PREDICTING THE FATIGUE OF STEERING KNUCKLE ARM OF A SPORT UTILITY VEHICLE WHILE DEPLOYING ANALYTICAL TECHNIQUES USING CAE

[1]Kiran S.Bhokare, [2]G.M.Kakandikar, [3]Swapnil S. Kulkarni
[1](ME- Design) Dnyanganga COE, Pune, India
[2]Associate Professor, Dnyanganga COE, Pune, India
[3]Advent ToolTech Pvt. Ltd., Pune, India

ABSTRACT

Automobile components and structures are regularly subjected to cyclic loading and they are consequently prone to fatigue damage. The steering knuckle, being a part of the vehicle's steering and suspension system, undergoes time-varying loading during its service life. This work shall be consisting of analyzing the steering knuckle for the main operating conditions. The Finite Element methodology would be adopted to solve the problem while determining the fatigue life of the steering knuckle. The process of validation for this method is sought through the physical Experimentation for determining stress levels and/or deflection at the designated locations (identified using F.E. Modeling). Since the input used for Fatigue is the stress in the component, validation is sought through comparison of this input data. Fatigue life experimentation is usually not feasible since this is a case of high cycle fatigue. In the physical experimentation we will be finding out the graph for stiffness i.e. Load Vs Deflection for the component. The results of Experimental work shall be compared for results with the F.E. Modeling. The concurrence of the results shall offer validation for this thesis work.

KEYWORDS: *Fatigue life, Steering Knuckle, Forging, MSC Fatigue*

I. INTRODUCTION

A Steering Knuckle is one of the critical components of vehicle which connects brake, suspension, wheel hub and steering system to the chassis. It undergoes varying loads subjected to different circumstances, while not distressing vehicle steering performance and other desired vehicle characteristics. The knuckle is the major pivot in the steering mechanism of a car or other vehicle, free to revolve on a single axis. The knuckle is vital component that delivers all the forces generated at the Tier to the chassis by means of the suspension system. The design of the knuckle is usually done considering the various forces acting on it which involves all the forces generated by the road reaction on the wheel when the vehicle is in motion. The design also includes various constraints that are related to the knuckle such as brake system, steering system, drive train and suspension system [3].

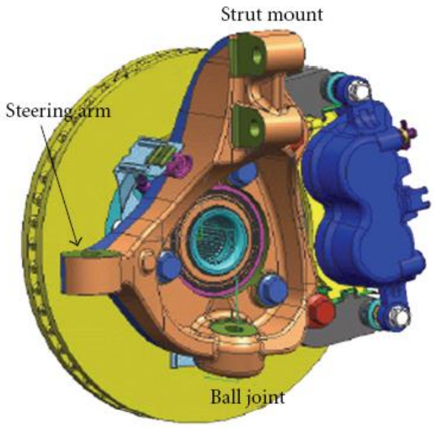


Figure1: Steering Knuckle System [4]

The steering knuckle, being a part of the vehicle's suspension system, has alternatives of forging and casting as its base manufacturing process. Since it is connected to the steering parts and strut assembly from one side and the wheel hub assembly from the other, it has complex restraint and constraint conditions and tolerates a combination of loads.

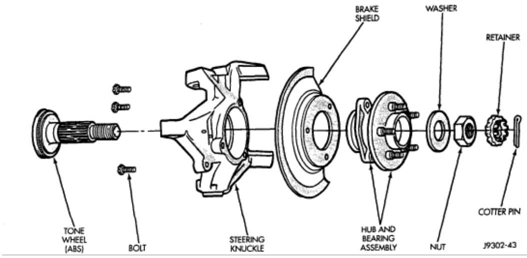


Figure2: Steering Knuckle Assembly

In addition, parameters such as internal defects, stress concentrations and gradients, surface finish, and residual stresses can have considerable influence while designing for fatigue [1].

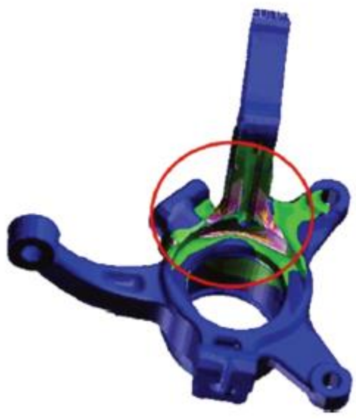


Figure 3: Critical Stress location obtained by FEA [4]

A common practice of fatigue design consists of a combination of analysis and testing. A problem that arises at the fatigue design stage of components is the transferability of data from smooth specimens to the component. The component geometry and surface specifications often deviate from that of the specimen investigated and neither a nominal stress nor a notch factor can be defined in most cases. An advantage of component testing is that the effects of material, manufacturing process parameters, and geometry are inherently accounted for, even though synergistically [5].

