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РЕВЕРС-ИНЖИНИРИНГ И МОДЕЛИРОВАНИЕ НИЖНЕГО РЫЧАГА СИСТЕМЫ ПОДВЕСКИ ТУРИСТИЧЕСКИХ АВТОМОБИЛЕЙ

Аннотация: *Данное исследование включает в себя этапы создания 3D компьютерной модели нижнего рычага подвески туристического транспорта. Это достигается за счет применения концепций и методологий обратного инжиниринга. Методика, используемая в этом исследовании, включает определение данных реальной модели предплечья с использованием доступных измерительных устройств, а затем использование этих реальных данных для рисования и моделирования руки вычислительно с помощью программы CAD /CATIA/. В конечном итоге создается трехмерная компьютерная модель руки, которая соответствует реальной модели, что позволяет проводить последующий структурный анализ для выявления и решения проблем с помощью ANSYS.*

Ключевые слова: *реверс-инжиниринг, подвеска МакФерсон, компьютерное моделирование.*

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REVERSE ENGINEERING & MODELING OF LOWER ARM FOR SUSPENSION SYSTEM IN TOURISM VEHICLES

Abstract. *This research involves the steps to create a 3D computer model of the lower arm in the suspension system of tourist vehicles. This is achieved by applying reverse engineering concepts and methodologies. The methodology utilized in this research involves determining the data of the real lower arm model using available measuring devices, and then using this real data to draw and model the arm computationally with the CAD program /CATIA/. This ultimately produces a three-dimensional computer model of the arm that matches the real model, enabling subsequent structural analysis to identify and solve problems with the assistance of ANSYS.*

Keywords: *reverse engineering, MacPherson suspension system, computer modelling.*

Introduction:

The vehicle suspension system is a complex vibrational system with multiple degrees of freedom, designed to isolate the vehicle body from road inputs. Suspension systems serve dual purposes:

- They ensure the vehicle remains in contact with the road, providing good braking performance and safe, enjoyable driving.
- They keep passengers comfortable by isolating them from road noise, bumps, and vibrations.

Figure 1 shows the components of the suspension system, which include:

- **Control Arm:** Connects the steering knuckle to the vehicle body or frame.
- **Steering Knuckle:** Supports the wheel hub and bearings.
- **Ball Joint:** Allows the control arm to move up and down while the steering knuckle pivots side to side.
- **Spring:** Supports the vehicle's weight and allows the control arm and wheel to move up and down.
- **Shock Absorber:** Prevents the suspension from continuing to bounce after compression and rebound.
- **Control Arm Bushing:** Allows the control arm to swing up and down.

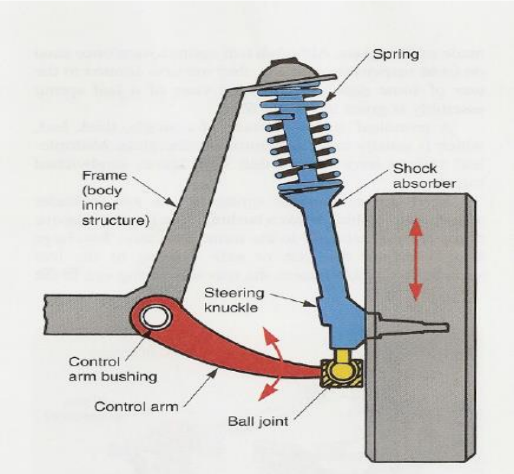


Figure 1 shows the main parts of the MacPherson suspension system.

Designing vehicle suspension systems has recently become more challenging as this specialty has become mathematically more comprehensive and innovative. However, the basic steps in designing suspension arms remain the same: creating 2D sections using all geometric variables that define the arm and then generating a 3D model. Various software tools are now available to facilitate this process based on user needs.

Research Importance and Objectives:

In traditional engineering design, a 3D model of a product is created in CAD software, which is then used for manufacturing. Reverse engineering is the reverse of this process, designing backward from a manufactured product to a 3D model. It involves measuring an object and reconstructing it as a 3D model. The entire process comprises two main stages: acquiring design data and processing and modelling the data, using various tools and software for data acquisition and modelling.

