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WEIGHT IN MOTION SYSTEMS FOR RAILWAYS

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Abstract — *Weight in Motion (WIM) in Railways is an innovative technology of measuring the train load in the dynamic feature. WIM is required for the monitoring of the railway tracks and the train wheels and thus help in controlling the number of trains and passengers on the train and the particular railway tracks. In this presented paper, we discuss the various types of WIM methods that are being used in the railways. The report briefly describes the principle, uses, advantages and demerits of various sensors. Next we discuss the progresses that have been done in the field of railway WIM. Many researchers have developed different algorithm using different sensors, each having certain merits and demerits. After analyzing the progress we discuss the need for the WIM, demerits of existing system and how we can overcome them. Next we discuss the model prepared and analysis done on it, to represent our result.*

Keywords: *- Weight in Motion; Strain Gauge; Piezoelectric; Optical Fiber; Electromagnetic interference.*

I. INTRODUCTION

Weigh-in-motion (WIM) devices are designed to record vehicle's axle weights while passing over a measurement site placed along a road. WIM has a huge impact in applications including traffic management, road safety and monitoring of road infrastructures. With the rapid development of the transport industry, overloading and overweight of vehicle is becoming more apparent. Overloaded vehicles not only cause damage to road infrastructure, but also easily lead to accidents. Therefore, weigh in motion (WIM) systems will become more important in the transportation management system.

Over the last few decades, rail transport has become one of the most effective means of transporting passengers and goods. According to recent statistics, the number of passengers will be doubled within ten years, while the volume of goods transported by railway will be tripled. Thus, it is expected that the axle load will strongly increase in the next years, and the trains will operate at faster speeds. This fact puts major pressure on the infrastructures and therefore innovative maintaining and inspection techniques are required. Three are various methods employed for this purpose. Some of the methods being covered here are as follows:

1. Strain Gauge Sensors
2. Piezoelectric Sensors
3. Optical Fiber Sensors

The development of efficient WIM systems capable of estimating the axle loads of railway vehicles in motion is an interesting topic from both an industrial and academic point of view. The importance of this kind of systems lies in the safety and the maintenance of track since it allows the verification of the loading conditions of a wide population of vehicles through a limited number of WIM devices placed along the railway network. The evaluation of the axle load conditions is fundamental especially for freight wagons, more subjected at risk of unbalanced loads which may be extremely dangerous both for the vehicle safety and the infrastructure maintenance. In particular unbalanced loads could cause structural overloads which could drastically reduce the expected life of safety related components like the axles and the programmed maintenance and inspection cycles of both vehicle and infrastructure.

Let us study each method in brief:

1. Strain Gauge Sensors

Conventional monitoring systems in railway infrastructures use strain gauge sensors to detect train dynamic load, train speed, axle load, and wheel flats. The working principle of the strain gauge sensor is based in a variation of resistance caused by the strain transmitted to the rail during the train passage. Four special resistance strain transducers were embedded in the concrete section of the deck supporting the two railway tracks. The strain gauges are all connected as a full Wheatstone bridge. The cables are routed inside the steel tube, which has indeed been encapsulated with several coatings for protection and to ensure that the deformations are only introduced at the anchor plates. As the main interest is in measuring/calculating actual traffic loads and load effects on the high speed line, three of the transducers were placed under that track. Only one transducer, called U3, was placed under the second track, a track only for commuter trains and therefore chosen to be of less interest in this project. All transducers were oriented to measure the longitudinal strains and were placed approximately 100 mm from the bottom of the concrete section. In addition to the above described instrumentation, an accelerometer for measuring vertical accelerations was installed temporarily. It was mounted onto the edge beam close to the mid-span to measure the bridge deck vertical acceleration.

