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Structural analysis and weight optimization of integrated steering knuckle

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ABSTRACT

The aim of this project is to reduce the weight of the steering knuckle without compromising the strength of the steering knuckle. This Steering Knuckle is one of the critical components of a vehicle that links suspension, steering system, wheel hub, and brake to the chassis. It undergoes different loading under different conditions. There has been a strong trend towards the adoption of optimum materials and components in the automotive industry. The reason for this research paper is to design a knuckle that has low weight so that vehicle unspring mass can be reduced. In this project, the integrated steering knuckle is used. This research program aimed to optimize the best use of material for the steering knuckle and compare the analysis of steering knuckles made from three materials i.e. Gray cast iron, aluminum which is recently using and Mild steel is the suggested material.

Keywords*— Steering knuckle, Structural Analysis, Shape and Weight Optimization, Ansys, FEA.*

1. INTRODUCTION

The steering knuckle is one of the important components of a vehicle which is connected to steering, suspension, and brake to the chassis of the vehicle. It undergoes various loading under various conditions. There has been a strong trend towards the adoption of optimum materials and components in the automotive industry. Automotive designers have an extensive range of materials and processes to select from. Steel forgings are in competition with aluminum forgings and castings, cast iron, and sintered powder forgings. The competition is particularly acute in the chassis, and it is not unusual to find a range of various materials and manufacturing automation employed within modern chassis components.

Mass or weight reduction is becoming an important issue in the car manufacturing industry. Weight reduction will give a substantial impact on fuel efficiency, efforts to reduce emissions and therefore, save the environment. Weight can be reduced through multiple types of technological improvements, such as advances in materials, design and analysis methods, fabrication processes and optimization techniques, etc.

2. LITERATURE REVIEWS

Sanjay Yadav et al. [1] has studied Design and Analysis of Steering Knuckle Component. The Steering Knuckle component is the most necessary part of the vehicle which is connected to the front wheel with the help of the suspension system, wheel hub, and these are also connected to the steering system and brake to the chassis. The Steering Knuckle component provides movement to desired directions with the help of the steering system. It undergoes various types of varying loads under different conditions. In the Automobile industry-low, fuel utilization and lightweight are the two main demands for the vehicle because the lighter steering knuckle resulting in greater power and less vibration because inertia is less.

In this paper, we have done a static analysis of the steering knuckle component. The design of the Steering Knuckle component is done with the help of CAE. The steering Knuckle model is formulated in Creo and the static analysis is done in ANSYS by constraining the steering knuckle and applying load on steering knuckle due to caliper mounting, longitudinal reaction, vertical reaction, vehicle weight, and steering reaction. In this, we have focused on develop the best use of material for the steering knuckle component and compare it, made from two material i.e. Cast Iron and Mild Steel which is recently using, and Forge Steel EN 47 which is recommended material. This result is verified by comparing it with analytical calculations. Considering these results, the model is modified.

Jukanti Reddy et al. [2] his studied Design and Structural Analysis of Steering Knuckle for An Electric All-Terrain Vehicle. The steering knuckle is a component that is used as a connection between the wheels, suspension, and braking system and also helps the wheels of the vehicle to turned in the required direction. The reason for this research paper is to design a knuckle that has low weight so that vehicle unspring mass can be reduced. Design is an important factor in the product development cycle. By the decrease of the unspring mass of the vehicle the riding characteristics of the vehicle can be improved. The strength and durability of the component are maintained by the usage of the lightweight aluminum T6 7075 rather than the grey cast iron and mild steel. This study involves two steps. The first step is to design the component and the second step is to do the finite element analysis to find the stresses induced and to know the deformation of the component. The design is done with the help of the Catia V5 and the analysis is done with the help of Ansys workbench 15.0.

Geun Yeon Kim et al. [3] has studied Structural Optimization of a Knuckle with Consideration of Stiffness and Durability Requirements. The automobile's knuckle is connected to the parts of the steering system and the suspension system and it is used for accommodating the direction of a rotation through its attachment to the wheel. This study changes the existing material made of GCD45 to Al6082M and recommends the lightweight design of the knuckle as an excellent design approach to be installed in small cars. Six shape design variables were selected for the development of the knuckle and the criteria relevant to stiffness and durability were considered as the design requirements during the optimization process. The metamodel-based development method that uses the kriging interpolation method as the development technique was applied. The result shows that all constraints for stiffness and durability are satisfied using A16082M while reducing the mass of the knuckle by 60% compared to that of the existing GCD450.