Reverse engineering is one of the most important methods to obtain a 3D computer model of a previously manufactured real model. This research aims to:

- Determine the lower arm model data using available measuring devices.
- Create a 3D computer model of the lower arm in the vehicle’s suspension system using CAD and CATIA based on real specifications.
- Maintain consistency and simplicity in inputs while allowing extensive design flexibility and retaining comprehensiveness and flexibility of the design tool, ensuring the software is executable.
- Prepare the model for evaluation through structural analysis using the Finite Element Analysis (FEA) method to achieve the optimal design.

Additional Research Goals and Plan:

- Manual reverse engineering of the suspension arm.
- Create a 3D parametric model of the lower arm using CATIA.
- Divide the model into tetrahedral finite elements in ANSYS.
- Conduct structural analysis to find Von Mises stresses.
- Analyze static deformation in ANSYS.

Research Methods and Materials:

I. Problem Definition:

The control arm is the main component of the suspension system with various functions. When a vehicle goes over bumps and brakes, various forces are transferred from the wheels to the control arm through the ball joint assembly, determining the load forces. The primary focus of this study is to determine the maximum stress values on the control arm and correlate these values with the tensile yield strength of the material.

II. Research Methodology:

To solve the above problem, we first performed manual reverse engineering of the lower control arm using special tools like Digital Vernier Caliper, Radius Gauge, Divider, etc. (Figure 2). All measured dimensions were recorded on a drawing, and using these dimensions, the lower control arm was drawn and modelled in CATIA. After modelling, the IGES file was imported into ANSYS for structural analysis using the finite element method.

Figure 2 shows the digital Vernier caliper used for measurements.

Additionally, the model must be meshed using tetrahedral finite elements. Tetrahedral elements provide better results compared to other element types, hence their use. The next step involves applying the loads, i.e., forces specified in the load cases. The material used is Mild Steel. After selecting the material, boundary conditions must be applied according to actual working conditions, specifying where the arm is fixed and its free end. The next step is to begin the model analysis and obtain results. If satisfactory, the problem is solved; if not, the model is adjusted, and steps repeated.

III. Building B-Splines in CATIA and Modelling Stages:

The following table shows the specific conditions of the model component selected for the study [4].

Table 1 shows the vehicle’s specifications

Parameter	Value
Wheelbase	2365 mm
Overall Length	4095 mm
Overall Width	1575 mm
Overall Height	1395 mm
Ground Clearance	170 mm
Turning Radius	4.8 mm
Empty Weight	870 kg
Loaded Weight	1315 kg

Acquiring Arm Data:

Data acquisition involves measuring the profile or geometric shape of the part to create a 3D model. The data is acquired using a digital Vernier caliper (Figure 2). The caliper measures three types of dimensions: external dimensions, thickness, and diameter of a part; internal dimensions or internal diameter of pipes; depth or height of a part or depth of a hole.

Data Transfer Stages:

The arm's cross-section is drawn and divided into points defining the arm's perimeter. These coordinates are entered into an Excel file, imported into CATIA, and connected using a spline curve, transferring the arm’s profile to the computer for modelling and applying necessary thicknesses.

Figures 3, 4, and 5 illustrate these stages: transferring reference points into the program and connecting them to create the model, drawing the front bushing of the arm, and the 3D design of the lower arm in the vehicle’s suspension system, respectively.

