Application of Mechatronics in Railway Industry

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***Abstract*— Railways has been a field which has been there for at least 200 odd years but since the last 50 years the advancement in technology has facilitated us to use the field of Mechatronics in this domain. This review paper covers many such control systems, the recent advancements made in the field of railway systems and application of mechatronics in the railway industry. It sets up the very basic layout of a railway system to build upon.**

***Keywords*—mechatronics, railway, actuators, sensors.**

I. Introduction

Use of Mechatronics in the railway system has been there for a while and it is there to stay. The use of mechatronics has been limited in the railway industry as compared to the Automobile and aircraft industry. In railways it is specifically used for tilting as well as in wheel set dynamics. Hydraulic and electric actuators are incorporated into the control system to achieve a desired motion control. Many sensors are also used to extract data from the real world scenarios. Crack detection on tracks, defects and unalignment can be detected using PIR and EFS modules. Mechatronics have also been proved useful in the development of the Maglev trains.

II. Summary of Mechatronics in Railways

A. *Mechatronic developments for railway vehicles of the future:*

Railway systems have been present since the 1800s.The arrival of active suspensions has heralded the ''Mechatronic Design Period'', although it will be seen that there is still a long way to go in terms of fulfilling its promise. Also With advent of computers scientists and engineers have been trying to run simulations[28] in various softwares in which mechatronics has been incorporated. Until now these models have been theoretical and no practical implications have been achieved.

Some future technologies in which mechatronics can be utilized are as follows:

Tilting Trains: In this phenomenon the vehicle is tilted inwards so that the acceleration felt by the passengers is reduced.

Mechanical schemes for tilt: A typical arrangement of a train is shown in the figure in this arrangement there are air springs attached to the bogies via inclined swing links these springs act like suspensions. There are hydraulic actuators as well which provide the necessary tilting force for the bogie.

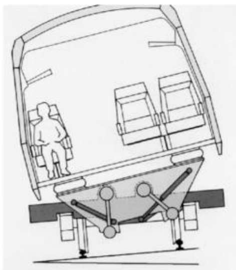

Figure 1: Tilting action of a typical train

Mechatronics approach: The most basic approach is to put an accelerometer inside the train thereby reducing the acceleration. There are two things that one needs to take care of:

1) If the passengers are left without lateral acceleration, then they are prone to motion sickness
2) The problem is the interaction of the accelerometer with the lateral suspension

These problems can be avoided by fixing the accelerometer on the non-tilting part i.e., the bogie. Here the accelerometer will give the tilt angle signal through the feedback loop so that the driver can decide how much the tilt should be in order to avoid motion sickness. So, mechatronics equipment can be used in such areas to automate the process.

Wheel set dynamics: Another application of mechatronics can be in the field of wheel set dynamics. But before delving into the mechatronics part first let us understand the mechanism of it.

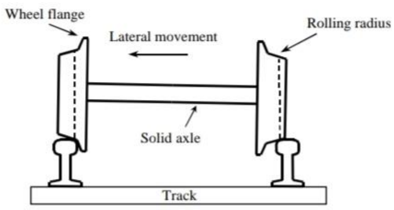

Figure 2: Wheel set dynamics

A wheel set basically works on the difference between the velocities between the two wheels. When moving through a curved path the outside wheel covers a bigger radius as compared to the inner wheel and also both wheels are connected via an axle therefore the angular velocities are the same but the linear velocities are different therefore this difference gives the bogie a curved path. Unfortunately, when moving through a wheel track the wheels tend to have

an up and down motion. In order to address this mechatronics can be used:
In the following figure an actuator has been placed in series with a spring in the longitudinal direction.so when the train tends to curve the springs get elongated or compressed and the actuators try to minimize these forces so that the passengers don't feel any jerk. Also, the wheelsets [5] don't get damaged.

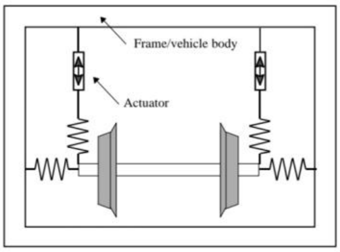

Figure 3: Actively steered wheelset

B. Mechatronics in Motion: Some railway applications

This paper gives a brief overview of the overall development in the field of mechatronics and its application in the railway industry. The author has reviewed some of the important papers and projects dated from the 1970s till recent years. There is a significant development in technologies in the aircraft and automobile industries. However, the use of technologies in the railway industry was limited.

