JSESD007: Design of an All-in-One System Lightweight Motor Vehicles Maintenance Machine: A Case for an Underground Mine

Guide. S. Ganyani[1] and Tawanda Mushiri[2]

[1]*AMTEC Motors, Zimbabwe*

[2]*Scientific and Industrial Research and Development Centre (SIRDC), Zimbabwe*

Abstract

Equipment availability is one major priority in any mining activity, and the motor vehicle is one such equipment that needs rigorous and strategic maintenance to maximise reliability. The case study mine experiences extended downtime when major components of its Low Value Mineral Venture (LWMV) fail (engine, transmission, etc.). Addressing LWMV downtime sometimes requires hoisting of components to the surface, where equipment is abundant, for maintenance. The machine proposed in this article, the Grouped Maintenance of Ten Total Operations (GM-OT10), eliminates the need to hoist anything to the surface by facilitating all major maintenance activities underground. The GM-OT10 facilitates maintenance activities by integrating various maintenance components which can be assembled in any place. In addition, it links well with the Internet of things and artificial intelligence to facilitate fault diagnostics and prediction. The proposed machine has not been utilised in any mining sector globally. The GM-OT10 design utilises pneumatics for most of its actuations, thus reducing direct dependency on electricity. The choice of pneumatics is influenced by the widespread use of compressed air in most underground mining operations. The proposed GM-OT10 has been designed to suit the harsh and unpredictable underground mining environment. Specifically, the beams and robust framework were designed with a higher safety factor using SOLIDWORKS. Finite element analysis, carried out on critical load-bearing components, showed von-Mises stress values below the design stresses. A displacement and a strain analysis were also carried out using the SOLIDWORKS simulation package, and the numerical values obtained indicate minimum strains and displacement within the allowable range.

Keywords: automobile, finite-element-analysis, maintenance, SOLIDWORKS

Introduction

Automobiles have proved to be of great importance in this modern world. They consist of a variety of mechanical mobile parts linked together in order to generate and transmit power. Vehicles contribute to a conspicuous part in the current industrial economy. Light trucks and small utility motor vehicles offer a reliable and quick way of mobility-on-demand to the continuously growing industry in the entire world (Harrington & McConnell, 2018). For efficient and proper running of a motor vehicle, it is necessary that it should be properly maintained and repaired. Light motor vehicles have also proved to be of great importance in an underground mine situation mainly because of their portability. However, their maintenance from the underground section poses a massive challenge due to space confinements, which complicates the ease of maintenance (Tripathy & Ala, 2018). The most dominant structure layout in an underground mine is a series of interconnected tunnels or mine drives (horizontal tunnels), ramps (inclined tunnels) and vertically-oriented haulage shafts which give access to areas of ore and also conduits which are used for the transportation of ore outside (Brazil, 2007). This much of an orientation implies a limit in the space that is found underground. Mining activities always differ from one place to another, level to level as ore occurrence sites constantly change. Since mining activities constantly change (usually going downwards), most mines do not construct important structures such as garages and service facilities as they quickly become too far to reach, hence a waste of resources.

In the appropriate environment, vehicle maintenance and repair can be done safely and effectively, but in an unconducive environment, it can be very dangerous (Crawford, 2018). Apart from such requirements as the qualification of the driver, the condition of the road and the weather conditions, vehicle condition is one of the fundamental aspects to consider in accident prevention (Muvuringi, 2012). Vehicle maintenance can occur at a garage, service station or a specialist repair shop, with the three offering different services. A garage is a place where a car is stored, maintained or repaired and comprises departments such as vehicle sales, and auto supply sales and storage (Knowles, 2011; Crawford, 2018). The vehicle undergoes maintenance by a mechanic who uses proper tools and equipment in the changing of tyres, lubrication and pressure checks, and so on. The vehicle is also maintained from a service station which offers additional services such as car washing, lubrication, fuel provision and other simpler tasks that are required daily (Heywood, 2018).