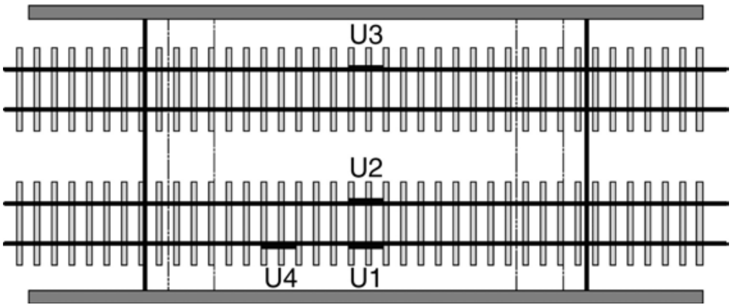


Figure 1 Location of four sensors, embedded in the bridge deck

R. Karoumi, presented the WIM algorithm, which has been implemented in the MATLAB language, produces the following results: number of axles; position of each axle (axle distances); static load of each axle; speed and acceleration of the train; direction of the train; track on which the train is crossing. Axel Liljencrantz, conducted experiments with 33 trains. The speeds of the recorded trains (commuter trains, high speed trains, and regional trains) varied between 38 and 114 km/h. For all the 33 registered train sets the locomotives' static axle loads were well known. Thus, these were used to verify the accuracy of the implemented WIM algorithm. The implemented locomotive identification algorithm correctly identified all locomotives, which was not a very difficult task since only three types of locomotives were measured, all with significant differences in both axle loads and axle distances. Strain gauge sensing technology is well-known and consolidated; it is also inefficient for railway systems since it can be adversely affected by electromagnetic interferences.

Ham and Young, due to continuously monitoring and increasing sensitivity of measuring system, used the glued strain gauges on the wheel-web. Eventually, they chose to use non-contact sensors that attached on non-rolling part of the bogie i.e., ‘‘axle box.’’ In this method, the wheel distortion calculated from displacement of the wheel rim, instead of detecting strain used in the other methods. One of the continuous measurement methods is installing the measurement instruments on each carriage. Another method for continuous measurement is installing strain gauges on the rail. Installation of strain gauges is performed by sticking them directly on the web and foot of the rail, hence strain gauge exposed to aggressive environment, that make it difficult for system to measure exclusively vertical force component.

2. Piezoelectric Sensors

The proposed solution relies on a non-destructive way of recording histories of strains evolving in the rail due to train motion. The strains are collected by piezoelectric sensors mounted on the bottom part of the rail foot in between the sleepers. Two kinds of piezoelectric sensors are considered – the popular ceramic ones and the more sophisticated fibre-based ones. The electric signal (proportional to strain) from the piezo sensor is first preconditioned by amplifying, filtering and digital sampling operations. The objective of this signal processing is to have the signal in its optimal form before sending it to a remote centre using wireless transmission. In order to improve the reliability and accuracy of the proposed WIM system, some extra sensors are applied. Sensors are mounted in pairs on both rails in such a way, which makes the devices well hidden in the railway track in order to avoid devastation. An important aspect of hardware is to supply power for the system in a reliable manner. In order to make the system independent, the power is supplied by accumulators permanently charged by photovoltaic modules. For the sake of energy saving, the system is active only during the ride of the train over the WIM measurement point. When the train is gone, it switches to a passive mode. Additional sensors, operating in a standby mode to detect the coming train, are needed to realize this energy saving idea.

K. Sekuła & P. Kołakowski, proposed a pattern recognition approach for solving load identification problem which consists in comparing an analyzed pattern with a set of already existing patterns and specifying the most similar one from the set. In the mentioned method the crucial task is to prepare a data base containing a collection of strain histories for diversely loaded railway cars weighed in various operational conditions. The data can be obtained from experiments using many railway cars of known load distribution but this way is inefficient due to the time and cost involved. Knowing the mass of a locomotive and each car in the train from quasi-static measurements, a relation between mass and voltage recorded by piezo-sensors of the proposed WIM system at regular train speed can be found.

Mirko Ignesti, Alice Innocenti, Enrico Meli, Luca Pugi, Andrea Rindi proposed another algorithm in which to estimate the axle loads, the authors approximates the measured physical input through a set of elementary functions calculated by means of a single fictitious load moving on the track. Starting from the set of elementary functions, the measured signal is then reproduced through Least Square Optimization (LSO) techniques. Delprete and Rosso after investigations designed MPQY transducer (Multi-Purpose Q and Y load detector)[3], that relief it's conventional known defects. The conventional method and MPQY method of strain measuring on the rail are modelled and compared by using FEM. They used a movable C structure to simulate the vertical force. A rolling bearing represented the train wheel and a screw that gave the vertical force on the rail by squeezing the rolling bearing on the rail head and a load cell displays this force. The load cells provided the actual amplitude of the vertical force and allow the sensor calibration. The authors used quasi-static analyses to simulate the calibration test situations which were performed with low loading rate by squeezing the rolling bearing on the rail head.

