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Enhancement of Mobility of a Tracked Armoured Fighting Vehicle by Introducing an Automatic Track Tensioner

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Abstract: A prototype automatic track tensioner was developed and test evaluated. The automatic track tensioner mitigates the chances of track shedding under dynamic condition in a tracked armoured fighting vehicle and also avoids exposure of crew in battle field. This research paper focuses on virtual performance evaluation of hydro-pneumatic type automatic track tensioner, by fitting its 3D model on a Multi-Body Dynamics model of the vehicle and subjecting for virtual simulation for various road profiles and vehicle speeds. The Multi-Body Dynamics analysis affirms that the automatic track tensioner plays a vital role in enhancing the off-road mobility of armoured fighting vehicle by providing real-time track tension during running of the vehicle in different surface undulations. This paper also covers a lab level experimental evaluation carried out on the actual hardware of the prototype, by subjecting it under an endurance test with various input loads and frequencies, in which the performance of the automatic track tensioner was excellent in the entire duration of the test.

Keywords: Tracked Armoured Fighting Vehicles, Track Adjuster, Automatic Track Tensioner (ATT), Track shedding, Track, Running Gear System, Hydro-pneumatic track tensioner.

1. Introduction

A track tensioner in a tracked Armoured Fighting Vehicle (AFV) is a mandatory system to adjust the track slackness and thereby to retain the track in position during running of the vehicle. In general, the track tensioners used for this purpose would be of conventional type, which is operated manually at static condition of the vehicle. But it calls for crew exposure in the battle field which will affect their safety. Basically, the Running Gear (RG) system of an AFV comprises of six elements viz., Sprocket, Track, Track Adjuster, Suspension, Roadwheel and Top Roller as shown in Figure1. Tracked vehicles are exposed to severe ride environment due to dynamic terrain-vehicle interactions, written *by Saayan Banerjee et al* [1]. Mobility of a tank is generally defined as the capability to move effectively in various kinds of road profiles for large ranges and the ability to change its position rapidly in a short response time, stated by *Tolga Dursun et al* [2].

A sprocket is mounted on the final drive of the transmission at the rear end of the hull while a track adjuster is mounted at the front end of the hull as show in Figure. 2. The track is made up of a series of individual links connected together to form a chain like system. The track links are connected by means of rubberized track pins which would get worn-out or perished over a period of vehicle running. This will result in increase of pitch of the track and overall length as well, leading to a possibility of track shedding. The track was represented as a complex internal force element that acts between ground, wheels, and the chassis of the vehicle and the track tension was computed from a relaxed catenary, by *Mohamed A Omar* [3]. Weight of the track lines affect magnitude of track tensioning force. Track tightening influences possibility of track falling and magnitude of friction forces between track elements, *by Eng. Neumann V* [4].

Fan Beibei et al [5] explained that the track tension changes with the driving conditions, and there are many influencing factors, which makes the theoretical modelling and analysis difficult. *Vladislav Klubnichkin et al* [6] states that a tracked running gear of the designed radio-controlled harvester totally comprises 8 support rollers, 2 idler wheels with a spring-type tension devices, 2 driving sprockets and 2 tracks. To avoid track loosening, a conventional track adjuster is employed to stretch the track and maintain a minimum sag in the top run of the track as indicated in Figure. 2. Hence, the role of the track adjuster is to move away the idler wheel with respect to the fixed centre of sprocket.

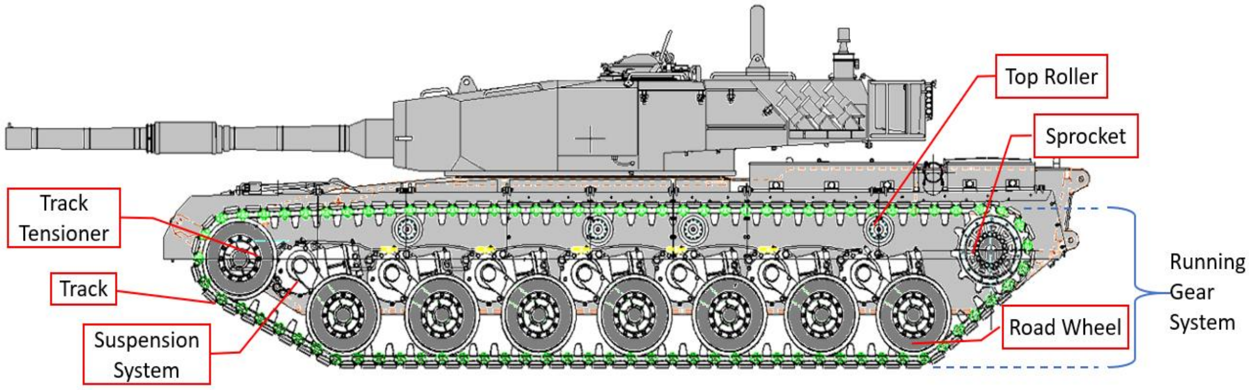


Figure 1. A typical tracked Armoured Fighting Vehicle with its Running Gear System

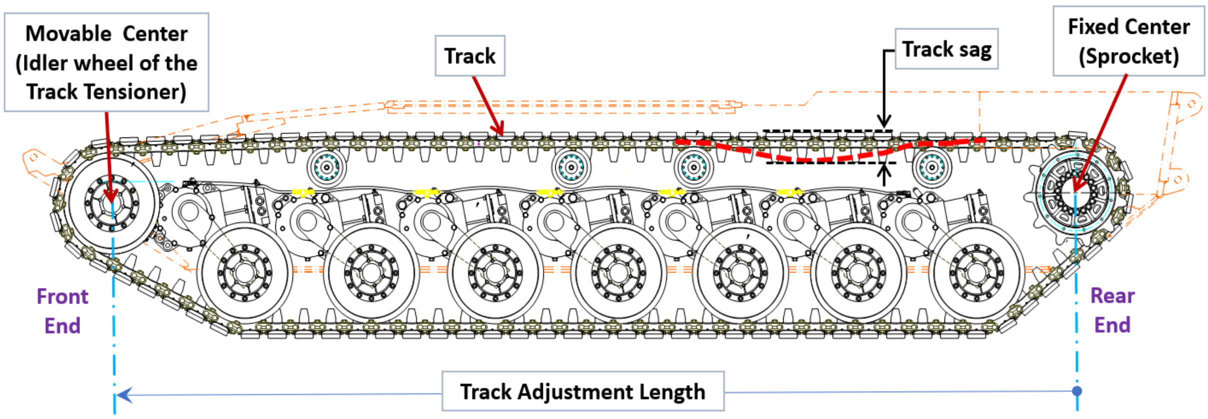
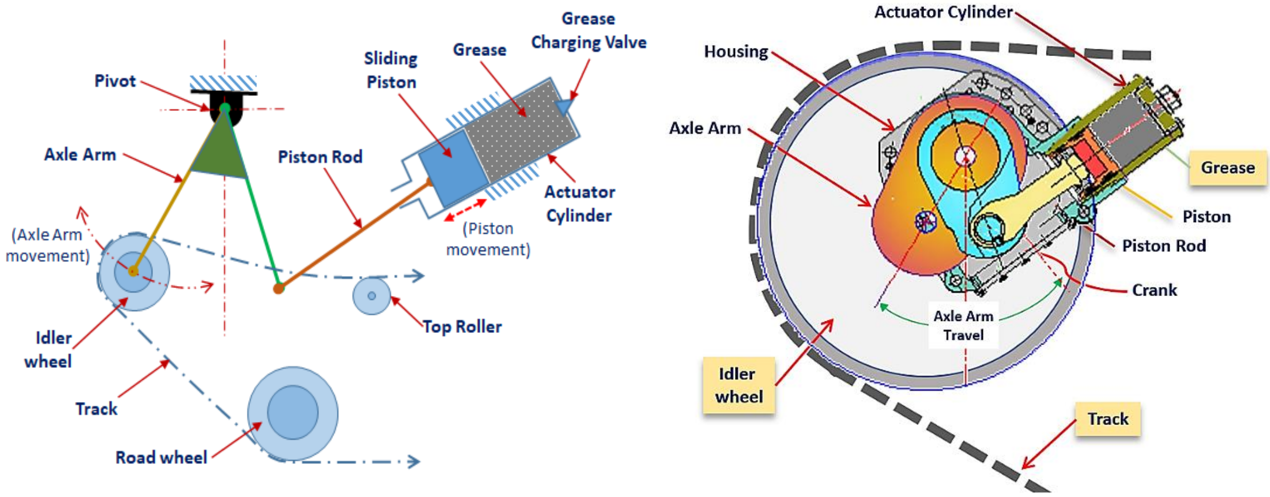