Background

Vehicle maintenance, as a crucial activity in proper service delivery of the vehicle, must be done correctly in a facilitative environment whenever and wherever required (Hasan, 2017). Preliminary studies show that maintenance equipment comprises of separate, single-function devices designed to carry out specific tasks. Typical versions of integrated equipment are found on the assembly lines in vehicle production, which is not the case with vehicle maintenance. Research also shows that underground mining activity constantly shifts from place to place, which means utility vehicles also move from place to place, and break-downs are likely to occur at any point.

Equipment availability has to be kept at its maximum to reduce downtime and overtime. Availability of equipment refers to the amount of time a piece of equipment is available for operations, and is determined by the equipment's condition. (Qingfeng & Wenbin, 2011). The unavailability of a compact system which supports maintenance directly from underground results in excessive time loss in carrying out maintenance for underground vehicles. Some broken down vehicles or parts have to be hoisted to the surface for the maintenance process, which consumes more time than if the process was simply done from the underground.

Most Maintenance Equipment is found as Separate Units

Equipment required for full maintenance of a vehicle is currently not found as a single unit, but at different compartments, requiring that the vehicle either moves from one place to another, or that the mechanic brings the required equipment to the vehicle to complete its maintenance. This has not only posed several drawbacks in terms of the time required to complete the process, but has also increased cost since one might need to drive from place to place to exhaust the maintenance process.

Unavailability of Mobile Machines

There are no mobile machines which assist in maintaining a vehicle wherever it is. This means that the vehicle has to be driven to the garage, which is if the engine is still running, or else it has to be towed to the garage. There is, therefore, a need to come up with a machine that will offer vehicle maintenance at any place. This would be more like a mobile garage such that in the case of an underground mine, vehicles would be serviced regardless of where the vehicle is operating.

Vehicle Mechanical Failures - Major Cause of Accidents

Workplace safety is the first major priority for employers and employees. A lot of incidents and accidents that take place underground are characterised by a series of vehicle mechanical failures, mainly as a result of the non-stop operations of the vehicles (Bair et al., 2011). The same vehicles are used for every shift, hence the great need to constantly repair and maintain them so that they function properly. Underground spaces are very confined, thus the environment does not safely facilitate a conducive space for vehicle maintenance. However, the creation of a conducive space would be a waste of resources, given that mining activities shift to other areas.

Highly Labour-Intensive and Unsafe Procedures Done in Vehicle Maintenance

The highly labour-intensive processes involved in vehicle maintenance offer severe complications in terms of job performance, for example, working from below a vehicle which has not been lifted makes it uncomfortable for the mechanic; therefore, there is no guarantee for a perfect job. Moreover, there are places such as underground mines, where the space is too confined to allow a proper working environment, unless if the vehicle is hoisted to the surface for maintenance.

Automobile Physical Configuration

Automobiles date to long back, and the first of their form consisted of carriages into which a primitive engine, transmission and steering controls were integrated (Lavhale & Salunke, 2014). The typical cars had strong steel frameworks that supported the body of the vehicle, and wheels were added with a set of springs and dampers that made it conducive for the car to travel on most uneven surfaces. As indicated in Fig. 1, the current motor vehicle system mainly consists of the chassis onto which the vehicle body is rested, and is supported by a suspension system, with another system of brakes connected to the other end of the suspension system. The steering wheel and other mechanical systems, mounted onto the chassis and frame, are connected to each other and various subsystems through a network of linkages, mounts, and drives. For some basic understanding, the researcher used basic vehicle configurations. Due to increasing attention to the significance of fuel efficiency and government-oriented regulations, vehicle designs have altered significantly. Also, most of the cars have their engines located at the front, thus adding an advantage of protection in the event of a crash, and an efficient engine cooling system.

