CHAPTER 1

INTRODUCTION

1.1 STRATEGY OF INTEGRATED PROCESS PLANNING

The manufacturers of today are producing more customized products of high quality, in smaller series, with shorter lead-time, and at reduced costs. In manufacturing, process planning can be defined as the function, which establishes the sequence of the manufacturing processes to be used in order to convert the raw material into the finished part, activities with the optimal sequenced process, optimal process parameters and the selection of the manufacturing resources. In a computer integrated manufacturing (CIM) environment, Computer Aided Process Planning (CAPP) integrates the Computer Aided Design and Manufacturing stages. The recent applications of knowledge based Computer aided process planning (CAPP) were capable of generating plans through the integration of design and manufacture with the other stages of the product development.

Computer aided process planning (CAPP) systems are broadly classified into variant and generative type. The variant type that evolved from manual process planning is based on the group technology where the plan is generated by retrieving a plan from a similar part, following which small modifications are done. Here, the process planner retrieves the plan for similar components, using the coding and classifications of parts, and then edits the retrieved plan to create a variant to suit the specific requirements of the component being planned. This technique is based on the principle, that geometrically and technologically, similar parts have similar process plans.
Computers are used to assist in identifying similar plans, retrieving them and then editing them, according to the geometrical difference. Here, the parametric information between the technological operations and the part feature does not exist.

Computer aided process planning (CAPP) is generated by decision logic, formulas, algorithms and the geometrical data of the part to be produced. The process plan is generated from the information available in the manufacturing databases, and a framework is created (Chang 1985). It can be concisely defined as a system which automatically synthesizes a process plan for a new component. The generative approach envisions the creation of a process plan from information available in a manufacturing database without human intervention. Upon receiving the design model, the system is able to generate the required operations and operation sequence for the component (Tien-Chien Chang and Richard A.Wysk 1985).

Knowledge of manufacturing has to be captured and encoded into computer programs. By applying decision logic, a process planner’s decision-making process can be imitated. Other planning functions, such as machine selection, tool selection, process optimization, etc., can also be automated using generative planning techniques (Chang 1985). There is no fixed representation or procedure that can be identified with generative process planning. The general trend is to use a solid model CAD-based input and expert system or an object-oriented planner construct.

In the present work, an attempt has been made to develop an integrated process planning system for the manufacture of the leaf spring assembly. The proposed generative CAPP module maps the design features into manufacturing features. This work describes the implementation of an integrated CAPP system for the design and manufacture of feature-based leaf spring parts.
1.2 LEAF SPRING AND ITS ASSEMBLY

The suspension system in automobiles is a very important component in deciding vehicle drive comfort and the stability of the vehicle. As the tyre revolves, the suspension system is in a state of dynamic balance, continuously compensating for and adjusting to changing driving conditions. The components of the suspension system perform basic functions such as maintaining the correct vehicle ride height, reducing the effect of the shock forces, supporting the vehicle weight, carrying the driving torque, etc (Lupkin et al 1989).

In a vehicle, the leaf spring is located between the axle housing and the vehicle chassis, and it can be considered as a simply supported beam with a concentrated load at the center. The bending moment is the maximum at the center of the spring, and it reduces towards the ends, and hence, the spring selection is varied from a maximum at the center to a minimum at the ends. In a conventional multi-leaf steel spring construction, this is achieved by assembling a number of leaves of variable length in such a way, that the thickness is maximum at the center and reduces towards the ends.

The leaves are placed one over the other, and are held together by clamps and a bolt at the center. The leaf that extends the full length of the spring is known as the master leaf. The ends of the master leaf are formed into loops which are called eyes. Each metallic leaf has a hole at the center through which the spring bolt passes to hold the leaves together. Spring clips are used to hold the outer ends of the shorter leaves with the master leaf. When the leaf spring bends during operation, the leaves rub against one another. This rubbing produces frictional resistance due to leaf flexing. If the inter laminar friction is high due to the absence of lubrication, the spring will stiffen considerably. Leaf springs are sometimes fitted with inserts, such as
rubber waxed cloth or oil bronze disks between the leaves, in order to reduce inter laminar friction (Sternberg 1976).

A leaf spring commonly used in automobiles is semi–elliptical assembly. It is built with number of plates. The leaves are usually given an initial curvature or cambered, so that they will tend to straighten under load. The leaves are held together by means of a band shrunk around them at the center, or by a bolt passing through the centre. Since the load exerts stiffening and strengthening effect, the effective length of the spring for bending will be the overall length of the spring minus the width of the band. In the case of the central bolt, two thirds distance between the centers of the u- bolt should be subtracted from the overall length of the spring, in order to find the effective length. The spring is clamped to the housing by means of u- bolts (Nakhaie Jazar (2008), Shigley (2008).

