CHAPTER-1

INTRODUCTION

The manufacturing sector faces a lot of difficulties to compete in the market and nowadays most of the foreign companies started their manufacturing operations either with partnership or on their own, in diversified areas with the support of already existing ancillary industries. The tremendous growth in the expectations and need of the manufacturing sector calls for lot of critical processes with very higher quality levels and at the mean time, there is a huge competition arises, between market participants in terms of cost, quality and delivery. Nowadays customers also demanding the technical and quality requirements and they are more sensitive to cost of the products as well. It is mandatory to optimize all critical manufacturing processes (Productivity to be maximized, Cost to be minimized and Quality at its best level) to stay competitive in the global environment and at the same time the optimum prediction in manufacturing process involves lot of experimentation as it involves time and cost. So it is essential to optimize any manufacturing process for better quality parameters and productivity requirements. At the mean time optimum parametric combination has to be identified with minimal effort (minimum experimental runs) and with highest possible accuracy as it involves lot of cost and time.

Traditionally quality and productivity have been emphasized separately (not simultaneously) as two important and different indexes of performance. Any manufacturing process in the present state requires multi objective optimization model to optimize cost, quality and productivity requirements simultaneously. Optimum prediction is critical as it requires lot of experimental or trial runs with replicates for data capturing which involves time and cost. But it is essential in the real time environment to do simultaneous optimization of process parameters with very minimal number of experiments. Most of the optimization techniques available for optimization of real time problems, but it is mandatory to use robust techniques, which uses minimal trails for
optimum prediction and the results to be achieved at right first time.

Taguchi Parameter Design, a known fraction factorial design (A fraction of full factorial combinations are tested, but results can be derived and it is one among full factorial combination), for which requires lesser number of experimental runs are required for identifying optimum parametric combination in real time optimization problems. It uses orthogonal array for minimizing the experiments and it uses Signal to noise ratio to identify the variability in the process and finally response graphs to identify the optimum parametric combination. In many cases Taguchi method identified parametric combination was not in the tested trial combination, so identified optimum parametric combination to be confirmed through confirmation tests, which is also a part of Taguchi parameter design procedure. It is easier to identify optimum in single objection function problems using Taguchi parameter design but in case of Multi objective function problems with different objective functions, Taguchi Paremeter design requires some supporting method to convert real time multi objective function problems in to single objective function problems. Grey relational analysis is quite useful in converting the multi objective function problems in to single objective function problems Taguchi method in combination with Grey relational analysis can be used successfully in real time applications.

Sleeve Synchronizer is a part used in Gear boxes of passenger car and commercial vechicles, having critical manufacturing operations such as Rough broaching of inner splines, Internal teeth roll forming using roll forming machine, Inner teeth V Chamfering, Key way milling for hub locking, groove turning at soft condition, gear hobbing for gear teeth forming, Gear Radius chamfering for burr removal, Gear shaving for gear teeth finishing, Carburising, Gear teeth Induction hardening (Case hardening) and sleeve hard groove turning. Main purpose of Sleeve synchronizer is to power shifting of second gear and first gear in gear box (manual transmission). The input gear drives the countershaft. The countershaft gears drive the 1st, 2nd and 3rd gears on the output shaft. The 1-2 synchronizer hub is splined (connected) to the output shaft. If the Sleeve 1&2 synchronizer is shifted rearward using shift lever which is operated by a fork, the first gear will be engaged to the output shaft through the synchronizer hub. When the Sleeve synchronizer is shifted forward using shift lever which is operated by fork, the second
gear is engaged to the output shaft. Sleeve synchronizer is the most safety critical product and it is used often by customers while shifting the gears. Sleeve synchronizer needs to demonstrate its performance while gear shifting. A good sleeve synchronizer ensures smooth shifting and noiseless shifting of gears in manual transmission of passenger cars.

Gear Hobbing and Groove (Hard) Turning are the critical processes in Sleeve Synchronizer manufacturing process with high quality requirements. Gear hobbing is the most critical machining process as we need to work below 10 microns accuracy and in 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. There are four process control parameters involved in gear hobbing. They are Hob cutter rotational speed, Hob cutter Feed rate, Type of Hob cutter Coating (TiN, TiAlN, AlCrONa) and Cutting type (Up milling, Down milling and Plunge) and gear hobbing process have two critical responses, profile bias which is regarded as Pressure Angle Variation and Lead Bias which is regarded as Helix Angle variation.