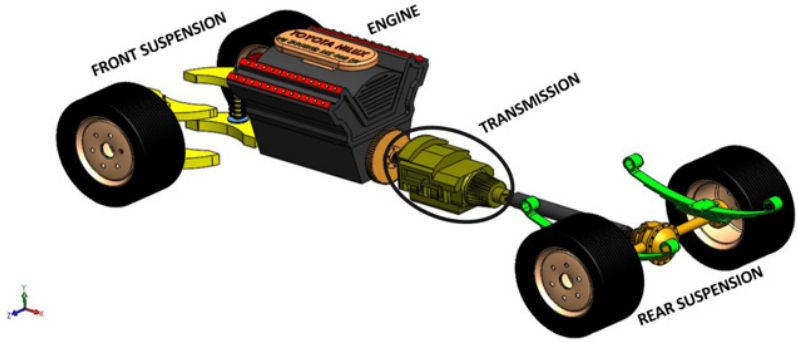


Figure 1: The automobile's physical configuration excluding the body

To ensure safety and stability, the front wheels are used to control the vehicle. A rear wheel drive system was used for earlier cars, but this configuration does not offer optimum traction since the massive weight of the engine and transmission is primarily at the front wheels. Later designs improved to take advantage of the engine weight by combining the steering and drive wheels in the front. In front-wheel-drive vehicles, the engine is oriented transversely and the transverse orientation is the east-west. The power transmission is oriented adjacent to the engine and its axis is parallel to the engine axis. The differential and the axle are mounted in the transmission, forming the so-called transaxle.

Maintenance

Maintenance is a process that refers to the necessary work required to keep things in a proper manner and perfect state in terms of repairs. Maintenance processes are applied differently from one firm to another, depending on the firm's objectives (Plint, 2007). To ensure that the equipment is in a good operational state, a planned or scheduled preventive maintenance programme should be put in place. To ensure that machinery equipment functions consistently, components that quickly wear off and have a limited lifespan need to be inspected periodically. Routine maintenance should ensure that the components are always in perfect condition.

General Maintenance of a Vehicle

Vehicle maintenance aims at preserving the original factory state of the vehicle, and to keep the vehicle in a state that is conducive for a repair process.

The key areas of vehicle maintenance (Fig. 2) are wheels and suspension, power transmission and the engine (Pierson, 1996). Hundreds of thousands of vehicles are manufactured every year all over the world. These vehicles are not identical, and generally each vehicle make and model has its own user manual to which one can refer to for general maintenance of the particular vehicle. Vehicle users should thus be well acquainted and comfortable with the manual, as almost any subject regarding maintenance is contained in the manual. Typically, most users' manuals contain a maintenance chart with all the necessary data regarding when to carry out periodic vehicle maintenance such as replacement of air and fuel filters, tyres, fluids, and so on. It is of great importance to appreciate factors that may cause automobile accidents. Moreover, vehicle maintenance records might contain very valuable information with regards to the forecasting of automobile accidents.

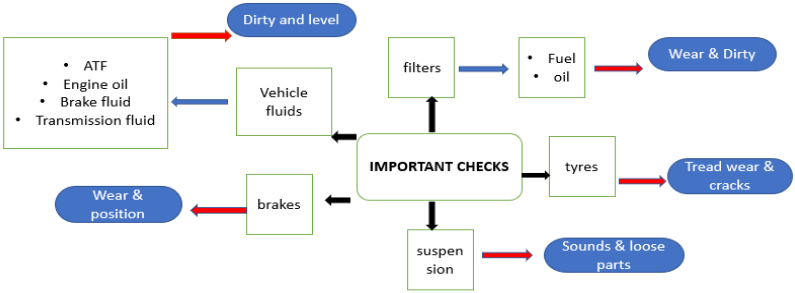


Figure 2: Some of the critical checks carried out on a motor vehicle (Pierson, 1996)

Maintenance Equipment

Maintenance equipment is currently found as separate entities, with each piece of equipment being a separate unit designed to address a single maintenance task. For example, wheel alignment equipment is specifically for wheel alignment, while a lifting ramp is specifically designed to lift a vehicle to different heights. There is no machine that integrates all the maintenance equipment into a single unit such that maintenance is completed at a single point. Rather, a vehicle has to move from one point to another to complete the maintenance process.