Figure 2. Track adjustment length between Sprocket and Track Tensioner in RG system



(a) Schematic view

(b) Construction Details with track

Figure 3. Arrangement of a conventional Track Tensioner mounted with idler wheel and track

Generally, these types of track adjusters are working based on the principle of slider-crank mechanism. When an excessive sag is occurred on the top run of the track segment which is hanging between the two top rollers near to sprocket, grease is manually injected into the actuator cylinder through a grease charging port by using a portable grease pump. This causes movement of the idler wheel in the forward direction by means of the kinematic linkage arrangement of the track adjuster as shown in Figure 3 (a) & (b). This exercise will be repeated every time the excessive sag is noticed due to continuous increase of pitch. If the track tension is adjusted when the track sag is more, it leads to track shedding and the vehicle becomes immobile. *Liu Weiwei et al* [7] elaborates that the initial track tension (ITT) is essential to the tracked vehicle mobility on soft ground and that when the ITT is too small the ground pressure under the track will increase and the vehicle passability will decrease even to chain off, whereas when the ITT is too large, the fatigue life of the track will decrease. *Kunsoo Huh et al* [8] indicated that dynamic variation in the track tension cannot be compensated for by the passive tensioner because it is impossible to adjust the tensioner pressure during maneuvering.

To avoid such hazardous situation, an Automatic Track Tensioner (ATT) would be a most preferred and desirable one since it shall provide a real-time track tensioning, during running of the vehicle and thereby avoiding the chances of track shedding and crew exposure in the battle field. *K Huh et al* [9] explain that for estimating track tension around the idler, the dynamic models are derived for the idler assembly and geometric relations are obtained for idler, idler arm and the track tensioner. The track tension information around the idler can be estimated from a geometric model of the idler assembly and the actuator pressure, by *Kunsoo Huh et al* [10]. *Pingxin Wang et al* [11] elaborates the formation of mathematical modelling of hydraulic unit and a method for calculating the wheel envelop perimeter with the use of the motions of all road wheels in order to maintain the track tension within a certain range and improve the service life of the track. Further, it is explained that the active track tensioning system does not increase the vibration of the chassis and has no negative effect on the ride comfort.

2. Concept and construction of automatic track tensioner

This paper proposes an ATT which is working by virtue of force balancing principle in the system of forces comprising of the spring force (FP) in accumulator cylinder of the ATT and the spring force (FT) of the suspension system, in conjunction with horizontal component of the catenary force (H) occurred in the top run of the track, at any given incident, as shown in Figure.4. The schematic of track sag catenary occurred in the track segment held between the span of the 3rd and 4th top rollers is depicted in Figure.5. This sag (f) causes variation in the magnitude of horizontal component (H) of the catenary force as shown in Figure 4, and accordingly the resultant force (FR) of the force polygon of that particular track segment gets varied.

The tension corresponding to this sag can be calculated by considering the track as a uniform cable spanning between two points, by *R.H. Keays* [12]. This is an approximation, as the cable consists of a series of links connected by rubber bushes with a certain amount of torsional stiffness as shown in Figure.5. The horizontal force variation with respect to sag depth is depicted in Figure.6. The horizontal component of catenary sag force [12] is given by,