Hard groove turning operation is a crucial operation as it ensures smooth gear shifting. Hard Groove turning operation is carried out in three cut cycles as this operation is carried out after carburizing and Induction hardening. For every cut cycle, Speed, feed and Depth of cut are the important process parameters need to be optimized. Butting first cut feed, Butting first cut speed, Butting second cut feed, Butting second cut speed, Butting second cut depth of cut, opposite cut feed, opposite cut speed and OD cutting feed rate are the important process parameters need to be optimized. Hard groove turning process has two critical responses, Cycle time (Productivity measure) and Surface Finish (Quality measure), which needs to be optimized simultaneously.

1.1 Multi Objective function problems in Taguchi method

Taguchi methodology holds good for single objective function problems, but most of the real time problems involved multi objectives, which need simultaneous optimization. So Taguchi method will be combined with some other methods to handle multi objectives Most of the investigations on Taguchi application are on the optimization of single quality characteristic, as the technique was initially designed by Taguchi to
optimize single response variable or Quality characteristic. In multi objective optimization the objective is to simultaneously optimize the all quality characteristics (response variables) of interest. Several approaches were suggested in Taguchi parameter design for handling multi objective optimization such as Quality loss function approach, Weighing average type, competitive parameter optimization method, Principal Component Analysis (PCA), Utility concept approach, Desirability function approach, Grey relational analysis method, Fuzzy combined with Taguchi, etc. This paper aims at reviewing all these approaches in a practical manner.

1.1.1 Quality Loss Function approach

Quality Loss function was used by taguchi to calculate the deviation between the experimental value and actual value. This quality loss function is further converted in to signal–to-noise ratio. There are three type of signal–to–noise ratios available depending on the quality characteristic either smaller is better or Larger the better or Nominal is best. Quality Loss function uses three step methodologies to arrive optimum parametric combination for multi objective function problems.

Step1: Quality Loss function normalization
Step2: Assigning proper weighing factors for each of the normalized quality loss functions.
Step3: Multi response Signal to Noise ratio calculation.

This method has been successfully employed in the past for multi objective optimization of several processes such as drilling, helical gear precision forging, and ductile iron production.

1.1.2 Competitive Parameter Optimization

In competitive parameter optimization, the influence of process parameters on several response variables (quality characteristic) need to be identified separately (not simultaneously) as its first stage. An orthogonal array between identified optimum process parameters can then be proposed for competitive optimization in attaining the multi quality parameters to compromise one or more quality characteristic with other. This method can
be effectively user for competitive parameter optimization in multi quality turning to optimize multi objectives such as tool wear, surface finish and Material removal rate.

1.1.3 Utility Concept

In order to optimize the multiple responses, in which each performance characteristic may not have the same measurement unit, Taguchi design cannot be applied directly. Hence, the evaluations of various characteristics should be combined to give a single value which is called composite index. Such a single composite index represents utility of the product. The overall utility of a product is the sum of utilities of product and process quality characteristics.

Utility concept is successfully employed in multi – objective optimization of different processes such as Electro chemical honing, Laser transformation hardening and free machining of steel by many of the researchers.

1.1.4 Principal Component Analysis

Principal component analysis involves the below mentioned steps for identifying optimum parametric combination for multi objective function problems.

**Step 1:** Normalization of the Quality characteristics (Response variables)

**Step 2:** Correlation between two response variables - Checking

**Step 3:** Principal component score evaluation which involves 3 major steps

- Calculate the Eigen value and the corresponding Eigen vector from the correlation matrix formed by all the existing quality characteristics.

- Principal component scores evaluation for the normalized reference sequence and comparative sequences calculation.

- The principal component is having highest accountability proportion, it can be treated as the overall index for Quality; which is a final index for optimization. The quality loss of that optimization index (compared to ideal situation) is calculated.
Optimal setting is then evaluated by optimizing this quality loss estimate as single function optimization instead of multi objective function optimization by using Taguchi method. PCA is successfully employed by many researchers for multi objective optimization problems in Taguchi method. Researchers used PCA for optimization of End milling parameters and other researchers applied PCA successfully for optimization of plastic injection molding. However in PCA smaller set of uncorrelated principal component variables are derived through transformation of a set of correlated response variables. When more than one principal component is selected trade off to select feasible solution is unknown. Also when the chosen Principal component with only less variation can be explained by total variation, the multi response performance index is not evident enough to replace the multi-response.