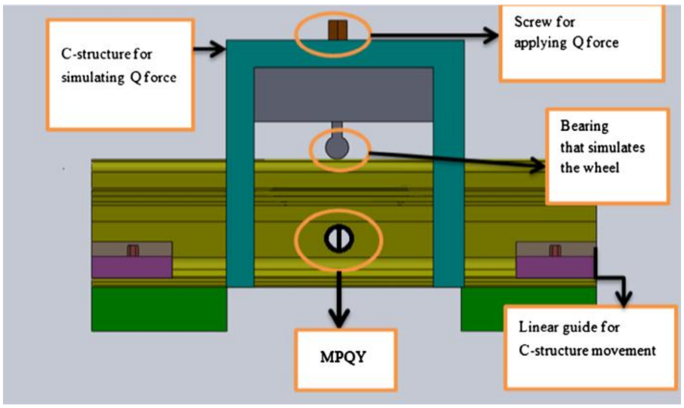


Figure 2 C-structure for applying the vertical force on the rail head, which is used by MPQY designers

3. Optical Fibre Sensors

Optical fiber has a good safety performance, high transmission efficiency, resistance to electromagnetic interference, stability, small size, light weight, the installation to use and easy maintenance, etc. The fiber-optic dynamic weighing become a great research value and necessary. Its working principle is based on fiber-optic light modulation effects which irradiate parallel and monochromatic light to the end of the optical fiber. The optical intensity will change when the external environment factors such as temperature, pressure and other changes. Therefore, if we can measure the light intensity changes of the fiber, we can get to the change of the measured physical quantity.

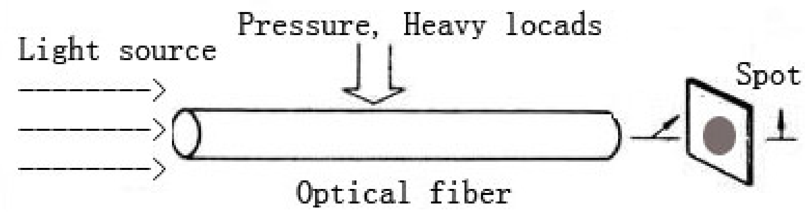


Figure 3 operation process of the fiber-optic WIM system

Linlin Wang, Xue Hu, Yongjian Huang, Huaiyu Xu conducted various experiments and pushed to sum up a formula of weight and optical intensity. The experiment involves the selection of parameters and settings, such as the protection of the optical fiber material selection, the temperature variation of the experimental environment and the vehicle's dynamic pressure impact. With the help of camera they recorded the light intensity change and then use computer to calculate weight according to the corresponding spot. There are two types of optical fibre sensors being used.

a) Optical Fibre Bragg gratings (FBGs): FBGs are very small, short-length single mode fiber devices that display a periodic refractive-index variation in its core. When a broadband light transmits through the optical fiber, the FBG written in the core reflects back a wavelength depending on the Bragg condition. The shift in the reflected wavelength of the Bragg grating sensor is approximately linear to any applied strain or temperature (within a certain measurement range). Therefore, the detection technique used by the monitoring system is to identify this wavelength shift as a function of strain or temperature. They are small, flexible and lightweight, making them embeddable in most hosts; they have extremely high sensitivity, they employ fibres with an extremely low attenuation, enabling remote interrogation of WIM devices; and they allow sensor multiplexing, creating complex multipoint sensing networks.

b) Multiplexed Interferometric fibre optic sensor: D.J. Hill, P.J. Nash and N. Sanders developed a prototype of this sensor as shown in the figure. . As part of the interferometric design it was necessary to include a semi-reflective element with each sensor. This was achieved by using semi-reflective fibre couplers. Each such sensor can be connected to the next sensor thus it can be used to cover a large distance. These sensors have some advantages like they are simple in design, highly sensitive, high dynamic range, and have the ability to multiplex many together along a single fibre.

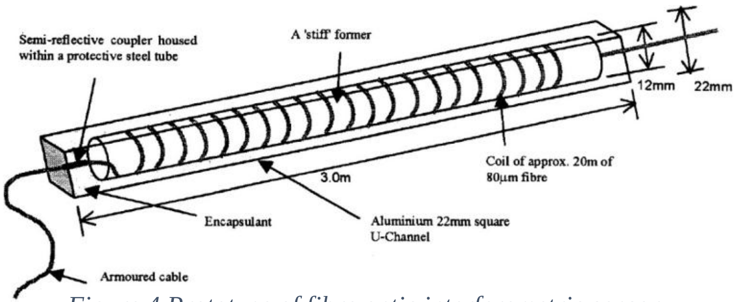
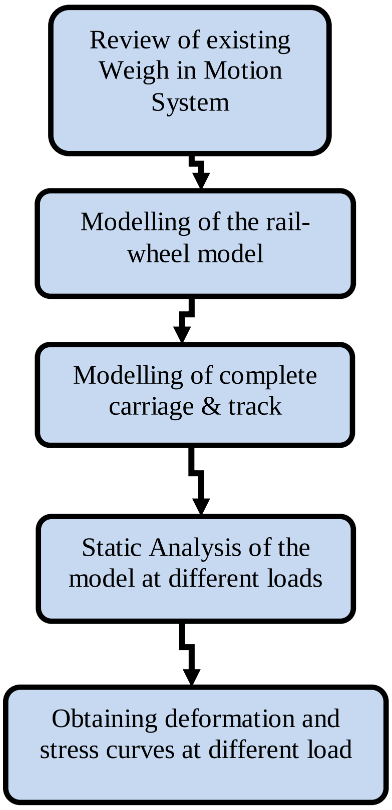