$$H = \frac{m.g.L^2}{8f}$$

Where,

f = sag, m

m= Mass per unit length of track, kg/m

g = Acceleration due to gravity, m/s^2

L = length between supports, m

H = The horizontal component of catenary sag force, N

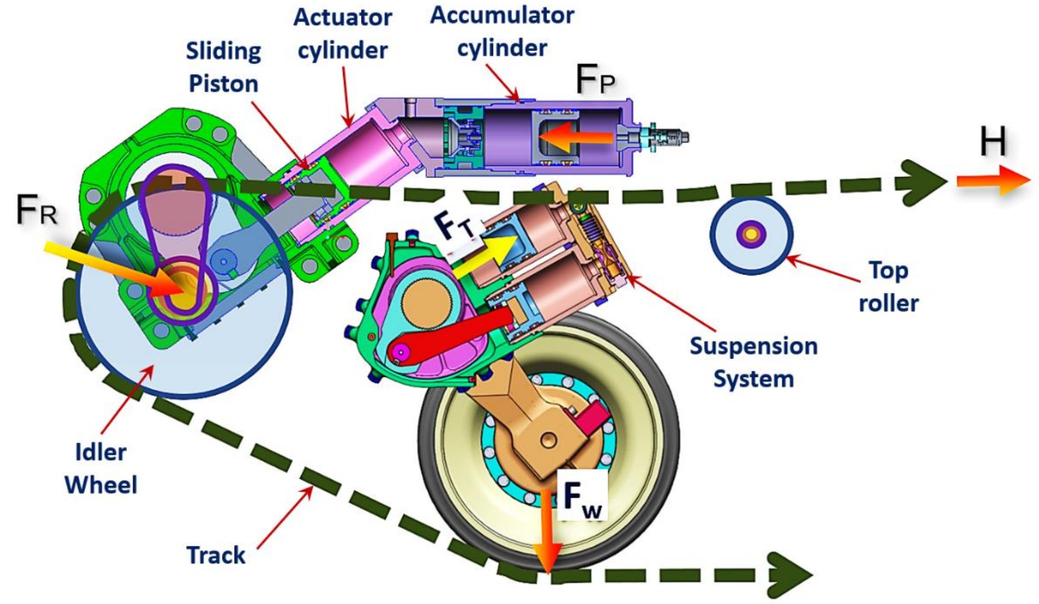


Figure 4. System of forces acting in ATT and Suspension unit

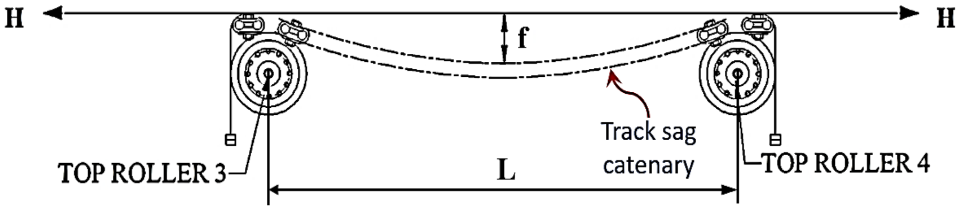


Figure 5. Catenary of track sag occurred between 3rd and 4th top roller

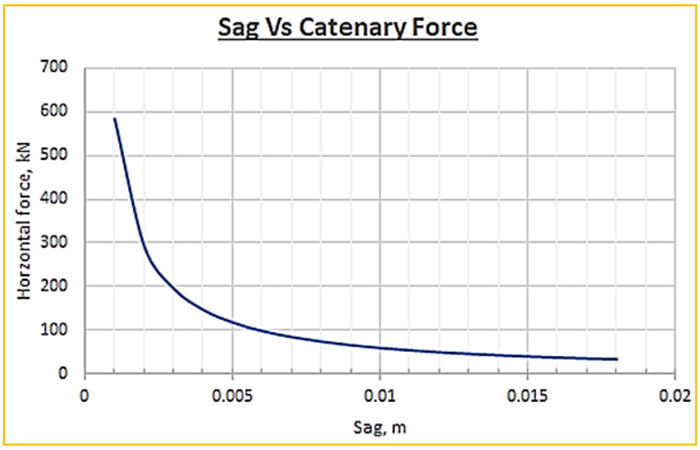


Figure 6. Catenary force variation with respect to depth of sag

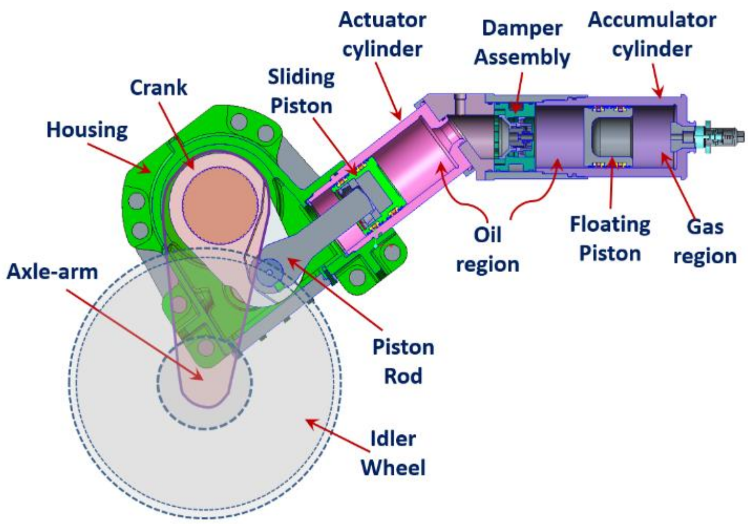


Figure 7. Construction detail of ATT

Ping-xin Wang et al [13] designed a track dynamic tensioning device which was composed of an idler arm and an electro-hydraulic servo system with a constant tension estimation control strategy. Also, *Ping-xin Wang et al* [14] described that a constant hydraulic driving force control method was employed for tracked vehicles in the driving process. *Kunsoo Huh et al* [15] explained that although the active track tensioner is believed to be very useful for tracked vehicles, its development was very slow mainly because of on-line real-time information of the track tension cannot be easily obtained in the harsh environment of maneuvering.

The proposed ATT is comprising of a housing, axle-arm, crank, crank pin, piston rod, an actuator cylinder with sliding piston, an accumulator cylinder with floating piston, and an interface block housing damper assembly as shown in Figure 7. In this, the axle-arm, crank, crank pin, piston rod and sliding piston form a slider crank mechanism to convert the linear motion of the sliding piston to rotary motion of the axle-arm.

The interface block used to join both the actuator and the accumulator cylinders is housing the damper assembly as well. Gas is filled in the accumulator cylinder while the oil is filled between the sliding and floating pistons and through the damper assembly.

2.1 Working principle of automatic track tensioner

In an AFV, the track loosing is taking place mainly due to two reasons. In the first case, it happens owing to increase of track pitch due to depreciation of pin joints of the links and in another case, it occurs due to change of overall shape of the track as a result of ground undulations under dynamic condition of the vehicle. The tightening of the track must be done in both the conditions. The tightness of the track is measured in terms of the track sag occurred in the top rollers positioned closer to sprocket wheel. Now, in the ATT, the charging pressure of the gas in the accumulator cylinder is set in-line with the specific sag requirement and the equilibrium condition of the system of forces when the vehicle is in static condition with normal ground clearance as shown if Figure 8 (a). When there is a track loosening happens due to various condition of the vehicle as explained above as shown in Figure 8 (b), the magnitude of resisting force at the axle-arm is reduced which in turn causes the gas to expand resulting in movement of the kinematic chain and thereby track is stretched as shown in Figure 8 (c). The stretching will be continuous and instantaneous if the track loosening happens due to pitch increase. Also, the track stretching will happen in another situation wherein the overall path of the track has a change of shape due to ground undulation.

2.2. Multi-Body Dynamics Modeling and Analysis

Kunsoo Huh et al [15], in their study of estimation of track tension, elaborated various mathematical modelling carried out for track tension flow, road wheel assembly, around idler wheel and around sprocket for both longitudinal travelling and turning cases. Also, it was indicated that a Multi-Body Dynamics (MBD) simulation tool was used to generate the true data of track tension under different dynamic conditions including longitudinal and traverse cases. *Ping-xin Wang et al* [13] carried out the track tension estimation around the idler wheel by assuming the track as flexible chain and compared with the MBD model of tracked vehicle incorporated with track structure, the engagement between sprocket and track, and the contact between track rollers. It was found to be close to actual simulation and the effectiveness of the estimation formula was verified with the results obtained from MBD simulation under various operating conditions. *Rubinstein et al* [16] stated that a 3D multi-body simulation model was developed using the LMS-DADS simulation program incorporating detailed description of the track, the suspension system, and the dynamic interaction between its components. It was developed for simulating the dynamic behaviour of tracked off-road vehicles in which the bodies of the model are the chassis, the wheel-arms, the wheels, and each track link. Three-dimensional contact force elements were used to describe the interaction of the track links with the vehicle's road wheels, sprocket, and idler.

In this work, a multi-body dynamic model of an AFV fitted with automatic track tensioning mechanism was developed in ADAMS Tracked Vehicle (ATV) toolkit of MSC ADAMS software as shown in Figure 9. The ATT which contributes to real time track tensioning, was fitted in the dynamic model incorporating all necessary design parameters.

