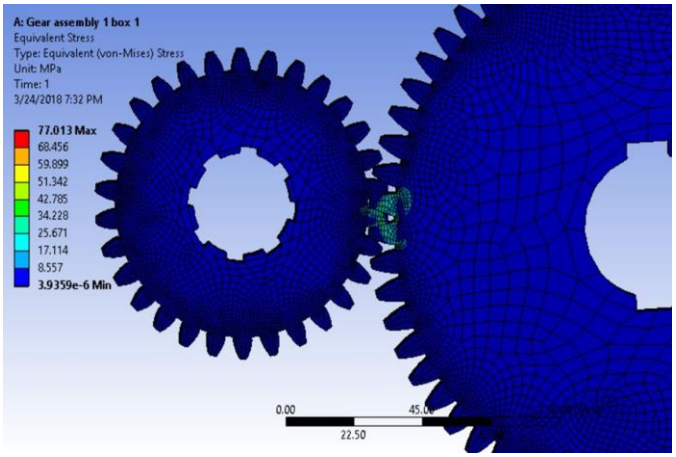


Fig. 2.4.1 Gear pair 1 (Indirect Drive)

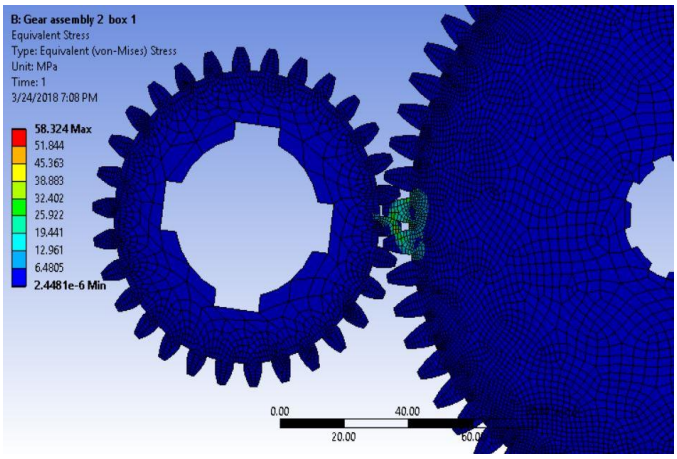


Fig. 2.4.2 Gear pair 2 (Indirect Drive)

