CHAPTER-3

PROBLEM DEFINITION AND OBJECTIVE OF RESEARCH

3.1 Problem Definition

Problem definition and objective of research are crisply explained now and it is further explained in detail in the subsequent sections in the same chapter. Sleeve Synchronizer is a part having critical machining operations used in manual transmissions in a passenger car. Main purpose of Sleeve synchronizer is to power shift of gears. Noiseless smooth shift during gear shifting and noiseless run during vehicle running condition are considered as critical parameters for customer satisfaction index. Out of all manufacturing processes associated with sleeve synchronizer, only two processes such as hard groove turning and Gear hobbing are identified as the sources for the generation of noise during gear shifting and vehicle running condition. When the surface finish produced by the groove turning is poor, which may result in hard shifting and noise during gear shifting. Therefore the optimization of hard groove turning for noiseless shifting without sacrificing productivity is essential. Gear hobbing is one of the important gear manufacturing processes, where profile bias (Pressure angle variation) and Lead Bias (Helix angle variation) considered as critical characteristics contributed to noise generation during vehicle running. Optimization of gear hobbing process for lesser pressure angle variation and helix angle variation is mandatory to make process robust and to ensure noiseless running of vehicle. Both Hard groove turning and gear hobbing processes are critical in nature, associated with number input parameters with stringent quality response characteristics.

Hard groove turning and gear hobbing for noiseless shifting and running are considered as critical elements in the sleeve synchronizer manufacturing process and in this research work both these parameters have been taken in real time production environment and endeavoured to optimize the process in lesser possible time.
3.2 Objective of the research

This research aims at optimization of sleeve synchronizer manufacturing processes for noiseless shifting and noiseless running of vehicle with lesser number of experiments and the results has to be achieved right first time.

Optimization of sleeve synchronizer hard groove turning process for better surface finish and better cycle time aimed at reducing the noises during gear shifting. Eight number of process parameters are associated with the process, to reduce the time taken for trials, experimentation is planned through Taguchi parameter design. Grey relational analysis is used to convert multi objective functions (cycle time and surface finish) in to a single objective function named as Grey relational grade and further optimization is planned by Taguchi parameter design. Taguchi combined with Grey relational analysis is used to handle multi objective function problems in real time production environment with lesser number of experiments.

Even though Taguchi parameter design is considered as successful method for parametric optimization with lesser number of experiments, confounding due to interactions between the input process parameters are considered as one of the major drawback in achieving results right first time, while optimizing any complicated process through Taguchi parameter design. To achieve the results right first time in Taguchi method, a new algorithm has to be developed to minimize confounding effects which has to be used along with Taguchi parameter design for parametric optimization. RABAL algorithm has to be developed for achieving results right first time while using Taguchi Parameter design. Initial testing of RABAL Algorithm has to be done in a real time experiment, so sleeve synchronizer cycle time experiment is used for the purpose.

Optimization of Gear hobbing process for better pressure angle variation and helix angle variation aimed at reduction of noise during vehicle running condition by Taguchi methodology and RABAL algorithm. RABAL Algorithm minimizes the effect of confounding effect, while optimizing the process using Taguchi parameter design and it ensures the result from Taguchi parameter design is achieved right first time.
3.3 Sleeve synchronizer and its functioning

Sleeve Synchronizer is a part having critical machining operations used in manual transmissions. Main purpose of Sleeve synchronizer is to power shift of first gear & second gear. During neutral condition, the input gear drives countershaft. The countershaft gears drive the first, second and third gears on the output shaft. All synchronizers are centered. No gears are engaged to the output shaft and the output shaft is not engaged to the input shaft. Sleeve synchronizer hub is splined in the inner area which is press fitted to the output shaft splines. When the Sleeve synchronizer is moved backward using fork, the 1st gear is engaged to the output shaft through Hub. When the Sleeve synchronizer is moved forward position using fork, the 2nd gear shifting was carried out. Sleeve synchronizer surface roughness is a critical characteristic to ensuring smooth shift (noiseless shift) by shift lever and fork.

