Experimental Stress Analysis and FEA Validation of chain link for 280 cc Drive

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Abstract **- Observing the gaps in literature, development of a complete model for FE analysis of the drive chain link is attempted to develop. The model is first planned to develop for a structural analysis for tensile testing. Study chain link design parameters in drive chain. The design for the chain would be subjected to F.E Analysis to find the effect of loads (tension) on the links. The link being a `unit' of the existing chain would be assessed for performance while tensile loads are exerted at both its ends. Work is to find the strength for the chain link to be used for the demanding application without failure and severe loading conditions exist during the usable life of the chain. The chain to be analyzed using F.E.Methodology for the given application.**

Results obtained by the Numerical Methodology shall be compared with the Methodology using the Physical Experimentation for given application. This work is being evaluation of the design using software in the F.E.A. followed by experimentation to validate the theoretical outcome.

Keywords - Drive Chain, Finite Element Methodology, link, Numerical Methodology, Structural analysis, Tensile loads.

1. INTRODUCTION

A chain is a machine component, which transmits power by means of tensile forces, and is used primarily for power transmission. [1] The function and uses of chain are similar to a belt. In motorcycles, the final transmission is carried out by roller chain and sprockets and those chains have some problems as reported that need to be studied. In this regard, to understand the problems of chain, general construction, properties and constraints in manufacturing of chains are studied and discussed. Moreover, motorcycle transmission chains affect the performance of motorcycles and greatly influence customer satisfaction. In this aspect, in order to carryout possible improvement in its performance, the various research works on chains that have been carried out are studied using literature survey [2]. In the present work, existing motorcycles transmission chains are considered for studying and improving performance

2. REVIEW OF LITERATURE

Chain drives are used for a long time; most of the published research on it has been concentrated to the latter half of the 20th century. Today, four types of chains are commonly found: roller chain, Leaf chain, Conveyor chain, silent chains. The work is related to roller chain so further discussion will be limited to chain of this type.

Chain drives were poorly understood through the 1980's for a variety of reasons, including the polygonal action, nontrivial sprocket geometry, intentional clearances and unintentional dimensional variations due to manufacturing tolerances, friction, and the large number of bodies that make up the typical chain and sprocket system. The manufacturer of roller chains has been standardized by the American National Standards Institute (ANSI, 1972) since 1913. The first report in an ASME journal devoted to the study of roller chain drive based upon sprocket impact loads and experience. (Wright and Shigey, 2005).

Gerhard Hippmann et al. have investigated Bush chains and roller chains are frequently used in valve train systems of combustion engines.

There are two basic strategies to keep the numerical effort in time integration within reasonable bounds: On the one hand it may be reduced by adapted modeling, on the other hand specific time integration schemes may be used to solve the equations of motion. The paper introduces methods in both fields and presents simulation examples to show their effect on efficiency and to validate their implementation (Gerhard Hippmann et al., June 2005).

Bhoite T. D. and Pawar P. M. published the paper on Finite Element Analysis based study of Effect of Radial Variation of Outer Link in a typical Roller Chain Link Assembly. Studied the scope of this paper is to review the applications in the industry and explore the design considerations that go into the design of the assembly. Finite Element Analysis (FEA) has been used to conduct shape optimization (Bhoite T. D. and Pawar P. M., 2012).

Jagtap M. D. et al. studied on Roller Conveyor Chain Strip under Tensile Loading From a theoretical viewpoint chain is a continuous flexible rack engaging the teeth on a pair of gears. Certainly a sprocket being a toothed wheel, whose teeth are shaped to mesh with a chain, is a form of gear. Based on its history and development, chain is a mechanical belt running over sprockets that can be used to transmit power or convey materials. Chain strips are machine elements that are subjected to extreme service conditions, such as high tensile loads, friction, and sometimes aggressive operating environment (e.g. presence of humidity, seawater, chemicals). Apart from tensile overload fracture, double shear is also an important failure mechanism which occurs under lower applied loads. Chain is the most important element of the industrial processes required for transmitting power and conveying of materials.