The longest leaf known as the main leaf or master leaf has its ends formed in the shape of an eye through which the bolts are passed to secure the spring to its supports. Usually the eyes, through which the spring is attached to the hanger or shackle, are provided with bushings of some antifriction material, such as bronze or rubber. The other leaves of the spring are known as the graduated leaves. In order to prevent digging in the adjacent leaves, the ends of the graduated leaves are trimmed in various forms. The master leaf has to withstand vertical bending loads as well as the loads due to the slanting of the vehicle while taking a turn (Nakhaie Jazar (2008), Shigely (2008). Due to the presence of the stresses caused by the loads, it is usual to provide two full length leaves and the rest graduated leaves.

Rebound clips are located at intermediate positions in the length of the spring, so that the graduated leaves also share the stresses borne by the full length leaves when the spring rebounds. The general leaf spring assembly is shown in the Figure 1.1.
1.2.1 Types of Leaf Springs

Several designs of leaf springs are employed in automobiles. These are

- Semi-elliptical and quarter-elliptical (or cantilever) type leaf springs.
- Longitudinally and transversely located type leaf springs.
- Tapered and progressive (or helper) type leaf springs.

Among these, the semi-elliptical leaf springs are most common.

1.2.1.1 Semi-elliptical leaf spring

The leaf spring is made-up of a number of steel leaves. Each leaf is of a different length, but with equal width and thickness. The uppermost longest leaf having bushes at its two ends, is called the master leaf. The ends are directly connected to the side member of the vehicle frame.

1.2.1.2 Quarter-elliptical leaf spring

This is also known as the cantilever type leaf spring, since it’s one of the end is fixed on the side member of the frame while the other end is
freely connected to the front axle. In such springs the camber is provided on the upward side so that the leaves tend to straighten when the front axle beam is subjected to shock load.

1.2.1.3 Transversely mounted semi-elliptical inverted leaf spring

In this arrangement, a semi-elliptical leaf spring is mounted transversely along the width of the vehicle. The springs are placed, so inverted that the longest leaf is located at the bottom. The speciality of this arrangement is the use of two shackles. The rolling tendency of this type leads to its unsuitability for vehicles.

1.2.1.4 Taper leaf spring

The leaf springs discussed above are prepared with leaves of constant cross-section throughout their lengths. Such leaves may be called conventional leaves, and the springs as conventional leaf springs. The taper leaf spring consists of a single leaf having a varying cross-section. Such a spring is termed as a taper leaf spring or taperlite spring. This is of a parabolic profile. This type of spring is pre-stressed to withstand higher stresses.

1.2.1.5 Helper spring (progressive spring)

Many heavy commercial vehicles are provided with an auxiliary leaf spring in addition to the main leaf spring. This is done, so as to combine the soft suspension with adequate resistance to heavy loads. It is mounted above the main leaf spring. The helper spring is cambered while the mainspring is of a flat type.

The helper spring performs no functions until the main spring is loaded beyond the flat stage (acquiring a negative camber). When the vehicle is lightly loaded, the load is borne by the main spring only. But in the case of
a heavy load, the helper spring comes into operation and shares the load on the vehicle. In that case, the upward deflection of the main spring transfers the load to the helper spring. The combination of the helper spring and the main spring is known as a progressive spring.

### 1.2.1.6 Three quarter, full elliptic type leaf springs

The three quarter elliptical spring is clamped to the axle in the usual manner. One end is bolted to the frames while the other being rigidly held by spring clips to the frame. A spring shackle holds the two members of the spring together, allowing enough movement to compensate for the elongation of the main leaves when the spring is compressed. The full elliptical spring is attached rigidly to both: the axle and the frame, in the usual manner. Spring shackles are not necessary, since both the top and bottom members will elongate by the same amount when compressed. Figure 1.2 shows the types of leaf springs used in vehicles.

![Figure 1.2 Types of Leaf Springs (JAI 2002)](image-url)
1.2.2 Spring Material Characteristics

From the consideration of vehicle dynamics, it is required to minimize the unsprung weight of a vehicle. Any amount of weight reduction achieved in the unsprung weight will have a direct bearing on the fuel efficiency. It is due to this reason, that the weight reduction in automobiles is mainly aimed at parts such as the leaf spring, drive shaft and road wheel, which constitute the unsprung weight (SAE 1996). Leaf springs constitute about 20-25% of the unsprung weight. Several studies have revealed that the fuel savings in vehicles due to weight reduction is estimated to be about 0.26 gallons for every pound weight reduction, obtained for the life period of the vehicles (SAE 1996).

Further, the energy absorbed by the leaf spring is stored in the form of elastic strain energy. The elastic strain energy absorbed, is equal to the work done by the external load, when the leaf spring moves through a distance equal to the deflection in the spring. Therefore, the material used for the making of the leaf spring should have the maximum elastic energy capacity.