Fig 3.1 Sleeve Synchronizer assembled condition in output shaft

Assembled condition of sleeve synchronizer is shown in figure 3.1. From the figure is very clear that sleeve synchronizer will move forward or rearward through the synchronizer hub which is splined to the output shaft. Synchronizer rings are attached in first gear and second gear. Forward or rearward movement of sleeve synchronizer through hub is done for gear shifting operation in manual transmissions.
Fig 3.2 Sleeve Sync Gear Shifting – First Gear

From figure 3.2, it is very clear that if the sleeve synchronizer is moved rearward through the synchronizer hub and inner diameter splines mate with the synchronizer assembled in the First gear, will be resulting in shifting of first gear in passenger car manual transmissions. Gear shifting is done through the gear shift lever and fork which is attached in hard turned outer diameter portion of sleeve synchronizer.

From figure 3.3 shown below, it is very clear that if the sleeve synchronizer is moved forward through the synchronizer hub and inner diameter splines mate with the synchronizer assembled in the second gear, will be resulting in shifting of second gear in passenger car manual transmissions. Gear shifting is done through the gear shift lever and fork which is attached in hard turned outer diameter portion of sleeve synchronizer. Gear shifting is considered as one of the key factors for users selection of brand as gear shifting carried out continuously while driving.

Similarly sleeve synchronizer 3&4 is used for power shifting of third gear and fourth gear and sleeve synchronizer 5 & R is used for power shifting of 5th gear and reverse gear as well. All five speed manual transmission gear boxes should have three synchronizers. For 3rd and 4th gear shifting and 5th and reverse gear shifting similar type synchronizers are used.
3.4 Sleeve synchronizer manufacturing processes

Sleeve synchronizer of 1st type is used for shifting first and second gear. Sleeve synchronizer manufacturing process has three stage operations such as before heat treatment operations, Heat treatment operations and after heat treatment operations. Before heat treatment operations starts from rough broaching of inner diameter splines followed by roll forming and finish broaching operation for removing the burrs generated during the roll forming operation and followed by inner diameter spline v chamfering and key way milling. Then Gear hobbing is used for gear teeth forming followed by radius chamfering which is meant for burr removal and followed by gear shaving, which is a gear finishing operation.

Heat treatment operations such as Carburizing and Induction hardening are carried out where hardness and microstructure of the sleeve synchronizer improved considerably. After heat treatment, hard groove turning, which is considered as critical operation as material at more than 60 HRC is turned using CNC machine.
Figure 3.4 shows the manufacturing process flow of sleeve synchronizer that is used for shifting first gear and second gear. It has 7 before-heat treatment machining operations, 2 heat treatment operations and 1 after-heat treatment operations.
Figure 3.5 Sleeve synchronizer – For shifting first and second gear

- Rough Broaching
- Internal Roll forming
- Finish Broaching
- V Chamfering and Key way milling
- Carburizing
- Induction hardening
- Groove hard turning

Fig 3.6 Sleeve synchronizer manufacturing process flow (3rd Gear & 4th Gear)
Sleeve synchronizer used for shifting 3rd gear and 4th gear as well as 5th gear and reverse gear has only seven manufacturing operations such as Rough broaching, Internal rolling, Finish broaching, Key way milling and V chamfering then it has heat treatment operations such as carburizing and induction hardening followed by hard groove turning operation which is carried out after heat treatment.

Fig 3.7 Sleeve synchronizer – For shifting 3rd Gear & 4th Gear

3.4.1 Rough Broaching

The rough broaching process, which is almost similar to shaping with multiple teeth, is used to machine internal surfaces such as circular shapes, keyways and teeth of internal gears. In sleeve synchronizer teeth machining has to be done in inner diameter of a circular area. Rough broaching is meant for initial roughing operations whereas final dimensional accuracy will be maintained by finish Broaching operation. A broach is a long multi-tooth cutting tool with deeper cuts which is carried out by successive teeth of long broach. Every tooth cuts a predetermined and predefined amount of material in an already well predetermined and predesigned location. The total depth of material removed in one path is the sum of the depth of cut of each tooth. Broaching can produce parts with excellent surface finish and with excellent dimensional accuracy.
Tooling is the heart of rough broaching process. The broaching tool is based on a concept unique to the process all types of teeth such as rough, intermittent finish and semi-finish cutting teeth combined in a single tool. Internal broaching requires a starting opening or hole in the workpiece so the broaching tool can be travelled through the part. The broach tool is then pulled and the sleeve synchronizer is pushed with force so that the broach travel can happen from the starter opening or hole. Broach is similar to a single point tool with multiple points each of which removes material like a flat-ended shaper tool, so that any deeper depth can be produced due to material removal is carried out in multiple cutting edges.