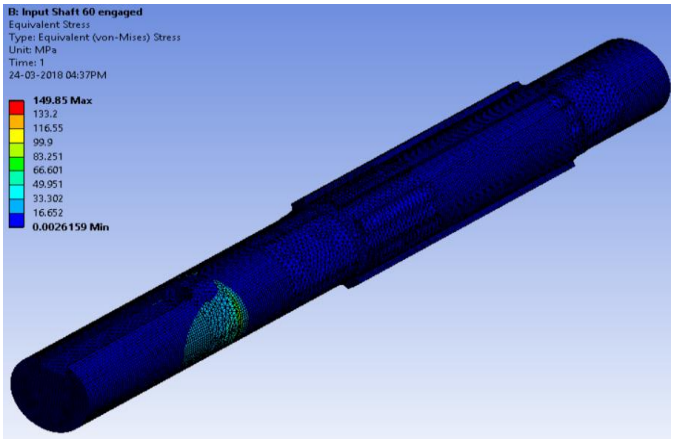


Fig. 2.4.3 Input Shaft

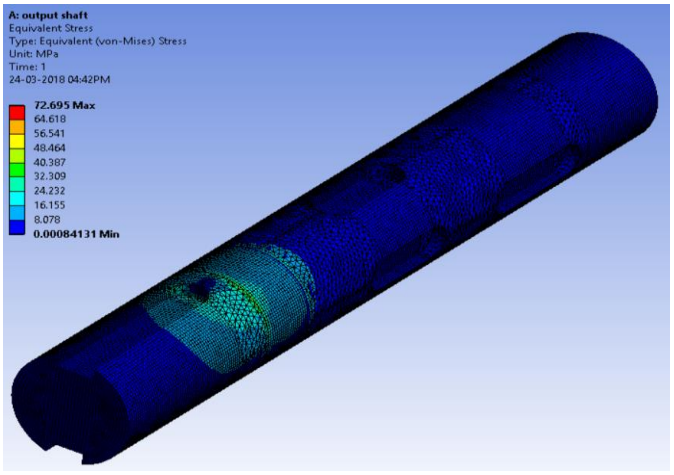


Fig. 2.4.4 Output Shaft

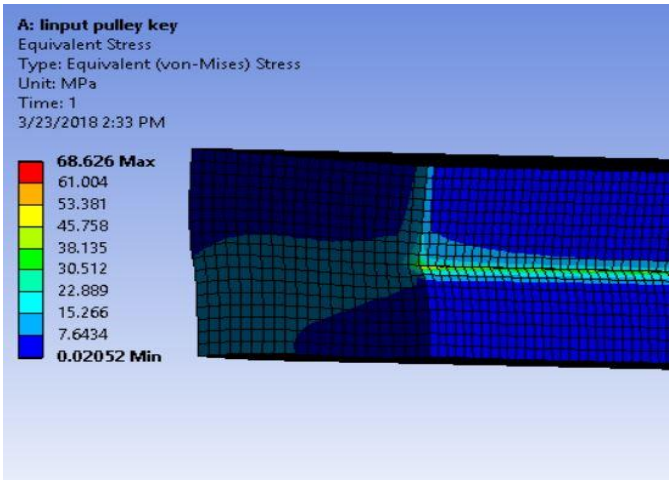


Fig.2.4.5 Input Pulley Key

## 3. DESIGN OF INDIRECT DRIVE (Using Clutch)

### 3.1 Ray Diagram

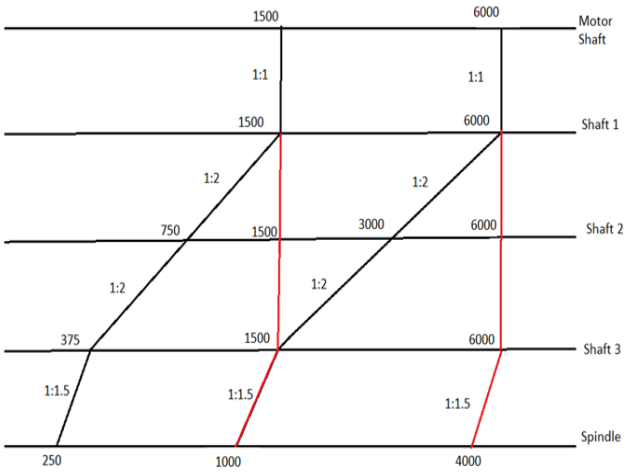


Fig.3.1.1 Ray Diagram for the improved gearbox design

A ray diagram can be used to easily explain the speed reduction stage. V belt- pulley assembly is used to provide a speed ratio of 1:1. Two gear pairs are provided to reduce the speed to the required speed range when the motor is in low power range. The last stage is another V belt stage with a speed ratio 1:1.5. All these stages helps to get a speed range between 250 RPM to 1000 RPM of spindle. Once the motor speed reaches 1500 RPM it produces constant power which can be transmitted directly. Now the gear is disengaged and the clutch is engaged. Hence constant power is transmitted directly through the clutch in the range of 1000-4000 RPM of spindle.

### 3.2 Motor selection for spindle drive

The characteristic between power and speed in rpm of the given input motor is shown.

Table 4- 35 SINAMICS, 3-ph. 400 VAC, Active Line Module, (ALM), 1PH8087-□□F□□

| $n_{rated}$ [rpm] | $P_{rated}$ [kW] | $M_{rated}$ [Nm] | $I_{rated}$ [A] | $n_{max1}$ [rpm] | $n_{max2}$ [rpm] | $n_{max3}$ [rpm] | $n_{max, Br}$ [rpm] | $n_2$ [rpm] | $M_{max}$ [Nm] | $I_{max}$ [A] | $M_0$ [Nm] | $I_0$ [A] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1750 | 4.3 | 23 | 10.0 | 10000 | 14000 | - | 5000 | 5850 | 49 | 20 | 27 | 11 |
| 1500 | 3.7 | 24 | 10.0 | | | | | 6750 | | | | |