Figure 4 Prototype of fibre optic interferometric sensor

The response plot of sensors by passing of trains at different speed and different loads are recorded. It can be seen from this plot that the form of the signal differs with speed in regard to the peak spacing, pulse width and differing amplitudes. By integrating the area under each impulse corresponding to a passing axle, and dividing this figure by the vehicle speed, it is possible to determine axle weights. Also changes in the signal due to the increased axle load can clearly be seen.

II. METHODOLOGY



Rail In Motion Weighbridge Need & Design Requirements

Sl. No.	Description	Existing WB	Desirable attributes	Optical fiber	Piezo
1.	Capacity	Load cells shall be able to measure a load of up to 30 tons for each axle and software/hardware should be able to compute weights up to 120 tons for an individual wagon.	Up to 150t	Up to 247 t [15]	Upto 120t [1]
2.	Speed	15 km/h	100 km/h	>200 km/h [15]	Upto 80 km/h[1]
3.	Foundation/support	RCC Slab type	Not required	Not required [15]	No mention about foundation / support [1]
4.	Working environment		Work in all-weather condition	All weather conditions [2]	Indifferent to environmental influence[3]

5.	Track requirement	100 m straight track with max 1: 400 gradient	No constraints from track site conditions	Tracks are laid on ballast with min thickness of 35 cm. Sleepers of single block AI-99 type prefabricated and made of prestressed concrete with the following characteristics: weight 320kg length of 2600mm max base width of 300mm, and min height of 242 mm. Distance between sleeper axis is 0.6 mm. Rail used is 60E1 type(UIC 60) with hardness 2607300 HBW and tensile strength larger than 880N/mm^2 . The stiffness of track should be limited in order to reduce the vertical dynamic forces between wheel and rail. This is achieved by use of rail pads under rail. Pads used inthis line has 7mm thickness and static vertical stiffness of 100kN/mm [15]	No specific requirement for the track [1]
6.	Calibration	Calibration to be done at site with 5 test wagons.	Auto self-calibration, tamper proof.	Calibration is done using known standardized weights from electric locomotive travelling over the rail. [13][15]	Calibration may be performed by a quasi-static (at 5km/h) weighting system using strain gauges. Knowing the mass of locomotive and each car in the train from quasi static measurements a relation between mass and voltage recorded by piezo sensors at regular train speed can be found. [1]
7.	Data security		Tamper proof	Need to be done	An encrypted transmission using available internet cryptographic protocols can be used. Password protection can be done [1]
8.	Software requirements		Custom made, User friendly interface.	Lab View [15]	

9.	Communication	Wired, Un-common protocol.	Wireless in between track and equipment room. Common protocol, exchange data with FOIS and TMS etc, Remote controlled if possible	Optical signal is transmitted with the help of fibre optic cables. Wireless communication technology can be used for observation from remote places.[15]	Wireless transmission of the measured signals Using available internet cryptographic protocols e.g. Transport Layer Security (TLS).[1]
10.	Hardware	Difficult to maintain	Self-diagnostic and Modular for easy maintenance	One annual maintenance needed [13]	
11.	Cost	Rs. 9 lacs approx. for WB and total Rs. 25 lacs with civil works	Should be moderately higher.		Cheaper than strain gauge and optical fibre [1]
12.	Metrological requirements and Accuracy class of weighbridges	It shall meet the requirement of accuracy class-1 for wagon weighing and accuracy class 0.5 for rake/train weighing	Same	Uncertainty in speed is 0.012% [15]	
13.	Lightning and Transient Protection	Problematic Frequent failures from lightening.	As per relevant international standard.		
14.	Design	OEM specific	RDSO owned design	Design by IITR	Design by IITR
15.	Weigh rail	5.5 metre weigh rail	Not required. Sensor to be directly inserted into existing rail.	N/R	N/R
16.	Electromagnetic interference	Tampering possible	Should be able to work in track circuited area.	insensitive to electromagnetic interference.[13, 15]	Affected by electromagnetic interference
17.	Codal Life	8 years	Maximum possible. Min more than 8 years.	10 years [13, 15]	For piezoelectric: 4 years For quartz piezoelectric: >15 years [16]
18.	Statutory approval for design	OEM takes from legal Metrology dept.	IIT R has to obtain	Difficult, not use to this type of job. Will be happy to provide technical assistance and rather RDSO should do it as RDSO will own the design	