The author used a Mechatronic Score (MS) in order to assess the extent to which the mechatronic contact of the various projects has progressed with time. This score is dependent on the - use of embedded control, incorporation of computer processing, and the synergy arising from an integrated design approach.

Early Projects:

Low speed Maglev vehicle: Maglev offers a totally non-contacting transport technology. However the suspension system was not quite good. Thus a control system was developed to control magnetic flux to overcome the essential instability; stiff air gap control; a “complementary filter” structure using a measurement of absolute position. MS - 76%

Active lateral suspension: Two hydraulic actuators acting in the lateral direction were fitted in parallel with existing secondary suspension. There were two suspension control loops; one to control the pitch and the other to control the yaw by means of actuation of two hydraulic actuators. The accelerations of active and passive suspensions were compared. The active suspension showed a greater performance. MS - 48%

Tilting trains: The author of this paper made an important contribution related to developing and testing an electrically-powered actuator for tilting to replace servo[27]-hydraulic actuator that were old technologies used.

Broader Projects:

Mechatronic railway technologies: The primary motivation of this research is to re-establish the simplicity of the railway technologies using mechatronics as current technologies are heavier and complex. MS - 100%

Recent Projects:

Mechatronic Bogie: A research with Bombardier Transportation was concerned with using active control methods to enhance the stability and steering of a bogie for high speed operation. The linkage mechanism was developed using a rotary motor actuation. The lateral displacement of an active and passive bogie system was compared. An important achievement was demonstrated to actively control the stability of the bogie. MS - 72%

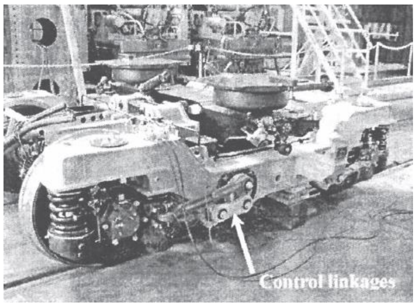

Figure 4: Control Linkage on Mechanical Bogie

Independently driven railway wheels: A permanent magnet synchronous motor was integrated into the mechanical structure of a railway wheel. This system provided high efficiency and mechanical simplicity. MS - 87%

C. Mechatronics for trains; Trends and Challenges

Uses and advantage of Mechatronics system in railway are:

1) Traction and braking: There are various control issues in regards to acceleration and deceleration but a bigger challenge is to provide control under low adhesion condition. Certainly with the advent of electronics traction control has been optimised to a greater extent

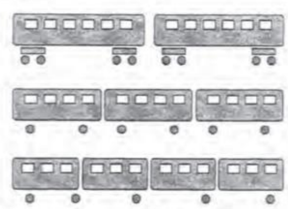

Figure 5: Vehicle Configuration

Vehicle weight: Mechatronic technology can provide the opportunity for vehicle configurations to be lighter and simple.

Also the wheelsets[22] can be reduced to a minimum number with the help of mechatronics. Also with a combination of techniques including mechatronics to reduce the weight per seat to a level which is similar to automobile.

D. Mechatronic system of control position of wheel pairs by railway vehicles in the rail track

Bogies with self-alignment wheel pairs in the curves showed low efficiency due to increased rail wear and increased resistance to movement.

Some better indicators of reducing the intensity of wear of wheel flanges in curved track sections is bogies with semi-forced orientation of wheel pairs axles

In RT bogies with radial installation of wheel pairs axles, the angles of attack on the rails when moving in curves is near to zero value. This means that the interaction of the wheels with the rails and the resistance to movement is ensured in the first place.

The software platform of such systems is a real-time RT operating system (OS), which must meet the following - respond to current events, managing to process them for a fixed time or by a certain point in time (hereinafter - have time to process them all in the corresponding time frames for each of them, regardless of the number, In the half-time control, industrial controllers (microcontrollers) are used to control the model of the controlled module in real time.

The control signals generated by the control device through analog-to-digital converters are fed In the semi-natural control, the hardware controls the simulated model, which is close to the control of the object in the real system.

The control signals generated by the microcontroller are fed through a digit-to-digital converter to the computer The software of the control module must contain: software tools for collecting, filtering and statistical processing of measurement information; program control algorithms, real-time expert system; database of accumulation of Software that generates code to automatically build a model in real time.

The most important tasks solved by the digital control system when managing a technical process are shown in Digital control systems operate only with information provided in digital form, therefore, the resulting electrical The digital process control system consists of the following components. The value of the steady-state pressure in the cylinders is calculated based on the law of isothermal gas outflow.