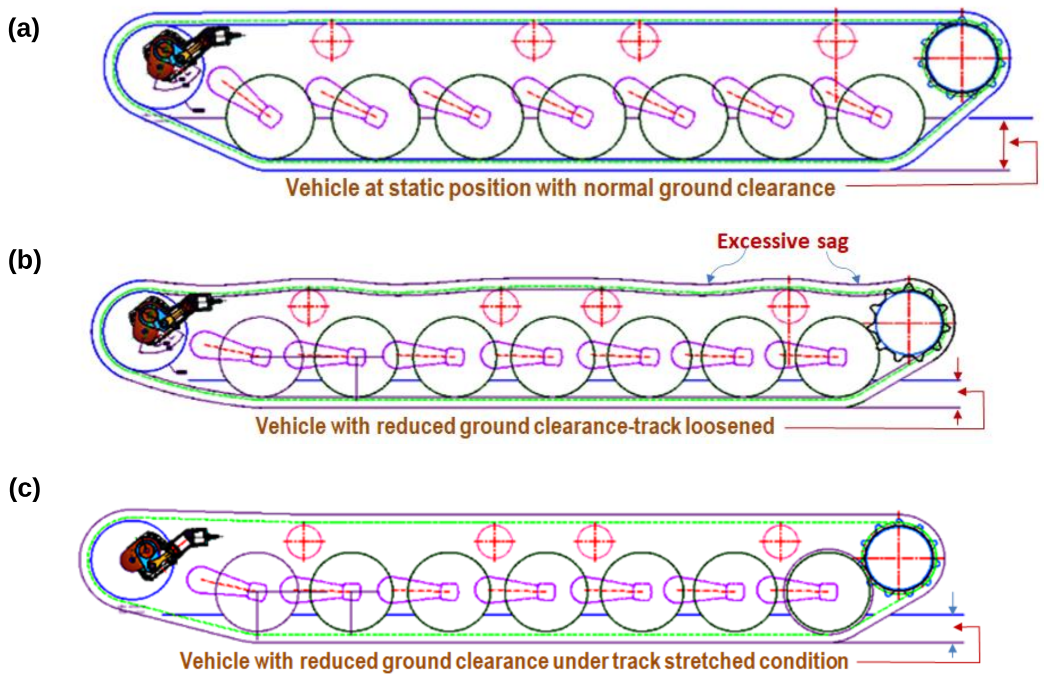


Figure 8. Schematic view indicating response of ATT for the excessive sag occurred

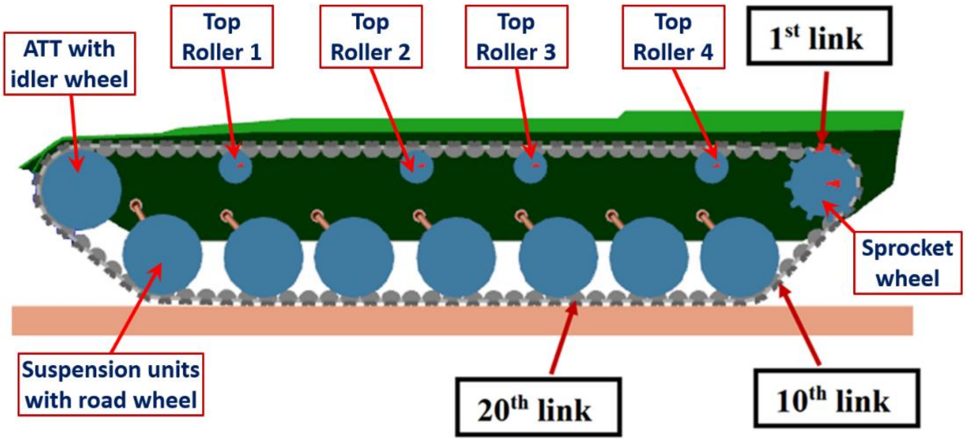


Figure 9. MBD model of an AFV fitted with ATT and indicated with links under study

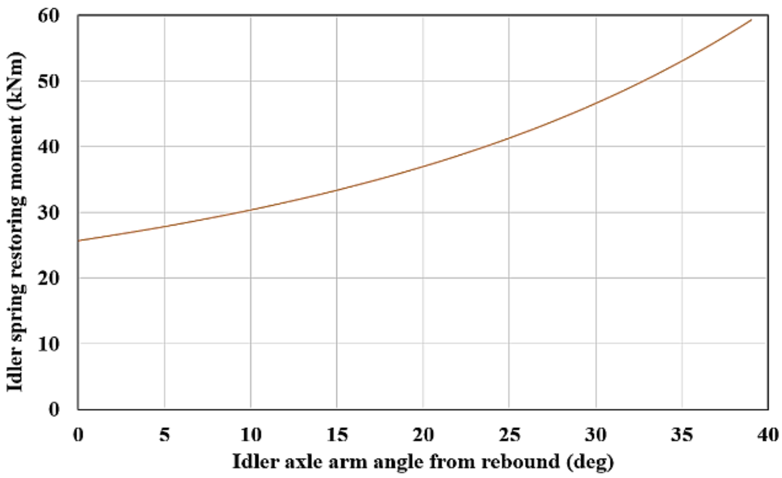


Figure 10. Non-linear torsional characteristics of the ATT gas spring

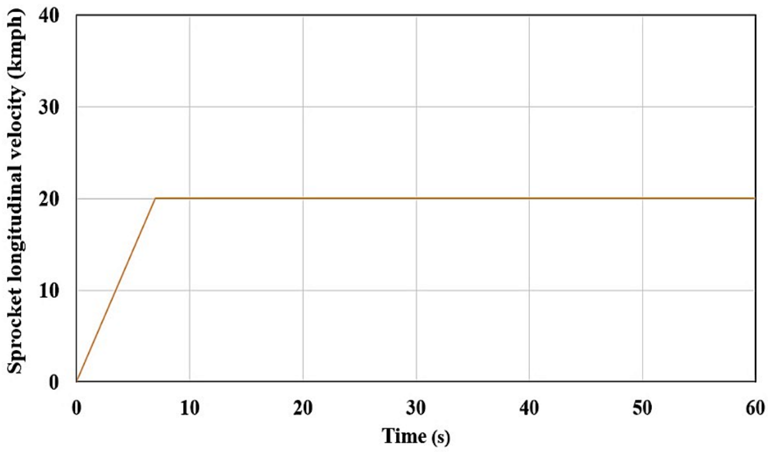


Figure 11. Variation of Sprocket velocity with time over flat terrain (Max velocity pertains to 20 kmph)

The vehicle fitted with suspension systems and ATT with a non-linear torsional spring characteristics as shown in Figure 10, was modelled in the rebound position and vehicle motion was imparted in the form of angular velocity at the sprocket end. Then, dynamic analyses were carried out after the vehicle had settled to static position and simulated over flat terrain and APG.

