INTERNATIONAL JOURNAL OF RESEARCH IN MECHANICAL, MECHATRONICS AND AUTOMOBILE ENGINEERING(IJRMMAE)
ISSN: 2454-1435 (Print) | 2454-1443 (online)
Volume 6 Issue 4, January – March 2021 - www.ijrmmae.in – Pages 66-76

A COMPREHENSIVE COMPUTER-AIDED PROCESS PLANNING SYSTEM FOR THE ASSEMBLY OF LEAF SPRINGS

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Received: 3rd December 2020 | Accepted: 13th February 2021

Abstract

This paper presents the development and implementation of an integrated Computer Aided Process Planning (CAPP) system tailored for the manufacturing of leaf springs. Leaf springs are crucial components in various automotive and industrial applications, demanding precise manufacturing processes to ensure quality and performance. The proposed CAPP system integrates various functionalities, including CAD (Computer-Aided Design), CAM (Computer-Aided Manufacturing), and CAE (Computer-Aided Engineering), to streamline the process planning workflow.

The system utilizes CAD tools to create detailed digital models of leaf spring designs, which serve as the foundation for subsequent manufacturing stages. CAM functionalities are employed to generate efficient tool paths and manufacturing instructions, considering factors such as material properties, manufacturing constraints, and desired product specifications. Additionally, CAE modules are utilized for virtual prototyping and simulation, enabling the evaluation of design iterations and manufacturing strategies before physical production.

The integration of these components within a unified CAPP framework facilitates seamless communication and data exchange throughout the manufacturing process, leading to improved efficiency, reduced lead times, and enhanced product quality. Case studies and experimental results demonstrate the effectiveness of the proposed system in optimizing the manufacturing process for leaf springs, showcasing its potential for broader application in the manufacturing industry.

Keywords: Computer-Aided Process Planning (CAPP), leaf springs, CAD, CAM, CAE, manufacturing optimization, integrated systems, automotive industry

INTRODUCTION

Today's manufacturers are creating higher-quality, more tailored items in smaller batches, with shorter lead times and lower prices. Process planning in manufacturing refers to the function that determines the order in which manufacturing processes should be used to transform raw materials into finished parts, as well as activities involving the best possible sequence for the processes, ideal process parameters, and resource selection for manufacturing [1]. Computer Aided Process Planning (CAPP) integrates the Computer Aided Design and Manufacturing stages in a computer integrated manufacturing (CIM) environment. Newer knowledge-based computer-aided process planning (CAPP) software have the ability to create plans by integrating design and manufacturing with other product development stages [2]. Systems for computer-aided process planning (CAPP) can be broadly divided into two categories: generative and variant [3]. The variation type that resulted from manual process planning is based on group technology, in which a plan from a similar section is retrieved and then slightly modified. Using the part codes and classifications, the process planner obtains the plan for comparable components in this case [4]. It then modifies the recovered plan to produce a variant that meets the particular needs of the component under planning. The foundation of this method is the idea that pieces with comparable technology and geometry have comparable process designs.

Based on the geometrical difference, computers are utilized to help find similar plans, retrieve them, and then alter them. A part's geometrical data, formulas, algorithms, and decision logic are used to develop computer-aided process planning, or CAPP. A framework is developed and the process plan is produced using the data found in the manufacturing databases (Chang 1985). A system that automatically creates a process plan for a new component is a concise definition of it. The generative approach aims to automatically generate a process plan from data found in a manufacturing database, requiring no human involvement [5]. The system can produce the necessary operations and operation sequence for the component after getting the design model. It is necessary to record and encode manufacturing knowledge into computer programs. It is possible to mimic a process planner's decision-making procedure by using decision logic. Generative planning approaches can also be used to automate other planning processes, such as process optimization, machine and tool selection, and so on [6]. Generative process planning is not associated with any fixed representation or approach. Using an object-oriented planner construct or a solid model CAD-based input and expert system is the general tendency. When it comes to determining the comfort and stability of a vehicle, the suspension system plays a crucial role [7].