In this project work we shall be using finite element methodology for analyzing the knuckle. In recent decades with development in mathematics and computers very efficient FEA software were developed like ANSYS, NASTRAN, RADIOSS for Structural Analysis and MSC Fatigue, FEMFAT, N-Code for Fatigue Analysis. This software in combination with high computational powered work stations (computers) are working very efficiently. The Design process is compromise of things (design may change several time from designers mind till it comes to actual practice). Such as manufacturability, maintainability, reliability, factor of safety, cost, size and shape.

Selecting best design is mere permutation and combination. Hence design may change according to person working as designer. As it is compromise of many things there will be always chance for optimization. Hence there is no exact answer to any design or related question codes are giving flexibility of using different design approaches and technology by stating that the code is not a handbook and cannot replace education, experience and use of engineering judgment, also it suggests for using of FEA software in many situations.

In traditional design process; design activity is carried out by using formulae developed by researchers or code formulae. This formulae change with change in loading, size, shape, location, material etc. Method of design by formulae is unable to account nonlinearity (such as loading non linearity, material non linearity, geometrical nonlinearity, contact nonlinearity) in design. To account non linearity; rigorous calculations are necessary which will be time consuming process and possibility of many errors. Use of numerical methods are allowing handling non linearity quite efficiently, one amongst such method is FEM. This is extensively used in design fields now-a-days.

II. PROBLEM DEFINITION

Steering knuckle is one of automotive part that frequently carries load from several directions. It is connected to the steering parts and strut assembly from one side and the wheel hub assembly from the other; it has complex restraint and constraint conditions and tolerates a combination of loads. Each circumstances of the road give the different impact to the steering knuckle. In addition, parameters such as internal defects, stress concentrations and gradients, surface finish, and residual stresses can have considerable influence while designing for fatigue. For this work, the need is to identify a typical load case for analysis while offering variation to the critical parameter/s of Design to determine the influence of the change in parameter over the fatigue results.

2.1 Probable Solution

The failure can be contained or minimized to an extent by deploying Analytical Methodology / Computational Methodology using CAE tools. The Hyper Works Suite offers modules for Pre-processor and Solvers for structural Analysis while the MSC software suite offers module for Fatigue Analysis. The performance of the component for fatigue life can be predicted using this approach. The material or the geometry of the component shall be varied for anticipating change in the output parameter i.e. fatigue life. The solution shall be presented in the form of recommendation for the variant with the specified Design parameters for achieving enhanced fatigue life.

III. LITERATURE REVIEW

Steering knuckle is a forging that usually includes the spindle and steering arm, and allows the front wheel to pivot. The steering knuckle is the connection between the tie rod, stub axle and axle housing. Steering knuckle is connected to the axle housing by using king pin. Another end is connected to the tie rod. Then the wheel hub is fixed over the knuckle using a bearing. The function of the steering knuckle is to convert linear motion of the tie rod into angular motion of the stub axle. The lighter steering knuckle resulting greater power and less the vibration because of the inertia is less. The steering knuckle carries the power thrust from tie rod to the stub axle and hence it must be very strong, rigid and also as light as possible. In the case of automobile vehicle, during steering and turning the steering knuckle is subjected to compressive and tension loads and due to the wheel rotation it is also subjected to torsional load.

Here is the list of some Research Papers regarding the project work:-

Mehrdad Zoroufi and Ali Fatemi [1]: This research program aimed to assess fatigue life and compare fatigue performance of steering knuckles made from three materials of different manufacturing processes. These include forged steel, cast aluminum, and cast iron knuckles. It is concluded that the forged steel knuckle exhibits superior fatigue behavior, compared to the cast iron and cast Aluminum knuckles.

Sharad Kumar Chandrakar, Dheeraj Lal Soni and Shohel Gardia[2]: The paper describes a vehicle steering knuckle undergoing time varying loadings during its service life. Fatigue behavior is, therefore, a key consideration in its design and performance evaluation. This paper is aimed to assess fatigue life and compare fatigue performance of steering knuckles.