The energy absorbed has to be displaced faster, so that the spring does not continue to oscillate after the initial deflection. The energy release rate depends on the damping characteristics of the spring material. Hence, in order to arrest spring oscillation after the initial deflection, the spring material should have a good damping. If the damping of the spring is not adequate, external damping devices, such as shock absorbers, are used along with the springs. Also, since the leaf springs are subjected to fatigue loading, the spring material should have good fatigue strength. The optimum properties of the truck leaf spring are with respect to the influence of amplitude and frequency. The desired characteristics of an ideal automotive suspension leaf spring material can be summarized as follows:
1) High strength to weight ratio
2) High elastic strain energy storage capacity
3) High fatigue strength
4) Good damping characteristics
5) Good corrosion resistance

1.2.2.1 Spring Loading

The Suspension springs experience three loading conditions. Initially, the weight of the vehicle alone acts under the unloaded condition. Subsequently, the weight of the loaded vehicle acts on the spring. Finally, the dynamic or inertia load will act, as the vehicle moves over uneven road surfaces. The suspension system has to provide the same quality of ride under all the three load conditions. Vehicles, such as trucks, have a high ratio of loaded to unloaded weight. These vehicles require a variable rate suspension spring, to minimize the change in ride heights, under varying load conditions. The variable rate is accomplished in the leaf springs by attaching an auxiliary leaf spring to the main leaf spring. As the spring deflects to a particular height, the auxiliary spring gets engaged along with the main spring, and increases the base spring rate.

1.2.2.2 Spring Materials

The material used for the leaf spring is usually a plain carbon steel having 0.9 to 1% carbon. According to Indian standards the recommended materials are (Robert C. Creese 1999, JAI 2002):

1. For automobiles: 50Cr1, 50Cr1V23, and 55Si2Mn90, all used in the hardened and tempered state.
2. For rail road springs: C55 (water-hardened), C75 (oil-hardened), 40Si2Mn90 (water-hardened) and 55Si2Mn90 (oil-hardened).

3. The physical properties of some of these materials are given in the Table 1.1. All the values are for the oil quenched condition and for single heat only.

Table 1.1 Physical properties of materials commonly used for leaf springs

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Material</th>
<th>Condition</th>
<th>Ultimate tensile strength (MPa)</th>
<th>Tensile yield strength (MPa)</th>
<th>Brinell hardness number</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>50Cr1</td>
<td>Hardened and Tempered</td>
<td>1680-2200</td>
<td>1540-1750</td>
<td>461-601</td>
</tr>
<tr>
<td>2</td>
<td>50Cr1V23</td>
<td></td>
<td>1900-2200</td>
<td>1680-1890</td>
<td>534-601</td>
</tr>
<tr>
<td>3</td>
<td>55Si2Mn90</td>
<td></td>
<td>1820-2060</td>
<td>1680-1920</td>
<td>534-601</td>
</tr>
</tbody>
</table>

1.3 LEAF SPRING MANUFACTURING

The lists of processes involved in leaf spring manufacturing are as follows (JAI 2002):

1. Shearing of a flat bar
2. Center hole punching
3. Eye forming for the main leaf
4. Taper rolling and wrapper forming for the second leaf
5. Eye width grinding
6. Edge grinding
7. V-cutting
8. Rivet hole drilling
9. Heating, Cambering and Quenching
10. Tempering
11. Shot peening
12. Painting
13. Eye reaming
14. Riveting
15. Bush fitting
16. Bush reaming
17. Assembly

The description of each process is given below.

1.3.1 Raw material

Generally leaf springs are made of various fine grade alloy steel. The most commonly used grades of steel are 55 Si 7, 60 Si Cr7, 50 Cr V4. The others are En 45 A, 65 Si 7, 55 Si Cr 7, 65 Si cr7, En 42 60 s 87. Usually the width of the raw material varies from 40-100 mm and the thickness varies from 4 to 20mm.

1.3.2 Shearing

Shearing is used for the cutting of the sheet metal, primarily to produce the initial work piece, called a blank, and for other sheet metal processes. Shearing is generally done by means of a guillotine shears. Sheet metals with different specifications are used in the manufacture of the leaf spring. The shearing process is one of the most important, frequent and unavoidable processes in leaf spring manufacturing.
The Various steps involved in the shearing process are:

1. Moving the material towards the machine by the roller conveyor
2. Measuring and marking the required length of the material to be cut, by adjusting the stopper setting.
3. Moving the material in to the marked area of the machine
4. Application of the load on the raw material by pressing the foot operated lever
5. Obtaining the required length of the material.

1.3.3 Center hole punching

A hole at the center of each leaf is provided to hold all the plates together. For this, a punching operation is performed. A mechanical power press is used for making the hole at the centre. Based on the diameter of the hole to be produced, the required punch is connected to the press. The work piece is placed in the required position for punching. The foot operated lever is activated to execute the punching process.

1.3.4 Eye forming on main leaf

The master blade is heated at its two ends for eye formation; this is done to attach the leaves to the frame of the vehicle. The heating is done in an end-heating furnace at a temperature of 1000°C. The heating is done only at the ends so that it will be easy to bend the ends. Furnace oil and the air are used for heating the furnace. The furnace is first allowed to heat freely for 45 minutes. The main leaves are placed in the furnace such that one of the ends for a length of 180 mm is heated (JAI 2002). After reaching the required
temperature, the hot end is bent to form the eye in two stages. The same process is repeated for the other end.