The suspension system operates in a state of dynamic balance while the tire rotates, continuously modifying and compensating for shifting road conditions. The suspension system's parts carry out fundamental tasks such sustaining the proper ride height of the vehicle, lessening the impact of shock forces, supporting the weight of the vehicle, transmitting driving torque, etc[8,19].The leaf spring, which is found in a car between the axle housing and the chassis, is essentially a simply supported beam with a concentrated load in the middle[9,22]. The spring selection is changed from a maximum at the center to a minimum at the ends due to the bending moment, which is at its maximum in the spring's center and decreases towards the ends [10].

This is accomplished in a traditional multi-leaf steel spring structure by assembling several leaves of varying length so that the thickness is greatest in the middle and decreases toward the ends. Clamps and a bolt in the middle hold the leaves together as they are stacked one on top of the other [12,21]. The master leaf is the one that stretches out over the entire spring. The master leaf has loops at its ends that are referred to as eyes. The spring bolt that holds the metallic leaves together travels through the hole in the middle of each leaf. The master leaf and the shorter leaves' outer ends are held in place via spring clips.

The leaves scrape against one another when the leaf spring bends while it is in use. Because the leaf is flexing from the contact, frictional resistance is created [13,18].

A leaf spring that is frequently found in cars is the semi-elliptical assembly. It is constructed using several plates. Usually, the leaves are cambered, or initially curved, so that when they are loaded, they will want to straighten [14,24].

The leaves are kept together by a bolt that goes through the middle or by a band that has shrunk around them in the center. The effective length of the spring for bending is equal to the total length of the spring less the band's breadth since the load has a strengthening and stiffening effect [15, 20].

To get the effective length of the spring in the case of the central bolt, deduct two thirds of the distance between the centers of the u-bolt from the total length of the spring. The ends of the longest leaf, referred to as the main leaf or master leaf, are shaped like an eye, through which bolts are threaded to fasten the spring to its supports. Typically, anti-friction bushings made of rubber or bronze are used in the eyes, which are used to connect the spring to the hanger or shackle. The term "graded leaves" refers to the remaining spring foliage. The ends of the graded leaves are cut in different ways to avoid digging in the nearby leaves. When making a turn, the master leaf must support loads resulting from the vehicle's slanting as well as loads bending vertically [16,24].

MATERIALS AND METHODS:

Optimization Methodology:

A study has been done to combine manufacturing and design. It was realized that creating part models with additional information beyond geometry and topology is essential to achieving CAD/CAM integration. Although CAD systems are now widely used in industries for part design, the quality of the part model data is still inadequate. The geometry for wireframe models, the geometry and topology for B-rep models and primitives, and the operators for CSG models are examples of low-level part models in CAD systems (2D or 3D). It is not possible to use these models directly for other applications, such as manufacturing processes. This is due to the lack of information on higher-level features like tolerances, material specifications, and manufacturing-related technological data. The introduction of feature-based modeling aims to address this problem. Its ability to correlate not just geometric and topological information but also form features, tolerances, material attributes, and other information that may be employed during process planning is one of its advantages over standard geometric modelling [17]. The feature is a representation of the part's engineering data. Features can be thought of as information sets that relate to certain form-related or other features of a part, and these sets can be utilized to make decisions about the assembly or part's manufacture, performance, or design. Features include things like bosses, webs (additive), holes, and slots (subtractive). As a result, features offer an implicit way to link the component representation and database knowledge [20].