Automobile Fault Diagnostics

Failure of automotive components directly or indirectly affects everyone's life. It might result in loss of lives and also cause damage to equipment and

valuable infrastructure. Usually, the failure of a component results in either a modification of that same component or its replacement (Heyes, 1998). The most important thing is to avoid any form of failure by all means or, if it happens, the failure should be addressed effectively in the shortest possible time and in a safe manner both to personnel and the environment. However, seizure of some of the components can actually cause loss of control of the vehicle, which often results in an accident that may damage property and affect life. The significance of these components leads to their classification as safety critical items.

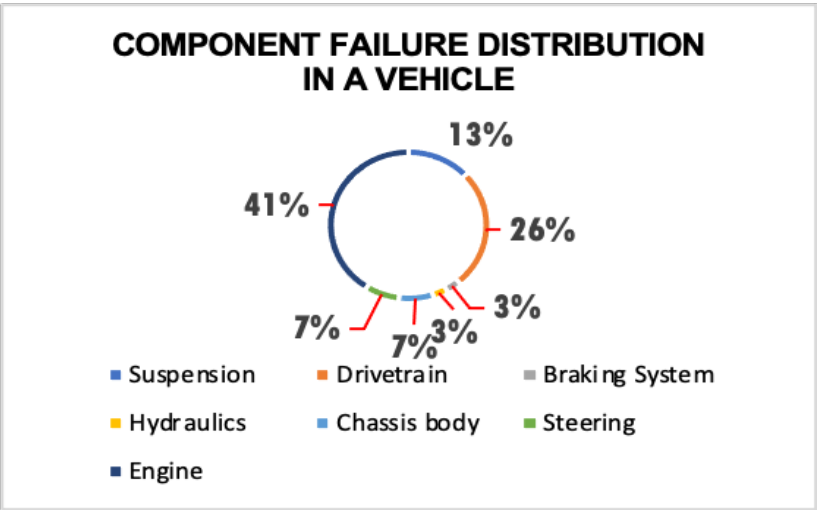


Figure 3: Component failure distribution on a lightweight motor vehicle (Heyes, 1998)

According to Heyes (1998), vehicle component failures are distributed as shown in Fig. 3. The engine, which consists of the major segment of the vehicle, contains the largest percentage of failure distribution within an automobile. This indicates the need for extra care when attending to the engine in terms of carrying out routine maintenance work. However, the drivetrain is also responsible for a significant vehicle failure, as shown in Fig . 3. The rest of the parts contribute minor percentages, but they also need attention as they too might lead to critical failures.

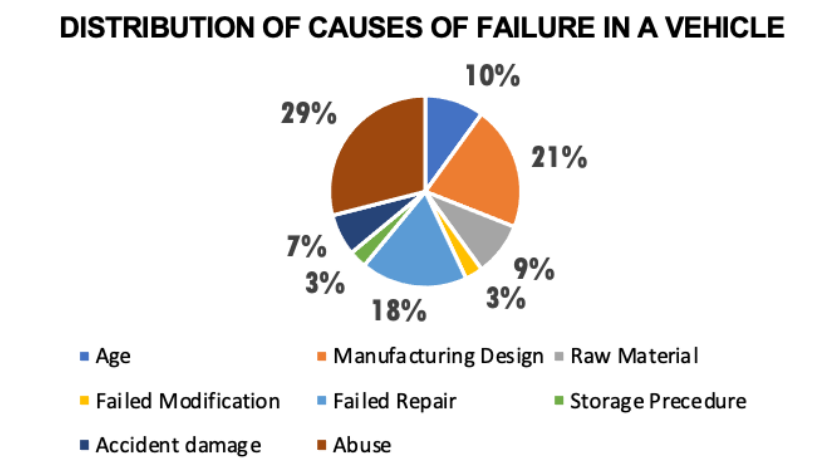


Figure 4: Failure cause distribution on a motor vehicle (Heyes, 1998)

Automobile failure is caused by a variety of factors as indicated by the pie chart in Fig. 4. It is, therefore, not in every case that failure is attributed to the operator. Abuse of the vehicle leads to 29% of automobile failure. This includes the use of the vehicle on undesired surfaces, overloading the vehicle to more than its GVM, and carrying out maintenance using the wrong type of oils. However, the manufacturer's design, failed repair and vehicle age also contribute a significant part to vehicle failures.