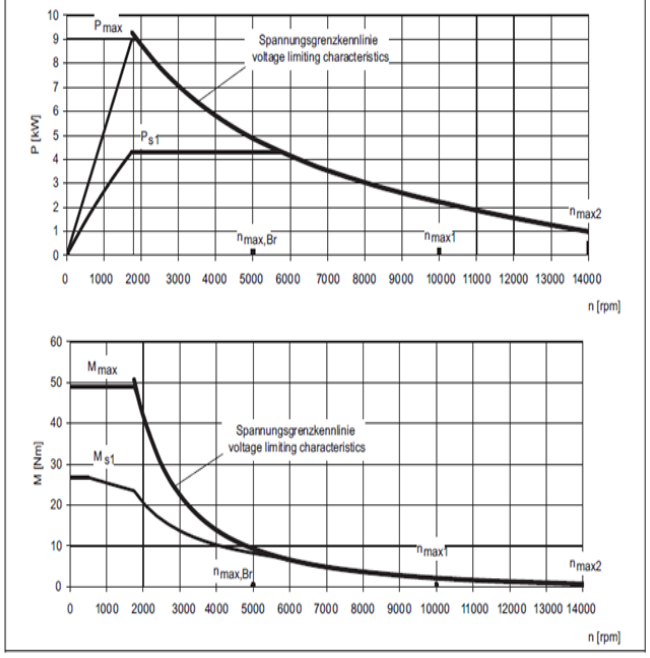


Fig.3.2.1 Power versus Speed characteristics of motor

### 3.3 Design of indirect drive system (Using clutch)

When the speed requirement for cutting comes in the constant power range of the motor power transmission can be directly to the spindle. Also transmission loss through gears can be avoided in these speed ranges. Hence a new gearbox design was developed incorporating a clutch. The clutch used is single plate dry friction clutch. This is a new design which is not currently in use.

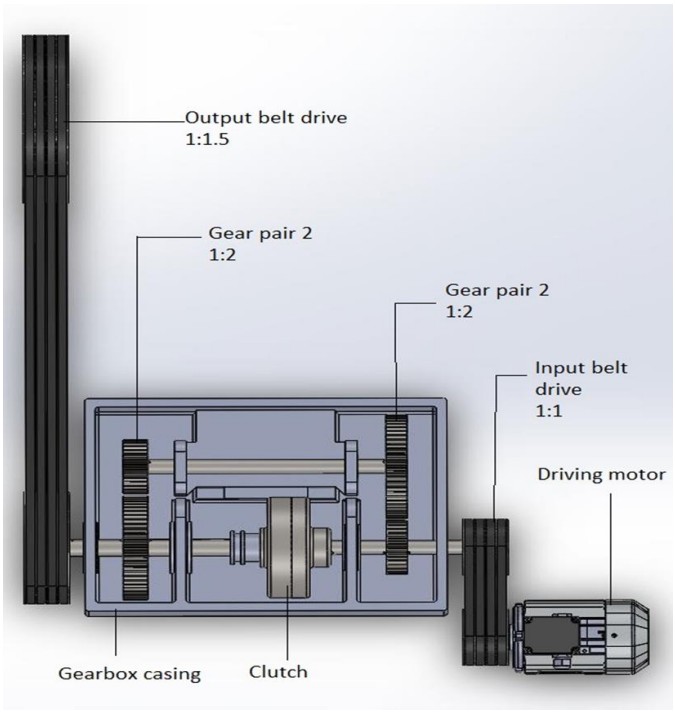


Fig.3.3.1 Top View

Fig.3.3.2 Isometric View

### 3.4 Static analysis of gear mesh pair (Using clutch)

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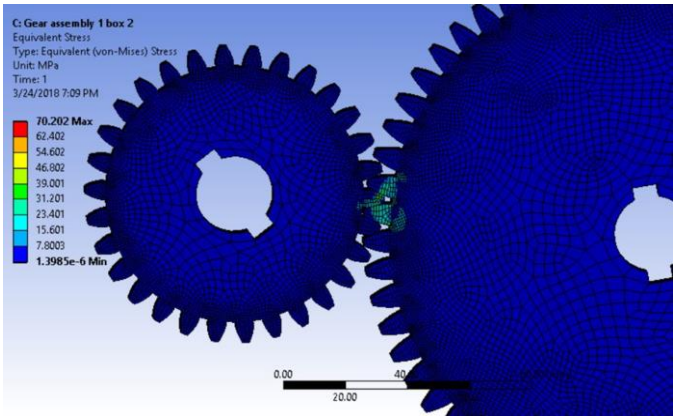


Fig.3.4.1 Gear Pair 1 (Improved design)

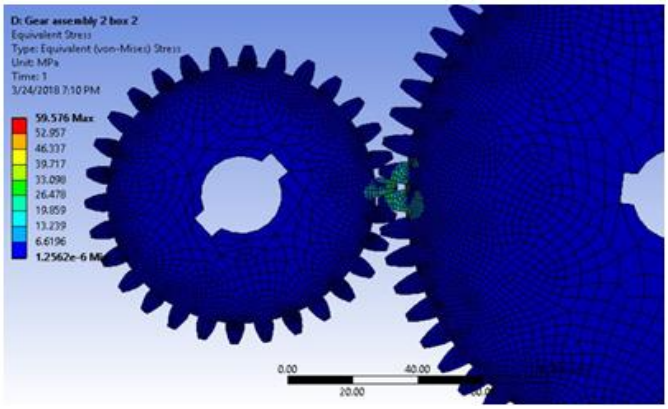


Fig.3.4.2 Gear Pair 2 (Improved design)