### 1.3.5 Taper rolling and wrapper forming for second leaf

The procedure of preparing the eye ends for the first (main) leaf is followed for the second leaf also. But the difference is, prior to the eye formation of the hot leaf the end is subjected to a tapering process. The second leaf end is kept in a cam based roller to form a tapered profile. Then the end is trimmed in some cases to control the curve length. After completing the trimming process, the eye will be formed, which reflects and supports the first leaf eye.

### 1.3.6 Eye width grinding

The hot processed eyes at both ends of the leaves are ground width wise, to obtain a regular surface, which helps in the proper alignment of the leaf spring assembly with the chassis.

### 1.3.7 Edge grinding

The edges of all the leaves (except the first and second leaves) are ground for 0.1 mm to 0.5 mm, to remove the unwanted materials, which helps in the controlling of the interleaf gap of the leaf spring assembly.

### 1.3.8 V-cutting

The edges of all the leaves (except the first and second leaves) are punched by a v-shaped blade to form the v shaped profile, which helps a part of the leaf spring assembly.
1.3.9 Rivet hole drilling

Apart from the center hole, the rivet hole is also drilled in the leaf spring. The rivet hole is used for riveting on the leaf, to fix the clips as per the requirement.

1.3.10 Heating, Cambering and Quenching

After completing the individual processes, all the leaves are heated to a temperature of 800°C to 1000°C in a furnace. The hot leaves from the furnace are passed through a roller conveyor to reach the curving machine. After reaching the curving machine, the hot leaf is subjected to a bend by a die to form the elliptical shape, which defines the camber distance for the individual leaf. Then the leaves are quenched in an oil chamber (JAI 2002).

1.3.11 Tempering

Quenched steel, while very hard and strong, is too brittle to be useful for most applications. This method is called tempering. For most steels, tempering involves heating to between 250 and 500 °C, holding at that temperature (soaking) for an appropriate amount of time (in the order of seconds or hours), and then cooling then slowly over an appropriate length of time (minutes or hours). This heat treatment results in higher toughness and ductility, without sacrificing all the hardness and tensile strength gained from rapid quenching. Tempering balances the amount of hard martensite with ductile ferrite and pearlite. The purpose of applying the tempering process is to improve the ductility and toughness, reduce the hardness, and to increase the percentage of elongation and relieve the residual stresses Aggarwal et al (2005).
1.3.12 Shot peening

It is one of the hazardous processes, in which the leaves are peened in a closed chamber to control the camber and the residual stresses.

1.3.13 Painting

After the completion of the individual processes, the leaves are painted individually, black in color. The leaf springs are placed in the painting chamber and the required paint is sprayed over them with the help of a spray gun.

1.3.14 Eye reaming

In the main leaf, the eye is prepared through the reaming process to fix the bush.

1.3.15 Riveting

To fix the clips, the riveting process is carried out for selected leaves as per the design. Rivets are used for holding the clips and the leaf springs together.

1.3.16 Bush fitting

The metal bush is fixed with the reamed eyes of the main leaf. It is used to protect the inner surface of the eye diameter and proper fitting with the chassis.

1.3.17 Bush reaming

As a finishing process, the eyes with the bushes of the main leaf are reamed.
1.3.18 Assembly

In this section the leaf springs along with the main spring are fitted together with the help of the center bolt and nut, clips, side bolts and nuts, and lock washer. Clips are the devices, used for holding the leaf springs together. Generally 4 clips are used for 12 plates, and 2 clamps for 7 leaf plates. The clamps are arranged at an equal distance from the centre. Bolts and nuts of different sizes are used in the holes provided on the leaf springs to hold them tightly.

The inspection and testing is carried out on the assembly to check the quality, and performance of the leaf springs. After inspection, the leaf springs with good quality and performance are allowed to stock storage.

1.4 APPLICATION OF AN INTEGRATED PROCESS PLANNING IN THE MANUFACTURE OF THE LEAF SPRING ASSEMBLY

The leaf spring is a widely used vehicle component which is designed and manufactured in the traditional way. This results in an improper coordination at the different stages and the quality problems in the leaf spring development. Through the integration of the design and manufacturing of the leaf spring, the objectives can be achieved (Aldakhilallah et al 1998).

The present work presents an approach to integrate the design and manufacturing of the leaf spring environment. The developed system includes three basic modules, such as the Feature-Based Design, the Factory Environment Module and the Parameter Optimization Module. The first module, Feature Based Design, offers the solid modeling of the part. For the interactive transformation of the feature data, a user friendly graphical interface is developed. The integrated features are specified by the numerical
values through the GUI. This design-by-features approach is used to derive the solid model of the leaf spring assembly. The design process is carried out through the application programming interface in the computer aided design system solid works 2010. The model is then validated. The various steps of the procedure are the creation of the three-dimensional model for each feature, storing the feature information in the database, validation of the features for any attributes, selection of operations, machines, cutting tools, etc., (assigned in the programme), and the generation of the optimal process parameters.