This work suggests employing integrated features that can use the knowledge base to create attributes required for downstream applications like process planning, machining, etc., in addition to representing the geometric information or design intent of the component. Here is an explanation of the top level information and the feature-based design process for the leaf spring assembly. The following actions are part of the FBD:

- Providing basic information needed to define the leaf spring assembly
- Defining the number of leaves in the assembly
- Defining the features to be added or subtracted from the part being designed
- Creation of the individual leaf, assembly and its validation
- Customized detailing of the individual leaves
- Storing and retrieving the part information from the database
- Integrating the manufacturing activities through the CAD data

PROPOSED METHODOLOGY:

The process's productivity and safety must also be taken into account when developing the product's quality. To meet these requirements, a number of process parameters must be set correctly. Because there are sometimes conflicts between the requirements and an exponential increase in the number of possible parameter settings as more parameters are involved, it is crucial to optimize the process parameters. Furthermore, because of the expense and safety hazards associated with carrying out the trials, parameter tweaking based on real-world experimentation is less practical. Therefore, using numerical optimization based on the computational model of the particular manufacturing process is the only way to optimize process parameters.

While trying to solve hard combinatorial optimization problems within practical time horizons, classical optimization methods are found to be inefficient in the optimization of the process parameters. They need completely defined objective and constraint functions. They are found to be inefficient in solving real world problems, which are very complex in nature, because of the involvement of more numerical steps and the need for more computation time. Many academics in various domains have recently proposed a vast array of optimization strategies, ranging from population-based algorithms to trajectory-based search algorithms, local search methods, evolutionary 110 algorithms, etc. Their advantages in terms of computing time required, ease of construction, and versatility for application to a wide range of simple to difficult issues are making them increasingly significant. The leaf spring is one of the simple elements, consisting of a number of steel sheets organized such a way as to carry vehicle loads and show the spring effect. The manufacture of the leaf spring assembly plays a major role in the application of the spring product. Each leaf has its own specifications and unique processing sequence. The processing sequence is characterized by various process parameters that vary from leaf to leaf. The manufacturing processes involved in the leaf spring for producing 11 regular leaves and 2 additional leaves. In the existing traditional method of the 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 exhibit a wide range. The selection of process parameters should meet the economic objectives, such as the cost, quality and productivity. So, it is clear that, the application of the Meta heuristic procedure, minimizes the manufacturing lead time, maximizes the utilization of the machine by proper scheduling, and determines the optimal process parameters for the various processes in the leaf spring manufacturing.

Simulated Annealing Algorithm:

Step 1: Set the Initial temperature (450°C), final temperature (20°C) and cooling rate(0.96), freezer count(5), accept limit (4) etc.
Step 2: Generation of the initial seed
Step 3: Evaluation
Step 4: Neighborhood generation
Step 5: Probability of acceptance
Step 6: Termination condition

Centre Hole Punching Process:

The central bolt, which holds all the plates together, is inserted into a hole in the middle of each leaf. The process of punching creates the hole. The central hole is created with a mechanical power press. The necessary punch is attached to the press according to the diameter of the hole that needs to be made. The work piece is positioned so that it may be punched. The punching procedure is started by pulling the foot-operated lever.

The raw material's sheared length is conveyed to the hole punching machine via a roller conveyor. The leaf is placed in relation to the length. After that, the punching machine is turned on, and 150–180 tons of punching force are produced. One of the crucial steps in the production of the leaf spring assembly is the hole punching procedure, which involves removing material in relation to the diameter using a solid punch. The work material is subjected to the power press force. A die is used to provide support for the work part and create an exact hole. A guideway with a tolerance value is used to position the metal plate. With this configuration, the leaf spring manufacturer's hole punching procedure is carried out. The variables influencing a leaf's hole diameter and hole offset are punch wear, die diameter, punching force, and horizontal deviations. In the leaf spring construction, the correct hole diameter and hole offset are crucial. A change in the hole diameter value causes the leaves to shift laterally and influences how tight the leaf spring assembly is the middle bolt and nut do not fit all the leaves properly due to the offset of the leaf's hole.
The Taguchi-based GRA and SAA approach is used to optimize the center hole punching process in order to improve the quality attributes of the hole in a leaf spring assembly.