![Broaching tool with trolley](image)

Fig 3.8 Broaching tool with trolley
Figure 3.8 shows the broaching tool used for rough broaching machine and handling of rough broaching tool is also important as due to more weight and lengthier in nature it is prone to have damages easily. Broach trolley also illustrated in the figure.

**Major Quality Parameters to be checked in Rough Broaching**

Major Diameter – Indirect method of checking root diameter

Minor Diameter – Indirect method of checking addendum circle diameter

Inner Ball Diameter – Indirect method of checking tooth thickness

Inner Ball Diameter run out – Indirect method of checking tooth spacing

Major diameter and minor diameter is checked in coordinate measuring machine and Inner Ball Diameter and Inner Ball diameter runout is checked using IBD comparator.

![Fig 3.9 IBD Comparator](image)
3.4.2 Internal rolling operation

Internal roll forming is the operation carried out for making taper in the involute inner gear which is used for locking purpose while mating. Internal rolling operation is carried out in Sanyo rolling machine which rolls inner circumferential gear (specially: spline) automatically to die particularly designed for the purpose at high precision with work set to the die. This machine consists of the spindle feed device, tail stock section, roller body for storing jig roller and pressure device. The cutter spindle speed was set by inverter control. The loading or unloading device also be used in the machine to reduce the operator Fatigue.

Sleeve synchronizer inner circumference taper is made by rolling cutter presses the sleeve synchronizer against the die and by uniform rotation with preset pressure the taper is made uniformly in all the teeth.

Fig 3.10 Internal roll forming cutter

Major Quality Parameters to be checked in Internal Rolling
Inner Ball Diameter at 4 mm from Face – Indirect method of checking tooth thickness

Inner Ball Diameter run out – Indirect method of checking tooth spacing

Fig 3.11 IBD comparator for roll forming

IBD checking in internal roll forming operation is similar to rough broaching operation but the height will be fixed separately for internal roll forming checking IBD comparator and a master with pre measured value is used. Before every checking the master has to be checked for the correctness of the height.

3.4.3 Finish Broaching

Finish broaching is similar to rough broaching, produced in same vertical pulled up type machine made by Kukje, South Korea with the broach cutter which is explained in detail in section 3.4.1. Finish broaching operation is carried out mainly to remove the burr generation in previous burr internal roll forming operation and all dimensions such as major diameter, minor diameter, Inner ball diameter and Outer ball diameter to be made in control. Finish broach tool to be made with all dimensions within specification as it ensures the final specification.
Broach Nomenclature

Front pilot:

For sleeve synchronizer internal pull broach is used, the front pilot and pull end are passed and travelled through the starting hole. Then the pull end is locked to the pull head of the finish broaching machine. The front pilot is made to ensure correct axial alignment of the tool with the starting hole, and assures the starting whole size.

Length:

The length of a broach tool, is determined by the type of material to cut, amount of stock to be removed in each cut and limited by the machine stroke.

Rear pilot:

The rear pilot is similar to front pilot but it maintains tool alignment at the final travel as the final finish teeth pass through the workpiece hole. The diameter of the rear pilot is slightly smaller than the diameter of the finish teeth.

Cutting teeth:

Broach teeth are usually divided into three different sections along the axis of length of the tool: the roughing teeth, semi-finishing teeth and finishing teeth. The first roughing tooth is proportionately the smallest tooth on the tool. The subsequent teeth progressively increase in size up to and including the first finishing tooth. The difference in height between each tooth, or the tooth rise, is usually greater along the roughing section and less along the semi-finishing section. All finishing teeth are the same size. The face is ground with an angle which is called as hook or face angle which is characterized by the workpiece material. Normally softer material requires higher face angles whereas slightly harder material requires higher hook angle.

Tooth land:

The land is the supporting part which safe guards the cutting edge against stresses. A slight clearance angle is ground in to the lands which avoids friction. In roughing as well as semi-finishing, the entire land of the teeth is relieved with a clearance angle. On finishing teeth, part of the land immediately beneath the cutting edge is often left straight, so that even after repeated sharpening by grinding, the face of the tooth will not alter its size.
Tooth pitch:

The distance between teeth is termed as pitch, which is determined by the type of and length of the work material to cut. Normally in roughing teeth large pitch is advised as material removal will be higher and in finishing teeth normally small pitch is recommended.

Tooth gullet:

The depth of the tooth gullet is related to the tooth rise, pitch and workpiece material. The tooth root radius is normally designed so that chips curl rigidly within themselves, which need to occupy less space possible.