1.1.5 Desirability Function Analysis

Desirability function analysis uses five step methodologies to identify optimum parametric combination of multi objective function problems

**Step 1:** Desirability index (di) for the individual corresponding quality characteristics using the formula generate by Derringer and Suich.

**Step 2:** Computation of index called composite desirability (dG). The individual desirability index of all the responses can be joined to form a single value which is called as composite desirability (dG).

**Step 3:** Optimal parameter combination with level identification. The higher composite desirability value corresponds to higher product quality.

**Step 4:** ANOVA to be performed for identifying relative significance of every parameters.

**Step 5:** Optimum condition prediction. Once the optimal level of the design parameters has been arrived, the final step is to predict the quality characteristic and verify the quality characteristics using the optimal parametric levels.

Desirability function analysis coupled with Taguchi method is used by many researchers for optimizing machining parameters for glass fibre reinforced plastic pipes, turning and turning operation of metal matrix composites.
1.1.6 Grey Relational Analysis

In Grey relational analysis, Signal to noise ratios of individual response variables (Quality characteristic) is normalized to a same measurement unit to form grey relational coefficients. After assigning weightage to individual grey relational coefficients, Weighted grey relational grade is identified, which is a single value, a combination of multi response variables, can be optimized easily as single objective function problem using Taguchi design it.

**Step 1:** S/N ratio normalization

**Step 2:** Deviation sequences determination

**Step 3:** Grey relational coefficient calculation

**Step 4:** Determination of weighted Grey relational grade (Multi to Single objective)

**Step 5:** Determination of optimum parameters

The weighted grey relational grade calculated for each sequence is considered as a single objective function optimization problem for further analysis which can be easily carried out using Taguchi PDE. TGRA is successfully utilized and proved by researchers in processes such as EDM, milling of Aluminium, Milling of steel, Metal inert gas welding.

1.1.7 Fuzzy logic combined with Taguchi

In this method individual optimal values are first identified for all individual response variables or Quality characteristics of interest. Results obtained using different quality characteristics always contradict each other. Taguchi method will combine with fuzzy logic model to find the combination of process parameters that optimize the process. Combining experience of experts with semantic inference rules, fuzzy logic system does not need complicated mathematical equations, so it is commonly used in industry.

Many researchers used fuzzy-base Taguchi method to investigate the optimal process parameters that maximize multiple performance characteristics index (MPCI) for hot extrusion of magnesium alloy bicycle carriers.
1.2 Transmission basics and synchronization mechanisms

The engine and transmission system is regarded as heart of vehicle system as it determines power, behavior and fuel economy of any passenger car or commercial vehicle. Gear box performance is usually identified using gear noise while running the vehicle, gear efficiency and gear shifting comfort during changing the gears of a vehicle. In 1920s Synchronizer mechanisms were developed for changing or shifting gears in a smooth manner, in a noiseless method and also without vibrations to provide comfort to driver and with improved durability of gear box.

Transmission systems can be categorized into three classifications

Manual transmissions, where shifting of gears will be done manually
- Unsynchronized Constant mesh transmission
- Synchronized manual transmission

Automatic Transmission, where gear shifting will be carried out automatically
- Planetary automatic transmission
- Dual-Clutch Automatic Transmission
- Mechanically engaged automatic transmission

Continuously Variable Transmission and example of this type is given below
- Electro mechanical Transmission

The following automatic transmission types such as Dual Clutch automatic Transmissions, mechanically engaged automatic Transmissions and manual transmissions used synchronizers to carry out the gear shifting process. However, the mechanisms used in manual transmissions are different and mechanisms used in both the the types of auto transmission are different.

Shift systems in manual Transmissions consist of a shifting mechanism which operates externally that connects gearbox with the driver and a shifting mechanism will be done internally that transmit the force while shifting to the respective synchronizer and
synchronizing mechanism. But in case of Automatic transmissions such as Dual Clutch automatic Transmissions, mechanically engaged automatic Transmissions there will not be any direct connection between synchronizer and the shift lever. Instead of that, the shifting force is directed towards the shifting internal mechanism either hydraulically or electromechanically.