Underground mine utility vehicles are used for various purposes including transportation of spare parts to their required points, transportation of damaged parts and transportation of workers to their designated workplaces. The most fundamental aspect of a vehicle is to be readily available and functional without any delay. The dominant structure in an underground mine environment is described by a special network of interconnected tunnels which are also known as mine drives or horizontal tunnels, ramps (inclined tunnels) and vertical haulage shafts which provide access to ore zones and conduits for the conveyance of ore to the surface (Brazil, 2007).

The machine Design

The all-in-one mobile machine was designed to provide efficient service to the underground mine environment, and also facilitate vehicle maintenance

on the surface. This article furnishes all the steps and procedures required in coming up with the mobile machine. The aim is to produce a better innovative version compared to the available methods. The list of operations the machine is able to carry out is shown in table 1.

Table 1: List of operations to be carried out by the machine

Component	**Operation**
Wheel alignment machine	Wheel alignment
Diagnostics machine	Engine diagnostics
Exhaust gas tester	Emission testing
Overhead crane	Engine lifting and fitment
Press fitter	Press fitting
Strut compressor	Strut compressing
Computer system	Fault prediction and analysis
Gear box lifter	Fit and remove gearbox
Tyre machine	Tyre fitment and balancing
Ramp	Lifting the vehicle

The mega device incorporates at least 10 major maintenance operations that are required on a vehicle. The whole machine forms a unique robotic framework which will address most of the critical challenges that Zimbabwe is facing as far as underground maintenance of light motor vehicles is concerned. The idea of combining all the equipment required for a complete maintenance process will enhance and push technology to the limit. The device to be implemented is a great innovative step in the mining industry in terms of facilitating the ease of lightweight motor vehicle maintenance.

SOLIDWORKS Design Drawings

All engineering drawings in this research article were generated by the researcher using SOLIDWORKS software, and only limited and important information has been displayed within the context of the drawings.

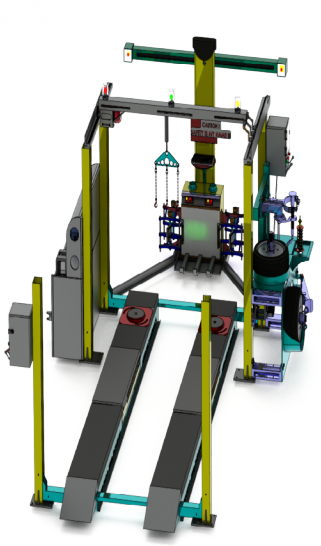


Figure 5: GM – OT10

The idea is to unite every maintenance aspect into a single entity as shown in Fig. 5. As indicated, every critical maintenance component is available. One can carry out vehicle maintenance at a specific point, without moving from point A to point B. Further, more than two operations can be carried out simulteniously.



Figure 6: GM – OT1O loaded

The vehicle can be lifted in two ways as indicated in Fig. 6. For suspension repairs, the vehicle will be lifted using the extension scissor lifts, while most of the other operations which require the vehicle to be on its wheels will use the main ramp. This brings to 10, the total number of operations which are highly critical for a complete vehicle maintenance. Table 2 shows the vehicle dimensions that can be accommodated on the device.