Feature Based Design of the Individual Leaf and BOM

The user interface has provisions for accessing the mechanical modeling Solid works® software to model the part file. The details of the machine tool, cutting tool, gauges and all other manufacturing details are entered in the database, which can be modified or updated through the second module. The process parameters are optimized in the third module. Finally, the process plan is generated. The processing of the individual modules is explained in the following sections. The first module, Feature Based Design, offers the solid modelling of the part. The use of an interactive feature creation approach is adopted in developing the integrated design and manufacturing system for the leaf spring product development. The part is defined by features, and appears like real-world objects, such as machined parts. This is because of the logical means of the features. Compared to the traditional approaches to the design and implementation of software systems, this approach offers the advantages of increased flexibility, incremental system development and reusability. In interactive feature modeling, any real world entity is modeled asa feature. Each entity has a state and behavior. The state of an entity consists of properties, and the behavior consists of methods. These methods are similar to procedures and functions in conventional programming languages. The conventional feature modeling approach includes the acquisition of data, processing, summarizing and customizing. In the interactive graphical user interface, the standard menu bars are used in a simple way. By dragging the file menu bar the options are displayed like new design, open design, clone design and exit for closing the GUI.

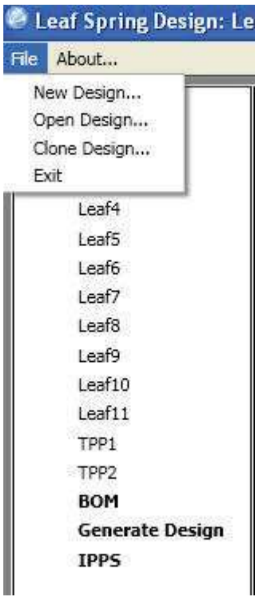

Figure 1. Menu bars in the developed CAPP system

Initially, in the interactive creation of features, the new leaf spring assembly is defined with the basic specification of the product, such as the number of leaves in the assembly (includes regular leaves, pressure plates and H plates which are located above the main leaf, and this is applicable to heavily loaded vehicles), total assembly thickness, camber distance (distance from the top surface of the master leaf to the eye to eye line), spring rate, applied load, deflection, and rated load stress value were entered as shown in Figure 2.

The composition of materials and related properties were fed into the program for the downstream activities.

After entering the required details in the new design, the confirmation of the number of leaves in the assembly is displayed by clicking the button ‘next’. The second window in the new design provides the name of the part or design, the confirmed leaves, and the design path as shown in Figure 3. The design path provides the way to store and retrieve all the information.

The option ‘back’ button is used to modify the specification in this design. The interactive feature definition environment is expanded by the button ‘create design’.

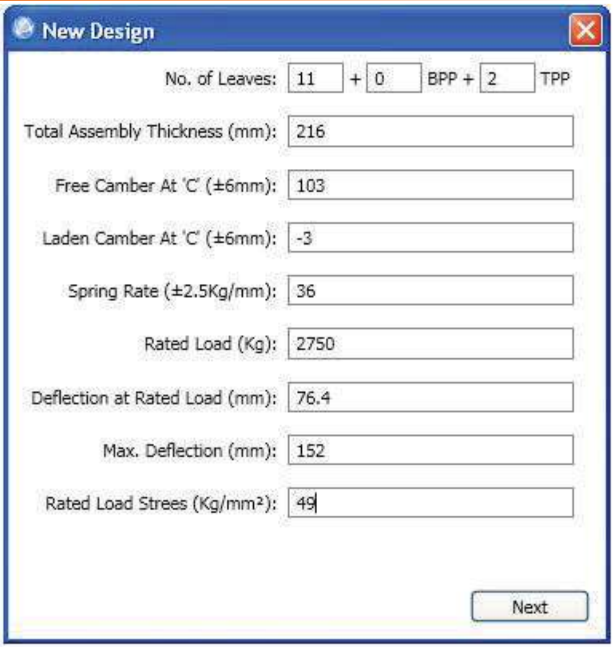

Figure 2. Specification of the new leaf spring assembly

Figure 3. Confirmation of the new design and design path creation

RESULTS AND DISCUSSION:

