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DESIGN AND FABRICATION OF LOW AND HIGH-SPEED GEAR BOX FOR PSG CNC150 LATHE

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ABSTRACT

In view of providing additional support to PSG CNC 150 lathe, a key product of P.S.G Industrial Institute, by enabling the machine to be operated on a wide range of spindle speeds together with increased and constant power at lower spindle speeds. The design of gearbox involves the selection of number of stages and number of speeds required, based on the available speed range of the input FANUC A.G. Spindle motor and the output speed range desired. The subsequent step involves the design of gears, input and output shafts, pulleys, keys, hydraulic shifting unit and selection of appropriate bearings, V-belt, circlips, oil seals for the gear box. The design parameters are then transferred into assembly and part drawings and sent in for production, after which the gear box is assembled. Thus, a compact, suitable gear box has been designed and fabricated to suit the PSG CNC 150 lathe.

Key words: Plastic Deformation, Fits and Geometrical Tolerances, Process Planning, Surface Roughness, FANUC

1. INTRODUCTION

Engineering applications warrant a wide variety of power requirement. It is not practicable to have prime mover that would address to the whole gamut of applications. This demands a device to bridge the gap between the power available and power required, which can effectively manipulate the former to satisfy the latter. A gear box is a solution to this problem. The gear box of general-purpose machine tools should provide a wide range of speeds and feeds consistent with the materials of tools and workpieces, shape of the tool, the type of machining process and the required quality of surface finish.

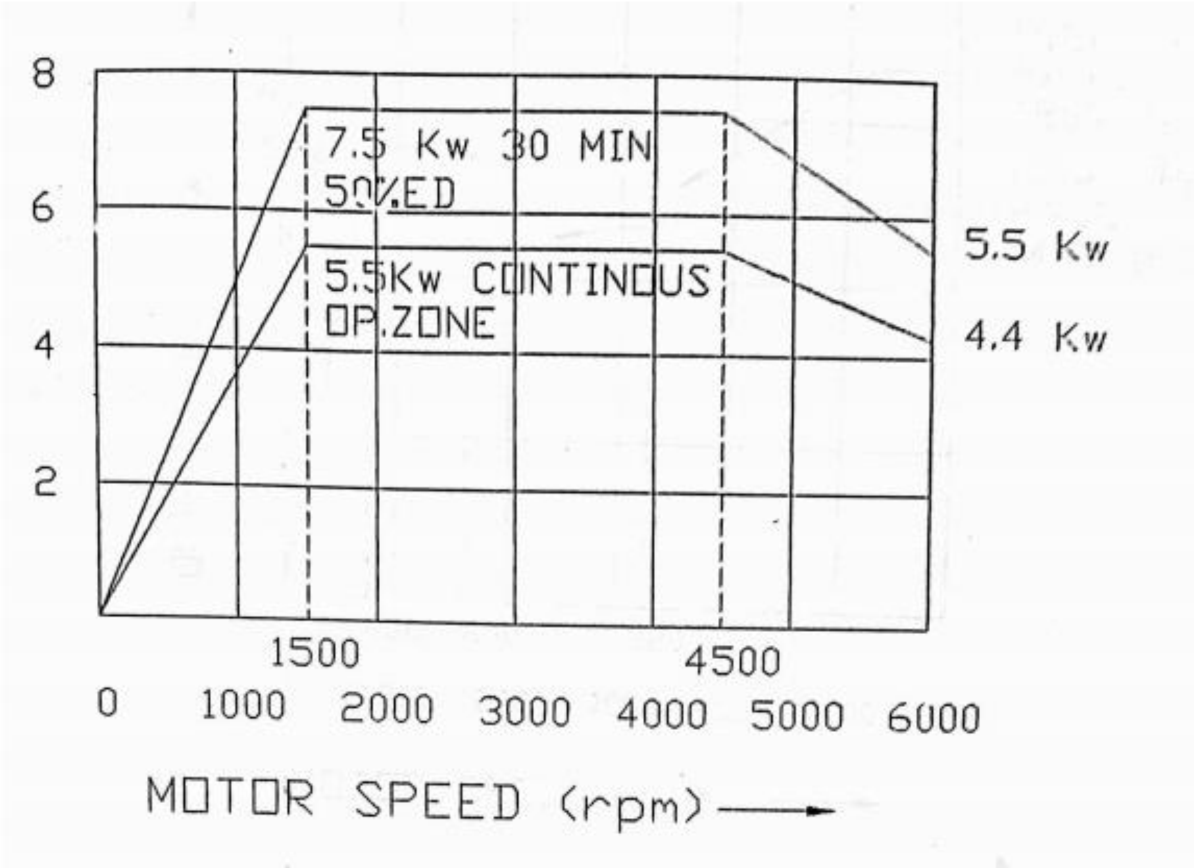
1.1. Need for a Gear Box

The need for a gear box will be better understood by studying the characteristics of the Fanuc AC spindle motor, which currently provides the drive to the main spindle directly.