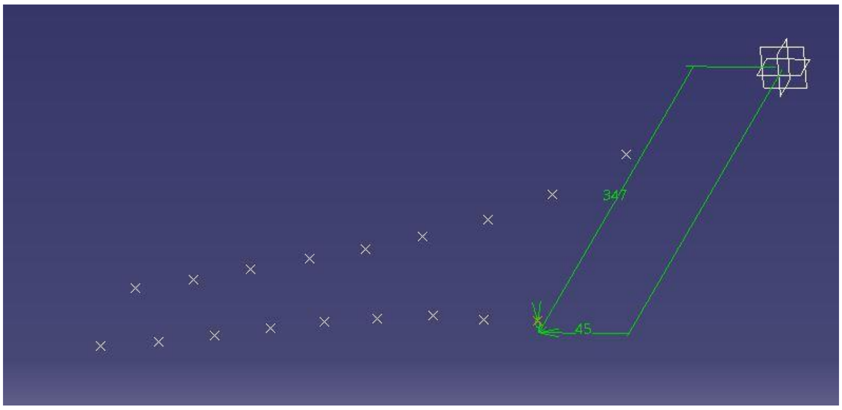
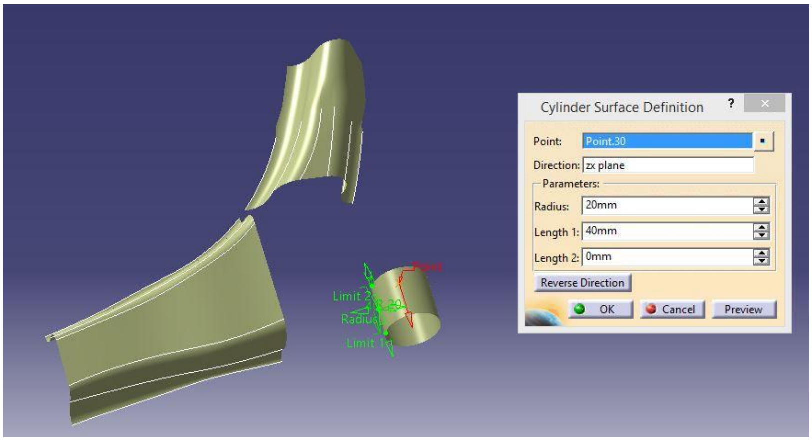


Figure 3: Transferring reference points into the program and connecting them to create the model.



Cylinder Surface Definition

Point: Point.30

Direction: zx plane

Parameters:

Radius: 20mm

Length 1: 40mm

Length 2: 0mm

Figure 4: Drawing the front bushing of the arm.

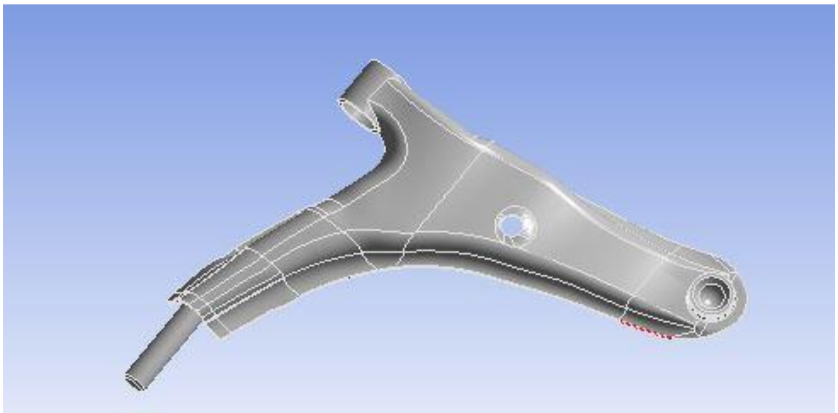


Figure 5: 3D design of the lower arm in the vehicle's suspension system.

IV. Static Analysis Stages:

This includes:

Meshing: In this analysis, meshing is created automatically by ANSYS after assigning a 5 mm thickness to the arm. Tetrahedral elements are used to mesh the lower control arm into finite elements. Figure 6 shows the meshed arm.

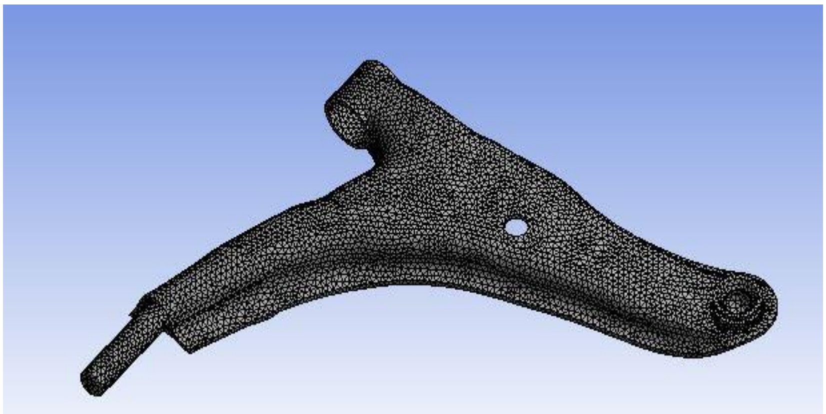


Figure 6: Meshing the arm into finite elements.