The present work is aimed as the third module, the modeling and optimization of the process parameters in the leaf spring manufacturing, using the Taguchi based Grey Relational Analysis and Simulated Annealing method. The experiments were carried out for the shearing, hole punching, eye forming and cambering processes, using Taguchi’s orthogonal array. The performance of each process is evaluated by using performance indicators, such as squareness, length, hole diameter, hole offset, eye diameter, eye end gap, eye twist, camber distance and hardness number. Statistical analysis and optimization are important tools used for modeling and multiple objective optimization for achieving the selected objectives. The nonlinear regression model has been generated based on the Grey Relational Grade and factors of the selected processes. This nonlinear regression model is subjected to a Meta heuristic algorithm, the Simulated Annealing Algorithm, to obtain near global optimal solutions.

With the above procedure, the feature based design environment integrates the shop floor and then the report is generated. The generated process plan contains the feature data, manufacturing resource data, optimal parameters of the processes and their sequences.
1.5 PROCESS PARAMETER OPTIMIZATION

Taguchi of Nippon Telegraphes and Telegraph Company, Japan, developed a method based on “Orthogonal Array” experiments, which gives much reduced “variance” for the experiment with the “optimum settings of the control parameters”. “Orthogonal Arrays” (OAs) provide a set of well balanced (minimum) experiments and Taguchi’s Signal-to-Noise ratios (S/N), which are log functions of the desired output, serve as objective functions for optimization, and help in data analysis and prediction of the optimum results. Taguchi’s response to quality differs rather greatly from the goalpost philosophy of the European and American practices. The Japanese implementation of Taguchi’s concept seems to work on the principle, that a product should be designed with the minimum loss, and as close to the optimum value as is possible. This would result in the product being manufactured with regard to its life cycle and customer satisfaction, right from the design stages. It would also mean that less repair work would be required in the long run.

Taguchi’s main objectives are to improve the process and product design through the identification of controllable factors and their settings, which minimize the variation of a product around a target response. By setting the factors to their optimal levels, a product more robust to changes in operation and environmental conditions can be manufactured. Taguchi removes the bad effect of the cause rather than the cause of a bad effect, thus obtaining a higher quality product.

1.5.1 Production Process Design (Off-Line Quality Control)

Taguchi addresses quality in two main areas: off-line and on-line. Both these areas are very cost sensitive in the decisions that are made with respect to the activities in each. Offline quality control refers to the
improvement in the quality of the product and process development stages. On-line quality control refers to the monitoring of the current manufacturing processes to verify the levels of quality produced. The most important difference between a classical experimental design and a Taguchi-method based robust design technique is that, the former tends to focus solely on the mean of the quality characteristic, while the latter considers the minimization of the variation of the characteristics of interest. Although, the Taguchi method has drawn much criticism due to several major limitations, it has been able to solve single response problems effectively (Taguchi 1990).

Assuring functional quality requires finding ways to reduce the effects of all three types of noise. The most important means is through a three-step design process, an aspect of off-line quality control involving:

1. System design (or primary design)
2. Parameter design (or secondary design)
3. Tolerance design (or tertiary design)

1.5.1.1 System design (Primary design)

System design (or primary design) is the functional design stage that focuses on the pertinent technology. System design requires technical knowledge and extensive experience in an area of specialization, to initially design or specify the process or product.

1.5.1.2 Parameter design (Secondary design)

Parameter design (or secondary design) provides a means both of reducing the cost and improving the quality by making an effective use of the experimental design methods. This involves the determination of the parameter values that are least sensitive to noise. When the goal is to design a
process or product with high stability and reliability, the parameter design is the most important step, in which functional non-linearity is used to the best advantage. This is also the step, in which the combination of the parameter levels that reduces the effect of noise, is sought. It is the central step in robust designing and the answer to the requirement to design a product or process, that exhibits high reliability under a wide range of conditions, despite the use of inexpensive, highly variable materials and parts that will easily deteriorate.

1.5.1.3 Tolerance design (Tertiary design)

Tolerance design (or tertiary design) is a means of controlling factors, which affect the target value by using higher grade components, and inevitably increasing the cost. After the system has been designed (through system design) and the nominal mid-values of its parameters determined (through parameter design), the next step is to set the tolerances of the parameters (through tolerance design). Noise factors as well as system parameters are considered in a design of experiment, to determine the extent of their impact on the output characteristics. Narrower tolerance must be given to noise factors that will have the greatest influence on the output characteristics.

1.5.2 Multi Response S/N Ratio

Historically, the objective of quality control has been to control functional variation and its related problems. However, since no method of the quantitative evaluation of quality or quality loss has been established, the problems of quality control and their resolutions have usually been treated subjectively. The objective of Taguchi’s Quality Loss Function (QLF) is the quantitative evaluation of quality loss due to functional variation. Taguchi recommends the achievement of a robust process or product design. A robust process or product is one, whose response is least sensitive to all noise
factors. The aim is fulfilled by considering the “signal-to-noise” ratio (S/N ratio) as the measure of performance which is supported by mathematical analysis. However, each product or process performance characteristic would have a target or nominal value. A robust design reduces the variability around this target value and marks any departure from that target value as a loss function. According to Taguchi, a quadratic loss function can meaningfully approximate the quality loss in most situations. Quality loss is the cost incurred after the sale of a product, whose quality characteristic deviates from the target value. However, a large number of different S/N ratios have been defined for a variety of problems (Taguchi 1990).