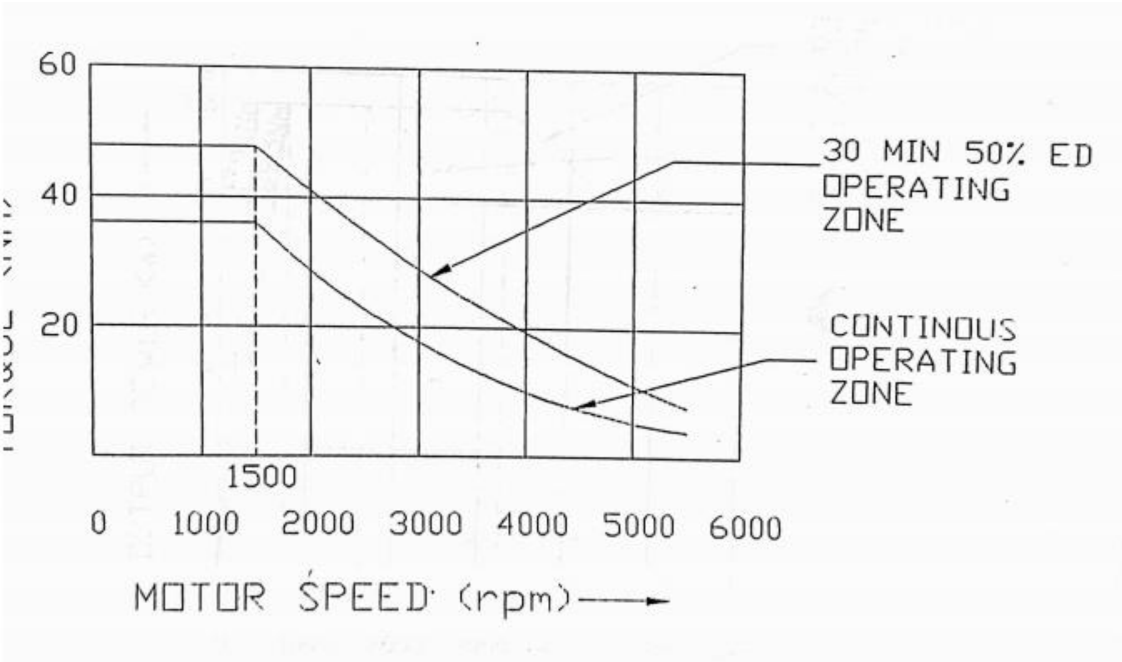
1.2. Characteristics of Fanuc AC Spindle Motor

Continuous Rated Power	5.5. Kw.
50% ED Rated	7.5 Kw.
30 min Rated	7.5 Kw.
Base speed	1500 rpm.
Maximum Speed	6000 rpm.

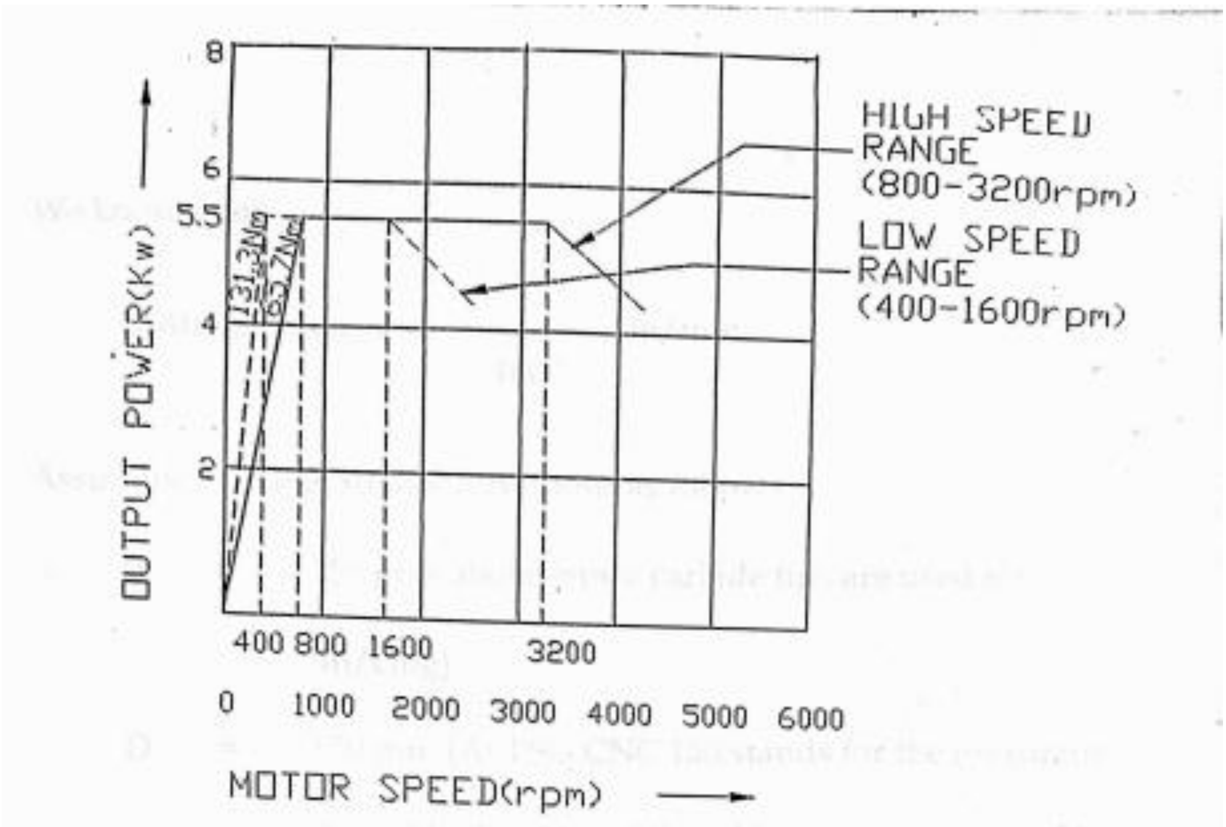
The graph showing Power Vs Speed and Torque Vs Speed characteristics gives a better understanding. The Fanuc AC Spindle motor, which has infinitely variable speed range however does not meet the requirement of the spindle drive which demands an increased and constant power to the spindle at lower output speeds to maintain a constant rate of metal removal. Any machining operation requires constant power supply for efficient metal removal. So, in this case, when the motor operates in the range of 0-1500 rpm, the output power delivered by the motor is not constant but found varying till 1500 rpm. The constant power output is obtained by operating the motor in the range of 1500 - 4500 rpm.