Chip load:

As each tooth travels into the workpiece, it cuts a fixed predetermined thickness of material. The fixed predetermined chip length and chip thickness produced by broaching create a load which is characterized as chip load which is determined by the predetermined feed rate and the design of the broach tool.

Chip breakers:

Chip breakers are nothing but notches, made parallel to the tool axis to facilitate chip removal activity and eliminate the packing of chip. Called chip breakers, are used on broach tools to eliminate chip packing and to facilitate chip removal. Chip breakers ensure that chip breaks before finishing stage so that proper tool life will be ensured.

Shear angle:

To reduce the tool chatter and to improve the surface finish broach teeth to be placed at a shear angle. When two adjacent surfaces are cut simultaneously, the shear angle is a crucial factor in removing chips away from the intersecting corner or plane for the prevention of chip crowding.

Side relief:

Side relief becomes essential while broaching slots, the tool should be enclosed by the slot during cutting and must carry away the chips produced through the whole length of the workpiece.
Fig 3.12 Finish Broach cutter used for finish broaching

**Major parameters checked in Finish Broaching Operation**

Major Diameter – Indirect method of checking root diameter

Minor Diameter – Indirect method of checking addendum circle diameter

Inner Ball Diameter – Indirect method of checking tooth thickness

Inner Ball Diameter run out – Indirect method of checking tooth spacing

Surface finish

Visual Inspection
3.4.4 V Chamfering and Keyway milling

V Chamfering and Key way milling is carried out using special purpose machine manufactured by Prawema, Germany. V chamfering is carried out using DCMT inserts with special type tool holders as mentioned in the below drawing.

![Sleeve synchronizer V Chamfering operation](image)

**Fig 3.13 Sleeve synchronizer V Chamfering operation**

V Chamfering operation is carried out in the inner spline so that the mating hub can enter freely in to the chamfer so the V chamfer is called as entry chamfer for the mating part to go inside. V chamfering will be carried out in all the teeth with less than 30 seconds time. The clamping unit is servo controlled and V Chamfering unit is also servo controlled, so synchronization will be taken place easily.

After V chamfering operation Keyway milling at 3 teeth will be carried out in the same machine with the special type of tool holder mentioned in the figure 3.14. In sleeve synchronizer, key way milled area are indicated in black arrows as shown in figure 3.14. After V chamfering operation burr in the teeth is projected, if it is unremoved it will cause obstruction for the mating hub to move freely inside the sleeve synchronizer. After V chamfering specially designed calibration tool will move inside the sleeve synchronizer and it will remove the burr generated in the Key way milling process.
Three critical operations are carried out in a combined manner so the machine is also called as combination machine.

**Major Parameters to be checked in Combination machine**

- Key way Depth
- Key way position
- V Chamfering angle in butting face
- V Chamfering depth in butting face
- V Chamfering angle in opposite face
- V Chamfering depth in opposite face
3.4.5 Gear Hobbing

Gear hobbing is a generating process, by which involute gear profiles are generated in a progressive manner. The term generating means that the gear tooth form cut is not exactly cut the conjugate form of the bob cutter, cutting tool. Sleeve synchronizer gear hobbing is carried out in Kisabhu, South Korea made gear hobbing machine. During hobbing operation both the hob cutter and the sleeve synchronizer rotate in a continuous rotational relationship ie in a synchronized manner. To ensure the synchronization both hob cutter rotation and work piece rotation are controlled by separate servo motors. During this rotation, the hob cutter is moved axially with all the teeth being gradually formed as the hob cutter moved in a vertical axis (traverses the work) towards the work. Hob cutter axial movement is controlled by a servo motor and transverse movement also controlled by a servo motor as well. Hobbing method is classified into three major categories based on the hob cutter movement towards the sleeve synchronizer width. Three types include plunge cut, down milling, climb hobbing. As the name indicates plunge hobbing means cutting takes place mostly by the axial movement. Down milling means vertical movement of hob cutter starts from top and it travels towards the bottom where as in climb hobbing vertical movement of hob cutter starts from bottom and it travels towards the top during the cutting cycle.

Fig 3.15 Hob cutter

Fig 3.15 shows the hob cutter used for sleeve synchronizer gear hobbing
In Gear Hobbing it is essential to do truing of hob cutter before putting in to the machine as this hobbing operation to be carried out in micron level accuracy.

