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Design and Analysis of Trellis Frame

S. K. Vinoth Kumar, K. K. Abishek, S. Anand, S. Surya Prakash
R.M.K. College of Engineering and Technology, Chennai, India
abishekabi004@gmail.com

Abstract

A frame serves as the basic foundation on which all the parts of a machine rest. In an automobile, the frame acts as a skeleton on which the engine, transmission, driveshaft, differential, gearbox and suspension are mounted. Our work deals with comparing the dynamic analysis – static, transient thermal and transient structural analysis of the three different frames with the precursor TVS super XL frame. The two different trellis frames are designed and modeled for conventional and economic purpose. Initially, the TVS super XL frame was considered to design the first trellis frame and considering this frame the second trellis frame is designed and modeled. Ultimately using the software ANSYS workbench 16.0, the three results are obtained for dynamic analysis from three different frames and compared.

Keywords: ANSYS Workbench 16.0, static, transient thermal and transient structural analysis.

1. Introduction

A chassis serves as the basic foundation on which all the parts of a machine rest. In an automobile, the chassis acts as a skeleton on which the engine, transmission, driveshaft, differential, gearbox and suspension are mounted. The chassis should be structurally sound in every way and support the body panels over the expected life of the vehicle and beyond. The engine generally sits inside the frame, the rear swing arm is attached by a pivot bolt (allowing the suspension to move) and the front forks are attached to the front of the frame. The frame can also help to protect the more sensitive parts of the motorcycle in a crash. Any good chassis must do several things: Be structurally sound in every way over the expected life of the vehicle and beyond. This means nothing will ever break under normal conditions. Maintain the suspension mounting locations so that handling is safe and consistent under high cornering and bump loads. Support the body panels and other passenger components so that everything feels solid and has a long, reliable life. Protect the occupants from external intrusion. Help the wheels align on a single straight line. A frame design is dependent on the suspension, steering and transmission subassembly design of the particular vehicle and hence gives flexibility to optimize it in terms of weight and durability. Among the vehicle structural components, the frame is the most important part in the vehicle. The centralization and reduction in weight of the chassis improves vehicle's handling and performance. The frame is required to support the various loads of the components and systems of the vehicle as well that of the rider, pillion and payload and sustain numerous forces and torques induced by bumping, braking and acceleration. Under normal operating conditions, it is subjected to dynamic forces transmitted from the front and rear suspension systems. The frame is subjected to time varying loads during its service life which may lead to fatigue failure. Thus, in the design and optimization of a motorcycle frame, the weight must be minimized, centralized and lowered, while factors such as strength, stiffness and durability should meet the design targets. An effective design is one which performs the required task efficiently and is safe under extreme operating conditions, while being economical in the material used as well as the manufacturing process needed yet having an aesthetic appeal. Analysis aids in understanding the behaviour of a component under a particular loading cycle for both failures and redundancies.

2. Literature review

For the design and optimization of a chassis for an electric motorcycle it is necessary to look into the design aspects and literature available in order to better understand the need of the industry and deliver high performance components and systems. The literature available has increased considerably since the past decade and multiple forms of design structures, FEA methods and optimization techniques have emerged. Tony Foale in 'Motorcycle Handling and Chassis Design - the art and science' provides practical, applicable, design guidelines and theories to design and fabricate a motorcycle chassis. He elaborates on various geometries associated with frame building and the different forces and moments on the frame and other vehicle systems during the dynamic behavioural conditions like acceleration, braking, cornering, etc. of the vehicle. The author explains the use and applications of various materials and cross-section types of the frame along with various manufacturing processes for the fabrication of the motorcycle frame. In the book ‘The Finite Element Method: Its Basis and Fundamentals’, Zeinkiewicz, Taylor and Zhu explain the concepts behind the mathematical modelling of component under study with emphasis on the mesh generation and mesh relevance parameters. Their work is a skeletal structure on which the FEA method for the steering knuckle optimization was developed.

3. Design Considerations

While designing a frame for an electric motorcycle, it is very important to take into consideration the type of frame structure that will be appropriate to mount the components required for electric mobility such as the motor, battery pack, battery charger, etc. as well as the essential components and systems that are present in a conventional motorcycle. Following are the various types of motorcycle frames that are in practical use:

Spine or Backbone Frame: It comprises of a large diameter tube which acts as the spine of the bike upon which the components are hung thus acting like a core structure.

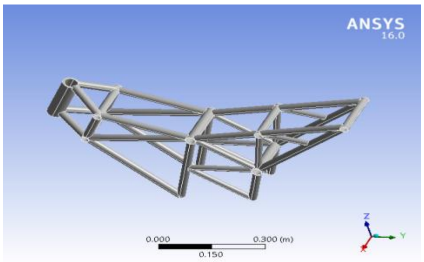
Single Cradle Frame: It consists of a single top tube and a single down tube that runs from steering head to swing arm pivot thus forming a loop on which various components are mounted.