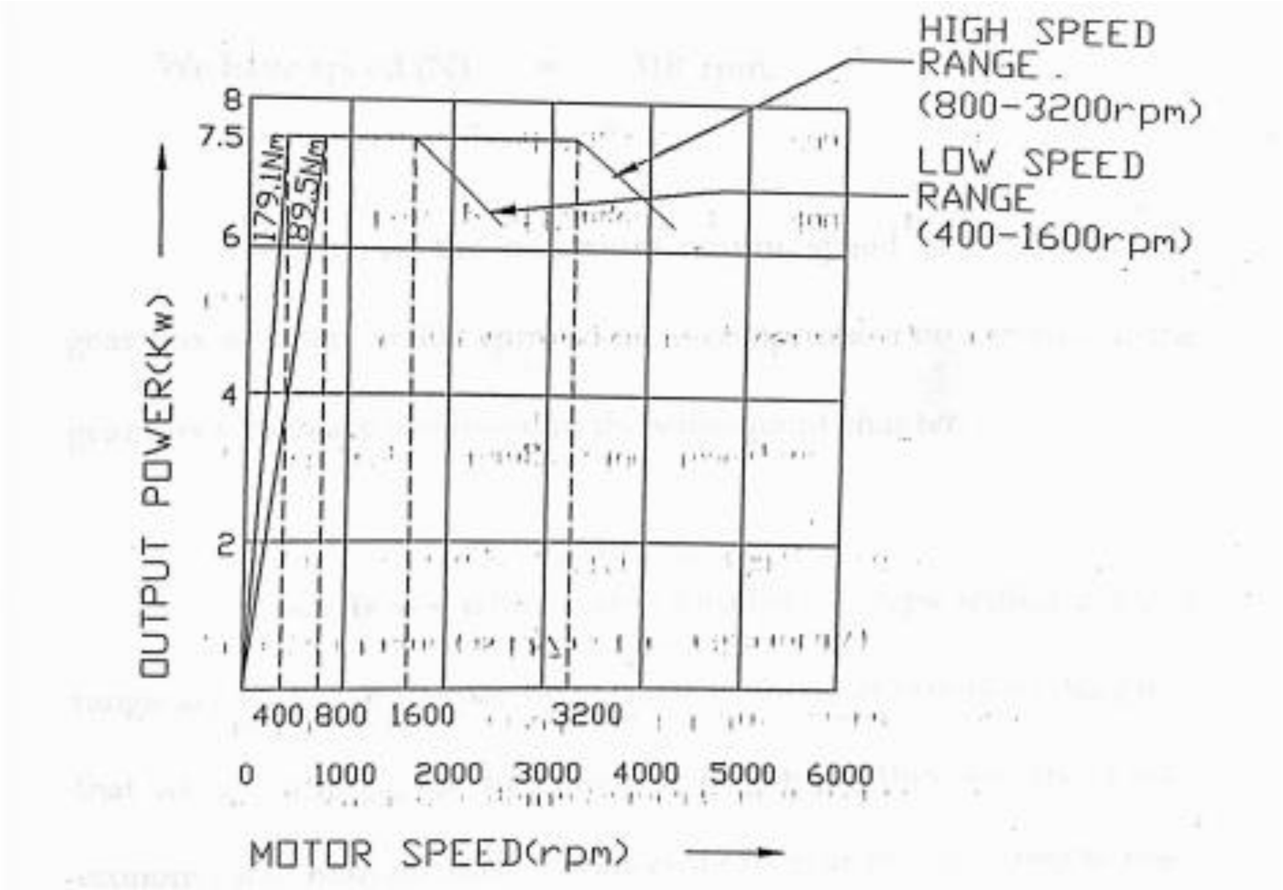


Graph1 Power Vs Speed Characteristics



Graph 2 Torque Vs Speed Characteristics





We Know that

Cutting Speed $V = \pi \mathrm{DN}/1000$ m/min

Assuming the operational conditions as follows

V= 150 m/s above (since carbide tips are used for m/cing).