Fig 3.16 Hob Truing stand

Once hobbing is carried out it is essential to check the over ball diameter which is the indirect method of checking tooth thickness and OBD run out which is the indirect method of checking tooth spacing. Figure 3.17 illustrates OBD comparator used for checking OBD and Fig 3.18 illustrates the deflection tester used for checking OBD run out.

Fig 3.17 OBD Comparator
Major Quality Parameters to be checked in Gear Hobbing

Over Ball Diameter – Indirect method of checking tooth thickness

Over Ball Diameter run out – Indirect method of checking tooth spacing

Semi topping

Profile Bias – Indirect method of checking pressure angle variation

Lead Bias – Indirect method of checking helix angle variation

Profile bias and Lead bias are considered as critical parameters, when the values become more than the specification value then noise will be generated in the process which is elaborated in chapter 3.6

3.4.6 Gear R Chamfering

Gear R Chamfering is the operation used for removing the burr generated in gear hobbing through radius chamfering. As Gear hobbing is a roughing process carried out at higher speed and feed rate so it is essential to do deburring after gear hobbing and before gear shaving. If the burrs are not removed properly then it causes damage to the shaving cutter. To maintain the radius special type of tools and tool holders are used. Other purpose of Gear R chamfering is to provide a clear radius so that mating part would enter.
Figure 3.19 clearly shows the Radius chamfering cutter, with its height setting gauge. Radius chamfering machine used for sleeve synchronizer is made of Sanyo machine tools, Japan. Two Radius chamfering tools will take cut simultaneously, whereas the initial teeth position is sensed by sensor which is reference for Radius chamfering tool to take cut.

**Major Quality Parameters to be checked in Gear Hobbing**

- Front radius
- Side Radius
- Radius depth

**3.4.7 Gear Shaving**

Gear Shaving of sleeve synchronizer is carried out in Kanzaki, Japan made shaving machine. Gear shaving is one of the gear finishing operation similar to Gear Grinding. If we opt to do Gear shaving then it is mandatory to maintain Gear tooth thickness, spacing and profile and Lead variation as the possibility of getting unshaved portion is more if prior
hobbing is not on specification. In Gear shaving per flank 30 to 40 microns will be removed, whereas in gear grinding we can remove up to 100 to 150 microns.

Figure 3.20 shows the shaving cutter used for shaving sleeve synchronizer. Sleeve synchronizer after gear hobbing kept in a moveable, flexible fixture which moved in mesh with the shaving cutter. Before shaving operation to be carried out the shaving cutter will move up and down to check the meshing with hobbed sleeve synchronizer is proper, if the meshing is proper then shaving operation will be started. If meshing is not proper then shaving cutter and work fixture movement will be carried out until the proper meshing then only the shaving operation will be started. In shaving operation material removal in gear flank will be lesser.

The important quality parameters over ball diameter, over ball diameter runout are checked by OBD comparator (Figure 3.17) and deflection tester (Figure 3.18) respectively whereas profile bias and lead bias are checked using contour tracing equipment.
Quality parameters will be checked in Gear shaving

Over Ball Diameter – Indirect method of checking tooth thickness

Over Ball Diameter run out – Indirect method of checking tooth spacing

Semi topping

Profile Bias – Indirect method of checking pressure angle variation

Lead Bias – Indirect method of checking helix angle variation

3.4.8 Gear Carburizing

Carburizing or Carburization is a heat treatment process in which iron or steel absorbs carbon while the metal to be carburized is heated in the presence of a carbon-bearing material, such as charcoal / carbon monoxide. The main purpose is to make the metal harder. Depending on the amount of temperature used and time given, there must be variation in the carbon content of the affected area. If carburizing times are longer along with higher temperatures typically increase carbon diffusion depth. When the steel or is cooled rapidly by quenching. Outer surface becomes hard due to higher carbon content at the outer surface the by austenite to martensite transformation, while the core remains soft and tough as well due to ferritic and pearlite microstructure. Carburizing can be applied to low-carbon workpieces; workpieces have to be in contact with a high-carbon gas, liquid or solid so it produces workpiece surface hard and workpiece cores retain their toughness and ductility and by carburizing we can produce case hardness depths up to 6.4 mm. In some cases it serves as a remedy for undesired decarburization that happened earlier in a manufacturing process.