Mahendra L. Shelar, Prof. H. P. Khairnar[3]: This paper identifies the process of optimizing the design using a methodology based on durability and optimized design through probabilistic models of design variables (DOE). The necessity of assessing the robustness of a particular design requires a methodology based on strength and design optimization through probabilistic models of design variables.

E. A. Azrulhisham, Y. M. Asri, A.W. Dzuraidah, N.M. Nik Abdullah, A. Shahrumand C. H. CheHassan[4]: This paper intends to give a description of a method used in the fatigue life reliability evaluation of the knuckle used in a passenger car steering system. A Pearson system was developed to evaluate the predicted fatigue life reliability by considering the variations in material properties. Considering random loads experiences by the steering knuckle, it is found that shortest life appears to be in the vertical load direction with the lowest fatigue life reliability between 14000–16000 cycles.

Purushottam Dumbre, Prof A.K.Mishra, V.S.Aher, Swapnil S. Kulkarni[5]: Weight reduction of steering knuckle is the objective of this exercise for optimization using FEM software. Steering Knuckle is a non-standard part and subjected to various loads at different conditions. The targeted weight or mass reduction for this exercise is about 5% without compromising on the structural strength.

Wan Mansor Wan Muhamad, Endra Sujatmika, Hisham Hamid &Faris Tarlochan[6]: The objective of this research is reducing mass of an existing steering knuckle component of a local car model by applying shape optimization technique using FEM. The improved design achieves 8.4% reduction of mass. Even though there are volume reduction and shape changes, maximum stress has not change significantly.

Rajesh M. Metkar, Vivek K. Sunnapwar, Vidya Sagar Anki,Mahendra Dumpa[7]:
This paper provides an insight of LEFM and CDA methods along with its benefits to the designers to correctly assess the life of crankshaft at early stage of design. This paper also gives a detailed overview of failure analysis process including theoretical methods and result integration for predicting life of components as compared to life estimation by means of software.

Chang Yong Song, Jongsoo Lee[8]: This paper discusses reliability-based design optimization (RBDO) of an automotive knuckle component under bump and brake loading conditions. The probabilistic design problem is to minimize the weight of a knuckle component subject to stresses, deformations, and frequency constraints in order to meet the given target reliability.

Davide Gallina[9]: In this study, finite element prediction of crack formation induced by quenching in a forged valve used in the offshore oil drilling field is performed by means of the commercial FEM software. Microstructures which can be formed during the thermal treatment are taken into account. The simulation results, compared with the effects of the quenching on the actual component, indicate that this type of simulation can effectively predict the quench cracks formation in 3D components.

B.Babu, M. Prabhu, P.Dharmaraj, R.Sampath[10]: The main objective of this work is to explore performance opportunities, in the design and production of a steering knuckle. This can be achieved by performing a detailed load analysis. Therefore, this study has been done in two steps first modeling of steering knuckle as per design parameters and also analysis considering the loads and boundary conditions. This is done for finding out the minimum stress area.

3.1 Critical Review of Literature

A vehicle steering knuckle undergoes time-varying loadings during its service life. Fatigue behavior is, therefore, a key consideration in its design and performance evaluation. Finite element model of the steering knuckle was also analyzed to obtain stress distributions in each component. Based on the results of component testing and finite element analysis, fatigue behavior of steering knuckle can be predicted.

A common practice of fatigue design consists of a combination of analysis and testing. A problem that arises at the fatigue design stage of components is the transferability of data from smooth specimens to the component. The component geometry and surface specifications often deviate from that of the specimen investigated and neither a nominal stress nor a notch factor can be defined in most cases. An advantage of component testing is that the effects of material, manufacturing process parameters, and geometry are inherently accounted for, even though synergistically.

project overview

3.2 Scope

Existing Design of the Steering Knuckle shall be evaluated using Computational Methodology using suitable CAE tools. The geometry of the Arms of the Steering Knuckle shall be the input for this work which shall undergo Finite Element Analysis to determine its Fatigue life. The F.E Modeling for design evaluation shall be pursued for 'Structural' analysis. The aspect of 'fatigue' would be investigated to improve design & enhance performance over 'durability'. Conclusion phase is to include physical experiment for validating 'stiffness' of the spring. Recommendation to be offered upon comparison using Test Report.