The scope of this paper is to study the behavior of chain strip under tensile loading. In turn it will help in reducing down time and maintenance cost related chain assembly in various above said industries. In this paper we study the analytical, experimental and numerical behavior of strip under tensile loading (Jagtap M. D. et al., May, 2014).

Noguchi S. et al. have investigated Static Stress Analysis of Link Plate Roller Chain using Finite Element Method and some Design Proposal for Weight Saving. In this paper study some method of weight saving for roller chain. This method based on finite element method analysis of stress and deformation in link plate of a roller chain .The Authors suggest some approaches for reducing stresses and weight saving in link plate of roller chain. The weight saving thus achieved will have a significant impact on cost of the chain, and more importantly with a lighter chain, the cost savings during operation will also be significant (Noguchi S. et al., 2009). Chain Link assembly is extensively used in the industry, the scope of this paper is to review the applications in the industry and explore the design considerations that go into the design of the assembly.

The paper delves into various application aspects and manufacturing aspects to formulate an idea of the system. Finally Finite Element Analysis (FEA) has been used to conduct shape optimization. Since lot of work has already been done in other components, in this paper the focus has been narrowed down to specific component of outer link. (Shahane T.S et. al., February, 2015)

From the literature survey it can be seen that the motorcycle chain link has been topic of interest for many researchers. From the brief review of some of the literature from it can be noted that, some researchers based on improvement of efficiency and performance chain and focuses on improving life of the chain and minimization of its failure. It can also be noted that the analytical work in the literature is focused on load estimation. Very few researchers have explored the fatigue life estimation and stress analysis for the chain assembly.

3. TYPICAL STRUCTURE OF POWER TRANSMISSION CHAIN

A chain assembly consists of five main components Inner Link Plate/ Roller Link Plate, Outer Link Plate / Pin Link Plate, Roller, Bush, Pin. A typical configuration for roller chain is shown in Figure 2.1.While manufacturing the chain, Inner Link Plate is press fitted on both the sides of the bush and pin is press fitted on the Outer Link Plate. The pin is inserted in between the bush and the bush is inserted in between the roller.

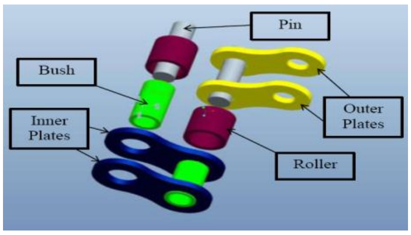


Figure 3.1: The Basic Components of Transmission Chain.

3.1 Functions of Chain Parts

3.1.1 Plate

Plate is a component that bears tensile load acting on chain during power transmission. Plate with a relatively larger punched hole, is inner / roller link plate, whereas plate with a smaller hole, is outer/ pin link plate as shown in Figure 2.1 Usually, plates are subjected to repeated loading, sometimes accompanied by shock.

3.1.2 Pin

Pins are made to meet specifications for high strength, sturdiness and wear resistance and rigidly press-fitted to link plates (Figure 2.1). Pins are subjected to shearing and bending forces transmitted by plates. At the same time, it forms a load-bearing part, together with bushing, when chain flexes during sprocket engagement. (U.S. Tsubaki, 1997).

3.1.3 Bush

Bushes are made to achieve high wear resistance and are press fitted to the roller link plates, providing a bearing surface for pin articulation Bushes are subjected to shearing and bending stresses transmitted by plates and rollers and also get shock loads, when chain engages sprocket. Hence they require strength against shearing and resistant to dynamic shock and wear. (U.S. Tsubaki, 1997).

3.1.4 Roller

Rollers are subjected to impact load as they strike sprocket teeth during chain meshing with sprocket. After engagement, rollers change their point of contact and balance. They are held between sprocket teeth and bushes and move on teeth faces while receiving a compression loads. (U.S. Tsubaki, 1997).

3.1.5 Cotter Pin, Spring Clip, T-Pin

These are parts that prevent Pin Link Plate/ Outer Link Plate from falling off pins at the point of connection. They may wear out during high-speed operation. These are parts that prevent Pin Link Plate/ Outer Link Plate from falling off pins at the point application; these parts require heat treatment (U.S. Tsubaki, 1997).