1.2.1 Manual transmissions

Multi-speed gear box transmissions are designed in such a way that all the gears are in constant engagement, running the gears of the individual speeds, even if the gears are not involved in the transmission of power. While a gear is fixedly coupled (most of the cases splined) to the countershift, the idler wheel associated with it can be rotated freely on the main shaft. When we required a specific speed, free wheel has to be attached to the shaft this is the moment, when the process of synchronization starts and synchronizers act. They are positioned between two different types of speeds hence the synchronizer system will be considered as double apart from the idler position they can be chosen between two linked gears.

1.2.2 Synchronization processes theory

Synchronization processes need to be used in order to shifting gears smoothly and to get a good shift feeling, by reducing synchronization time inside the passenger car or commercial vehicle gearbox and the load required to shift the gear by a driver using his hand. They prevent transmission gear box gears from shocking load, noise reduction and gear wear and to make the user feel comfortable while driving and shifting. The main objective of the synchronization process is to reduce the angular speed difference to zero between the gear wheel and rotating shaft. A friction torque is generated with a friction contact between the conical surfaces before the gear is engaged in a gear box through the positive locking for the transmission of Torque
1.2.3 Synchronizer types and its components

Different types of synchronizers are designed for gears in parallel shafts, most common types are given below

- Clark type, which is also called as pin type
- Baulkring-type
- Lever-type

Pin type is commonly used in transmissions. Baulkring-type is used in manual transmissions or gear boxes in either of the strut less or strut types. In the lever type the lever is connected in the inner circumference of the sleeve and it is arranged between synchronizing ring and synchronizer hub. As the sleeve is moving towards the position of engagement the lever pressed the synchronizer ring by the principle of leverage towards the gear.

Fig 1.1 Exploded view - Single cone synchronizer [Lovas et al. (2006)]
**Synchronizer hub**

Synchronizer hub is splined to input shaft or output shaft. In input and output shaft roll forming operations are carried out and in hub internal broaching operations were carried out and hub is press fitted to the output shaft or input shaft.

**Synchronizer sleeve**

Sleeve have groove diameter on its periphery where fork will engage and used to shift the sleeve. It has internal splines which is carried out by rough broaching, Internal rolling and finish broaching that should be in constant mesh with the hub which has external splines, so sleeve is restricted to move in axial direction for going to engagement position from neutral position.

**Synchronizer ring**

Internal teeth of the sliding sleeve in interlocked with the external teeth of a synchronizer ring. It has a conical surface which is fitted with the clutch body ring’s conical surface. It generates the friction torque which is needed to synchronize the output and input shafts. The cone surfaces are made with grooving thread like patterns and axial grooving to prevent the hydrodynamic oil film formation and to minimize force increase.

**Clutch gear with cone**

It matches the gear speed with Synchro hub speed. It is either fitted by press fitting or by laser welding with the gear wheel. The external teeth will have chamfer on either sides of the teeth interlock with the chamfers (made by V Chamfering operation) on the internal teeth of shifting sleeve.

**Gear wheel**

It is connected to the main shaft with the help of a needle bearing to secure relative rotation between both components against the axial movement relative to the connected shaft. It can also be fitted on the shaft with a smooth surface and with proper lubrication (hydrodynamic bearing).
**Strut key**

It is ball with spring load or roller fixed in a cage. It is arranged on the outer circumference of the synchronizer body, assembled between the outside groove in synchro hub and the inner groove made by key way milling in sleeve. So it can be rotated with the hub and it can move axially with the shifting sleeve. This component is used for the process of pre-synchronization. Pre-synchronization means load to be generated in synchro ring for performing the synchronization process. In addition to that, it maintains the sleeve (which is in sliding) in a center position on the hub between both of the gear wheels and for limiting the axial force.

Often, the synchronizers are composed by three of strut keys; if it is three then it is arranged at 120°. For large synchronizers, four strut keys are needed which will be arranged at 90°. In heavy vehicle gearboxes there is a requirement of increasing the synchronizing torque for a given effort during shifting or even in order to minimise it, especially when downshifting into low gears due to larger gear reduction ratio.

**1.2.4 Synchronization phases**

Depending on the synchronizer designs the number of phases will be varied, but there will not be any change in the working method or principle.