A quality characteristic is the objective of the interest of a product or process. It may also be called a functional characteristic. Generally, any quality characteristic will have a target. There are three types of targets:

1. The Nominal-the-best
2. The Smaller-the-better
3. The Larger-the-better

1.5.2.1 The Nominal-the-best

The nominal-the-best characteristic is a measurable characteristic with a specific user-defined target value given in equation 1.1. In the nominal-the-best type of problems, the quality characteristic is that it is continuous and non negative; it can take any value from 0 to $\infty$. Its target value is non-zero and finite. When the mean becomes zero, the variance also becomes zero. Additionally, an adjustment factor can be used to move to the target.

$$S/N \text{ Ratio } (\eta) = 10 \log_{10} \left( \frac{\mu^2}{\sigma^2} \right)$$  \hspace{1cm} (1.1)
Where  \( \mu = \frac{y_1 + y_2 + \cdots + y_r}{r} \)

\[ \sigma = \sum_{i=1}^{r} \frac{(y_i - \bar{y})^2}{r-1} \]

where  \( r \) = Number of replications. \( y_{ij} \) = Observed response value.  \( i = 1, 2...n; j=1, 2...k; \)

It tries to minimize the mean squared error around a specific target value. Adjusting the mean to the target by any method renders the problem a constrained optimization.

1.5.2.2 The Smaller-the-better

The smaller-the-better characteristic is a non-negative measurable characteristic and a continuous one; that is, it can take any value from 0 to \( \infty \). Its most desired value is zero. These problems are characterized by the absence of a scaling factor or any other adjustment factor.

\[ S/N \text{ Ratio } (\eta) = -10 \log_{10} \left( \frac{1}{r} \sum_{i=1}^{r} y_{ij}^2 \right) \]  (1.2)

Equation 1.2 is used for the smaller-the-better type problem, where a minimization of the characteristic is intended.

1.5.2.3 The Larger-the-better

Here, the quality characteristic is continuous and non-negative; that is, it can take any value from 0 to \( \infty \). Its target value is non-zero and, ideally, as large as possible. These larger-the-better problems can be transferred into the smaller-the-better type problems, by considering the reciprocal (inverse) of the quality characteristic and the equation given in 1.3.
\[
S/N \text{ Ratio } (\eta) = -10 \log_{10} \left( \frac{1}{r} \sum_{j=1}^{r} \frac{1}{y_{ij}^2} \right)
\]  

(1.3)

where \( r = \) number of replications.

The above quality characteristic is applied to problems, where the maximization of the quality characteristic of interest is sought. This is referred to as the larger-the-better type problem.

The application of the design-of-experiments (DoE) requires careful planning, prudent layout of the experiment, and an expert analysis of results. Taguchi has standardized the methods for each of these DoE application steps. This approach in finding factors that affect a product in a DoE can dramatically reduce the number of trials required to gather the necessary data. Thus, the DoE using the Taguchi approach has become a much more attractive tool to practicing engineers and scientists. The original Taguchi method is applied to optimize a single quality characteristic. However, most of the products/processes have several performance characteristics, and hence, there is a need to obtain a single optimal process parameters setting. Several modifications are suggested to the original Taguchi optimization technique, for multi performance characteristics optimization.

The optimal factor-level combination, determined using these procedures, may result in small quality losses associated with some responses, but very large losses associated with others, even if the average quality loss is sufficiently small. Sometimes it cannot be accepted in such a result of optimization. Some more methods for optimizing several responses have been developed.

A methodology is presented for optimization, within the framework of Taguchi’s methodology, using the Response Surface Methodology (RSM),
and the dual response approach (Erol Kilickap 2010). A nonlinear programming solution, i.e., the Generalized Reduced Gradient (GRG) algorithm, can lead to better solutions, than those obtained with a dual response approach (Narender Singh et al 2004). In the present work an attempt has been made to optimize multi-responses, using Taguchi’s quadratic loss function. A systematic procedure viz the application of the fuzzy set theory has been developed, to optimize multi-response production processes. From the literature, the multiple responses were optimized by applying various methods with Taguchi’s concept, such as the principal component analysis, artificial neural network (Tatjana V. Sibalija and Vidosav D. Majstorovic 2010), the VIKOR method from Multi Criteria Decision Making (MCDM), data envelopment analysis, multi response signal-to-noise ratio, Desirability function analysis and Goal-programming approach Lee-Ing Tong et al (2007), Kai et al (2004).

This research work illustrates the application of the Taguchi method with the Grey Relational Analysis and the Simulated Annealing concept, for optimizing multiple quality characteristics.