3.2 Chain Characteristics

3.2.1 Breaking Strength

There is a standard test to determine tensile strength of a chain (Wright and Shigley, 2005). The manufacturer takes new, five-link-or-longer pitches and firmly affixes both ends to the jigs as shown in Figure 3.1 Now, a load or tension is applied gradually until the chain breaks and the breaking load is recorded. By sampling technique, average breaking load of a particular batch is found. If the average breaking load is above the specified minimum value, the chains in that batch are accepted. Otherwise, chains in that particular batch are rejected (U.S. Tsubaki, 1997).

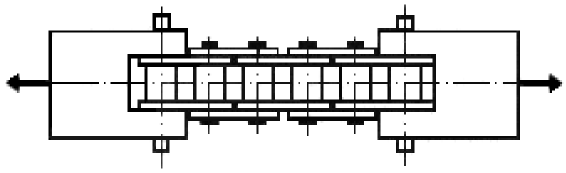


Figure 3.2.1: Chain Tensile Test

3.2.2 Transmission-Ability Graph: (Tent Curve)

The transmission-ability graph, which is sometimes called a "tent curve”, is an important tool when making chain selection. Figure 4.4 illustrates the concept of a tent curve (U.S. Tsubaki, 1997).

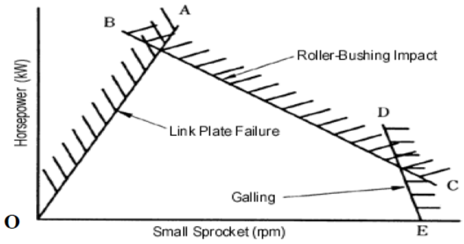


Figure 3.2.2 Transmission-Ability Graphs (Tent Curve)

In Figure 1.8 Line O-A is decided according to the chain's allowable tension, which includes the fatigue strength of the connecting or offset links, as well as the centrifugal force in high-speed rotation. Line B-C is decided by breakage limit of the bushing and roller. In this kind of breakage of the bushing and roller, there is no fatigue limit as there is with the link plates. Therefore, it is shown within 15,000 hours of strength-in-limited-duration. Line D-E is decided by the bearing function of the pin and the bushing. The range defined within these three lines (O-A, B-C, and D-E) is the usable range. When the chain is used at low speeds, it is limited by line O-A, the fatigue limit (U.S. Tsubaki, 1997).

4.1 PROBLEM DEFINITION

The new motorcycle to be launched in the automobile market needs to be ensured for safety and efficiency. Chain drives being efficient means of power transmission are preferred for this product the limitation of course being catastrophic failure at virtually no prior notice. At high speed, accidents are very likely in case of failure in the chain link. Transmission chains used in two wheelers are single strand roller chains with mostly 12.7 mm. smaller pitch chains are suitable for high speed applications compared to larger pitches due to small variation in velocity, whereas larger pitch chains are suitable for transmitting high torques. Two wheeler manufactures use different design parameters to highlight their product features, with different engine power, torque and acceleration characteristics and the total number of chain links for each model are either same or different.

4.2 PROBLEM FORMULATION

Observing the gaps in literature, development of a complete model for FE analysis of the drive chain is attempted to develop. The model is first planned to develop for a structural analysis for tensile testing. Study chain link design parameters in drive chain. The results of these models are validated with the results of standard one as the practical use. The same has been collected from a leading drive chain manufacturing company.

The design for the chain would be subjected to F.E Analysis to find the effect of loads (tension) on the link. The link being a `unit’ of the existing chain would be assessed for performance while tensile loads are exerted at both its ends. Work is to find the strength for the chain link to be used for the demanding application without failure and severe loading conditions exist during the usable life of the chain. The chain to be analyzed using F.E.Methodology for the given application.

Results obtained by the Numerical Methodology shall be compared with the Experimentation methodology using the Physical Experimentation for given application. Safe loads would be determined and the design tested for safe use in the Automobile. The problem for this work is being evaluation of the design using software in the F.E.A. followed by experimentation to validate the theoretical outcome.