2.3 Dynamic simulation of an AFV with ATT and fixed idler configurations over flat terrain at 20 kmph speed

The MBD models of the AFV with movable and fixed axle arm configurations were simulated over flat terrain with maximum sprocket angular velocity corresponding to 20 kmph speed as shown in Figure11 and accelerated @ 0.8 m/s^2. It is planned to conduct a field performance evaluation on the prototype ATT in future by running the vehicle on 4m and 7m wave length sinusoidal test tracks. The maximum speed at which the vehicle can run on these tracks with respect to the maximum tolerable level by the driver is ascertained as 20 kmph. Hence, this simulation is confined within the maximum speed of 20 kmph. The dynamic sag has been determined for selected LH and RH track links while the respective link tends to be in the middle of the 1st and 2nd top-rollers as well as 3rd and 4th top-rollers (Figure 12). The time instants at which the respective track link tends to be in the middle of the 1st and 2nd top-rollers as well as 3rd and 4th top-rollers, were captured while the vehicle moves over flat terrain and APG. This procedure was repeated for the other selected links as well. The above studies were carried out with fixed idler configuration as well for comparing the ATT dynamic performance in terms of standard deviation of the LH and RH track link dynamic sag. The displacement pattern of the link No.20 on LH track has been captured while it was travelling along the entire path of the track for both the conditions namely, with fixed axle arm and with movable axle arm as shown in Figure 13a. This picture shows a number of top-runs, bottom-runs and vertical runs of that particular link captured for 50 s. Also, an enlarged view of the same showing only 5 cycles of the top-run movement captured between 10-20 s is shown in Figure 13b. Also, a further zoomed view showing only one top-run cycle captured between 12.5-14 s is shown in Figure 13c. It is very evident, as shown in Figure 13c that with the ATT (movable axle arm) fitted condition the vertical displacement of the track link during the entire length of top-run is relatively lesser as compared to that of the vertical displacement with the fixed axle arm, indicating the real-time controlling of sag minimization by ATT.

2.4 Dynamic simulation of an AFV with ATT (movable idler) and fixed idler configurations over a test track APG course at 20 kmph speed

The multi-body dynamic models of an AFV with movable and fixed axle arm configurations were simulated over a test track with Aberdeen Proving Ground (APG) course with maximum sprocket angular velocity corresponding to 20 kmph speed.

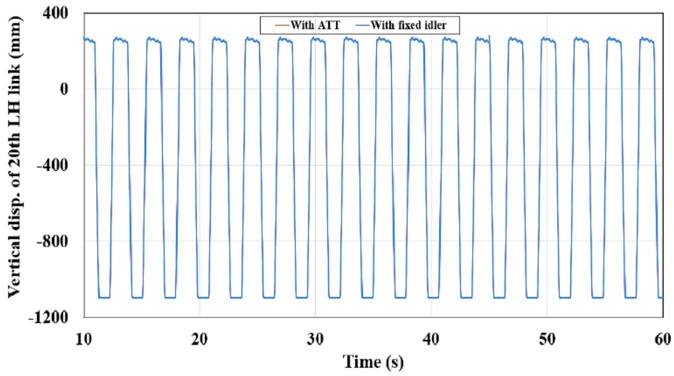


Figure 13a. Vertical displacement variation between 10 to 60 s.

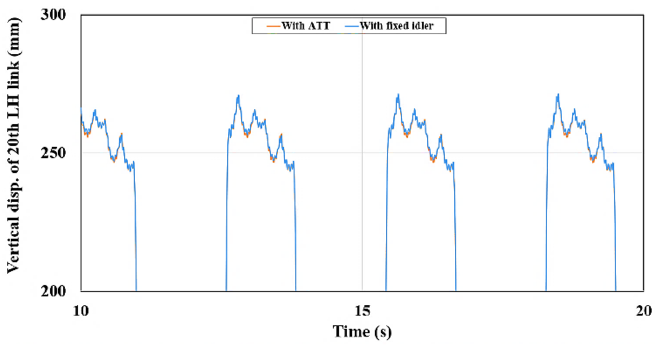


Figure 13b. An enlarged view of the vertical displacement variation between 10 to 20 s.

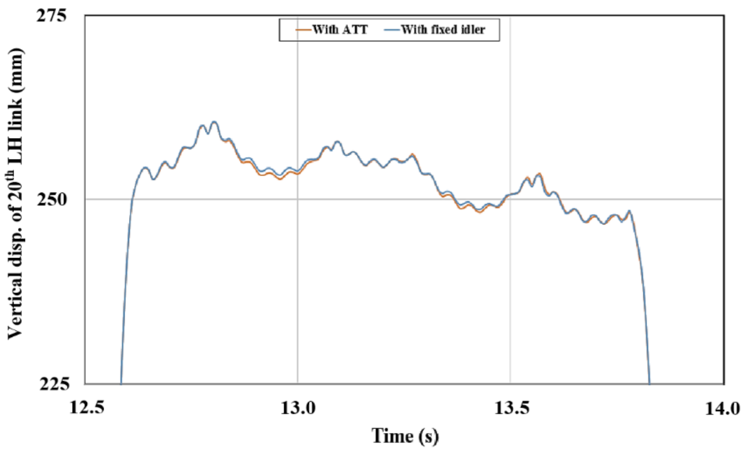


Figure 13c. Further enlarged view of vertical displacement variation between12.5 to 14 s

Figure 13. Vertical displacement variation (at 20th LH track link) over flat terrain at 20 kmph for the fixed and movable idler configurations

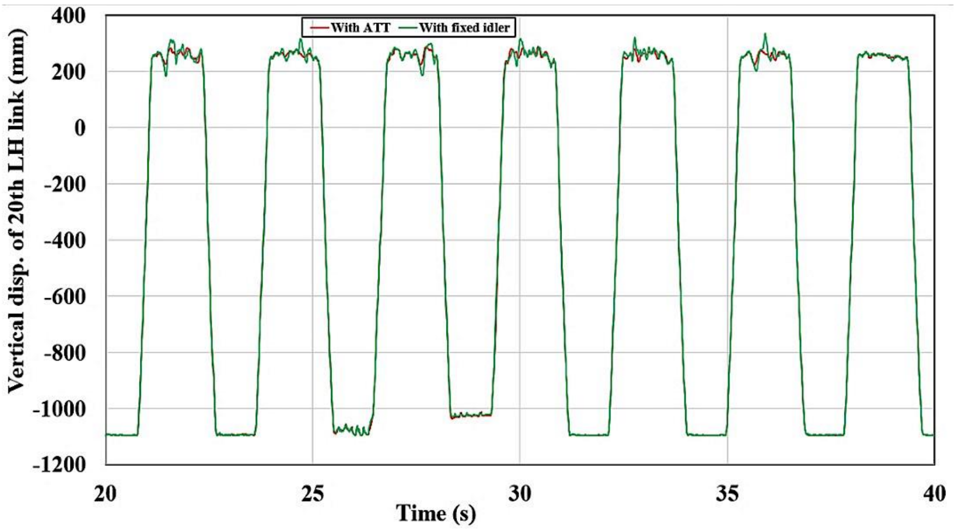


Figure 14a. Captured between 20 to 40 s

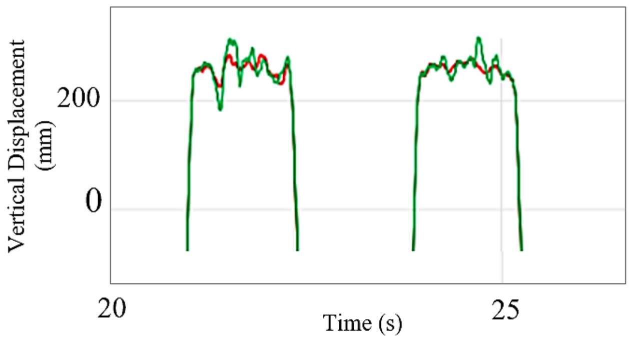


Figure 14b. Captured between 20 to 25 s (Zoomed view)

Figure 14. Vertical displacement variation (at 20th LH track link) over APG course at 20 kmph for the fixed and movable idler configurations

The vehicle MBD model was made to start over a flat road at an appropriate distance from the APG in order to achieve the desired maximum angular velocity of the sprocket (with an acceleration @ 0.8 m/s2) before negotiating the APG terrain.