1.5.3 Simulated Annealing Algorithm

The Simulated Annealing Algorithm (SAA) is a random-search technique which exploits the analogy between the way in which a metal cools and freezes into a minimum energy crystalline structure (the annealing process), and the search for a minimum in a more general system; it forms the basis of an optimization technique for combinatorial and other problems.

The simulated annealing algorithm was developed in the mid 1970s by Scott Kirkpatric, along with a few other researchers, and Simulated Annealing was developed in 1983 to deal with highly nonlinear problems. Simulated annealing simulates the actual process of annealing. The
Simulated Annealing approaches the global maximization problem by using a metallurgical process of heating up a solid and then cooling it slowly until it crystallizes. The atoms of this material have high energies at very high temperatures. This gives the atoms a great deal of freedom in their ability to restructure themselves. As the temperature is reduced the energy of these atoms decreases. If this cooling process is carried out too quickly, many irregularities and defects will be seen in the crystalline structure. The process of too rapid cooling is known as rapid quenching. Ideally, the temperature should be decreased at a slow rate. A slower fall to the lower energy rates will allow a more consistent crystalline structure to form. This more stable crystal form will allow the metal to be much more durable. Simulated annealing seeks to emulate this process.

The simulated annealing algorithm begins at a very high temperature, where the input values are allowed to assume a great range of random values. As the simulation progresses, the temperature is allowed to fall. This restricts the degree to which the inputs are allowed to vary. This often leads the simulated annealing algorithm to a better solution, just as a metal achieves a better crystal structure through the actual annealing process. It has been proved that by carefully controlling the rate of cooling of the temperature, the Simulated Annealing can obtain the global optimum. However, this requires infinite time. Fast annealing, and very fast simulated re-annealing (VFSR) or adaptive simulated annealing (ASA) are each, in turn, exponentially faster, and overcome this problem. The strengths and weakness of simulated annealing are as follows.

**Strengths**

- Simulated annealing can deal with highly nonlinear models, chaotic and noisy data, and many constraints. It is a robust and general technique.
• Its main advantages over other local search methods are its flexibility and its ability to approach global optimality.

• The algorithm is quite versatile, since it does not rely on any restrictive properties of the model.

• SA methods are easily "tuned". For any reasonably difficult nonlinear or stochastic system, a given optimization algorithm can be tuned to enhance its performance, and since it takes time and effort to become familiar with a given code, the ability to tune a given algorithm for use in more than one problem, should be considered an important feature of an algorithm.

Weaknesses

• Since the SA is a Metaheuristic, a lot of choices are required to turn it into an actual algorithm.

• There is a clear tradeoff between the quality of the solutions and the time required to compute them.

• The tailoring work required to account for different classes of constraints, and to fine-tune the parameters of the algorithm, can be rather delicate.

• The precision of the numbers used in the implementation of the SA, can have a significant effect upon the quality of the outcome.
1.6 NEED FOR THE PRESENT STUDY

Surface transportation has become more essential now than ever before; hence, the manufacture of vehicle components has also rapidly increased. Among all the vehicle components, the suspension system plays a vital role in comfort travel. Even though advanced methods of suspension systems have been introduced, most of the commercial vehicles utilize leaf springs. Hence, the quality of the leaf spring leads to a better suspension system for transportation. Further, product development should respond to market changes.

Even though technological improvement in manufacturing methods has led to improving the quality and productivity of many parts, leaf springs are still manufactured in the traditional way. The traditional way of manufacturing the leaf spring faces several challenges, such as medium volume, large variety of production, the requirement of high productivity and quality, and shorter lead times from design to manufacture. To improve the product quality and productivity and minimize the manufacturing lead time, it is necessary to integrate the design and the shop floor viz process planning.

In the existing traditional method of manufacture of the leaf spring, the process parameters for various operations are determined using handbooks and manuals. The values obtained in such cases are not optimal, but exist a wide range. The selection of the process parameters should meet the economic objectives, such as the cost, quality and productivity. So, it is clear that, the application of the optimization procedure to minimize the manufacturing lead time, maximize the utilization of the machine, and the selection of the optimal process parameters for the major processes.

This research work focuses on the modeling and optimization of the process parameters in leaf spring manufacturing, using the Taguchi based
GRA and Simulated Annealing Algorithm. The experiments were conducted as per Taguchi’s design of experiments. The effect of the process parameters (blade clearance, shearing force, die length, stopper allowances and horizontal deviations in the shearing process; punching force, die diameter, punch wear and horizontal deviations in the centre hole punching process; heating time, mandrel diameter, front span and temperature in the eye forming process; heating temperature, walking beam cycle time, oil temperature and soaking temperature in the cambering and tempering process; heating length, heating temperature, pressure setup and walking beam cycle time in the tapper rolling process) on different responses (such as squareness, length, hole diameter, hole offset, eye diameter, eye end gap, eye twist, camber distance and hardness number) were studied to improve the overall quality of the product, the leaf spring.