Consider the process of changing the gas pressure for a variable volume flow chamber, the state of gas in the chamber can be assumed isothermal, since the mass of the chamber is many times greater than practically no heat exchange between the gas and the medium in the holes due to the high gas velocity and the small.

E. *Benefits of mechatronically guided vehicles on railway track switches*

In this paper, the author has compared the performance of the Driven independently rotating wheelsets (DIRW) and the IRW on track switches.

The basic mechanism of track switching has not changed for more than 200 years. Vehicle based switching proposed to perform switching from on-board the vehicle. In order to analyse the concept, a track switching model was made in CAD software. The model was made considering the standard RE/PW/1602 B. This model was then imported into MATLAB. The Simpack tool was used to generate the interpolation between the consecutive cross section to form a continuous rail.

Active Vehicle Modelling: The vehicle model was also developed in Simpack. This model takes into account the non-linearities in the rail-wheel profiles. The primary suspension and secondary suspension were modelled using appropriate stiffness parameters.

Controller Design: The controller design was based on a linear model that can analyse the frequency response of the system. It was performed by using the system identification from the input torque to the output wheelset[39] lateral displacement. Once the controller is designed, it is applied to the non-linear Simpack model using co-simulation[35]. The torque supplied to each wheel motor was controlled using a PIP controller.

Results:

C Switch: The responses for the passive and DIRW vehicle models were fairly comparable, so the active vehicle is not performing any worse than the passive vehicle in terms of running safety. Rail life is dominated by RCF and plastic deformation. Further work is needed to understand these phenomena on IRWs as they are likely to be different than solid-axle wheelsets.

F. *Development of active suspension system with electromechanical actuators for railway vehicles*

Define abbreviations and acronyms the first time they are used in the text, even after they have been defined in the abstract. Abbreviations such as IEEE, SI, MKS, CGS, sc, dc, and rms do not have to be defined. Do not use abbreviations in the title or heads unless they are unavoidable.

Electro pneumatic actuators can be used in railway vehicles for active suspension system. Active suspension system are used for the better comfort of passengers. The system consists of accelerometers on the body, a control box that receives vibration information from the accelerometers and outputs control signals to the actuators, and actuators provided between the body and the bogie trucks to suppress lateral sway. So for building this various pneumatic actuators and lateral dampers were used.

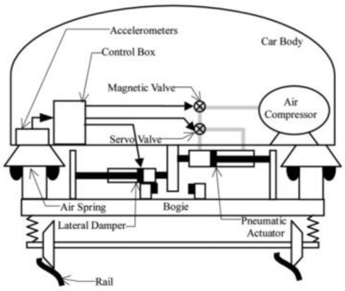

Figure 6: Construction of active suspension system

Specifications of electric actuators: Thrust should be 6KN

Frequency band of vibration to control: 3Hz or lower electromechanical actuator (EMA) converts the rotation of a built-in electric motor into linear movement using a drive mechanism, which can be ball screw or any other.

With speeds of train increasing the shortcomings of pneumatically actuated systems were realised therefore this gave rise to electro pneumatic actuators in suspension system. In this many EMAs were used as well as lateral damper were used.

G. *Application of Sensors in Railway Tracks for Safety*

This paper focuses on the safety of the passengers and the train against natural or man-made phenomenon by incorporating sensors, microcontrollers and transmission through GSM.

The project includes three modules namely - Sensor module, Processing module and transmission module.

The sensor module includes the PIR sensor which senses the radiation emitted by any human or animal body within a range of 10 meters. An electromagnetic fatigue sensor is also used to detect any cracks or defects on the trail track that may cause damage to the train components or derailment.

The processing module consists of Raspberry Pi that can process the data received by the PIR and the EFS sensors. It also converts the signals into useful information and sends it to the transmission module.

The transmission module uses GSM Framework that has a capacity to convey 64 to 120 mbps. This module sends a message to the operator if there is any fault found by the sensors.

This method can be adopted to reduce the accidents on tracks as it provides a low cost and low power consuming solution.

H. Mechatronic solutions for high speed railway vehicles

This paper presents recent developments in the study of active steering control and studies what could be achieved when modem control techniques are used configurations are studied, which are solid axle wheelset, independently rotating wheelset and directly steered wheel pairs.

Vehicle scheme mainly consists of a vehicle body with two wheel sets connected to the body via the lateral suspensions.