5. OBJECTIVE

i. Well Definition of the problem.
ii. To study existing Roller chain in Indian market for possible design modifications.
iii. Learning and use of the ANSYS Software.
iv. The inputs for Design would be secured from the Sponsoring Company, typically the geometry (3D model). The same is normally created using a modeling interface like CATIA V5,
v. The input geometry received shall be discretized using pre-processor . The quality for the mesh shall be adhered to while meshing the geometry.
vi. Loads and boundary conditions shall be applied to the model in the pre-processor.
vii. Suitable solver for structural analysis (like ANSYS) would be deployed for finding the solution.
viii. Post-processor would be used to visualize the results obtained.
ix. Deals with nonlinearities in the element, for understanding nonlinearities in Chain link.
x. Recommendation to be made upon evaluating the results.
xi. Physical experimentation towards validation for the hypothesis proposed to be carried out.

6. 1 EXPERIMENTATION METHODOLOGY (USING PHYSICAL EXPERIMENTATION)

Benchmark chain link to be tested for Tensile Loading by using tensile load testing machine with Data logger suitable prototype would be built for testing purpose. The weakest element would be tested for comparing the results with those obtained by Numerical (Computational) Methodology.

Vehicle Specification

Table 6.1.1: Inputs Data for 280cc Motorcycle.

Specifications of Drive 280cc	
Engine Type	Single Cylinder, 4 Stroke
Engine Displacement (cc)	280cc
Maximum Power	22kW@9500
Maximum Torque	19Nm@8500
Transmission	4-Speed Constant Mesh
Weight	160kg
Tyre size front	100/80 -17
Tyre size rear	110/70-17
Primary Reduction	2.96
1st Gear	2.46
2nd Gear	1.56
3rd Gear	1.33
Top Gear	1.20
Final Reduction	2.96
Drive sprocket no of teeth, Z1	15
Driven Sprocket no of teeth, Z2	44
Chain Pitch, p	12.7 mm
Max. Speed of smaller sprocket, n1	5000 rpm

The force available at the contact between drive wheel tyres and road is known as 'Tractive effort'. The ability of the drive wheels to transmit this effort without slipping is known as 'Traction'. The tractive effort is given by the Equation(4.1)

$$F_t = \frac{T_w}{r_t} = \frac{T_e G \eta}{r_t}$$

Where Tw - Torque at drive wheels,Nm

Te – Mean engine torque, Nm

G – Overall gear ratio

r_t- Radius of tyre,m=0.086m

η - Overall transmission efficiency

Ft – Traction force in N

$$Pe = \frac{2\pi TencTe}{60000}$$

Where Pe - Engine power in kW

nc - Rpm of crankshaft.

Using Equations ,and selecting the values fromTables3 the Force on Chain is found. There results are shown in Table4.1 (Giri, 2006).

In the case of chain links it is done at lower speeds under maximum torque condition of engine. In the present investigation, in all theoretical evaluations except drive cycles, chain force and speed values are taken from Table 4.1. Forces acting on the tight span of chains which are in mesh with drive and driven sprockets that contribute for load acting on chain. The details of calculation are discussed in section 4.2 In motorcycles, chains are fitted with drive and driven sprockets and are enclosed in a cover to avoid dust and sand accumulation. There is no auto tensioner or tensioning idler sprocket. The chain tension is adjusted, when chain elongates, by adjusting the tension adjustment bolt provided in the rear wheel. The chain alignment and tensioning adjustment should be properly done; otherwise, excessive load will act on links causing twisting and quicker deformation. The upward movements of rear wheel along with rear sprocket due to road undulation like bumps, potholes may not cause appreciable load variation in chain due to slackness in the driven side of chain

Table 6.1.2:Force on Chain under Maximum Engine Power Condition

Description	I Gear	II Gear	III Gear	IV Gear
Drive sprocket speed rpm	2028	3158	4185	5037
Driven sprocket speed rpm	685	1067	1414	1702
Driven sprocket torque Nm	307	197	50	42
Force on chain at max power N	3570	2290	593	488