3. METHODOLOGY

There are some differences in methodology between the studies as showing in table.

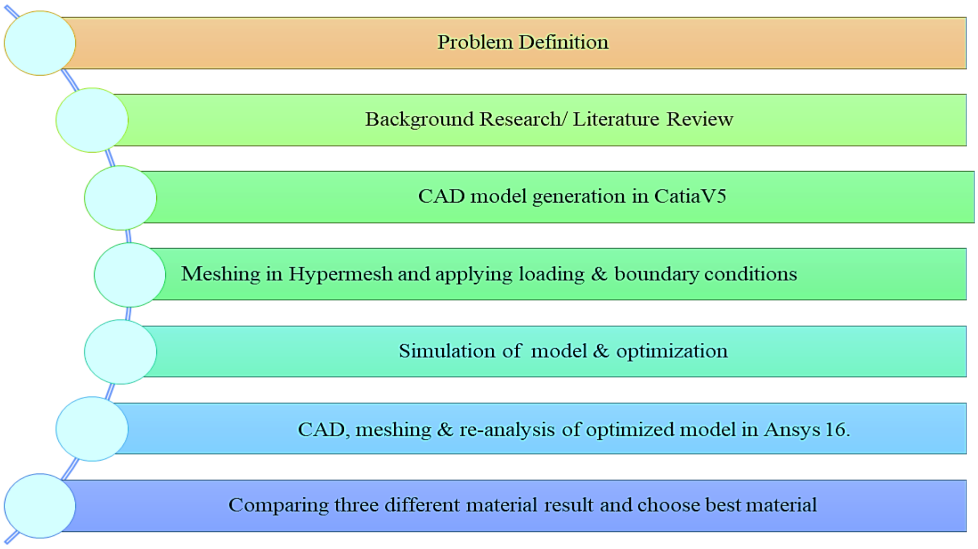


Fig. 1: Methodology

4. FORCE AND LOAD CALCULATION

Considering Stationary Bolero car, which is taken all loading conditions. The earth's gravitational pull (mg) acts through the center of gravity and the reaction (remember to every action there is an equal and opposite reaction) acts through the contact patches between the tyres and road. The vectors shown represent the combined reactions at both front wheels and both rear wheels.

- Seating capacity = 7
- Weight of the car without passenger = 1600 kg
- Total weight of the car (W) = 2200 kg = 21582 N
- This weight must be divided into front axle weight and rear axle weight, 52% of total weight is taken by front axle and 48% of total weight is taken by rear axle.
- Front axle weight (F1) = 1144 kg = 11222 N
- Reaction at one wheel = 1144/2= 572 kg = 5611 N
- Rear axle weight (F2) = 1055 kg = 10349.55 N
- Tyre-road friction coefficient (μ) = 1.5
- Wheel base (Distance between front axle and rear axle) (1) = 2680 mm
- Avg acceleration (ā) = 3.3 m/s^2
- Centre of gravity height from base (Hcg) = 940

1.Front Axle Breaking Force (FB)

FB = μ/2[Static+ dynamic load]
= μ/2[W* Bcg/l + m* ā *Hcg/l]
= (1.5*21582)/2[(1396.1/2680) + (3.3*940)/ (9.81*2680)]
=10.34 KN

2.Vertical Force (FV)

FV = 3/2 [Static+ dynamic load]
= 3/2 [W *Bcg/l + m* ā *Hcg/l]
= (3*21582)/2[(1396.1/2680) + (3.3*940) / (9.81*2680)]
= 20.68 KN

3.Lateral Force (FL)

FL = W [Static+ dynamic load]
= W [Bcg /l+ ā* Hcg /gl]
=21582[(1396.1/2680)+(3.3*940)/ (9.81*2680)]
= 13.78 KN