Table 2: Preliminary data (Toyota Hilux)

Parameter	**Specification**
Overall length	5255 mm
Overall width excluding mirrors	1835 mm
Overall height unladen	1795 mm
Wheelbase (WB)	3085 mm
Kerb weight	1830 kg
Gross vehicle mass	2875 kg
Max payload	1045 kg

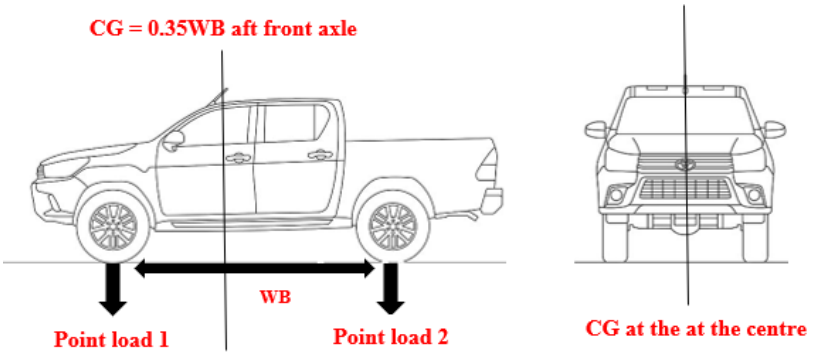


Figure 7: Point loads and centre of gravity locations

The centre of gravity CG = (35% – 45%) of the wheel base from the front axle.
Taking the lower limit, CG = 0.35 WB

The rear end has a mass of 503 kg
The front end has a mass of 934.5 kg

The preceding is shown in Fig. 7. This implies the weight of the vehicle on each sleeper is as follows:
At the rear axle = **4934.43N**
At the front axle = **9162.5N**

Table 3: Electric motors

Engine crane electric motor	6 kW	It generates the linear motion required for moving the engine crane back and forth along its rail. The motor drives a rack and pinion gear mechanism.
Wheel changer electric motor	2 kW	The motor directly provides the rotational motion for the tyre changing unit, it is directly coupled to the disc shaft where the tyre sits.

Two electric motors have been used to transmit the required motion for the linear movement of the engine crane and one for the tyre changing unit (Table 3).

Finite Element Analysis (SOLIDWORKS)
Critical components whose surfaces are exposed to a great deal of forces, stresses and strains require a transparent dig in terms of design strength. Finite element analysis analyses the various forces acting on a component and sums up the overall resultant distortions and deformations. It further gives the stress distribution throughout the component. The two extremes are red and blue: the red signifies the maximum stress region on the component, while the blue colour resembles the minimum stress region on the component.

- Ramp main beam
- Ramp crossbar beam
- Engine crane crossbar beam

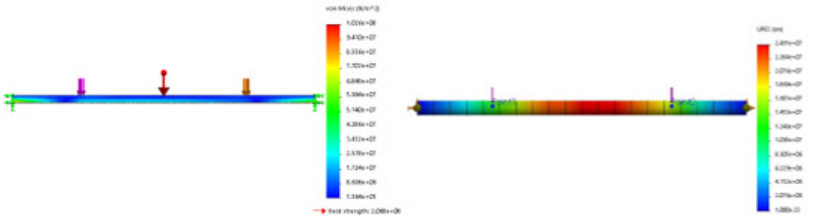


Figure 8: Ramp beam von-Mises and strain analysis

Fig. 8 above indicates the von-Mises and strain analysis for the ramp beam which is the key beam subjected to be largest force i.e. the two point loads as indicated in Fig 7.

Table 4: Finite element analysis data

Critical beams (*scientific values)*			
Parameter	**Ramp crossbar**	**Ramp beam**	**Crane beam**
σv_{max}	52MPa	103MPa	9.6MPa
σ_d	123MPa	123MPa	123MPa
σ_y	207MPa	207MPa	207MPa
BM	3.067kN.m	8.4kN.m	1.011kN.m
Displacement	1.22mm	3.5mm	0.0233
E	0.00003320	0.0004592	0.02215

Table 4 indicates the various design factors for the key beams on the machine i.e. the output values for the maximum displacement bending moments.

Frequency Analysis Study (SOLIDWORKS)

Every structure has a tendency to vibrate at certain frequencies referred to as natural or resonant frequencies. Each natural frequency is associated with a certain shape known as mode shape. This is the shape that the model tends to assume when vibrating at that frequency. When a structure is properly excited by a dynamic load with a frequency that coincides with one of the natural frequencies, then the structure undergoes displacements and stresses.