Table 6.1.3:Force on Chain under Maximum Engine Torque Condition

Description	I Gear	II Gear	III Gear	IV Gear
Drive sprocket speed rpm	1817	2809	3774	4508
Driven sprocket speed rpm	614	949	1265	1523
Driven sprocket torque Nm	342	222	166	138
Force on chain at max torque N	3976	2582	1930	1604

6.2 NUMERICAL METHODOLOGY (USING FINITE ELEMENT ANALYSIS)

Numerical / Computational Approach:

The proposed method utilizes software in the FEA domain for analyzing the effects of the variation in the values of the design parameters influencing the performance criterion and corresponding stress would be recorded for changing load within given range. The FEM method is used to analyze the stress state of an elastic body with a given geometry, such as chain link.

Steps for Finite Element Analysis

FEA is mainly divided into three following stages:

i. Preprocessing

Creating the model.

Defining the element type.

Defining material properties.

Meshing criteria.

Applying loads.

Applying boundary conditions.

ii. Solution: Assembly of equations in the software interface and obtaining solution for structural analysis.

iii. Post processing: Review of results.

Basic Steps followed in present to study.

6.2.1 CAD MODEL GENERATION

Two wheeler transmission roller chains are chains with 12.7 mm pitch. Motorcycle chains, which are being used in existing motorcycles, pin diameter and inner plate thickness compared with regular 12.7 mm standard chain used in Motorcycle. Construction is similar to that of standard roller chains and the total number of pitches differs for each type of motorcycle based on two wheeler manufacturers' design shows structure of roller chain as per chain specification of chain part.CATIAV5 were used to create model. Part Modeling shows how to draft a 2D conceptual layout, create precise geometry using basic geometric entities, and dimension and constrain geometry. It also shows how to build a 3D parametric part from a 2D sketch by combining basic and advanced features, such as pad, pocket, holes, and arrays. The pin diameter of 12.7 mm pitch motorcycle chain is 4.45 mm max. Thickness of chain is 1mm

Model for tensile test was easy to be created and is shown in Figure 3.1 and moreover, a parametric model could be easily developed which rejected the need of external data files. However the model for endurance and fatigue testing is a complex model, had a lot of geometrical operations and needs special care.

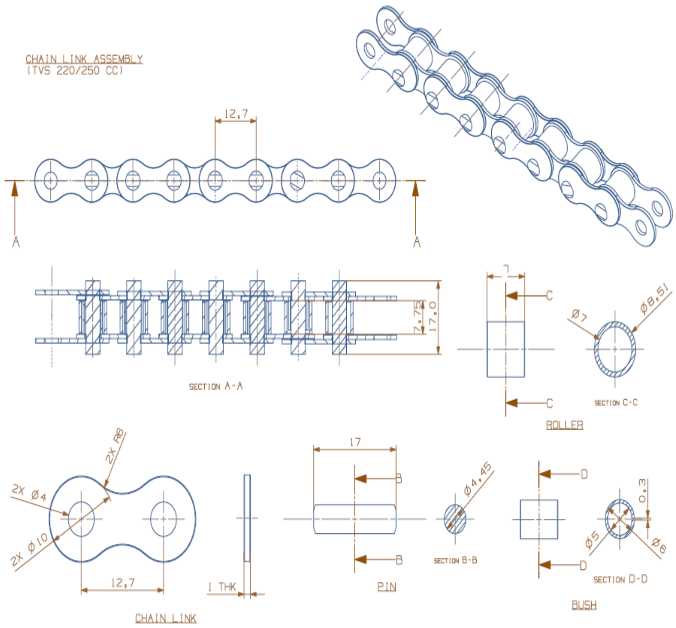
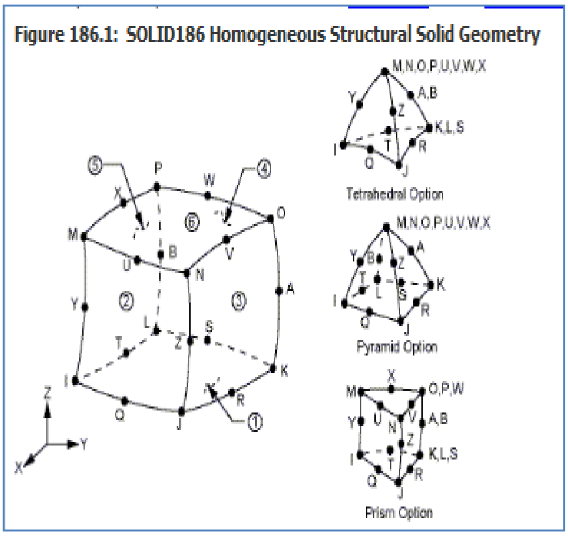