III. WORKDONE

In order to study the rail-wheel interactions we need a model of the tracks and rail wheel. So using Solidworks, we designed the tracks, wheel and sleepers according to the following Indian standards.

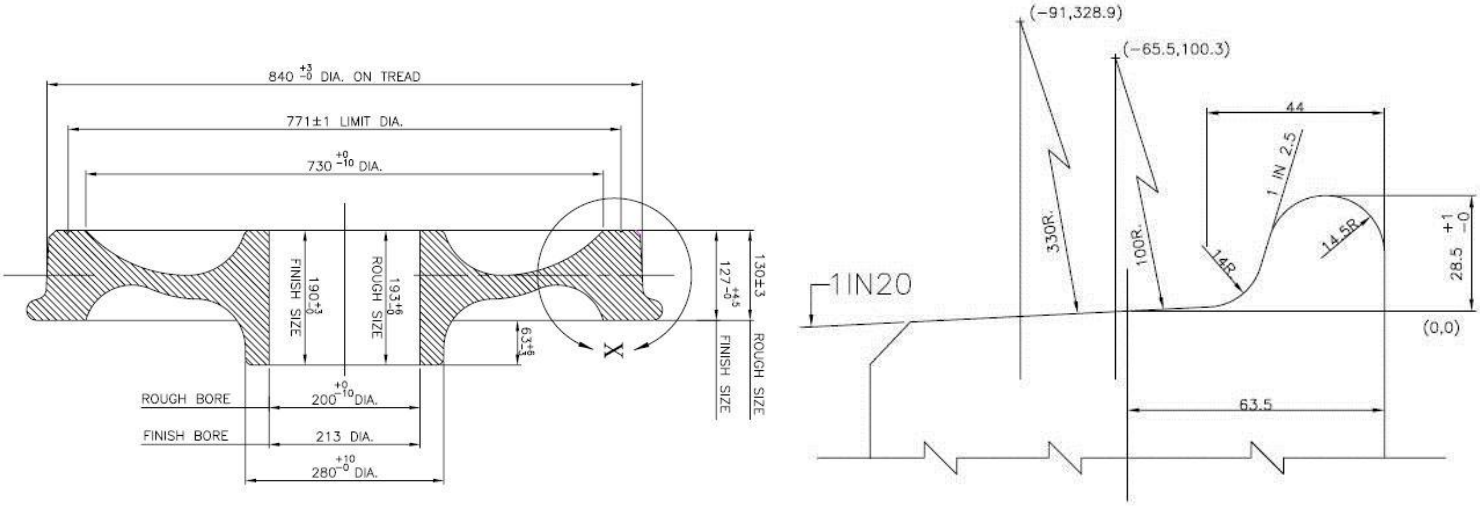


Figure 5 Cross-Section View of Wheel

DETAIL AT −X

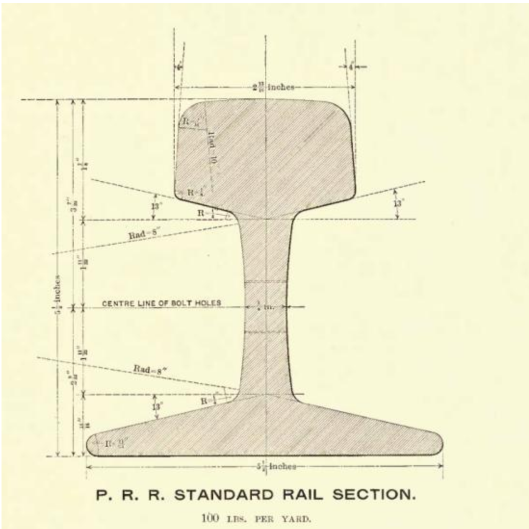


Figure 6 Cross Section of Railway Track

After modelling all the parts, they were assembled to complete the required model. The assembled model looked like as follows:

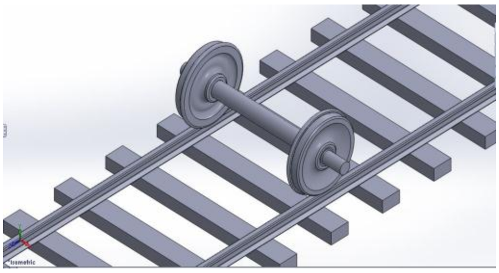


Figure 7 Isometric View of wheel and track

The above model was accurate but incomplete, so the simulation results were incomplete as well. Hence, the following drawings contain the information referred in order to make the rest of the parts for the carriage. These parts included the main beam of the carriage, the Bolster Plate and its supporting structure and the suspension system. The suspension system consisted of 12 helical springs. For further more accurate 3-D model we completed the suspension system of the wagon, according to the design of the all the required parts

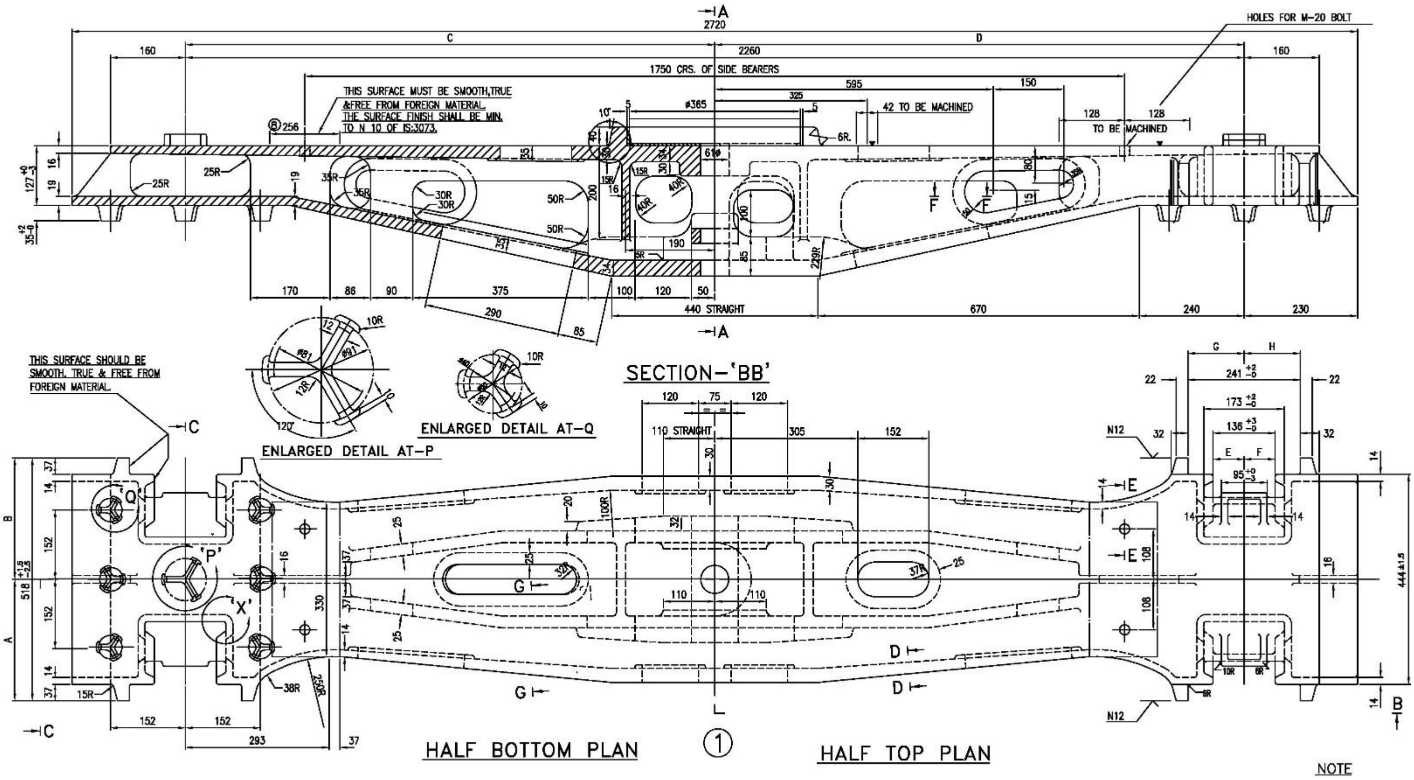


Figure 8 Drawing for Bolster

The complete model of the carriage is illustrated in the following figure.