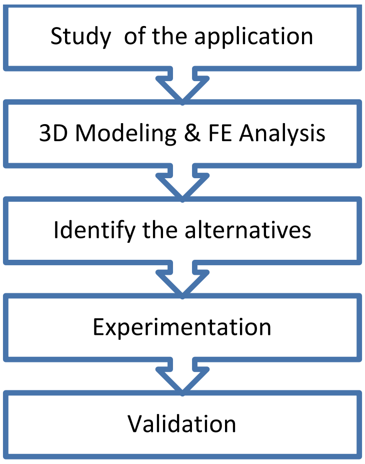
3.3 Objectives

1) Pursue research over causes of failure of the component.
2) Modeling and FEA analysis of the component :
   a) Secure input data in the form of CAD model (geometry).
   b) Engage pre-processor with loading & BCS.
   c) Apply solver and view results over post processor for structural assessment.
3) Conducting experimentation on the component: Record the load v/s defection OR load v/s stress through experimentation
4) Validate the hypothesis: Validation of results obtained by Finite Element Method with Experimental results.

3.4 Proposed Methodology

1. **Theoretical Work- Literature review**: The survey over the published literature on Analysis of suspension coil spring & fatigue life etc. will be carried out by referring journals like SAE journal, International papers, US patents, etc.
2. **Mathematical Calculations**: In this phase we calculate the fatigue life in preliminary level.
3. **Analytical Method**: For analysis purpose, Meshing and boundary conditions are applied using Hyper mesh as a pre-processor. For solving purpose typically MSC-Fatigue would be used. Results would be predicted using Hyper view Software.
4. **Physical Experimentation**: This methodology shall be deployed as an alternative methodology for validating the hypothesis. The results determined by Analytical methodology for the benchmark variant shall be compared with the results secured during Experimentation.

3.5 Flow Chart of Methodology



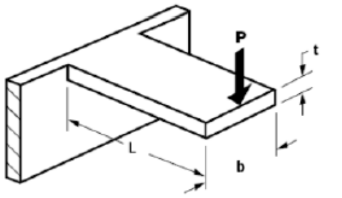
Software Used & to be Used:

- 3D modeling: CATIA (Dassault Systems)
- Pre-processor: Hyper Mesh (Altair Engineering)
- Solver: NASTRAN (MSC Software)
- Post-processor: Hype View (Altair Engineering)
- Fatigue Analysis**:** MSC Fatigue (MSC Software)

IV. CALCULATIONS FOR STEERING KNUCKLE

4.1 Mathematical Calculations for Deflection-Strain in Steering Knuckle

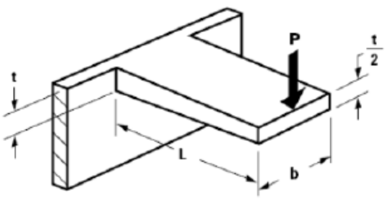
In case of Steering Knuckle the mathematical calculations are very critical due to complex geometry of the Steering Knuckle. To calculate the Stresses in the loaded arms of the Steering Knuckle we can consider the calculations for loaded Cantilever beam as shown below.



I) Uniform Cross Section, Fixed End to Free End

Stiffness: $k = \frac{P}{Y} = \frac{Eb}{4}\left(\frac{t}{L}\right)^3$

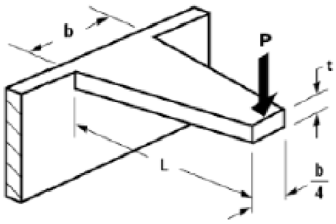
Strain: $e = 1.50\left(\frac{t}{L^2}\right)Y$



II) Uniform Width, Height Tapers to t/2 at Free End

Stiffness: $k = \frac{P}{Y} = \frac{Eb}{6.528}\left(\frac{t}{L}\right)^3$

Strain: $e = 0.92\left(\frac{t}{L^2}\right)Y$



III) Uniform Height,Width Tapers to b/4 at Free End

Stiffness: $k = \frac{P}{Y} = \frac{Eb}{5.136} \left(\frac{t}{L}\right)^3$

Strain: $e = 1.17 \left(\frac{t}{L^2}\right) Y$

Where:

E = Flexural Modulus

P = Force

Y = Deflection

b = Width of Beam

Cantilever beam deflection-Strain Formulas

V. STEERING KNUCKLE FATIGUE ANALYSIS (FE MODELING)

5.1 CAD Model of Steering Knuckle Using CATIA V5

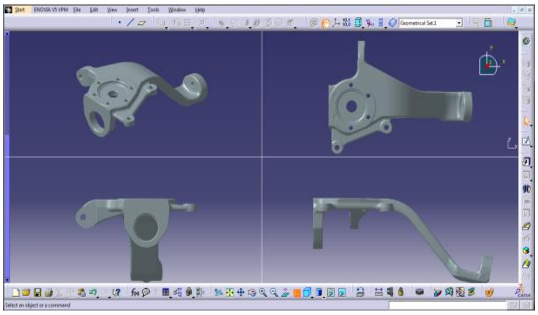


Figure: Cad model of knuckle steering

CAD model of the machined component is prepared using CATIA V5, which will be further used for Static and Fatigue Analysis of the Steering Knuckle

5.2 Connections at Different Points on the Steering Knuckle

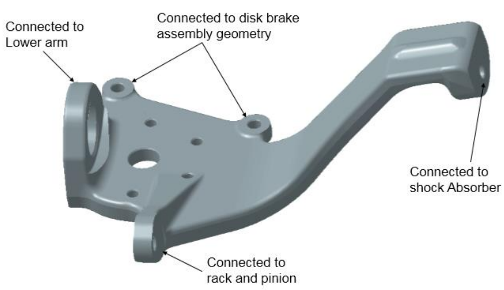


Figure: Different locations for connections in the Steering Knuckle Assembly are identified

VI. Scheme Of Implementation

Sr. No.	Activity/month	Sept 2014	Oct	Nov	Dec	Jan 2015	Feb	Mar	Apr	May
1	Literature Review									
2	Design the Parts									
3	Benchmarking Analysis									
4	Study the results									
5	Testing for validation									
6	Find-out the scope for improvement									
7	Revised the geometry									
8	Analysis of modified geometry									
9	Report making									
10	Submission of Report									

VII. Layout And Design Of The Setup

Figure: Typical Test setup for Physical Experimentation for determining Stiffness

Figure shows the typical test setup for determining the stiffness of the steering knuckle. The gradually increasing load will be applied and corresponding deformation is determined. The load from the load cells present on the UTM machine will be applied gradually. Display attached to the machine will give a corresponding plot for load V/s displacement i.e. stiffness of the component.

VIII. Conclusion

Fatigue life of the Steering Knuckle Arm can be enhanced using the FE Analysis tool. Experimental Setup helps to validate the fatigue analysis done using FEA.Fatigue life can be evaluated using varying material properties and material removal process. Optimization method can be used effectively in identifying the areas where we can remove the mass of the object but this cannot give consideration about the manufacturability. Therefore, the overall weight of the vehicle can be reduced to achieve savings in costs and materials, as well as, improve fuel efficiency and reduce carbon emissions to sustain the environment.

8.1 Expected Outcome

The Fatigue life for the existing variant is expected to be enhanced by at least 5% with the introduction of a new variant. The improved fatigue life shall enhance the utility of the part over working conditions of a severe magnitude or for a longer duration of its lifetime. The exercise might as well open up other areas of design improvement for better performance of the part in general.

8.2 Facilities available

The following facilities to carry out dissertation work are available at Able Technologies (I) Pvt Ltd, Pune.

I. Lab facility with MSC Fatigue, FEM FAT, Hyper mesh, ANSYS, CATIA
II. Library facility for books/ journal.
III. Manufacturing and testing facilities in workshop or test lab.

8.3 Validation

Validating the stiffness of the component by comparing results obtained from experimentation with results of FEA analysis. Will be finding out fatigue life by FEA analysis and that will be compared with the finite life obtained from mathematical calculation. The experimentation work for finding fatigue life will not be done; as it will required more time and also it is costlier. The stiffness of the spring is considered as a `response' parameter for validation.