Fig.5. 1 Three Dimensional Model

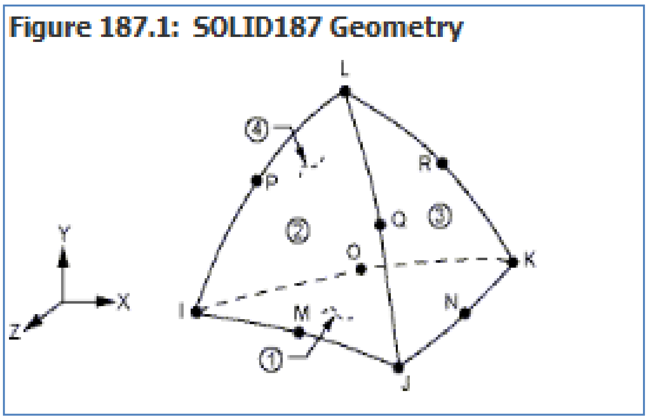
6.2.2 FINITE ELEMENT ANALYSIS

Numerical techniques consist of three basic steps: "pre-processor, processor and post-processor". The pre-processing stage consists of the procedures as constituting creating the model as per dimension. In ANSYS the Cad Model of Chain link is developed. After that for analysis the Finite element model is generated In engineering data define defining material properties. In that entering the physical and material properties of the model to the software,
defining the element type meshing criteria, Mesh body consisting of total solid body is created.

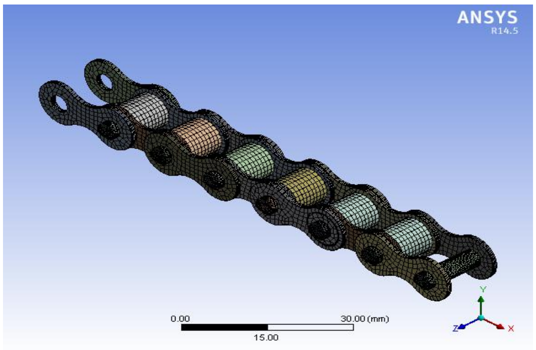
- The following two types of elements are used for analysis.
- Solid 186
- Solid 187
- SOLID186 is a higher order 3-D 20-node solid element that exhibits quadratic displacement behavior. The element is defined by 20 nodes having three degrees of freedom per node: translations in the nodal x, y, and z directions. The element supports plasticity, hyperelasticity, creep, stress stiffening, large deflection, and large strain capabilities. It also has mixed formulation capability for simulating deformations of nearly incompressible elastoplastic materials, and fully incompressible hyperelastic materials.

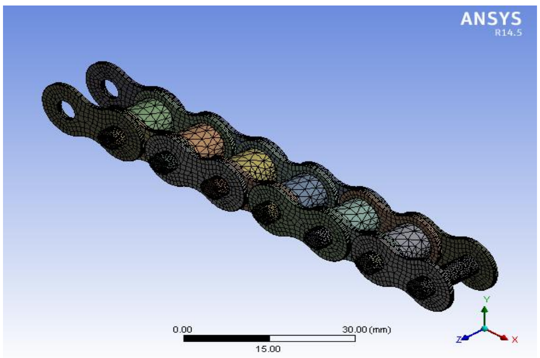


- SOLID187 element is a higher order 3-D, 10-node element. SOLID187 has a quadratic displacement behavior and is well suited to modeling irregular meshes (such as those produced from various CAD/CAM systems).
- The element is defined by 10 nodes having three degrees of freedom at each node: translations in the nodal x, y, and z directions. The element has plasticity, hyperelasticity, creep, stress stiffening, large deflection, and large strain capabilities. It also has mixed formulation capability for simulating deformations of nearly incompressible elastoplastic materials, and fully incompressible hyperelastic materials.