Normally synchronization process for engaging a gear from its neutral position will be done in eight major steps which is explained below in detail

First free fly

Initial and final position of this phase is explained in figure 1.2a. The sleeve axial movement will be from neutral position without any mechanical resistance and make the detent face has to be in contact with the synchro ring face. In this phase the axial force is low and axial velocity is high

Start of angular velocity synchronization

Frictional torque is generated by detent force which makes the ring to rotate within the available space in the region of the synchro hub, the oil film available between cone surfaces is removed and the spline chamfers of the sleeve and spline chamfers of
synchronization ring get the maximum contact area and huge coefficient of friction. This phase is initial and final position is illustrated in Figure 1.2a (right) and 1.2b.

Fig 1.2 Spline position during synchronization process [Lovas et al. (2006)]
Angular velocity synchronization

This phase is explained in Figure 1.2b. In this phase continues till synchro ring. Gear and sleeve will have same angular velocity. Otherwise, the equilibrium of tangential forces and axial forces will be applied on the spline chamfers to prevent the gear changing process continuation.

Turning the synchro ring:

Synchro ring will be turned by the displacement of sleeve and the clutch gear while the chamfers will remain in contact (Figure 1.2c)

Second free fly

The sleeve moves forward axially until spline chamfers of the clutch gear is approached (Figure 1.2d)

Start of the second bump

To maintain the axial velocity of the sleeve an increase of axial force is required, which breaks the oil film between the chamfer surfaces. The oil is discharged this axial force has a higher increment. This will stop only if the tangential force component on the chamfers is enough to turn the synchro ring, stuck in the cone (Figure 1.2e).

Turning the gear

The axial force needed to turn the gear depends on the relative position of the gear splines and sleeve splines which is explained in Figure 1.2f and Figure 1.2g.

Lovas et al. (2006) explained the sleeve synchronizer working process in detail. Even though the process is the same for both upshift and downshift, there will be difference in changing times which explained by Lovas et al. (2005).

In chapter 1, a brief description about current industrial scenario and criticality of sleeve synchronizer is crisply presented which will be elaborated in further chapters. Most of the real time problems have multiple objectives, needs simultaneous optimization, so methods available to multi objective function problems in Taguchi method is also
elaborated in chapter 1. Sleeve synchronizer, being a critical part in manual transmissions, Transmission basics, synchronization mechanisms, synchronizer process theory, synchronizer types and its components and synchronization phases are explained in detail in this chapter 1.

In chapter 2, Literature review is discussed elaborately and research gap is explained in detail and the significance of the research is also discussed. In chapter 3, based on the research gap, the identified problem is clearly defined and objective of the problem is also stated very crisply at initial stage. Function of Sleeve synchronizer and processes involved in manufacturing a sleeve and critical quality characteristics associated with the manufacturing of sleeve synchronizer has explained in detail with clear pictorial illustration. Based on the critical characteristics associated with sleeve synchronizer manufacturing, critical operations are identified and necessity and objective of the research is clearly stated.

In chapter 4, three methodologies adopted to derive the solutions are explained very clearly. First Taguchi methodology, which is a Fractional factorial design method which uses signal to noise ratio, linear graphs, orthogonal array and ANOVA for optimizing any complicated problem with lesser number of experiments. As Taguchi method is initially developed for single objective function problems, need arises to select suitable method to convert multi objective function problems in to single objective function problems. Grey relational analysis which is based on Grey theory elaborated in chapter 4 and finally RABAL algorithm which uses 12 step guide lines and 3 rules, for getting results right first time for the problems that are optimized through Taguchi parameter design.

In Chapter 5, Sleeve synchronizer hard turning process, controllable factors and its associated levels, noise factors, quality characteristic are explained in detail and hard turning process is optimized through Taguchi methodology. Multiple objectives cycle time and surface roughness are selected for optimization so grey relational analysis is first used to convert multi objective functions in to single grey relational grade which is further optimized using Taguchi parameter design as single objective function problem. Identified optimum parametric combination is further validated using confirmation tests in real time.
production environment. The Hurdles faced during hard turning optimization using Taguchi and Grey relational analysis was explained in detail

In Chapter 6, RABAL Algorithm is explained in detail with sleeve synchronizer hard turning cycle time experiment and Gear hobbing which is identified as one of the most critical operation in gear manufacturing process is optimized using Taguchi methodology and RABAL Algorithm. Results are documented

In Chapter 7, Overall conclusion is presented as a separate topic and explained how the objective of the research is achieved.