Full-duplex Cradle Frame: It consists of a single top tube and two down tubes that run from steering head to swing arm pivot thus forming a loop on which various components are mounted.

Perimeter Frame: It consists of two box-section beams joining the steering head with the swing arm in the shortest possible length for maximum rigidity and stiffness.

Monocoque Frame: It comprises of a structure where loads are supported through its external skin which acts as its core for component mountings.

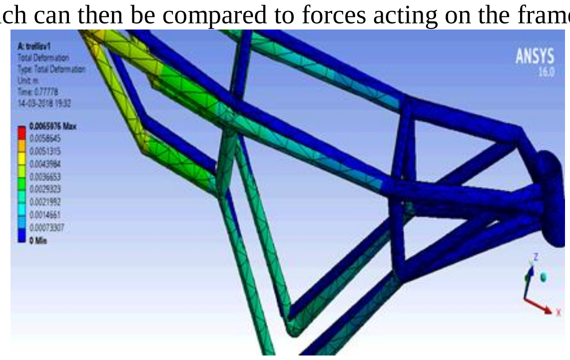
Trellis Frame: It consists of several short steel or aluminum tubes welded together into a series of triangles which provide the frame with strength and stiffness.



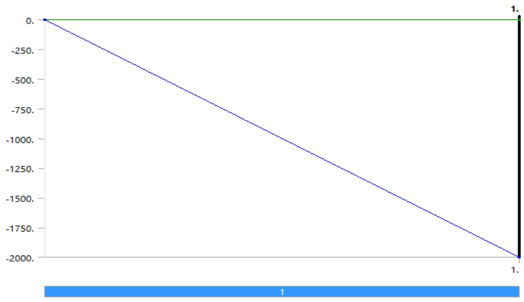
The major structural difference between a conventional IC engine motorcycle and an electric motorcycle is the power producing system of the vehicle. The components of the IC engine motorcycle such as the engine, exhaust system and the fuel tank is replaced by a battery pack system and an electric motor. The design and incorporation of various mechanical systems like the front and the rear suspension, transmission, braking and seating systems of the vehicle are similar for both types of motorcycles. Thus, the motorcycle frame must be designed in such a way that the space accommodated for the engine, exhaust system and the fuel tank previously will now be taken by the battery pack system and an electric motor without affecting the performance of the other related vehicle systems. Thus, considering various design and safety parameters, a custom trellis type frame was selected as the frame for the electric motorcycle. On comparison with the other frame types of the same material, the trellis frame is the lightest frame and yet provides high rigidity due to the triangulations provided by the tubes of the frame. The trellis frame thus, has the highest strength to weight ratio among all frame types. Unlike the cradle frame, the tubes of the trellis can accommodate components of larger size which also perform structural duties themselves thus providing increased strength and rigidity. Trellis frame provides better centralization and lowering of the overall vehicle weight. The custom trellis frame connects the steering head to swingarm pivot as directly as possible using metal tube arranged in a triangulated reinforcement using a metal plate on which the swingarm pivot is mounted. Using lattice girder principles, the custom trellis frame is constructed of round metal tubular segments that are welded together. The custom trellis frame provides a strong lightweight structure that simplifies the placement of all the essential components and systems of the electric motorcycle. One of the first considerations while designing the trellis frame was driver ergonomics. By using the 95th percentile anthropometric study, an ergonomic rider stance was derived by defining different positions and angles of the rider body parts likes arms, legs, back and head which helped in defining various primary dimensions of the frame like the distance of steering head from the rider seat, height of the rider H-point from the ground to determine the height of the frame required, pillion rider position for the overall frame length and seat width to find out the frame width. This helped in sketching out a preliminary figure of the trellis frame. Secondly, the position of various components and vehicular systems was determined according to the design considerations that helped design the triangulated reinforced structure of the frame. The steering head is designed and angled to mount the telescopic fork assembly to provide optimum suspension and steering performance for the vehicle. The space between the steering head and rider seat was provided with the required width and strong triangulations for housing the power source system of the electric drive that contained the battery pack, battery management system, on board charger and controller driver circuits. The swing arm pivot and the electric drive motor was mounted on a metal plate that connected the steering head and the rider and pillion seat structure with the metal tube structure. A lateral member is provided to mount the mono shock absorber which when connected to the swing arm delivers desirable suspension characteristics. Along with functional requirements like ergonomics and component mountings, the frame was designed to consider weight and strength also. The main aim was to reduce the weight, centralize the weight and lower the weight of the frame. Thus, the metal tubes were divided into primary, secondary and tertiary members based on the tube diameters and thicknesses in order to reduce the overall weight of the frame without affecting its strength. The centre of gravity of the frame is below the rider seating area thus ensuring a low and centralized frame weight. The trusses not only provide strength and rigidity but also safety of the driver and essential vehicle components against impacts.