After modeling the chain link meshing is done in ANSYS Workbench. Meshing involves converting of geometry into nodes and elements.3D Hex Dominant mesh type is used for meshing. It has compatible displacement shapes and well suited to model curved boundaries. Chain links is done by giving element size 0.5 mm for better results. Here the number of time meshing was done i.e. at 2 mm element size, 1.5 mm element size, 1mm element size, 0.8 mm element size, 0.6 mm element size but at 0.4 mm and 0.5 mm element size the result that is stresses are does not change. Therefore element size taken as 0.5 mm for better results. At the point of application of load the fine meshing is done. After meshing total 305600 No. of Nodes and 159126 No. of Elements are obtained for chain link having inner and outer link plate thickness is 1 mm.





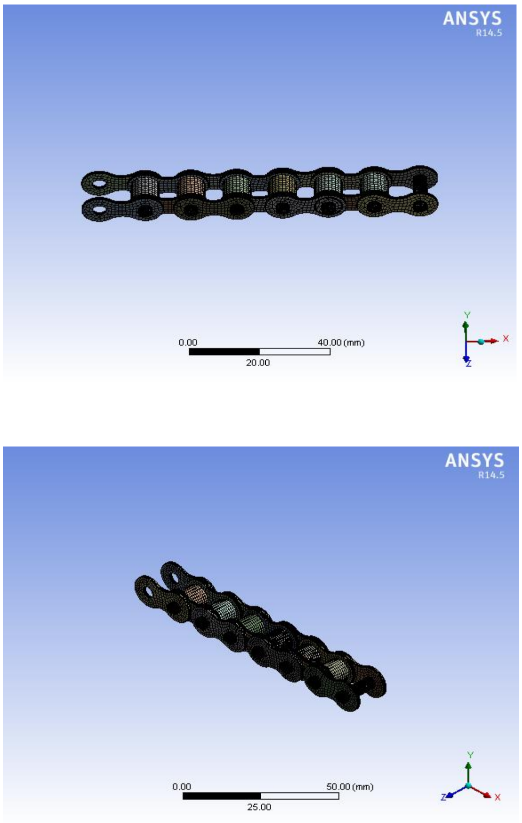


Fig.6.2.2 Meshing of Model

After modeling of chain links then give the actual supporting boundary conditions are applied i.e. fixed support and horizontal support. In fixed support there is no any degree of freedom i.e. there is no displacement at any direction. But in horizontal support only horizontal motion is present and vertical motion is restricted.While modeling link, imprint faces are created which are useful for selecting particular faces at the time of applying boundary condition..

6.3 Experimentation Methodology (Using Physical Experimentation)

Benchmark chain link to be tested for Tensile Loading by using tensile load testing machine with Data logger suitable prototype would be built for testing purpose. The weakest element would be tested for comparing the results with those obtained by Numerical (Computational) Methodology.

experimental setup is provided along with experimental procedure and experimental results. Experimentation is planned over the benchmark chain link for the validating the methodology. The design for the chain would be subjected to F.E Analysis to find the effect of loads (tension) on the link. The link being a `unit' of the existing chain would be assessed for performance while tensile loads are exerted at both its ends. Safe loads would be determined and the design tested for safe use in the Automobile. Benchmark chain link to be tested for Tensile Loading by using tensile load testing machine with Data logger suitable prototype would be built for testing purpose.. In order to carry out experimentation of safe loads would be determined and the design tested for its following instrumentation is required.