These optimal process parameters are required to integrate the shop floor information, and to generate the optimal process sequence for the individual leaves. The final process plan is generated with the feature information, optimal parameters of the processes and their sequences.

1.7 SCOPE OF THE PRESENT STUDY

The generation of an integrated process plan is an important area of research that is of current interest. The integrated process plan environment achieves a number of objectives for any kind of product development. From the available literature, it has been known that no systematic and comprehensive analysis has been carried out for the integration of the design and manufacturing of the leaf spring assembly, and hence, there is a need for carrying out the integration of the design and manufacture through process planning. Earlier, researchers have applied new methodologies and techniques for the composition of spring materials, the finite element analysis of the leaves, and the eye design of the main leaf and the design of the leaf springs.
In this work, a process plan is generated by integrating the design and the manufacturing environment. The generated process plan carries information, such as the product feature design, process data, optimized process parameters and all the manufacturing resources data. In all these information, parameter optimization plays a major role in the integrated process plan generation. The leaf springs are manufactured by using traditional methods, which include non optimal process parameters with a wide range.

It is necessary to generate a process model and optimize the process parameters in order to improve the quality of the leaf spring assembly. For this, the Taguchi based GRA method is applied to solve multi response problems. After converting the multi response problem into a single response problem through the GRG, a nonlinear regression model is generated, using a statistical tool. Then, the developed model is subjected to a meta heuristic algorithm, the simulated annealing algorithm, to get the optimal process parameters.

1.8 SIGNIFICANCE OF THE STUDY

An integrated process planning for leaf spring manufacturing is significant due to the following reasons.

- The generation of an integrated process plan improves the productivity in design and manufacturing.

- The integrated process plan increases the utilization of the manufacturing resources effectively.

- The Taguchi based GRA methodology is developed to solve multiple response problems; it analyzes the various responses in the leaf spring manufacturing process.
• A nonlinear regression model is generated; it produces the optimal level of the process parameters.

• The application of the simulated annealing algorithm generates global optimal solutions for the selected processes.

• The integrated process plan with optimal process parameters reduces the overall manufacturing lead time and product development cost.

1.9 OBJECTIVES

In the past few years, some works have been carried out in the field of integrated process planning. From the literature review, it can be understood that there is no systematic analysis for the integration of the design and manufacture of the leaf spring assembly. The integrated process planning for the leaf spring manufacture is one of the research areas having minimum literature. It is necessary to analyze the integration of the leaf spring product development at each stage. The important objectives of this research work are listed below.

• To develop an integrated environment for design and manufacturing.

• To reduce the overall product development time and cost through an integrated process plan.

• To utilize the manufacturing resources effectively.

• To generate and validate the leaf model.

• To prepare a customized process drawing for manufacturing.
To establish the parametric relation between the responses and factors.

To solve multiple response problems, using the Taguchi based GRA and Simulated annealing algorithm.

To obtain the optimal process parameters for the manufacturing processes in leaf spring manufacturing, such as Shearing, Centre hole punching, Eye forming and Cambering.

To find out the significant factors influencing the leaf spring manufacturing process.

1.10 OUTLINE OF THE THESIS

This thesis is organized in seven chapters.

This thesis deals with the generation of integrated process plans for the product ‘leaf spring’. The thesis is divided into three major parts. The first part deals with the integrated design of the leaf spring assembly using a CAD software and graphical user interface. The second part discusses the combination of the Taguchi based GRA and Simulated Annealing Algorithm to solve multiple response problems. The third part of the thesis presents the results and discussions of the output obtained from the integrated design and the multi response optimization.

Chapter 1 gives a brief description of the basic knowledge about integrated process planning. It also gives an overview of the design and manufacturing of the product, ‘the leaf spring assembly’. It describes the application of integrated process planning with parameter optimization for the manufacture of the leaf spring. The main objectives, scope and need for this work are presented.
Chapter 2 is devoted to the state-of-art of current knowledge of integrated process planning for various fields. The recent literatures about integrated process planning, design and manufacture of the leaf spring are reviewed. More attention is given to solving multiple response problems in the manufacturing environment. For obtaining the optimal solution, the applications of Meta heuristics are also discussed.

Chapter 3 deals with the methodology used in this work. The architecture of the integrated process planning is discussed. The three different modules in the integrated process planning framework are briefly given. The combination of the Taguchi based GRA method and SAA methodology is discussed. The generation of a nonlinear regression model and an overall view of the implementation methodology are presented.

Chapter 4 is described to the implantation of parameter optimization methodology. A description of the experimental work and its results, and solving important multiple responses optimization problems are presented.

Chapter 5 deals with the implementation of the integrated process planning methodology. The detailed future based design of the individual leaves with the bill of materials, generation of customized drawings for manufacturing, validation of the design through solid modeling and its assembly in the CAD software environment, are presented. It includes an overview of the shop floor data for the integration and generation of optimal process plans.

Chapter 6 deals with the results and discussion, including parameter optimization and scheduling for the integrated process planning environment.

Chapter 7 gives the conclusions of this research and suggestions for future work.