The displacement paths traced by link No.20 at LH track during the run of an APG course at a speed of 20 kmph are plotted as shown in Fig 14a & 14b for both the condition namely, with fixed axle arm and movable axle arm. It is clearly distinguishable between the two paths of different amplitudes and the favourable effect by having a movable axle arm in ATT in controlling the vertical displacement due to the real-time tension to the track by ATT. A whipping amplitude reduction of 2-3 mm is recorded in ATT case in comparison to the existing track tensioner.

3. Observations from frequency spectrum of the track link vertical displacements

3.1 Track link vertical displacements

Zhanlon Li et al [17] elaborate about establishing of a model of hydropneumatic suspension and leaf spring suspensions for a high-speed wheeled excavator, using Amesim software and simulated running on uneven roads. Also conducted an experimental work on the actual vehicle by installing accelerometers on the frame of the vehicle and obtained the RMS value of vertical accelerations. It was found in their study that the experimental result proved that the simulation result was correct. *Balamurugan S et al* [18] explain about shortening the design cycle and evaluate the performance of infantry fighting vehicle using advanced multi body dynamics (MBD) environment before physical prototypes built. It was well explained in their study that the methodology presented in their paper proves to be efficient both in time and cost for simulating different vehicle configurations and study its dynamic behaviour before physical prototyping and testing.

In the MBD simulation, the LH idler axle arm angular acceleration variations were captured in time and frequency domains for both the movable and fixed idler configurations while the vehicle negotiates APG at 20 kmph and shown in Figure 15a. In the figure, it may be noted that negative acceleration values indicate angular motion of the corresponding axle arm towards its rebound direction (i.e., towards the vehicle front end) and positive acceleration values indicate angular motion of the corresponding axle arm towards its bounce direction (i.e., towards the vehicle rear end).

It is observed that RMS angular accelerations of the LH idler axle arms are comparatively much higher with movable idler than that with fixed idler in the entire frequency spectrum as shown in Figure 15b. This is due to the presence of non-linearity in the movable idler configuration; whereas, the angular response of the fixed idler axle arm is influenced by the vehicle chassis bounce, pitch and roll modes predominantly.

The vertical acceleration responses of the 20th LH track link have also been captured in time and frequency domains for both the movable and fixed idler configurations as shown in Figure 16. It is noteworthy that the reductions in the track link vertical acceleration magnitudes are observed with ATT while negotiating APG at 20 kmph. It is also observed that the frequency domain RMS vertical accelerations of the track link in Figure 16b have predominant magnitudes below 10 Hz for both the fixed and movable idler configurations. However, the RMS vertical accelerations of the track links with movable idler have lesser magnitudes than that with fixed idler at entire spectrum of frequencies.

3.2 Experimental validation with prototype ATT

An experimental work was carried out with a prototype ATT as shown in Figure 19 which was developed towards achieving the objective of providing real-time track tension to the track in a tracked AFV. It was built as per an intended configuration and subsequently subjected for a lab test performance evaluation under dynamic condition. The ATT is similar to the track adjuster explained in introduction section of this paper.

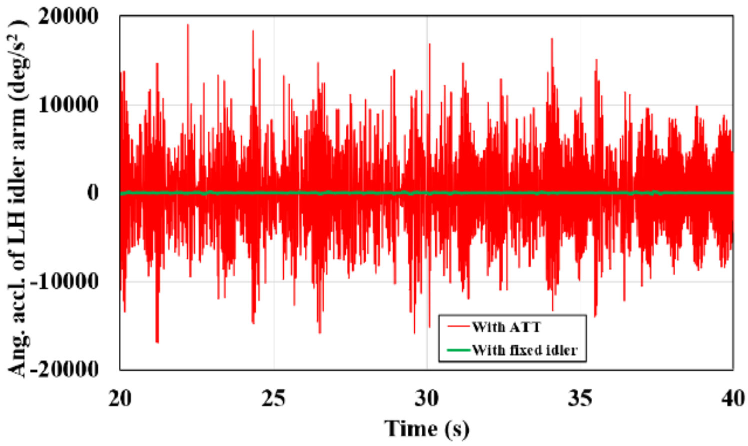


Figure 15a. Angular acceleration variation of the LH idler axle arm in time domain

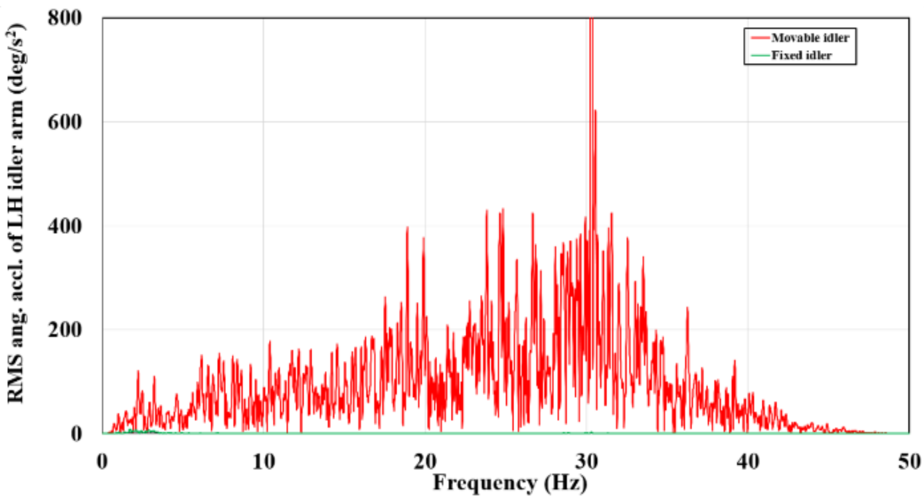


Figure 15b. RMS Angular acceleration variation in frequency domain

Figure 15. Angular acceleration variation of the LH idler axle arm over APG at 20 kmph with both fixed and movable idler configurations