6.4 Tensile Testing of Chain Links

There is a standard test to determine tensile strength of a chain (Wright 2005). The manufacturer takes new, five-link-or-longer pitches and firmly affixes both ends to the jigs as shown in Figure . Now, a load or tension is applied gradually until the chain breaks and the breaking load is recorded. By sampling technique, average breaking load of a particular batch is found. If the average breaking load is above the specified minimum value, the chains in that batch are accepted. Otherwise, chains in that particular batch are rejected (U.S. Tsubaki).

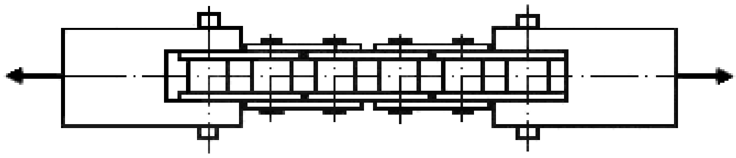
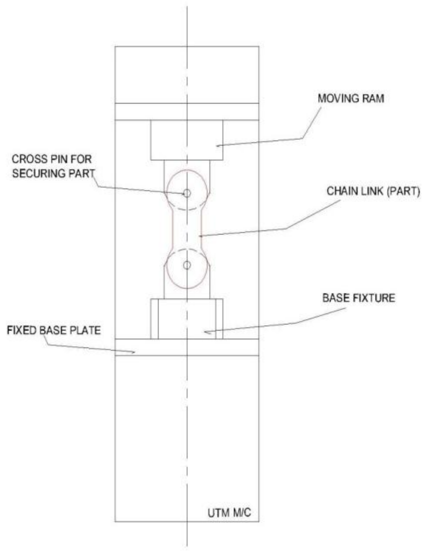


Figure 6.4 : Chain Tensile Test

The tensile test is most applied one, of all mechanical tests. In this test ends of test piece are fixed into grips connected to a straining device and to a load measuring device. If the applied load is small enough, the deformation of any solid body is entirely elastic. An elastically deformed solid will return to its original from as soon as load is removed. However, if the load is too large, the material can be deformed permanently. The initial part of the tension curve which is recoverable immediately after unloading is termed(U.S. Tsubaki).



CHAIN LINK
EXPERIMENTAL SET-UP
(SCHEMATIC LAYOUT)

TESTING SYSTEM INFORMATION

UNIVERSAL TESTING MACHINES (TENSILE LOAD TESTING MACHINE) WITH DATA LOGGER

The most common are universal testing machines, which test materials in tension, compression or bending. There are two classes of testing machines, electromechanical and hydraulic. The electromechanical machine uses an electric motor, gear reduction system and one, two or four screws to move the crosshead up or down. A range of crosshead speeds can be achieved by changing the speed of the motor through the software control. A microprocessor based closed-loop servo system can be implemented to accurately control the speed of the crosshead. The main components of the universal testing machine are actuator, attachment kit and measuring and safety devices. Universal testing machines are commonly used, which are driven by hydraulic systems. Hydraulic testing machine using the pressure of oil in a piston for load supply.

A more modernized closed-loop servo-hydraulic machine provides variations of load, strain, or testing machine motion (stroke) using a combination of actuator rod and piston. Machine is linked to a computer-controlled system in which the load and extension data can be graphically displayed together with the calculations of stress and strain. General techniques utilized for measuring loads and displacements employs sensors providing electrical signals. Load cells are used for measuring the load applied while strain gauges are used for strain measurement. A Change in a linear dimension is proportional to the change in electrical voltage of the strain gauge attached on to the specimen.

7. CONCLUSION

Roller chains, Mathematical models have been build up which have helped in determining to the key values in design of chain drive, static stress analysis of link plate roller chain. This information helps understand the present research status in the field. Further, the need for the research is identified. Deals with Theoretical study of motorcycle chains and typical motorcycle specification, the method of manufacturing and methodology. Theoretical study of Presents Input data for secured for sponsoring company for to find load on chain link. Study of Input Design for secured for sponsoring company. Study of Design parameters of chain links by using ANSYS. Focuses on verification change in boundary condition, Deals Experimental analysis of chain links of roller chain subjected tensile load. Deals with validation of results obtained by numerical analysis by ANSYS, with the Experimental result.

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