D = 150 mm (As PSG CNC 150 Stands for the maximum turnable diameter of the job)

We have speed (N) = 318 rpm.

Therefore, the minimum output speed delivered by the gear box is taken as 400 rpm, so as to compromise on the size of the gear box which are discussed in the subsequent chapter.

Gear boxes with many steps within a given range are bulky and expensive. Hence the gear box is so designed that while fulfilling the functional requirement, they are also made economical to manufacture. As the cost of a gear box is related to the number of shafts and bearings required, care has been taken considerably to minimise these, at the same time fulfilling the functional requirement.

1.3. Selection of Speed Range

The minimum (base) speed of the motor is 1500 rpm and the minimum output speed required through the gear box is 400 rpm. So, a reduction of 3.75 (1500/400) has to be made in order ko achieve this. Since the power from the input motor has to be transmitted through a belt drive to the input shaft of the gear box, a considerable amount of speed reduction can be achieved through the belt drive.

i.e., the belt drive will provide a reduction of 1.875 and one pair of gear (low speed) will give a reduction of 2. (ie.,1.875 x 2 = 3.75, totally).

Low Speed Range: 1500/3.75 = 400 rpm; 6000/3.75 = 1600 rpm: 400-1600 rpm

The Starting Speed for the high-speed range is selected as 800 rpm thereby requiring a total reduction of 1.875 is provided by the belt drive and the second pair off gear giving a 1:1 ratio (as 1.875 x1.0 =1.875 totally)

High Speed Range: 1500/1.875 =800 rpm; 600/1.875= 3200 rpm

Low Speed Range: 400-1600 rpm.

Therefore, the gearbox gives a two-speed range as given Below:

Low Speed Range: 400- 1600 rpm

High Speed Range: 800- 3200 rpm

2. DESIGN CONSIDERATIONS

The design of gear box involves the design of gears, shafts, pulleys, keys, splines, selection of bearings, V belts. This chapter deals with the design procedure of the different components involving a standard design sequence.

2.1. Gear Design:

Input Parameters:

Power of input motor	7.5 Kw.
Speed	400 rpm.
Gear material	15Ni2CrlMo15(En354)
Gear ratio	1:2

Design Twisting Moment (Mt):

[Mt] =97420 x Kw/n x kkd
97420 x 7.5/400 x 1.3 = 2374.61 Kg.cm.

Design surface stress [ac] = CR I-IRC.kcl

= 31. x 60 x 0.585 (hardness of 60 FIRC is obtained through heat treatment)
= 10,881 Kg/cm2

[al)] = 3200 Kg/cm2

Centre Distance (a):

a > 80.99 (minimum centre distance)

Module (m):

Standardising m = 2.0 mm

Fixing the number of teeth for the low and high-speed gear pair we have

First Pair (low Speed) 1:2 ratio = 36:72 teeth

Second Pair (high speed) 1:1 ratio = 54:54 teeth

Actual centre distance a = m (Z1 +Z2)/2 = 108 mm

Checking σc :

σc ≤ 0.74 x 2.0 + 10.8 x (2.0 +1/2.0 x3) x 2.15 x 10^6 x 2374.61)1/2
= 10,385.55 Kg/cm2

Since, this is less than the actual value, this is a safe design for checking kkd:

Checking σb :

$$ab = \frac{2.0 + 1.0}{10.8 \times 2.0 \times 3.0 \times 0.4546} \times 2374.61$$

= 241.83 Kg/cm3
Since, this is less than the actual value, this is a safe design for checking kkd:

Checking for kkd:

k x kd = 1.0 x 1.25 = 1.25 < assumed.

Check for Plastic Deformation under Bending

σmax=241.83 x 6173.9/3086.95

[σbmax]1 = 0.36. σu/kσ

= 0.36 x 9000/1.2 = 2700 Kg/cm2 = 483.66 Kg/cm2

[σbmax]2 = 0.8 x σy

= 4320 kg/cm2

[σbmax]1 > σb max

[σbmax]2 > σb max

Check for Plastic Deformation Under Compressive Loads:

M1max / m1 =2

σc max < [σc max]

Hence Safe Design

Final Dimensions:

Centre Distance a = 108 mm
Module m = 2.0 mm
Face Width b = 30 mm
I.S . Quality = 6
First gear pair (low speed) = 1:2 ratio = 36:72 teeth
Second gear pair (high speed) = 1:1 ratio = 54:54 teeth

Pitch Circle Diameter:
First Gear Pair
Pcd1 (36) = 72 mm
Pcd2 (72) = 144 mm

Second Gear Pair
Pcd3 (54) =108 mm
Pcd4 (54) =108 mm

2.2. Gear Force Analysis

	Gear Force	Tangential Force (kgf)	Radial Force (kgf)
Final Gear Pair (low)	Gear 1 (36)	507.4	184.68
	Gear 2 (72)	253.7	92.34
Second Gear Pair (High)	Gear 3 (54)	338.26	123.12
	Gear 4 (54)	338.26	123.12