5. INTEGRATED CAD MODEL

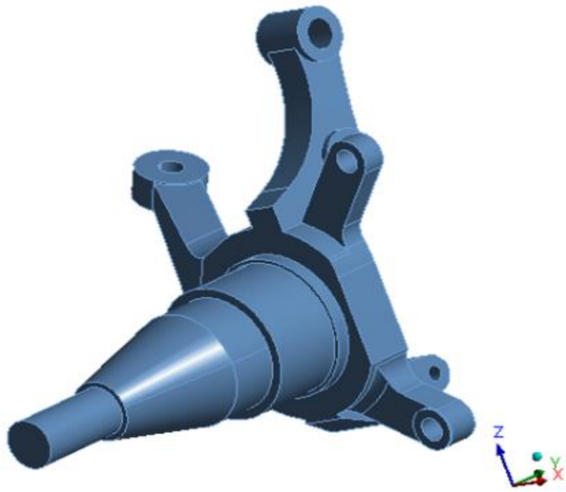


Fig. 2: Integrated Steering knuckle cad

Steering knuckle cad step file which is made by the commands in CATIA software of Pad, pocket, fillet and geometrical selections in part design module. Dimensional parametric model is generated in drafting module of CATIA having top, side and front view as given.

6. LOADING AND BOUNDARY CONDITION

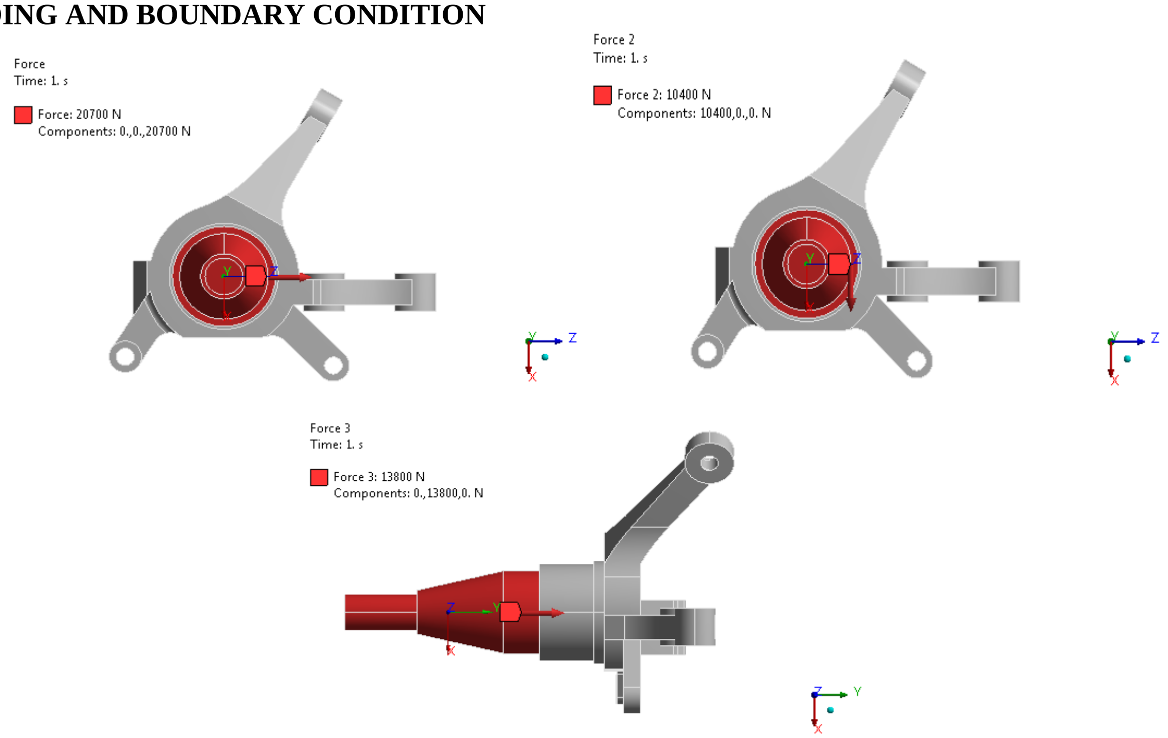


Fig. 3(a): Lateral, vertical, and braking forces applied at the hub

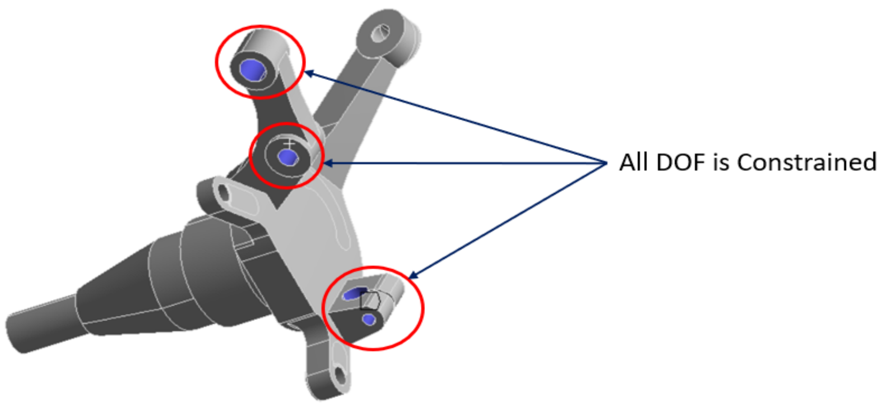


Fig. 3(b): Fixed location of Steering knuckle

Loading and boundary condition (forces and constrained) of integrated steering knuckle.

6.1 Existing material of steering knuckle is mild steel

Table 1: Material Properties of Mild Steel