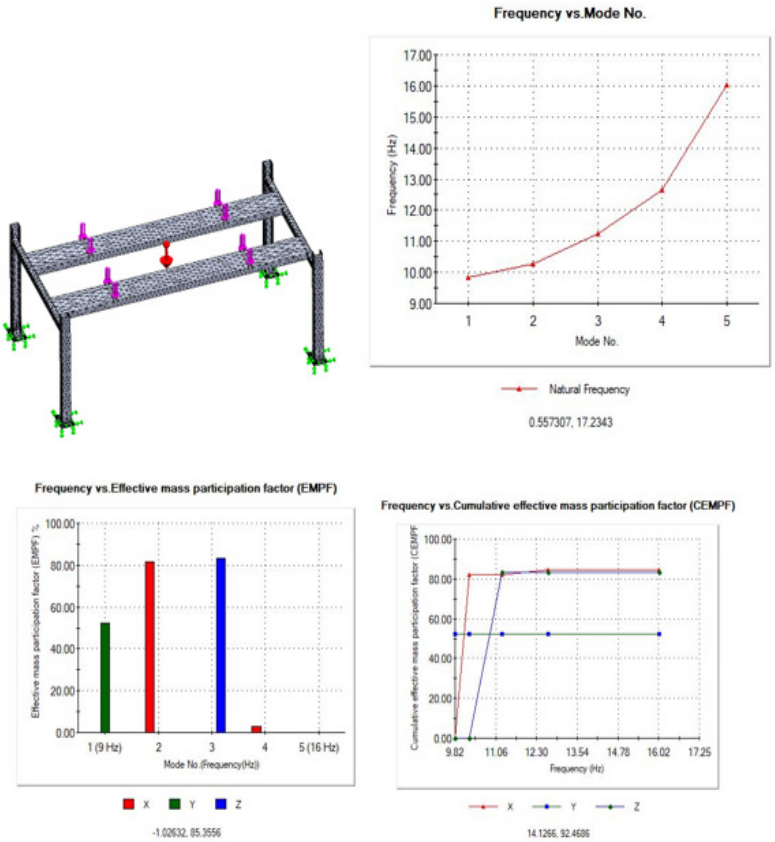


Figure 9: Mesh diagram and frequency analysis graphs

The lifting ramp is the major component of the whole machine, having to lift the vehicle to various heights and also allowing for other operations such as wheel alignment to be conducted. Fig. 9 shows the meshed diagram in preparation for the frequency analysis study. The graphs erected shows the distribution of the frequency against natural frequency, frequency against EMPF and frequency against CEMPF respectively.

Conclusions

The whole machine (GM-OT10) forms a unique framework which will address most of the critical challenges that Zimbabwe is facing as far as underground maintenance of light motor vehicles is concerned. The designer rigorously simulated all the critical components bearing major loads, and the results indicate a safe design for each. The factor of safety was well above 1.5 and, in some critical components, was above 2, thus guaranteeing safety for the machine.

The factor of safety plots did not indicate any region of weakness and, therefore, all the components are in the safe design. The initiative of combining major equipment that facilitates maintenance has been a step to ease the hustle of complications that are associated with the maintenance of LWMV in an underground mine environment. The GM-OT10 will combine 10 major operations that are required for maintenance. These operations include tyre fitting, press fitting, strut compressing, wheel alignment, engine diagnostics, engine crane, gearbox lift, fault prediction, lifting ramp and exhaust gas testing.

Recommendations

Lightweight motor vehicles have a staggered maintenance system ranging from mechanical to electronic, which need standard attention. There is need for in-depth research and attention to the source of power when operating the machine, be it solar or mains power supply and, if possible, integrating the two. The researcher did not cover good ground in terms of electronic maintenance on the vehicle, apart from general diagnostics and troubleshooting that is needed for electronic maintenance. The possible reduction of weight on the machine material to enhance mobility remains an area of study.

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