3.4.9 Induction Hardening

Induction heating is a non-contact heating process which make use of electromagnetic induction principle to generate heat inside the surface layer of sleeve synchronizer. If sleeve synchronizer (conductive material) is placed into a strong alternating
magnetic field, electric current can be induced to flow in the material enormous amount of heat is generated. In magnetic materials, further heat is generated below the curing point due to hysteresis losses. The generated current predominantly flows in the surface layer, the depth of this layer being decided by alternating field frequency, power density in the surface, the permeability of the material, the heat time and the diameter of the bar or material thickness. If this heated layer is quenched in water, oil, or a polymer based quench, the surface layer is altered to form a martensitic structure which is the hardest structure and it is normally harder than the base metal of sleeve synchronizer. The sleeve synchronizer is heated by means of an alternating magnetic field to a temperature above or nearer to the transformation temperature range followed by immediate quenching in water or oil or polymer quenchant. The core of the sleeve synchronizer remains soft and is unaffected by the treatment and its physical properties are remain unchanged, whilst the hardness of the case can be within the range 60 to 65 HRC. Carbon and alloy steels with lesser carbon content in the range 0.40/0.45% are most suitable for this process High frequency source of electricity is used to drive a large alternating current through a induction coil. The passage of current flows through this coil generates a very high intense and rapidly changing magnetic field in the space within the induction coil. The Sleeve synchronizer to be heated is placed within this intense alternating magnetic field where eddy currents are generated within the workpiece and resistance leads to Joule heating of the sleeve synchronizer.

The effectiveness of these treatments depends both on surface materials physical properties and microstructure modification and on the introduction of residual stress as case is hard and the core is soft. Among these treatments, induction hardening is one of the most widely employed to improve sleeve synchronizer durability. It determines in the work-piece a tough core with tensile residual stresses and a hard surface layer with compressive stress. It is proved to be very effective in extending the sleeve synchronizer wear resistance and fatigue life. Induction surface hardened low alloyed medium carbon steels are widely used for critical automotive and machine applications which require high wear resistance. Wear resistance behavior of induction hardened parts depends on hardening depth and the magnitude and distribution of residual compressive stress in the surface layer
Fig 3.21 Induction Hardening machine

The Sleeve synchronizer Induction hardening in carried out in HFI (HFT-01) induction hardening machine with the specification of 100 KW 50 KHz - 50KW 10KHz.

Major Quality Parameters to be checked in Induction Hardening

Hardness in HRC

Inner Ball diameter

Major Diameter

Minor Diameter

Microstructure

Case Depth

3.4.10 Hard Groove turning

Hard Groove turning is carried out only after carburizing and induction hardening so the material has higher hardness ranges around 60 to 65 HRC. The hard turning CNC lathe must have higher rigidity so that the hard sleeve synchronizer can be machined
During hard groove turning the sleeve synchronizer is clamped on a hydraulically operated chuck with three finger jaws which can clamp the sleeve synchronizer at 120 degrees. For sleeve synchronizer used for shifting 1\textsuperscript{st} and 2\textsuperscript{nd} gear the turning width would be 12 mm and for sleeve synchronizer used for shifting 3\textsuperscript{rd} and 4\textsuperscript{th} gear the width would be 8.5 mm. In both the cases same 5 mm plunge type insert will be used.

WIA Hard turning Lathe is used for conducting Experiments. 5.0 mm Plunge type CBN insert grade TSG 5.00-0.2-HDTB 650 is used for machining. (0.2 mm nose radius). Groove width is checked using Vernier caliper for first part approval and using snap gauges in line. Surface finish is checked using Profile tracing Machine Hammel Werke using Probe type Surf scan / 66011/10011801 SC ITB. It’s measuring range 3000 microns and Transverse length of 4.80 mm

**Major Quality Parameters to be checked in Induction Hardening**

- Groove width
- Groove Diameter
- Groove finish
- Groove width 1 and 2
Table 3.1 Sleeve synchronizer manufacturing process flow