Density (Ton/mm3)	7.87e-9
Modulus of Elasticity (MPa)	2.5e5
Poisson Ratio	0.30
Yield Point (MPa)	370
Ultimate Point (MPa)	440

6.2 Result- Total deformation and maximum stress plots

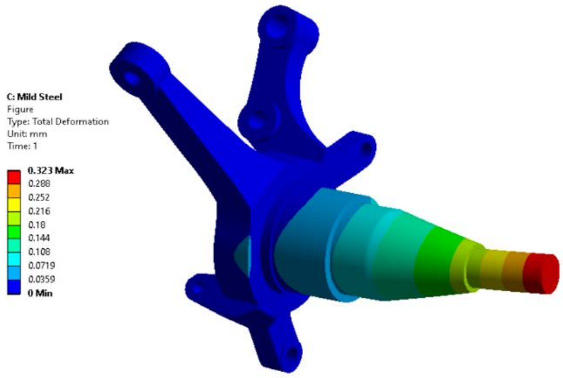


Fig. 4(a)- Maximum Deformation 0.323 mm

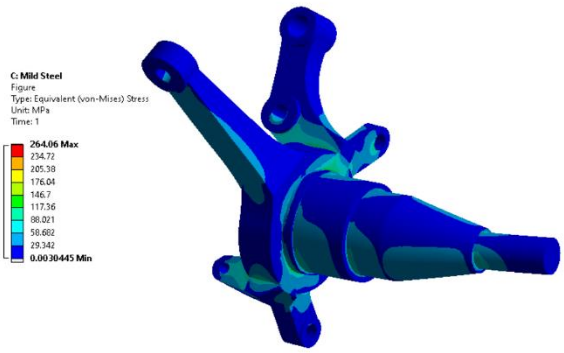


Fig. 4(b)- Maximum Stress 264.06 MPa

The maximum deformation is found to be **0.323 mm** which is very less and the max stress obtained is **264.06 MPa** which means the design is safe.

7. OPTIMIZATION OF INTEGRATED STEERING KNUCKLE

- Optimization methods were developed to have lighter, less cost and may have better strength too.
- Many optimization types, methods, software technique and tools are available due to the revolution of the high speed computing and software development.