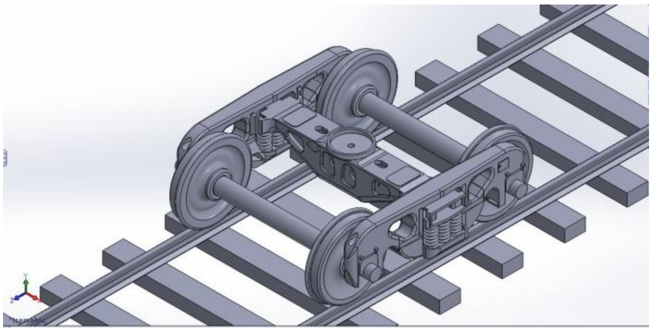


Figure 9 Isometric view of model of carriage

Since our aim is to find out the weight of a moving train, deformation in the rails needs to be calculated. This deformation would be picked up by piezoelectric sensors. Now, in order to calculate the deformation, the system (carriage) was simulated on Ansys 15.0. The various components of the system and their materials and properties are mentioned below:

Bolster: B Grade steel (UST 400MPa, YTS 315MPa, Bulk Modulas 140GPa, Shear Modulas 80 GPa)
Bogie Frame: B Grade steel
Spring: 60Si2CrVAT (High Strength Spring Steel)
Sleepers: Concrete
Wheel: B Grade Steel

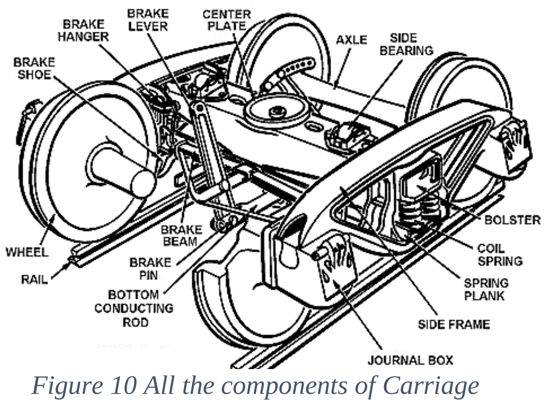


Figure 10 All the components of Carriage

After defining all the materials, different load are applied on the carriage and deformation and stress are analyzed at the track (i.e. at the location of sensors). All the recordings of the deformation is shown in Figure 10.

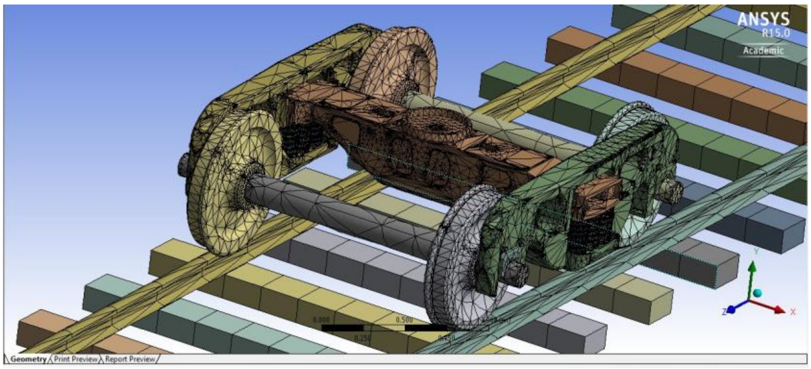


Figure 11 After meshing of the model

The load is applied on the carriage and for different load conditions the deformation and stress are recorded