Almost all railway vehicles use the conventional solid axle wheelset, where two coned/profiled wheels are axle wheelset is also unstable at non-zero speeds and typical passive vehicle therefore also consists of wheelset and deteriorate wheelset performance on installed to drive the track rod to control the angle of the wheel-pairs relative to the track to achieve both stabilisation and guidance. Although this paper concentrates upon active steering schemes using actuators, there are other possibilities. E.g. a different scheme is proposed for the active control of the independently rotating wheelset, where a differential rotation torque between the two wheels on the same axle is used to provide the guidance control

Active Steering scheme: Concepts to steer wheelsets actively via mechatronic steering of railway wheelsets.

Active control schemes for railway vehicles offer a solution to the difficult design trade-off between stability and curving performance of a conventional passive vehicle. The best performance is achieved by using independently rotating wheels, rather than solid axles, researchers have shown in a study.

I. Mechatronic Rail Vehicle Design Based on the Passenger Comfort

Passenger comfort is highly affected by the vehicle speed and so the rail imperfections. Improving the RV performance is that the key to avoid perturbations transmitted from the wheels to the passenger. Some researchers have considered adding an active suspension to the RV so on boost ride comfort. Mechatronic design considers the close interaction of mechanics, actuators and control engineering so on achieve a design with better performances. Important improvements of the rail vehicle performance could also be achieved by using the mechatronic approach.

For the vertical dynamic studies of the RV system it's common to contemplate the quarter of the RV model

The figure below illustrates an actuated quarter RV model with a passenger seat. The second suspension includes an actuator that generates a force u t() in parallel with its stiffness and dumper. This arrangement reduces the actuator size and dissipates the unwanted vibrations of the car body, in order to improve the comfort.

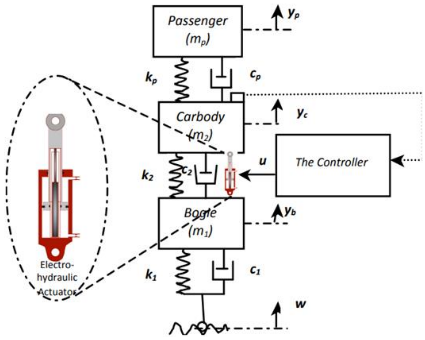

Figure 7: Actuated quarter RV Model

An electro-hydraulic actuator is employed for this study because it has the properties that make it best suited for research within the field of hydraulic engineering. A general description of the model of the actuator is given during this article, and a close description of its structure is additionally given.

The natural frequencies are going to be determined and also the most severe one are considered. A lead Lag compensator, which grants the stability of actuator response, are designed.

In this work, we've presented a mechatronic design of the rail vehicle. The obtained results showed that the passenger's comfort is significantly improved. Moreover, the MRV passenger can have a comfortable level in both cases of the considered rail imperfections.

J. Mechatronics in Japanese rail vehicles: active and semi-active suspensions

The objective mechanisms in the vehicle are classified into five orders similar as drive and retardation, auto body tilting, steering, pantograph and suspense. Next, the situation in the order of suspense is explained substantially on active control system and semi-active bone.

Table 1
Situation on application of mechatronics to rail vehicles in Japan

Category		Stage		
Mechanism	Item	A	B	C
Drive and braking	Anti-slip	○		
	Anti-slide	○		
	Pure electric brake	○		
Tilting	With control	○		
	Active	○		
Steering	Semi-active	○	○	
	Active		○	○
Pantograph	Anti contact-loss			○
Suspension	Semi-active	○		
	Active		○	
	With centering		○	○

In the Japanese railroads, the main development of rolling stock has been carried out competitively among

In the development, mechatronics technology was applied to colourful mechanisms and outfit in the rail vehicle for the enhancement in operation pets, lift comfort and for saving track conservation cost. Table 1 summarizes the situation of exploration and development relating to the operation of mechatronics technology. In Table 1, the mechanisms in rail vehicles, to which mechatronics technology is applied, are largely classified into 5 orders similar as drive and retardation, auto body tilting, steering, pantograph and suspense. In each order, present situations for the specified particulars are shown corresponding with three stages.

In this section, the figure of the recent progress in the mechatronics operation is described briefly on each order shown in Table 1. On auto body tilting, the ‘‘tipping with control’’ system has been employed successfully since 1990 in numerous trains of JR[21] companies, e. This system includes a curvaceous selector with comber attendants or bearing attendants in the tilting medium and it assists the movement of natural tilting medium being grounded on the information of track position. An analogous system is employed for practical use in Series2010967-0661/ 02/$- see front matter r 2002 Elsevier Science Ltd.