Loading Conditions: Static loads on the vehicle are calculated by considering the vehicle's weight acting at its Center of Gravity (CG).

$G= m.g$

About 39% of the vehicle's weight is supported by the front wheels and 61% by the rear wheels. The reaction equations are:

The reaction on the front wheels

(R1) = 0.39 * G

The reaction on the rear wheels

(R2) = 0.61 * G

Therefore,

R1 S1 = R2 S2

As we know, S = S1 + S2

Therefore, the loads on the front and rear axles are calculated using the equilibrium equations:

GFA = G * S2 / S GRA = G * S1 / S

Considering the load is uniformly distributed on the front wheels, the load on one wheel is given by: GFAW = GFA / 2

The descriptions of the above symbols are listed in Table 2 below:

Table 2 describes the parameters used in these calculations.

Parameter	Description
G	Vehicle weight acting at CG
M	Mass
g	Gravitational acceleration
R1	Reaction on front wheels
R2	Reaction on rear wheels
S1	Distance between CG and front axle
S2	Distance between CG and rear axle
S	Wheelbase
GFA	Load on front axle
GRA	Load on rear axle
GFAW	Load on one front wheel

Table 3 shows the assumptions for calculations:

Parameter	Value
Force	2520 N
Material	Mild Steel
Density	7870 kg/m^3
Young's Modulus	2 x 10^{11} Pa
Tensile Strength	245 MPa
Poisson's Ratio	0.29

Figures 7 and 8 show the loading conditions and the arm’s fixation and loading points.

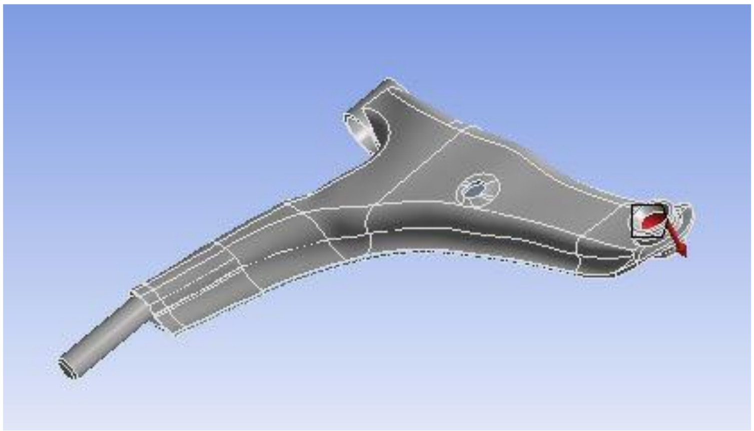


Figure 7: Fixing the arm according to its working conditions and loading.

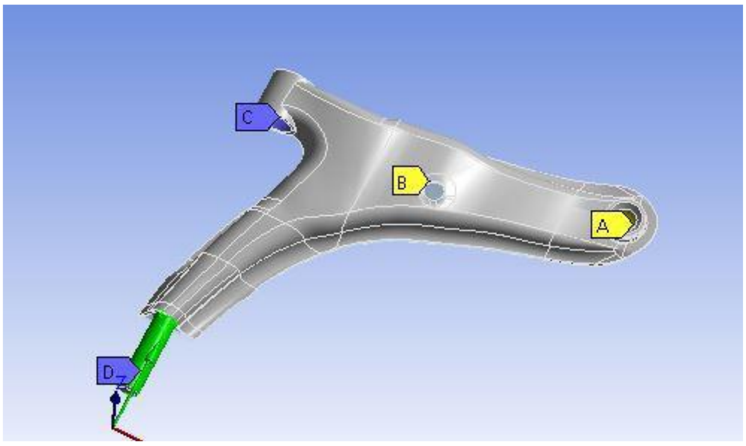


Figure 8: The loading position of the arm.

V. Results and Discussion:

Various features such as stress and displacement were analyzed using the Finite Element Method (FEM). The results are detailed below:

Stress Analysis: In the stress analysis of the lower control arm under high pressure (Figure 9), the design stress applied to the arm must be less than the material's yield strength. The resulting stress is 211.06 MPa, less than 245 MPa.