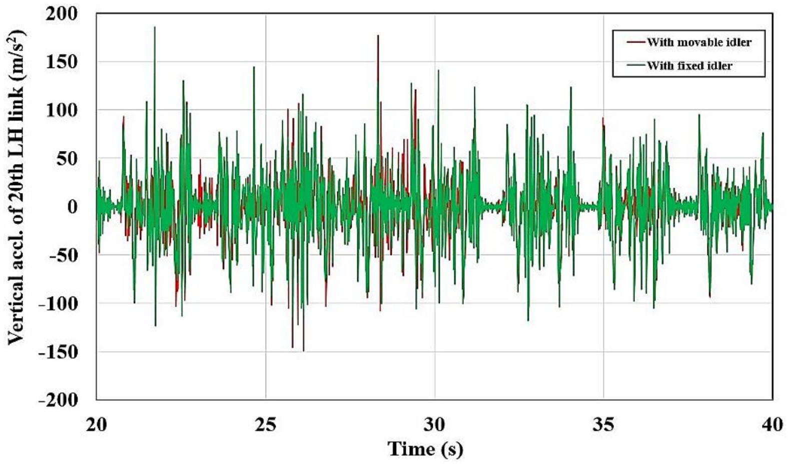


Figure 16a. Vertical acceleration variation in frequency domain

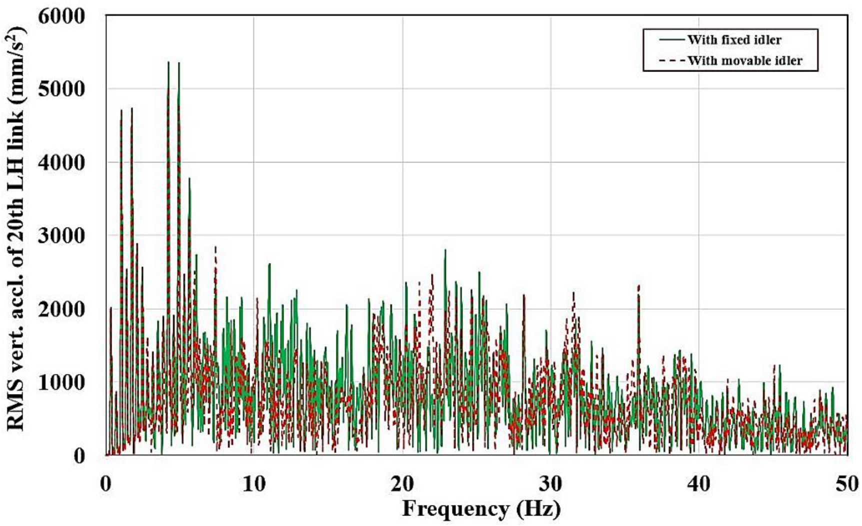


Figure 16b. Vertical acceleration variation in time domain

Figure 16. Vertical acceleration variation of the 20th LH track link over APG at 20 kmph with both movable and fixed idler configurations

Figure 17. A prototype ATT built for lab performance evaluation

However, it has been incorporated with some additional components such as an accumulator cylinder fitted inside with a floating piston and a damper arrangement connecting the actuator and accumulator cylinders. In this unit, SAE 10W30 oil and N_2 gas were used as damping and spring medium respectively. The gas with the required charging pressure was filled in the accumulator cylinder through a Schrader valve fitted at the end of it as depicted in Figure 17.

3.3 Dynamic Testing on ATT

The ATT unit was fitted on the mounting frame of the test rig which is having a vertical actuation mechanism as shown in a schematic view in Figure 18 and a photographic view in Figure 19. The idler wheels mounted on the unit will be in contact with the actuator platform of the test rig during stroking of the test. *Abd-Alaziz M M et al* [19] developed a model describing the dynamic behaviour of a hydro-gas unit using MATLAB/Simulink program.