REFERENCES

[1] Mehrdad Zoroufi and Ali Fatemi, "Fatigue Life Comparisons of Competing Manufacturing Processes: A Study of Steering Knuckle" - SAE International 2003.
[2] Sharad Kumar Chandrakar, Dheeraj Lal Soni and Shohel Gardia, "FEA of A Steering Knuckle for Life Prediction" - International Journal of Engineering Research and Technology, ISSN 0974-3154 Volume 6, Number 5 (2013), pp. 681-688.
[3] Mahendra L. Shelar and Prof. H. P. Khairnar, "Design Analysis and Optimization of Steering Knuckle Using Numerical Methods and Design of Experiments" 2014 IJEDR | Volume 2, Issue 3 | ISSN: 2321-9939.
[4] E. A. Azrulhisham, Y. M. Asri, A.W. Dzuraidah, N.M. Nik Abdullah, A. Shahrum and C. H. CheHassan, "Evaluation of Fatigue Life Reliability of Steering Knuckle Using Pearson Parametric Distribution Model" International Journal of Quality, Statistics, and Reliability Volume 2010, Article ID 816407, 8 pages.
[5] Purushottam Dumbre, A. K. Mishra, V. S. Aher, "Structural Analysis of Steering Knuckle for Weight Reduction" ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 4, Issue 6, June 2014.
[6] Wan Mansor Wan Muhamad, Endra Sujatmika, Hisham Hamid, &Faris Tarlochan, "Design Improvement of Steering Knuckle Component Using Shape Optimization" International Journal of Advanced Computer Science, Vol. 2, No. 2, pp. 65-69, Feb. 2012.
[7] Rajesh M.Metkar, Vivek K. Sunnapwar, Subhash Deo Hiwase, Vidya Sagar Anki, Mahendra Dumpa, "Evaluation of FEM based fracture mechanics technique to estimate life of an automotive forged steel crankshaft of a single cylinder diesel engine" Procedia Engineering 51 (2013) 567 – 572.
[8] Chang Yong Song and Jongsoo Lee "Reliability-based design optimization of knuckle component using conservative method of moving least squares meta-models" Probabilistic Engineering Mechanics 26 (2011) 364–379.
[9] Davide Gallina, "Finite element prediction of crack formation induced by quenching in a forged valve" University of Brescia, via Branze 38, Brescia 25123, Italy
[10] B.Babu, M. Prabhu, P.Dharmaraj, R.Sampath , "Stress Analysis on Steering Knuckle of the Automobile Steering System.
[11] Resolving Complexity in Fatigue-limited design - International Conference on Engineering Design ICED 03 Stockholm, August 19-21, 2003.
[12] Optimization and Finite Element Analysis of Steering Knuckle – Altair Technology Conference-2013 India.
[13] US1333878 (USA), AUG.7, I918, LOCKING DEVICE FOR AUTOMOBILE STEERING KNUCKLE ARMS, Mar. 16, 1920.
[14] US2631855 (USA), April 22, 1949, STEERING KNUCKLE CONSTRUCTION, March l6, 1953.
[15] US3801124 (USA), Oct. 13, 1972, KNUCKLE ASSEMBLY, Apr. 2, 1974.
[16] US3852872 (USA), Sept. 13, 1973, METHOD OF MAKING A KNUCKLE ASSEMBLY, Dec. 10, 1974.
[17] US3865394 (USA), June 11, 1973, SHEET METAL STEERING KNUCKLE WITH INTEGRAL STEERING ARM, Feb. 11, 1975.

AUTHOR'S BIOGRAPHY:

Kiran Bhokare I am Kiran S. Bhokare currently pursuing M.E Design from Savitribai Phule Pune University, Pune, India. I am having a total industrial experience of 11years and have almost worked in different industries such as Forging Industries, Process Industries, and IT Industries. Also during this long experience I have worked on different software such as CATIA V5, Unigraphics, AutoCAD, Hyper Mesh, ANSYS etc. I have also gone through training programs such as GD & T, Forging Die life Improvement Process, Die Wear Studies etc.

Ganesh Kakandikar I am pursuing Ph.D from SRTM University, Nanded, Maharashtra, India. He has 13 years of teaching experience. Presently he is working as PG Head Mechanical CAD/CAM/CAE at Dnyanganga COE ,Pune. His area of expertise are Sheet metal forming, Evalutionary Algorithms ,Optimization and CAD/CAM/CAE.

Swapnil S.Kulkarni Director, Advent Tool Tech India Pvt. Ltd., Pune. The Company offers Engineering Services and Manufacturing Solutions to Automotive OEM's and Tier I and Tier II Companies. He is a Graduate in Industrial Engineering with PG in Operations Management. With around 20 years of working experience in the domain of R&D, Product Design and Tool Engineering, he has executed projects in the Automotive, Medical and Lighting Industry. His area of interest is Research and Development in the Engineering Industry as well as the emerging sector of Renewable Energy.