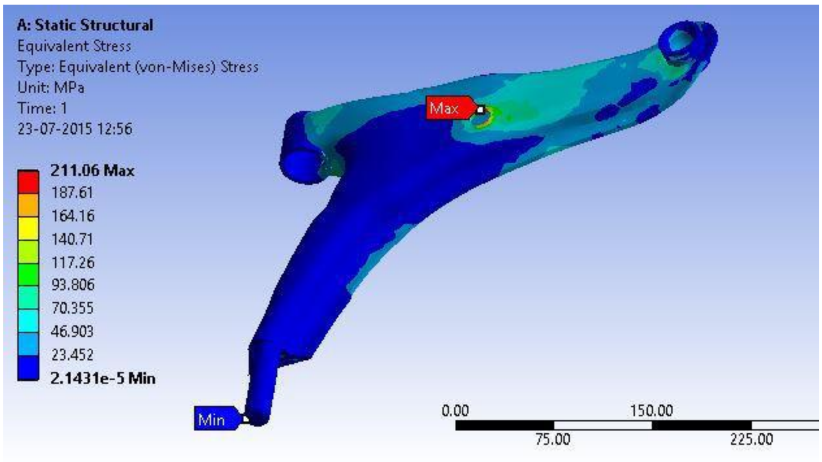


Figure 9 shows the equivalent Von Mises stress.

Total Deformation: The total deformation indicates how much the component deviates from its original position. The deformation must be within limits. The total deformation in the analysis is 0.65515 mm (Figure 10).

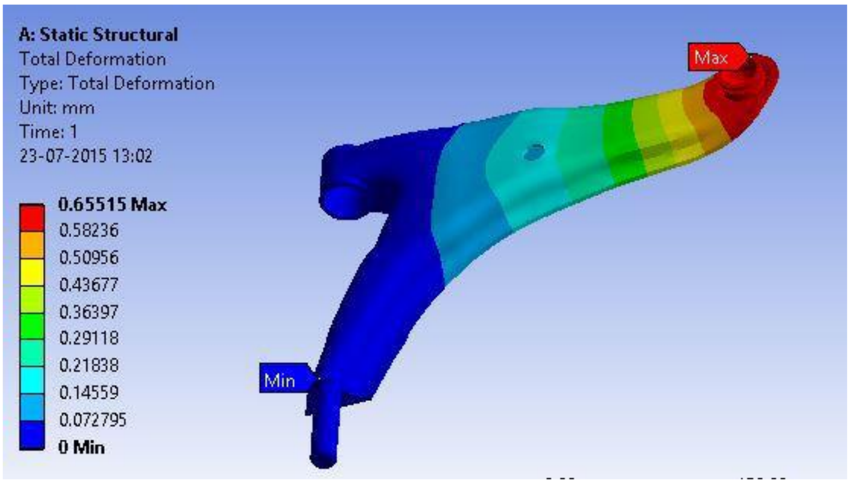


Figure 10 shows the total deformation.

Table 4 lists the analysis values for the studied lower control arm.

Parameter	**Result**
Equivalent Stress	211 MPa
Displacement	0.65515 mm
Safety Factor	1.1845

VI. Conclusions and Recommendations:

Conclusions:

- A 3D computer model that simulates the real model using reverse engineering was obtained.
- The materials used meet the working conditions for the lower arm in the MacPherson suspension system.
- In stress analysis, the material's stresses in the specified load condition are well within the yield stress, 211.06 MPa.
- The total deformation due to the applied force on the control arm is 0.65515 mm, with the maximum at the control arm ball joint.
- The minimum safety factor is 1.1845, indicating the suspension system's arm is safe.

Recommendations:

- Understanding the physical model and its function before reverse engineering significantly increases the accuracy of the results.
- Reverse engineering is an effective tool for testing, analyzing, and modifying design performance.
- Starting analysis tests with FEA and structural analysis facilitates achieving the optimal design.
- Analyzing the metallic mixture components and precisely studying the percentages and testing other metals can help reduce the suspension system's weight.

Future Studies:

- Further studies on other suspension system components are recommended.
- Future research should include dynamic and vibrational analyses of the suspension system.

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