Table 1 Gear Force Analysis value of Final Gear and Second Gear pair

2.3. Design of Shafts

Output Shaft:

d3 = 16/π x 40x106 ((2.0 x 116.52)2 + (1.5 x 179.2)2) 1/2

Output Shaft d= 35.64 mm

Input Shaft:

d3 = 16/π x 40x106 ((2.0 x 149.5)2 + (1.5 x 179.2)2) 1/2

Input Shaft d= 37.13 mm

2.4. Selection of bearings

Output Shaft Bearings

Left Side:

Shaft Diameter d = 45 mm
P = 1 x 95.6 x 1.5 + 143.4 Kg t
$C = (L/L10)^{1/3}$ P
$C = (20,000 \times 60 \times 400 / 10^6 \times 1)^{1/3} \times 145.57$
= 529.03 kgf < 2550 kgf (Selected Bearing)
Hence Safe Selection
Bearing No. SKF 6209

Right Side:

$C = (20,000 \times 60 \times 400 / 10^6 \times 1)^{1/3} \times 120.67$
= 438.54 kgf < 2550 kgf (Selected Bearing)
Hence Safe Selection
Bearing No. SKF 6209

Input Shaft Bearings

Left Side:

C = (20,000 x 60 x 400 / 106 x 1)1/3 x 151.95

= 552.51 kgf < 2550 kgf (Selected Bearing)

Hence Safe Selection

Bearing No. SKF 6209

Right Side:

C = (20,000 x 60 x 400 / 106 x 1)1/3 x 151.95

= 838.44 kgf < 2550 kgf (Selected Bearing)

Hence Safe Selection

Bearing No. SKF 6209

2.5. Keys

Keys are to be checked for bearing pressure on the critical bearing area. Parallel keys for m/c tools have more depth in the shaft and less in the hub. For Such Keys, the critical bearing area will be the contact area between the key and the hub.

2.6. Splines

Splines also must be checked for bearing pressure on the contact surface between the shaft and hub.

P = f/h11

h1 = (4.2- 3.6/2)- (2 x 0.5/10) = 0.2

F = 4 x 2374.61/ (4.2 + 3.6) = 1217.74 Kg

P = 12 = 1217.74 / l x 2 = > 1 = 50.74 mm

But the length required is 79 mm as per the assembly drawing. So, this can withstand bearing pressure safely.

2.7. V-Belts

Motor Pulley Pitch Diameter (d) = 191.6 / 1.875 = 102.18

Input Pulley Pitch diameter (D) = 191.6

D/d = 191.6/ 102 = 1.878

C/D = 1.2

Cmin = 0.55 (191.6 =102) + 11 = 172.48 mm

Cmax = 2 (191.6+ 102) +11 = 587.2 mm

For a belt speed = π x 3200 x190/60000 =31.83 m/s

Power rating = 5.44 Kw

No .of Belts = 7.5x 1.3/ 5.44 x 0.85.0.98 = 2.152

3. DESIGN METHODOLOGY

The Methodology adopted for the design of the gearbox for PSGCNC150 is as follows.

3.1 Creation of Assembly Drawings:

After the design stage, the process of creating the assembly drawing is started. The assembly drawing is created with the calculated dimensions of various parts such as gears, shafts & bearings. The other parts such as gear box housing, bearing caps, Bearing Bracket, fork unit and lubrication unit parts (such as spacer, Hub. bracket etc), pulley unit were designed based on the following criteria, via. /functional satisfaction, minimum space requirements, minimum no of parts involved, ease of manufacture and assembly etc. An assembly drawing showing the mounting arrangements of the gearbox on to the machine is also created.