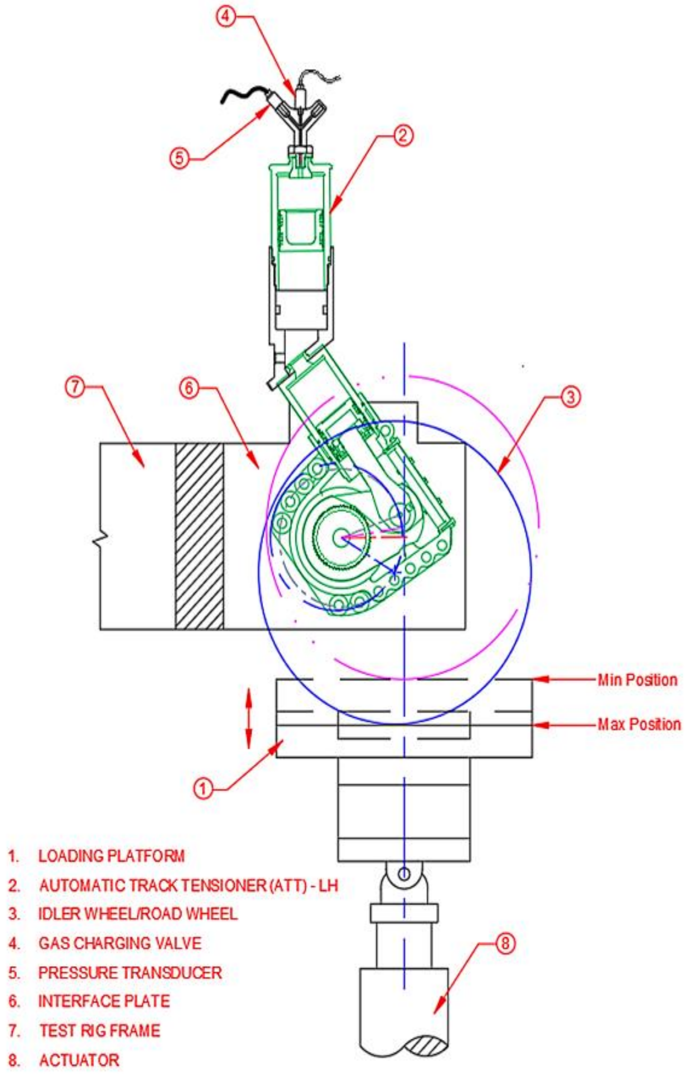


Figure 18. Schematic diagram of ATT lab test setup configurations

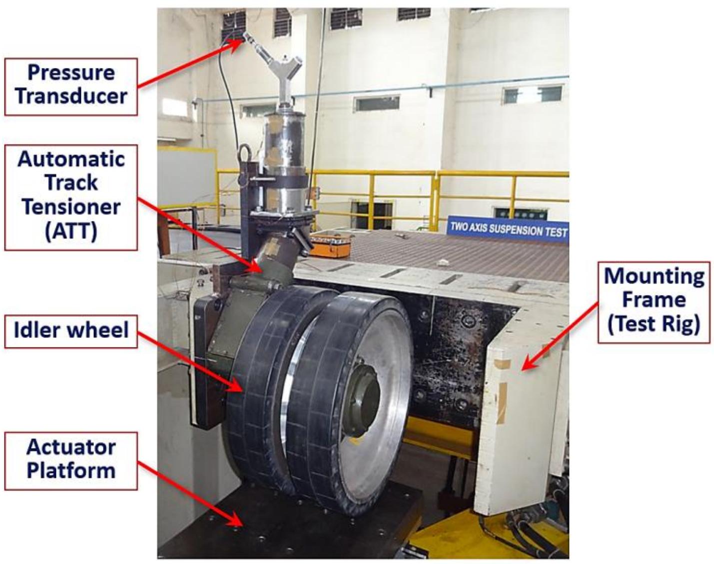


Figure 19. Prototype ATT under dynamic test in a test

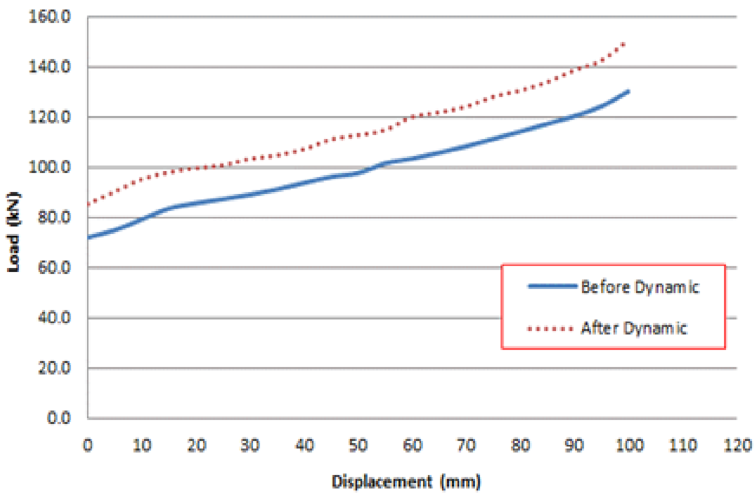


Figure 20. Spring characteristic curve of ATT

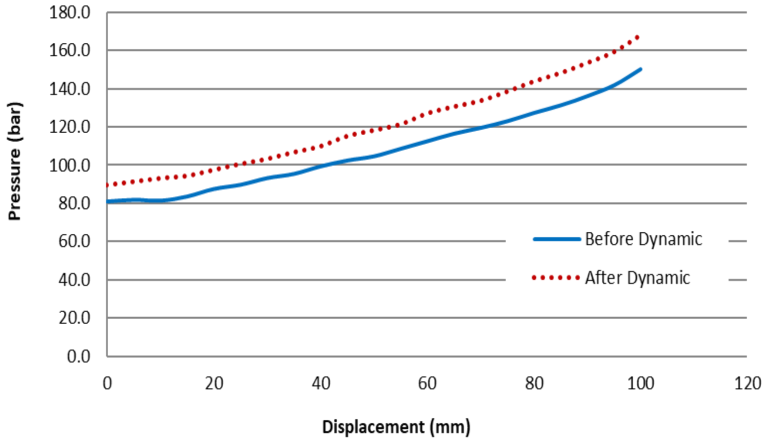


Figure 21. Accumulator Pressure variation in ATT

It was further explained in their study that the mathematical model was validated using an experimental work carried out on a prototype hydro-gas unit by a comparison between both the results. *Dobre A* [20] built an experimental model of a hydraulic damper of car and analysed its dynamic behaviour in a test bench consists of main components such as electrohydraulic servomechanism, position transducers, velocity transduces, accelerometer, servo valve, etc.

Prior to the test, the unit was filled with N_2 gas for a particular charging pressure and subsequently the test was carried out with specific test schedule. The idler wheel was raised to a mean position of 50 mm from rebound position and from there it was actuated for an amplitude of ±47mm at 0.1 Hz for 20 min duration. Then, it was actuated with an amplitude of ±40mm at 0.5Hz for another 20 min duration.

As part of the test, spring characteristic and pressure variation curves were recorded before and after the test as shown in Figure 20 & Figure 21. The stiffness was found to be increased by 9 to 11% in the after-test stiffness curve, which is normal for such a system under dynamic testing. The response of the ATT was found to be very good in every stroke of the test.

3.4 Static demonstration of ATT

The prototype ATT was fitted on an AFV platform in the same location where the passive track tensioner was fitted earlier as shown in Figure 22 and then the track was wrapped around in its original position. Now, the unit was filled with gas with required charging pressure at the static condition of the vehicle maintaining the regular ground clearance. At this condition, a sag was deliberately created in the bottom run of the track by lifting the nose end of the vehicle by means of overhead traction crane. While lifting the front end of the tank, the movement of the idler wheel was very visible that the track was getting stretched indicating a real-time active response by the ATT.

As discussed elsewhere in the paper, this innovative concept of providing instantaneous track tension to the track helps obviating chances of track shedding under dynamic condition of the vehicle. Due to limited availability of the proving platform, the demonstration of the prototype, done under static condition as part of this research work, substantiate only a limited capability of the ATT. However, a further demonstration of the prototype is to be carried out under the dynamic condition of the vehicle, which would further prove its fullest functional capabilities. Also, due to spatial limitations exist in the present proving platform, providing track stretching for a larger vehicle ground clearance is not possible with the present 220mm length axle arm.

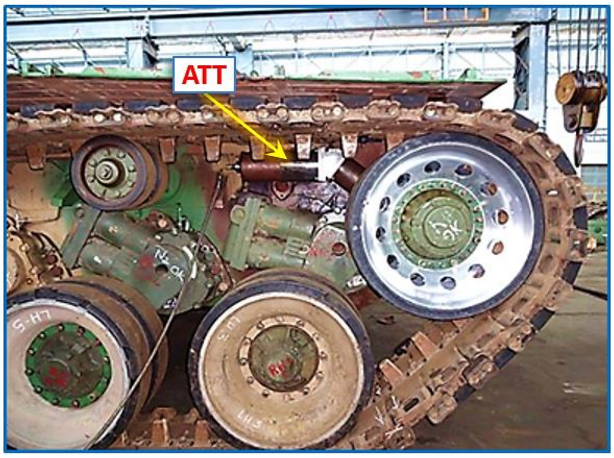


Figure 22. The photograph showing the prototype ATT fitted in the tank

4. Conclusion

An experimental work was taken up for providing a pragmatic solution for a track shedding issue of an Armoured Fighting Vehicle (AFV) by developing and proving the performance of an Automatic Track Tensioner (ATT) in lieu of the existing passive track tension adjuster of the vehicle. In line with this requirement, a design concept of an ATT was evolved and a virtual model was created based on the principle of slider crank mechanism. The model was subsequently fitted on a Multi Body Dynamics (MBD) model of an AFV and simulated on various terrain models and vehicle speeds. A case of 20 kmph run of the vehicle on plain road and APG course was taken up for this research work. Based on the simulation results, a performance comparison has been made on the track vertical displacement and accelerations under two different conditions of the vehicle fitted initially with ATT and then with the existing passive track adjuster unit. It was evident from the simulation that with ATT fitted condition, the vertical displacement was controlled with reduced amplitudes as compared to the existing one. Subsequently, a prototype ATT was built and test evaluated under laboratory conditions. Furthermore, the ATT was fitted on an AFV platform and a static demonstration was conducted ensuring the real-time response of the ATT in stretching the track was happening when a sag was intentionally created in the track. In this study, it was found that the ATT responded very well and provided real-time track tension under a condition of force balancing occurred between the gas spring forces of the ATT and the suspension unit in conjunction with the track catenary force. Both the lab test and static demonstration show that the ATT will certainly reduce the track sag instantaneously under dynamic condition of the tank.

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Authors Contribution Statement

V. Kavivalluvan: Conceptualization, Methodology, Experimental Work, Data Curation, Writing – Original Draft. K.R. Vijayakumar: Supervision, Writing – Review & Editing. Sayaan Banerjee: Resources, Investigation, Validation, Visualization. J. Rajesh Kumar: Project Administration, Writing – Review. All the authors read and approved the final version of the manuscript.

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Data Availability

The data supporting the findings of this study can be obtained from the corresponding author upon reasonable request.

Has this article screened for similarity?

Yes

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