This study is still in the laboratory stage, and the prototype system on a running outfit was tested in a yard. The completely active tipping system with acceptable cock angle is still in the phase of field test operation. The test train TRY- Z of JR- East, which aims to negotiate wind sections at the pets of 45 km/ h above the regulation, is used to test several kinds of auto body tipping system., the longitudinal stiffness in the primary suspense of which is asymmetric between leading and running wheelsets and it can be switched semi -actively with the running direction.

In recent times, not only road companies and rolling stock manufacturers but also universities have carried out exploration and development appreciatively in order to apply mechatronics technology to the suspense of road vehicle. In Table 1, the order of suspense is composed of three particulars similar as semi -active suspense, active suspense and suspense with centering. Owing to the fail-safe property of semi-active suspense system, it's now employed in new Shinkansen EC trains, and the control effect has got a favourable event on the enhancement of riding comfort. And, numerous running tests have been carried out also on active suspense systems.

In the following, the progress in the suspense systems up to now will be presented more in detail including the exploration results of the authors of this paper.

Semi-active suspense: In the road vehicles of Japan, the enhancement of riding comfort has been concentrated on the side vibration that tends to increase with the speed- up. In the progress of speed- up on Shinkansen lines, semi-active suspense system has been examined to suppress the growing vibration. In the semi-active suspense each truck has two variable mutes as shown in Fig.

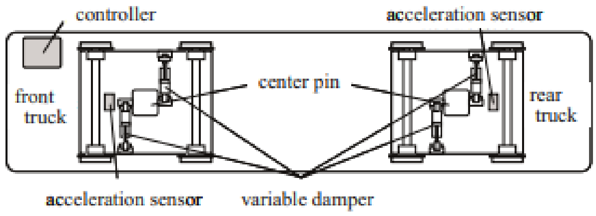

Figure 8: Sensor arrangement

JR- Central has also carried out the field test on semiactive suspense with the Series 300 EC train.

The control system grounded on the sky- hook proposition is analogous to the one of JRWest, using variable mutes. The variable mute in this system has 3 perforations and 3 high- speed solenoid faucets as well. still, it employs a different system for switching of the damping measure. This system was installed in Series 700 Shinkansen EC trains that started the marketable operation since March 1999, and they're getting a favourable event as well.

The said company has also developed a low-cost system for trains on the conventional narrow hand lines.

Active suspense: The vibration control was carried out with curvaceous selectors. February 1984, this system reduced the auto body side vibration about 50 at the pets up to 120 km/ h. After that, still, the examination couldn't be strengthened for the practical operation in the old JNR.

EC train, which was recently produced train for the through operation into Yamagata line from Tohoku Shinkansen. In the test train, completely active control system developed by Sumitomo Metal was applied for the repression of side vibration.

Then, the development of the control proposition and the fast computer speed contribute greatly to the experimental results.

Test train, an advanced active suspense system was tested at the pets up to 425 km/ h. The completely active suspense mentioned over was also installed in the test train WIN350 and the prototype of Series 500 EC train of JR- West. In this phase, self-checking function was added to make sure the system trust ability, and it sounded that the active suspense technology reached to the practical operation position for the marketable trains.

Centering control: One of the objects is the speed- up of 45 km/ h above the regulation- pets in wind sections. Then, ordinary tipping trains are allowed to run in the wind sections at the pets of 25 km/ h over the regulation. In the field test, it was made clear that hard contact of the side bump/ stop occurs in the wind sections due to the inordinate centrifugal force yielded by the running at the pets of 45 km/ h above the regulation- pets. Under similar conditions the active suspense system may increase the side vibration and beget wheel unloading.

K. *Mechatronics in ground transportation- Current trends and future possibilities*

The main systems on a road vehicle for which a mechatronic approach is applicable are the suspense. Traction and retardation systems. Of these, the suspense system is of the topmost interest, incompletely because traditionally it has been wholly mechanical, but also because it's more abecedarian to the complete vehicle design than either of the other two. Switzerland with a conception developed by SIG.

Utmost use a brace of inclined swing links combined with hydraulic selectors to give gyration of the vehicle body about the asked cock centre, Fig.4 Beforehand intimately-deduced control laws, grounded primarily upon acceleration measures, proved not to give sufficient performance in practice, and modem cock regulators take full advantage of digital processing and use fresh bias similar as gyroscopes and relegation detectors.