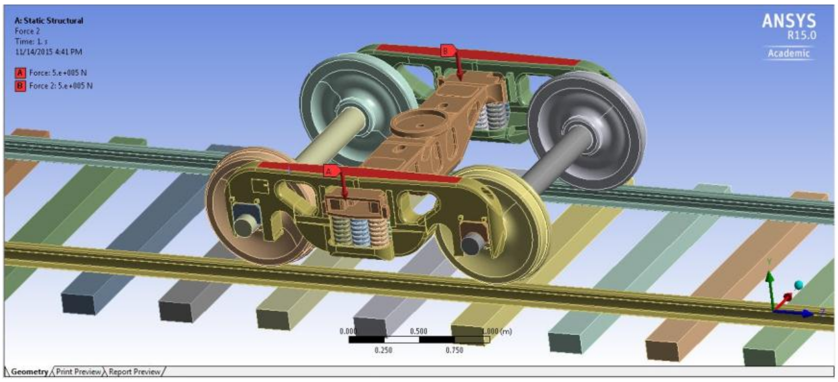


Figure 12 Application of Load

After applying load the deformation at the track is obtained

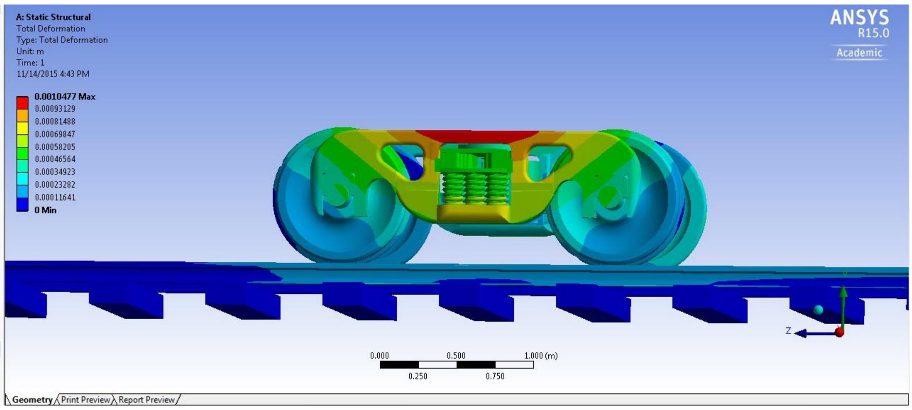


Figure 13 Deflection analysis due to load

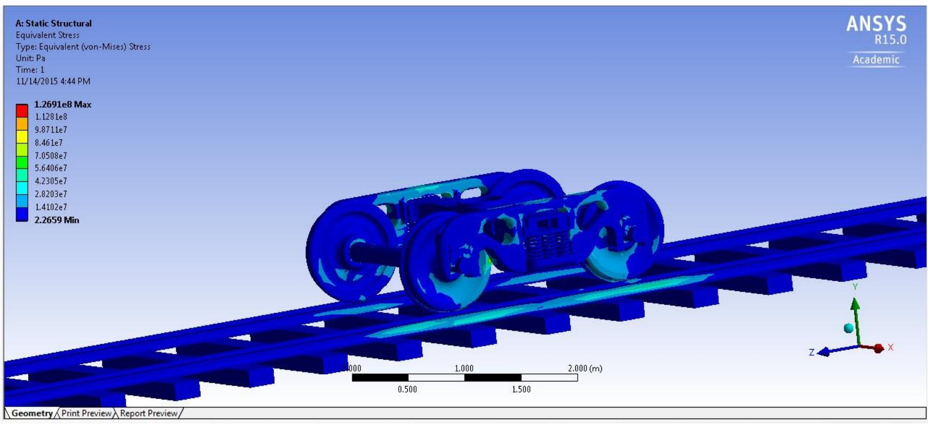


Figure 14 Stress Analysis due to load

From all the deformation the load-deflection curve is obtained as follows

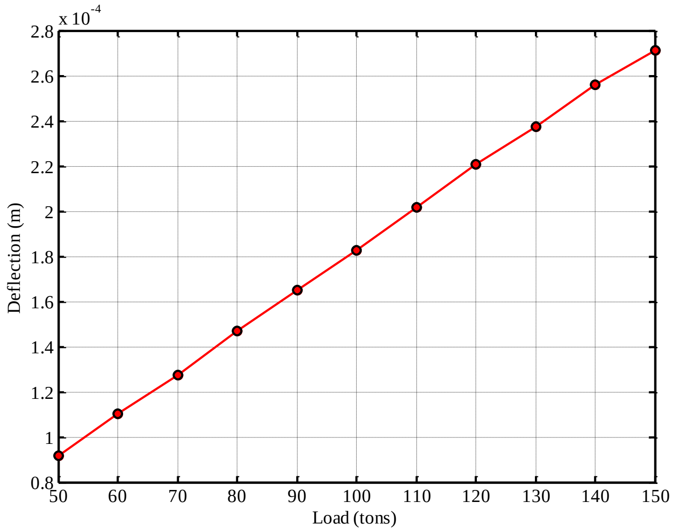


Figure 15 Deflection-Load Curve

IV. FUTURE PLAN OF ACTION

The static analysis of the model has been done, and now the analysis is to be done for the moving carriage. The dynamic analysis will be done on ADAMS-RAIL, in which rail-wheel interaction will be studied when a series of carriage pass over the track. The result of the dynamic analysis is in accordance to [1].

After the dynamic analysis, the exact results are to be obtained by LABVIEW. The results of dynamic analysis will be verified by the actual simulation of the model in LABVIEW.

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