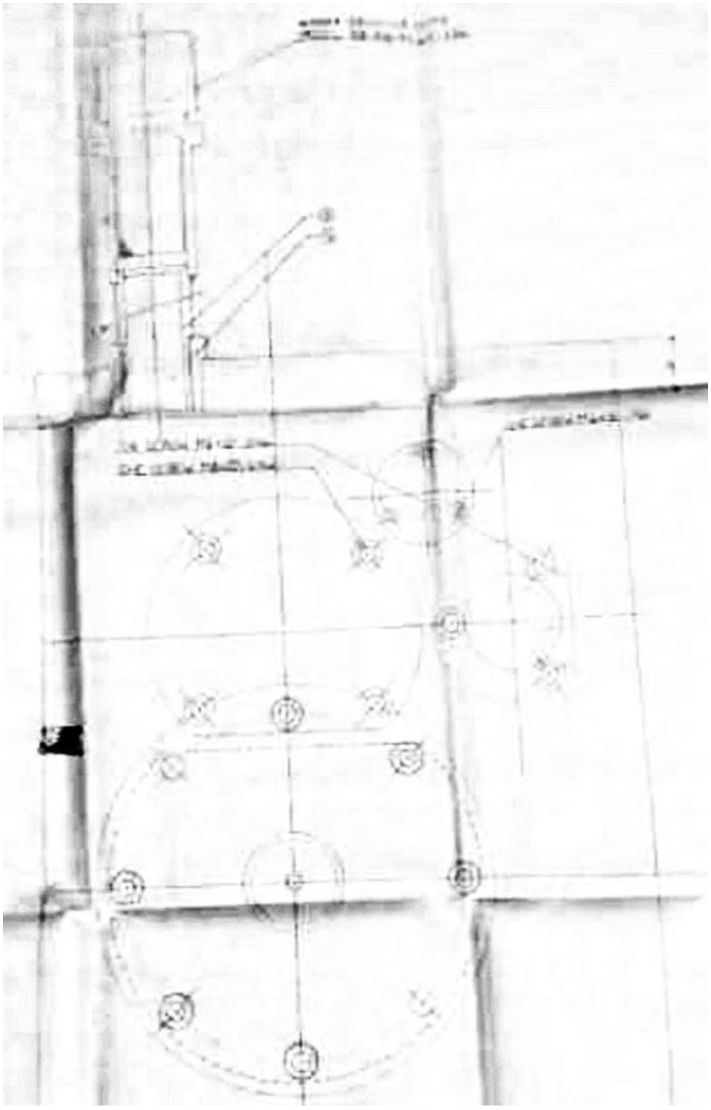


Figure 1

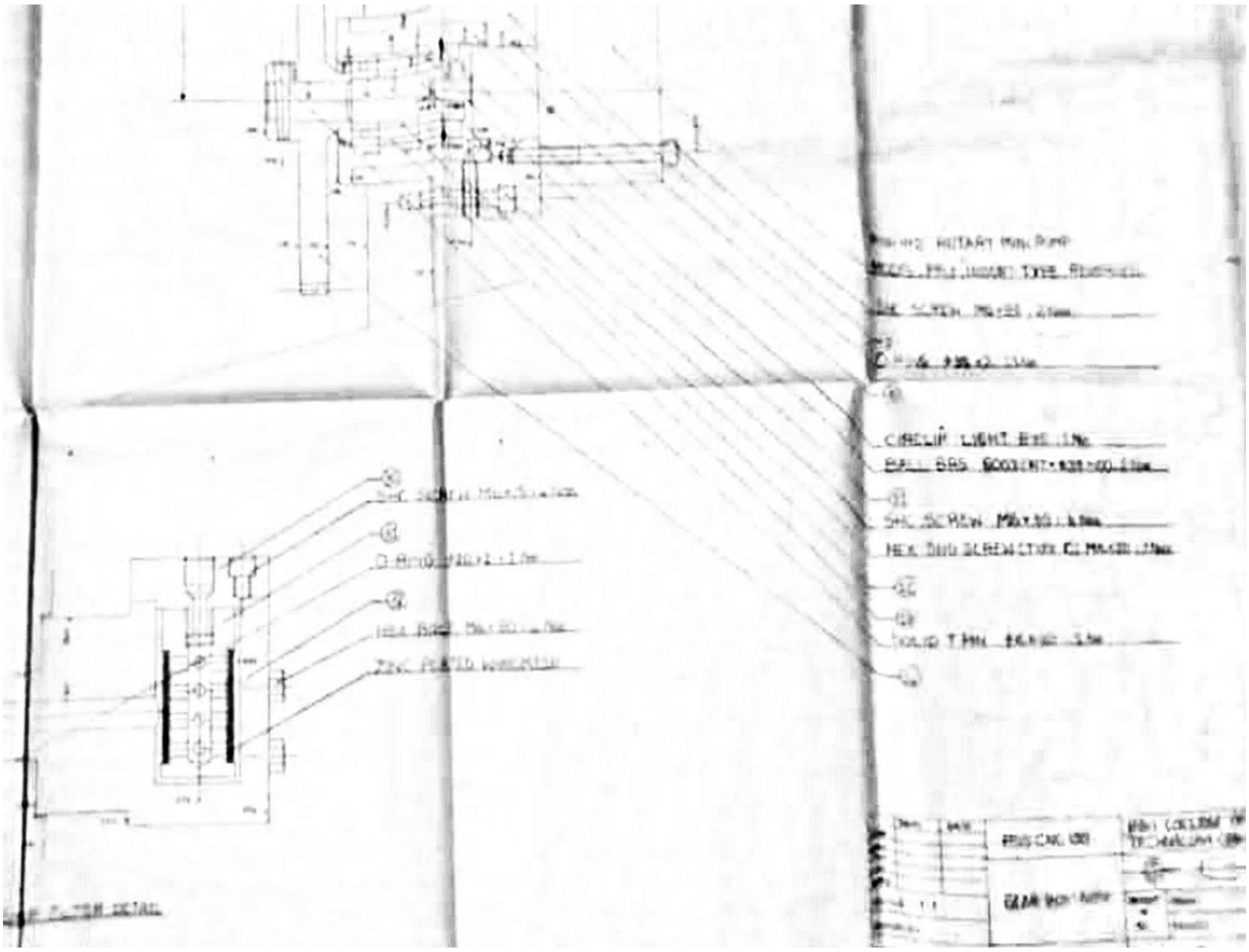


Figure 2

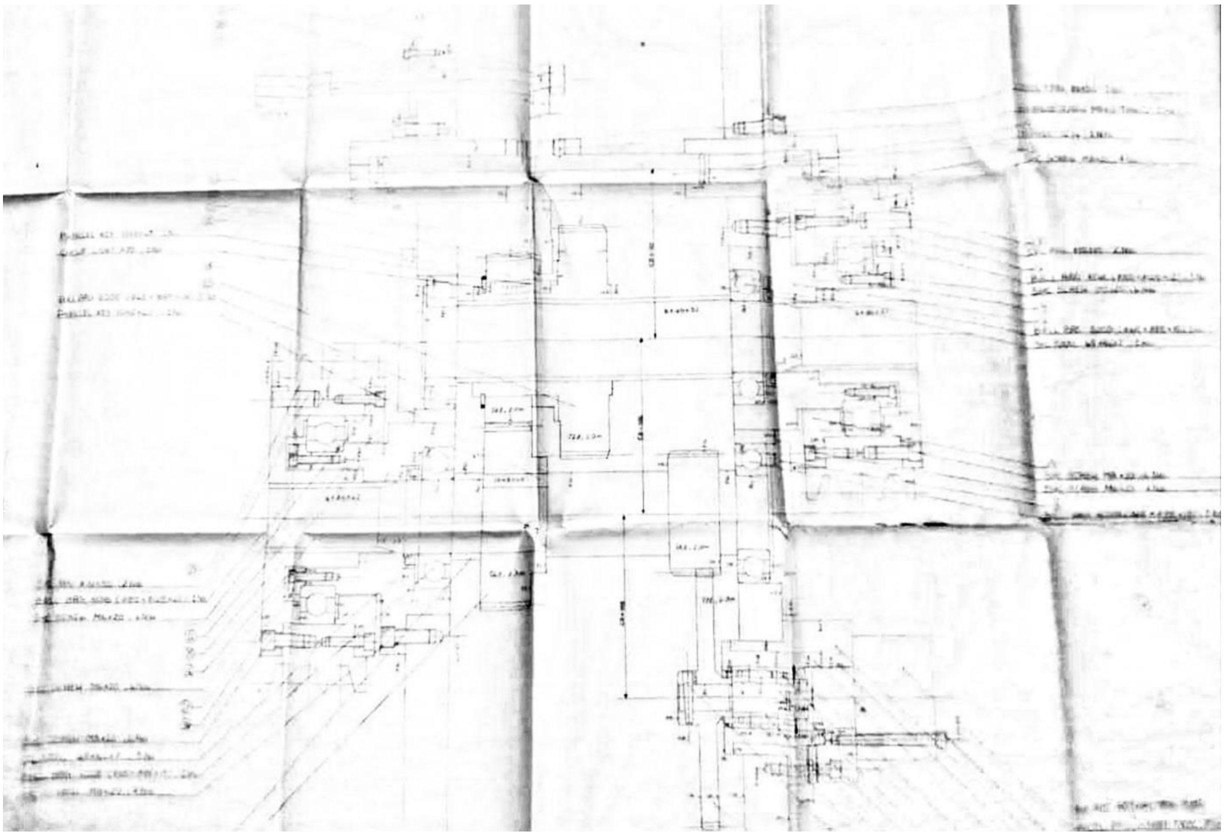


Figure 3

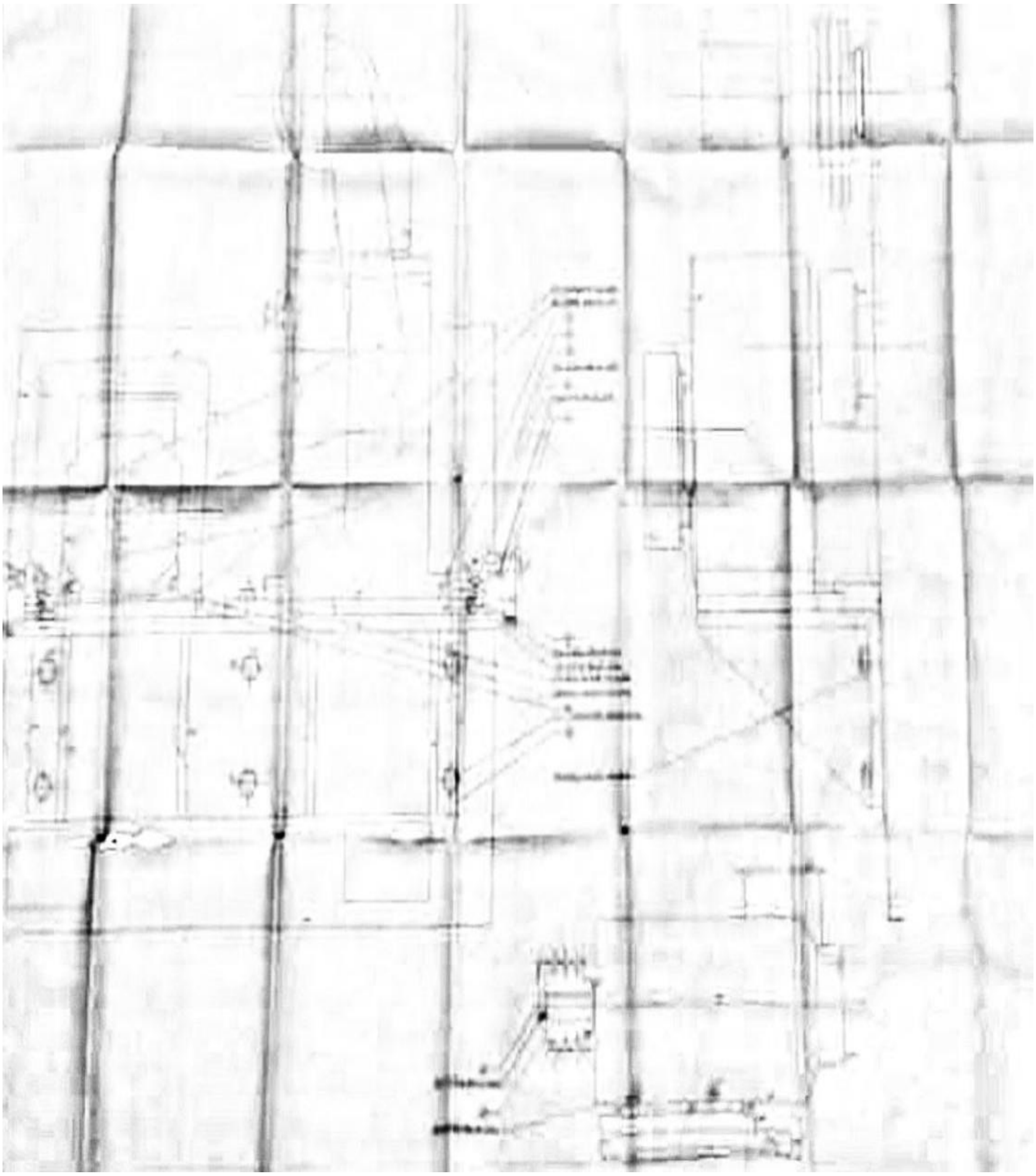


Figure 4

Fig 1,2 ,3 and 4 represents the Assembly Drawing views of Low and High-Speed Gear Box for PSG CNC150 Lathe

3.2. Creation of Part Drawings:

With the help of assembly drawings, part drawings for all the components were created. The parts were given numbers suitably for them for identification. All the details regarding the dimensions, fit & tolerances, geometrical tolerances, surface roughness, heat treatment (or) any other treatment required if any are mentioned clearly in part drawings.

3.3 Selection of Fits and Tolerances:

Selection of fits depends on the requirement of mating parts, its functional importance in the assembly, material of the mating parts, workmanship etc. All these factors should be considered while determining the fit. The recommendations of various fits were done based on the guidance of design engineers and handbooks.

As an illustration, some of the important aspects are given below.

- Location of mating part can be given a 1-17177, I-18F8 fit.
- Seating of bearing on the gearbox housing bore involves choosing J6 (hole) as fit for hole.
- The fit between fork bore and the piston is selected as 1-17m6. Such kind of combinations which are non-standard were also used due to the requirement