4. Analysis of forces acting on frame

The forces acting on the frame and the points of application of the forces are very important in the Finite Element Analysis study. As the geometrical and physical constraints of every vehicle are different, there is no standard range of values for forces acting on the frame. For this study, the following data is considered for studying the various forces acting on the frame of an electric motorcycle. The forces calculated in Newton are converted to G - Force by dividing with the weight of the car to present a standardized value which can then be compared to forces acting on the frames of other vehicles.



Deformed Trellis Frame Version 1



LOAD VS TIME

Table 1: Material used for the Frame

SAE AISI 4130	
DENSITY	7.85 g/cc
ULTIMATE TENSILE STRENGTH	560 MPa
YIELD STRENGTH	60 MPa

MODULUS OF ELASTICITY	210 GPa

The forces acting on the frame are:
Weights of all the Components and Riders: The frame supports all the major components of the vehicle systems such as the powertrain, suspension and other accessories as well as the riders and the excess payload they carry. Thus, the frame accounts for all the forces acting on it due to their weights in the downward direction.
Bump Force: When the vehicle undergoes a ground disturbance in the form of a bump or a hole a force is exerted on the frame. For design considerations, it is assumed that the rear suspension mono-shock and the front telescopic fork suspension has attained full travel which is 3 inches.

Lateral Force due to Turning: Lateral force or side force is the cornering force produced by a vehicle wheel during cornering. It is equivalent to the centrifugal force generated due to cornering. Inertia causes load transfer in lateral direction; i.e. the load from the right side is transferred to the left side while taking a right turn and vice versa.
Brake Force due to Torque required for Braking: Brake force is generated on the frame at the front collar where the steering handlebar is mounted and the metal plate where the wheel is connected using the swingarm when the brake is applied to retard the motion of the vehicle. It is calculated as the product of the pressure generated in fluid line with net area of calliper piston and the coefficient of friction between the brake pads and the brake disc.
Longitudinal Weight Transfer: During acceleration and braking, inertia of the vehicle components causes a load transfer in longitudinal direction on the vehicle; i.e. the load form the rear is transferred to the front while braking and the opposite effect takes place while accelerating. This load transfer (or weight transfer) exerts a force on the frame. A similar effect takes place while negotiating a corner.
Force on Impact: When the vehicle is subjected to a front, rear or side impact an impulse force is exerted on the frame. This force may lead excessive stress on the frame causing deformation.

Table 2: Calculated Force Values for Given Data

Bump Force	2943 N	2g
Lateral Force due to Turning	735.75 N	0.5g
Brake Force due to Braking	1471.5 N	1g
Longitudinal Brake Transfer	1471.5 N	1g

5. Finite Element Analysis

Finite Element Analysis is a numerical technique for finding approximate solutions to boundary value problems for partial differential equations by subdivision of a whole problem domain into simpler parts, called finite elements. Various methods from the calculus of variations are used to solve the problem by minimizing an associated error function. FEA as applied in engineering is a computational tool for performing engineering analysis. It includes the use of mesh generation techniques for dividing a complex problem into small elements, as well as the use of software program coded with FEM algorithm.

General Procedure

Set the type of analysis to be used.
Create the model.
Define the element type.
Divide the given problem into nodes and elements (mesh the model).
Apply material properties and boundary conditions.
Derive the element matrices and equations.
Assemble the element equations.
Interpret the results.
The general process of FEA using software is divided into three main phases: preprocessing, solution and post processing. Component is 1.7mm which is well within limits. Thus, the battery and its components are safe for extreme road conditions also. The Boundary conditions for a FEA problem are basically the points of application of the constraints as well as the forces on the frame. The boundary conditions depend mostly on the geometry and functionality of the frame. Here the suspension and wheel centre mounts are constrained. The lateral forces for the FEA model are applied to the battery

mountings on the frame. The forces due to braking and acceleration travel through the collar of the frame. The bump forces also travel from the collar and the rear suspension point.

6. Conclusion

The frame has been designed considering the design and functional requirements of an electric motorcycle. A trellis frame design was adopted as it provided not only better strength and rigidity but also better component mountings and freedom of design. An FEA model was created and an analysis of the frame was carried out with various load cases. It was clear from the analysis that the displacement during worst load cases was well within limits. The essential components like the battery pack and the motor are safe from the critical forces acting on the frame. The forces were considered to be acting in ideal condition which does not happen in practical application. The manufacturing process required to build a custom trellis frame is complex considered to other frame categories. Hence the cost of manufacturing could be more. No comparative study was done with respect to the cost of manufacturing, manufacturing process used large scale production feasibility between the various types of frames. The analysis performed is static structural analysis of the component, hence for further improvement of the component, fatigue analysis should be considered. The study does not include optimization of the frame to reduce the weight without compromising much on the strength and rigidity of the frame. Thus, further optimization and analysis can be performed. Similar to the frame, many other motorcycle components can be designed and subjected to FEA study to be used in design and development of electric motorcycles. Thus, we can conclude that the design and FEA of the frame plays a very important role in the design procedure of an electric motorcycle. It can be seen that there is also a scope in weight reduction of the vehicle by reducing the weight of the frame using design and FEA techniques in the future.

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