Integration of Design with the Shop Floor Activities by Feature Mapping:

An integrated CAD/CAPP system that integrates design and manufacturing through process planning has been developed and implemented. In the design stage, an interactive feature-based creation technique, and a mechanical modelling system have been utilized for modelling the mechanical parts. In the process planning stage, an interactive process planning system with optimal process parameters has been developed. In the above modules, the feature data has been created and extracted through the standard database, to facilitate the integration and implementation processes.

The interactive feature creation system is developed as a feature based design tool to integrate the design and manufacturing tasks. The developed system uses high-level 3D features as the basic design entities in the design process. The developed feature based design system relies on the following steps;

- Interactive creation of the part with the overall specification
- Creation of the individual leaf base
- Selection of the features to be added to or subtracted from the individual leaf designed,
- Providing the information required for defining the features, such as position orientation, and other attributes like surface finish, tolerances, etc.
- Generation of the individual leaves and validation,
- Generation of the leaf spring assembly and customized drawings,
- Mapping the interactive features with the manufacturing resources
- Generation of the optimal process parameters and scheduling

The developed CAPP framework generates a process plan for the manufacture of the leaf spring assembly. Commercially available CAD software, API, is used to define the integrated features of each leaf of the assembly. The GUI transfers the input information, and stores it to assign the process and generate its optimal sequence. The main goal of the generated process plan is to integrate design, process planning, and manufacturing into a seamless flow of data. The process plan is based on the concept of the manufacturing features. In the downstream direction, the design changes such as base size, feature location, rivet hole requirement, etc., can be conveyed through an automated process planning system to the shop floor activities, thus eliminating the tedious manual editing work. The changes in the shop floor program module are also made in the design and process planning system, through the database. The
performance of the proposed system was verified and the results are summarized, for a part number consisting of 11 regular leaves and 2 pressure plates and a computer aided process plan for the manufacture of leaf spring assembly has been generated. The entire part, the leaf spring assembly is defined as a feature through the CAD programming interfaces. The dynamic feature information is displayed, and the subsequent activities are carried out. The features are mapped with the existing manufacturing processes, the shop floor module, the manufacturing resources are selected. The information related to the shop floor activities such as, the manufacturing processes, specification of machine tools, cutting tools, inspection equipment, availability and the corresponding time standards are stored and retrieved by the program as required.

The leaf spring assembly is one of the simple important elements in automobiles. The design and manufacture of the leaf spring assembly leads engineers to develop a real world planning system. This planning system should satisfy the requirements in the design, and all other stages in the product development. By considering these aspects, a system has been developed to integrate the design and shop floor activities through computer aided process planning. In the developed system, a graphical user interface by MS. Net, a mechanical modeling system Solid works, and a database, oracle lite, is used. The design activities are automated and the factory environment is integrated. The process parameters for various operations are determined, using handbooks and manuals in the existing traditional method of manufacture of the leaf spring. A wide range of values are obtained, but they are not optimal.