4. FABRICATION METHODOLOGY

The part drawings thus created were submitted to the PPC department, after approval from design department in order to forward it to production. The casting items namely gear box housing, fork, gearbox cover was manufactured at PSG Neelambur foundry division. There drawings were released first as these casting take time for manufacturing.

The other manufacturing items (M/c -ing items) were manufactured at Heavy engineering Division, PSG II. The Bil1 of materials (Born) for the items were provided during the release of the drawings. The bill of materials for all the components are annexed with the latter page of their chapter. The list of purchase items required for the gearbox is then prepared and given in advance so that they be obtained before hand without any delay. The list of purchase items for the gear box is given in the lather pages of this chapter.

A regular and constant follow up was made regarding the production of components and assembly. The process planning for some important components are given in this chapter. The assembly of the gearbox is done according to the assembly drawings.

4.1. Process Planning

Process planning details for a part provides the information such as the sequence in which the part is going to be processed and on the kind of machine, the setting time and operation time taken, speed, feed, jigs/fixtures involved etc. Since, in this research work the number of components involved is higher, the process sheet for important components been recorded periodically with clear full list of purchased and manufactured items.

5. COST ESTIMATION

All the costs which lend to the manufacture of a product must be considered. The cost for the gearbox may be divided into material cost, manufacturing (Machining) cost, Purchase Item cost overhead cost. The overhead cost' in this case is included in the manufacturing cost itself. The material cost is determined by multiplying the cost per unit weight to the weight of the material.

The machining cost is calculated by multiplying the time required (both for setting and operation) for an operation to the m.c - hour rate of the machine used. The total cost is obtained by summing up the material cost, manufacturing cost and purchase item cost.

6. CONCLUSION

The gear box which provides additional support to the PSG CNC 150 lathe by providing larger speed ranges with constant power output is designed and fabricated at Heavy Engineering Division, PSG Industrial Institute. A more intensive approach was carried out in order to limit the number of components and its sizes, making the size of the gear box compact in nature, so that it works out as a economical accessory to the lathe. The gear box designed can be incorporated as Engineering standard feature of the CNC lathe to increase the machine's capability.