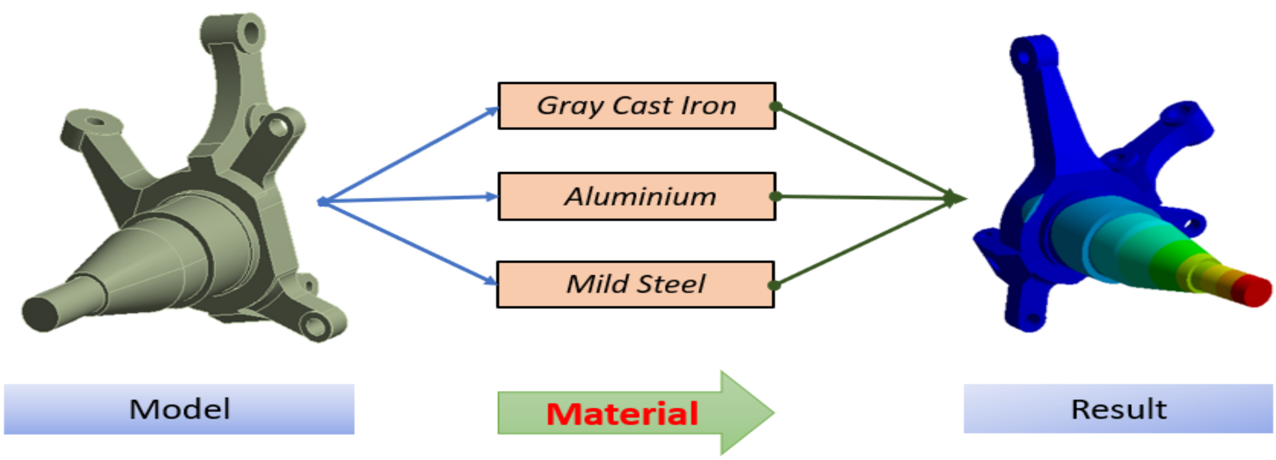
7.1 Material Optimization

There are several materials used for manufacturing of steering knuckle such as Gray Cast Iron, Aluminum and Mild Steel. But grey cast iron mostly used. Mild steel and Aluminum are most demanding material for this application.

Table 2: Material Optimization with 3 different material

Gray Cast Iron	*Aluminum*	*Mild Steel*

7.2 Material Process Loop



Loop 1- Material Process Loop

Gray Cast Iron, Aluminum and Mild Steel material iterations are continuing while having same loading and boundary condition.

7.3 Material Data

Table 3: Material Data

Sr No.	Material	Density (Ton/mm3)	Modulus of Elasticity (MPa)	Poisson ration	Yield Point (MPa)	UTS (MPa)
1	Gray Cast Iron	7.20e-9	1.10e5	0.28	280	280
2	Aluminum	2.69e-09	71000	0.33	280	310
3	Mild Steel	7.87e-09	205000	0.3	370	460

Material data includes Density, Modulus of Elasticity, Poisson ration, Yield Point and UTS with their respective units.

8. OPTIMIZATION IS FOLLOW BY NUMBER OF ITERATION

ITERATION 01

1. Integrated Model

ITERATION 02

2. Material removal from the longer arm

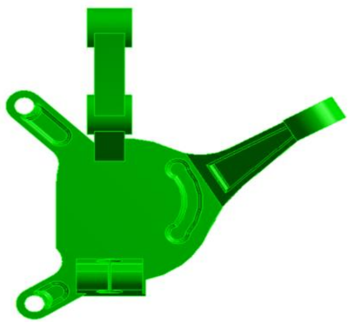
ITERATION 03

3. Material removal from the circular portion of hub

ITERATION 04

4. Material removal from the one smaller arm

ITERATION 05



5. Material removal from another one smaller arm

Optimization methods were developed to have lighter, less cost and may have better strength too. Many optimization types, methods, software technique and tools are available due to the revolution of the high-speed computing and software development.

9. RESULT- OBSERVATION TABLE

Observation table for comparisons of 3 forces with 3 different material with their deformation, stress and strain.

Table 4: Result observation table of all iteration

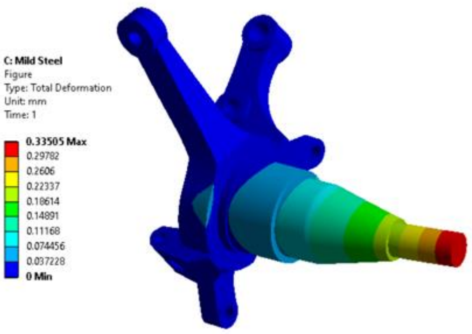
Sr No	Iteration	Material	Deformation (mm)	Stress (MPa)	Strain (%)	Yield Limit (MPa)	Weight (Kg)	Safe Zone
01	Iteration 01							
		Gray Cast Iron	0.604	261.07	0.24	280	5.370	
		Aluminum	0.932	269.42	0.34	276	2.060	
		Mild Steel	0.323	264.06	0.13	370	5.850	