<table>
<thead>
<tr>
<th>Machine Details</th>
<th>Actual measured</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rough Broaching</td>
<td>Major diameter of the ID Spline</td>
<td>Initial stock taking for Finish Broaching Operation</td>
</tr>
<tr>
<td>KUKJE - KOREAN MAKE</td>
<td>Minor diameter of the ID spline</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Spline Tooth Thickness</td>
<td></td>
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<tr>
<td></td>
<td>Spline Tooth spacing</td>
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<tr>
<td></td>
<td>Damages</td>
<td></td>
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<tr>
<td>Internal Rolling</td>
<td>Tooth Thikness</td>
<td>For Self Locking</td>
</tr>
<tr>
<td>SANYO - JAPAN MAKE</td>
<td>Angle</td>
<td></td>
</tr>
<tr>
<td>Finish Broaching</td>
<td>Major diameter of the ID Spline</td>
<td>Hub is Press fit in to the Output shaft. Sleeve ID has to be matched with HuB OD and free movement to be ensured</td>
</tr>
<tr>
<td>KUKJE - KOREAN MAKE</td>
<td>Minor diameter of the ID spline</td>
<td></td>
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<tr>
<td></td>
<td>Spline Tooth Thickness</td>
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<tr>
<td></td>
<td>Tooth spacing</td>
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<tr>
<td></td>
<td>Damages</td>
<td></td>
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<tr>
<td>V chamfering, Key way milling</td>
<td>V Chamfering Angle</td>
<td>Angle is for ease of entry in to the Hub</td>
</tr>
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<td>PRAWEMA - GERMAN MAKE</td>
<td>V Chamfer Symmetry</td>
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<td></td>
<td>Key way width and position</td>
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<td>Gear Hobbing</td>
<td>Gear Tooth Thickness</td>
<td>Gear engagement, Noise less operation</td>
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<td>KISHABU - KOREAN MAKE</td>
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<td>Visual check</td>
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<td>Helix Angle Variation</td>
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<td>R Chamfering</td>
<td>Radius</td>
<td>Burr Removal</td>
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<td>SANYO - JAPAN MAKE</td>
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<td>Gear Shaving</td>
<td>Gear Tooth Thickness</td>
<td>Gear engagement, Noise less operation</td>
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<tr>
<td>KANZAKI - JAPAN MAKE</td>
<td>Gear tooth Spacing</td>
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<td>Visual check</td>
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<td></td>
<td>Helix Angle Variation</td>
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<td>Carburising / Induction Hardening</td>
<td>Hardness</td>
<td>Durability</td>
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<td>DWSI - OSP</td>
<td>Case Depth</td>
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<td></td>
<td>Microstructure</td>
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<tr>
<td>Hard Groove Turning</td>
<td>Groove width</td>
<td>Gear Shifting, Noiseless shift</td>
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<tr>
<td>WIA - KOREAN MAKE</td>
<td>Groove Position</td>
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<tr>
<td></td>
<td>Surface roughness</td>
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3.5 Critical operations in Sleeve synchronizer manufacturing process

In Sleeve synchronizer manufacturing process, it is found that Gear Hobbing, Gear Shaving and Gear Hard groove turning are the three important operations related to
noiseless running of vehicle and smooth shifting of gears. In Gear shaving, the noise generating components are investigated and it is found that shaving is not done on the flank where the profile and lead variation is more and hobbing mark is noticed which shows improper gear hobbing led to the development of more pressure angle and helix angle variation. The material removal from the flank through shaving process is very less and eventually the Gear Hobbing is identified as one of the critical processes in achieving quality in Sleeve Synchronizer manufacturing process.

3.5.1 Gear Hobbing

Gear hobbing is the most critical machining process associated with generation of noise during vehicle running condition and we need to work in below 10 microns accuracy and gear hobbing process hob rotation, hob speed needs to be synchronized with work rotation and work speed through servo control to ensure flawless forming of gears. Process parameters selected for gear Hobbing study are Hob cutter rotational speed, Hob cutter Feed rate, Type of hob cutter Coating used (TiN, TiAlN, AlCrONa) and Type of Cutting (Up milling, Down milling and Plunge) and gear hobbing process have two critical responses, profile bias, a measure of Pressure Angle Variation and Lead Bias a measure of Helix Angle variation. Optimum parametric combination in gear hobbing for better pressure angle and helix angle variation ensures noiseless running of gear box.

3.5.2 Hard Groove Turning

Hard groove turning process is associated with generation of noise during shifting and in sleeve synchronizer manufacturing process, hard groove turning is carried out after carburizing and induction hardening and hence the hardness of the material would be increased significantly. It is so critical to turn the sleeve synchronizer at hardness of more than 60 HRC. Though the surface roughness is important for reducing the noise, cycle time also needs to be considered simultaneously to avoid bottleneck in the manufacturing process. So sleeve synchronizer groove turning has two critical responses, Cycle time and Finish, which needs to be optimized simultaneously.