## 4. RESULTS

The static structural analysis done using the Ansys 16.2 software shows that the stress generated is within the limits. The value of maximum stress obtained is 58.324 MPa, the value of minimum stress is obtained as 30.072 MPa for gear pair ratio of 1:2 and the value of maximum stress obtained is 77.02 MPa, the value of minimum stress is obtained as 30.031 MPa for gear pair ratio of 2:1. Thus we concluded that there is no need of further modifications. Maximum stresses are generated at the teeth contact and is minimum at the non-contact surfaces.

| Gearbox Components | | | Equivalent Stress (MPa) | Shear Stress (MPa) | Total Deformation (mm) |
|---|---|---|---|---|---|
| Indirect Drive | Gear Pair 1 | | 77.02 | 30.031 | - |
| | Gear pair 2 | | 58.324 | 30.072 | - |
| | Input Shaft | | 149.85 | - | 0.0298 |
| | Output Shaft | | 72.695 | - | 0.0266 |
| | Keys | Output Pulley | 68.626 | 4.9841 | - |
| | | Input Pulley | 43.976 | 3.5055 | - |
| | | Output Gear (30) | 11.842 | 0.8794 | - |
| | | Output Gear (60) | 83.282 | 6.1942 | - |
| Drive with Clutch | Gear Pair 1 | | 70.202 | 38.708 | - |
| | Gear Pair 2 | | 59.112 | 25.052 | - |
| | Keys | Input Pulley | 55.582 | 3.712 | |
| | | Output Pulley | 160.13 | 11.629 | |
| | | Gear Pair 1 (30) | 58.51 | 3.888 | |
| | | Gear Pair 1 (60) | 117.05 | 7.778 | |
| | | Gear Pair 2 (30) | 101.46 | 6.756 | |
| | | Gear Pair 2 (60) | 143.88 | 10.409 | |
| | | Clutch Fixed Plate | 87.78 | 5.834 | |

Table 4.1: Stress in each components

## 5. COMPARISON OF DIFFERENT TRANSMISSION TECHNIQUES IN CNC LATHE

| Conventional Drive | Indirect Drive | Drive using Clutch | Direct Drive |
|---|---|---|---|
| • Gearbox directly coupled to spindle | • Gearbox is coupled to spindle through a belt drive | • Gearbox is coupled to spindle through a belt drive | • Motor is directly coupled to spindle |
| • High vibrations in spindle | • Less vibration in spindle | • Less vibration in spindle | • Vibrations at higher speeds |
| • High heat transfer | • Less heat transfer | • Less heat transfer | • Motor losses increases at higher speeds |
| • Difficulty in maintenance | • Easy maintenance | • Easy maintenance | • Low maintenance |
| • Considerable losses in gears | • Considerable losses in gears | • Losses in gears are decreased | • No losses in the gears |
| • Low cost | • Low cost | • Medium cost | • High initial cost |
| • Less work accuracy | • Good work accuracy | • Good work accuracy | • Total energy consumption is 7% less than conventional drive |
| • Less complex | • Less complex | • Medium complexity | |

Table 5.1: Comparison of different transmission techniques in CNC lathe

## 6. CONCLUSION

The design of two speed variable speed gearbox for the headstock of CNC lathe as per the requirement has done successfully. The different speed ratios are now made available with this gearbox. The works which require lower rpm can done easily without any trouble. The design is mainly based on consideration like compactness, longer service life with minimum breakdown periods. Gear box uses existing casting of the mother machine. Since the gear box is fixed on the machine casting itself these is no need of separate base. Thus no extra floor space is needed. Less power motor is employed for supplying high torque. Also the designed gear box is small yet efficient, durable, reliable and provides sufficient torque. If the size of the gear box is not a design consideration, an intermediate shaft can be employed for effective power transmission. This eliminates overhanging gear on motor shaft. Speed increasing drives are not commonly used in gear box of machine tools. So it

can be replaced with a reduction gear of suitable gear ratio. The economic viability of design can be increased while choosing factor of safety for each component. However choosing an optimum factor of safety development in material science and manufacturing technology, new materials with greater design stresses and reduced stress concentration and precision machined will be available. These results in a more compact, safe and economical design suitable for industries.

On the comparison of the different types of drives, it was found that the cost of direct drive is very high, Vibrations and heat transfer was less in the gearbox with clutch, Ease of maintenance and losses are also moderate in the gearbox with clutch.

## ACKNOWLEDGEMENT

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