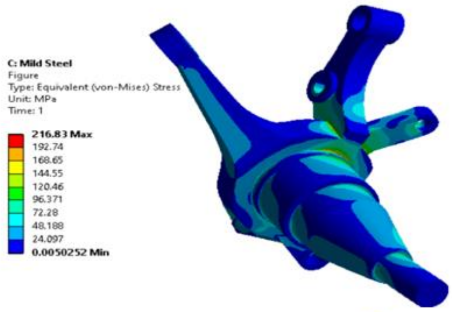
02	Iteration 02							
		Gray Cast Iron	0.605	297.18	0.27	280	5.183	
		Aluminum	0.9353	307.04	0.44	276	2.018	
		Mild Steel	0.332	301.05	0.15	370	5.733	
03	Iteration 03							
		Gray Cast Iron	0.606	293.85	0.27	280	5.183	
		Aluminum	0.9365	302.14	0.44	276	1.988	
		Mild Steel	0.333	297.17	0.15	370	5.647	
04	Iteration 04							
		Gray Cast Iron	0.609	210.67	0.22	280	5.131	
		Aluminum	0.9409	202.55	0.34	276	1.968	
		Mild Steel	0.334	207.38	0.12	370	5.590	
05	Iteration 05							
		Gray Cast Iron	0.609	219.66	0.23	280	5.106	
		Aluminum	0.9416	212.74	0.35	276	1.958	
		Mild Steel	0.335	216.83	0.12	370	5.562	

Design is safe, stress is produced under yield limit.
Local stress is produced there is no critical damage or fail.

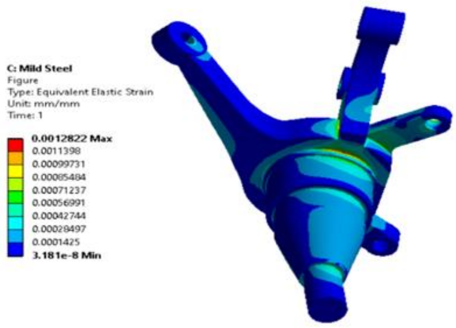
From the comparison table we are conclude that integrated steering knuckle with different iterations are below critical limit and hence they are safe in design that's **Iteration 05** design is best optimized model with **mild steel** material.

9.1 Result- Total deformation, maximum stress and strain plots





Deformation (mm)	**0.335**
Stress (MPa)	**216.83**
Strain	**0.12%**
Weight (Kg)	**5.562**



9.2 Weight Reduction

$$\text{Percentage Reduction} = \frac{\text{Existing Model} - \text{Optimized Model}}{\text{Existing Model}}$$

Table 5: Weight Reduction

Material	**Weight Reduction**	**% Weight Reduction**
Gray Cast Iron	5.370-5.1060/5.370	4.91~5
Aluminum	2.060-1.9587/2.06	4.912~5
Mild Steel	5.850-5.5625/5.850	4.914~5

Almost **5%** of weight reduction are optimize but we can check the best strengths of above material.

9.3 Factor of safety

$$\text{Factor of Safety} = \frac{\text{Ultimate tensile strength}}{\text{Working Stress}}$$

Table 6: Factor of safety

Material	Calculation	FOS~	FOS
Gray Cast Iron	280/219.66	1.27	1.30
Aluminum	310/212.74	1.45	1.45
Mild Steel	460/216.83	2.12	2.2

From the above table report when we compared to all three materials, **Mild Steel** material has the higher factor of safety is **2.2**.

9.4 Approximation per KG cost of material

Table 7: Cost of Material

Material	Per kg cost in Rupees	Actual Weight (Kg)	Total Price (Rs)
Gray Cast Iron	60 per kg	5.106	307
Aluminum	140 per kg	1.958	275
Mild Steel	55 per kg	5.562	306

- Nearest to same of cost of all three material.
- This is approximation cost of material.
- Material cost depends upon material grade and its property.

10. CONCLUSION

- **5**% weight reduction is obtained without compromising the strength of the integrated steering knuckle.
- From the result table we conclude that integrated steering knuckle with different iterations are below critical limit and hence they are safe in design that's ***Iteration 05*** design.
- The iterations are carried out through the optimization process and the best optimized steering knuckle material is ***Mild Steel.***
- Mild steel material is choosing for three different criteria**,**
  - ***Weight of material***
  - ***Factor of safety***
  - ***Cost of material***

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