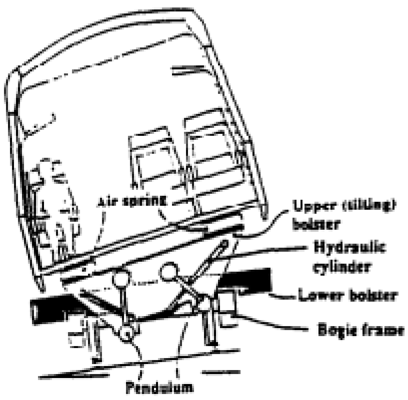

Figure 9: Semi-active suspension system

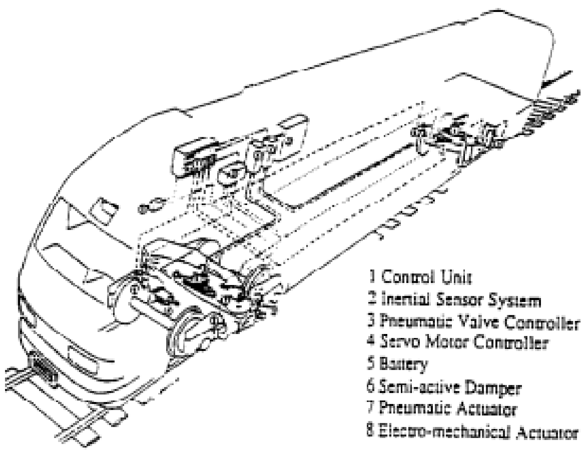

Figure 10: Electronically Controlled Suspension system

An alternate generation of systems with a advanced degree of functionality, integrated dimension systems for advanced trust ability and fault tolerance, and control laws which take a more complete view of the vehicle or train system. For secondary dormancies it's likely that the use of active control will follow the progression suggested above, beginning with a duly designed integration of the cock and side suspense functions, presumably within the coming five times. There's a continued drive towards lighter vehicle bodies, which brings a number of suspense difficulties. An egregious use of active control is to replace the relation by an selector, driven by an electronic regulator.

A detector measuring the gyration between the dread and the body can also be used to drive the selector and replace the mechanical steering relation. The electronic perpetration means that the control of the two bugbears under a vehicle can readily be linked, and this helps with the response at wind entry and exit. Another approach is to use active relaxation of the wheelset yaw suspense, in which the length of the longitudinal liaison between the dread frame and the axle boxes is acclimated in order to reduce to zero the yaw necklace applied to the wheelset at low frequentness, and this has proved to be veritably effective. There are easily a number of profound practical consequences of this approach, but it shows some of the possible advantages when a real mechatronic approach is applied to the primary suspense.

The significance is that with laboriously- steered independent bus a dread is no longer necessary, which can bring about radical changes in vehicle design leading to large reductions in weight and much lower bottom height. As mechatronic trains develop further and further electronics will appear within road vehicles, and more profound integration of the colourful systems is possible. The propulsion system formerly has a lot of electronics, and this can be linked in with active steering. It's possible to avoid having to fit a steering selector to a brace of independent bus if the traction motors on the bus are differentially controlled to achieve the steering action.

Obviously this needs a serious position of integration between the suspense and drive control systems, particularly to accommodate the conditions of safety critically. So it's possible to look forward to a full perpetration of mechatronic principles for the design of running gear, using single bus in which electronics is applied to an intertwined control system, controlling traction, retardation and suspense forces in an optimal way. This conception, in particular the use of active steering, is potentially liberating from the functional standpoint, because in principle it's possible to switch tracks from the vehicle rather than the track. Conventional track switches could vanish similar that the track is nonstop in both directions, with the vehicle detectors following one route or the other.

This requires the junking of the flanges on conventional road bus and leads to a major shift in train control generalities.

Maglev as an indispensable technology for guided ground transportation. In high speed Maglev vehicles the suspense, guidance, propulsion and retardation functions are all handed directly through electro- glamorous forces, and their integration is implicit in the conception.

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CONCLUSION

This review paper summarized the latest developments in railway systems across the world. Also use of Mechatronics in various phenomenon such as tilting, wheel dynamics, driving and breaking. Its use in trains such as maglev and in areas of crack detection, and fatigue stress were discussed. The use of mechatronics in JR trains were discussed.

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