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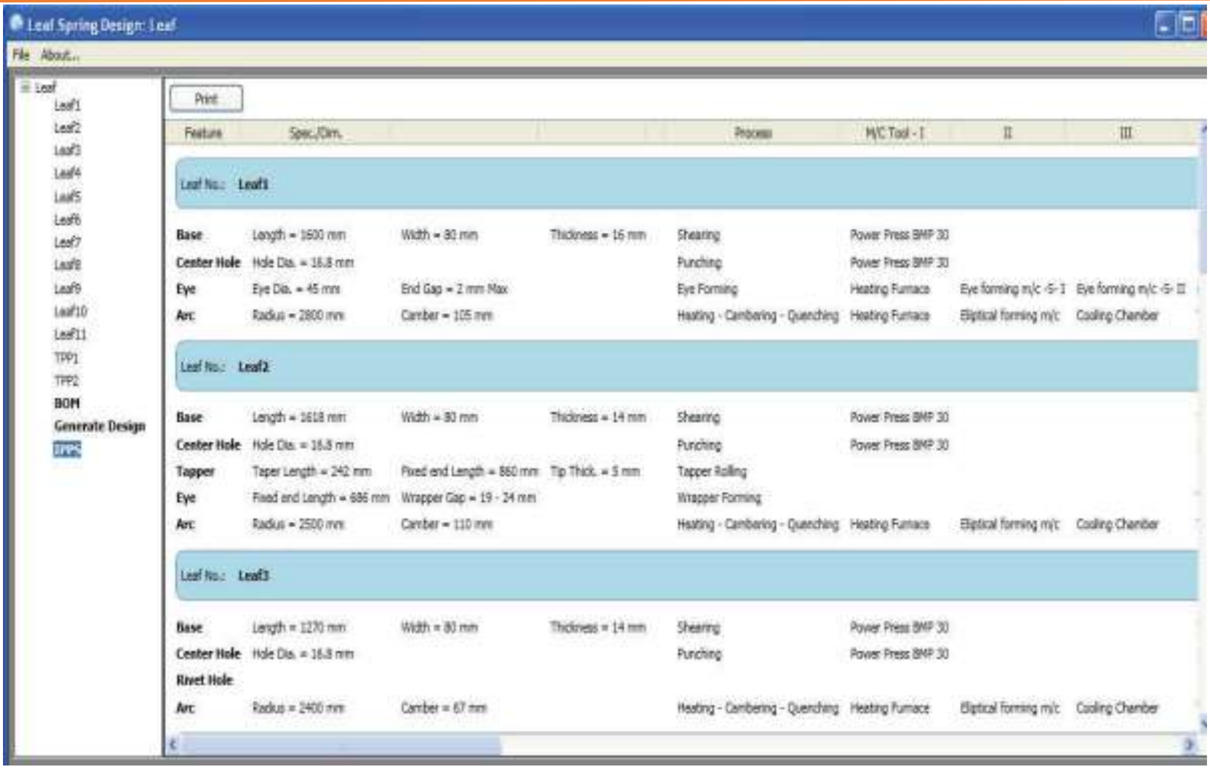

Figure 4. Features and their Mapping of the Manufacturing Resources

The main objectives of this work, are minimizing the manufacturing lead time, maximizing the utilization of the manufacturing resources by proper scheduling and determining the optimal process parameters for the various processes in leaf spring manufacturing, and they are obtained by the methodology. Based on the available manufacturing resources and the interrelationship between the factors, a combined objective function and the process models were formulated, which minimizes the make span and maximizes the percentage of machine utilization. The simulated annealing algorithm is applied for the process models and the optimal results are obtained. Then the objective function is analyzed to minimize the lead time and utilize the resources. The minor influence parameters with the process models are assigned in the program. The combination of multi response optimization and the metaheuristic procedure generates the optimal values for the significant processes, such as shearing, hole punching, eye forming and elliptical forming. With these optimal process parameter values, the scheduling task is carried out for the existing factory environment.

CONCLUSION

For the purpose of the leaf spring manufacturing industry, a software system model that incorporates the design and production of the leaf spring at different stages has been designed. The feature-based design maintains the feature data in the database and generates individual leaves in a leaf spring assembly. Every necessary detail is included in the generation of the individual leaf model. Following the design of each individual leaf, the required number of leaves are assembled. In the CAD environment, the entire leaf spring assembly is validated for eye end gap, assembly thickness, interleaf gap, and camber distance with BOM. A unique process diagram is created for the production operations. Sources, instruments, and gauges are kept in the database.

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