

Original Article

# Design of Damper for Hydropneumatic Dynamic Track Tensioning System

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**Abstract** - The cross-country mobility is a predominant characteristic of a tracked Armoured Fighting Vehicle (AFV) to efficiently manoeuvre through hostile terrain conditions prevailing in a battlefield scenario. A well-matched Running Gear System (RGS) with a suitable track tensioner of the vehicle ensures superior mobility and obviates the chances of track shedding. An introduction of a dynamic track tensioning system, in lieu of an existing manually operated track tensioner, ensures all-time instantaneous track tension and retention during vehicle running on undulated ground surfaces. In this research work, an effort has been made to develop an in-built damping system to be used in a Hydropneumatic Dynamic Track Tensioner (HDTT) to attenuate induced vibration in the system. This paper also elaborates on the concept of a compact damper configuration and its incorporation into the HDTT, the one-dimensional flow analysis using AMESim software, the realisation of damper hardware, and subjecting it to flow analysis in a hydraulic test bench. The novelty of this damping system lies in its integrated real-time control approach that combines dynamic track tension regulation with vibration attenuation, all within a compact hydropneumatic unit. The incorporation of the proposed damper within the HDTT ensures real-time vibration suppression and significantly reduces track shedding. The system is validated by one-dimensional flow analysis using AMESim software and experimental hydraulic test bench evaluation, bridging simulation and prototype testing. Thus, it enhances cross-country mobility, track life, and combat readiness of tracked armored fighting vehicles, representing a significant advancement over existing fixed or purely mechanical tensioning solutions.

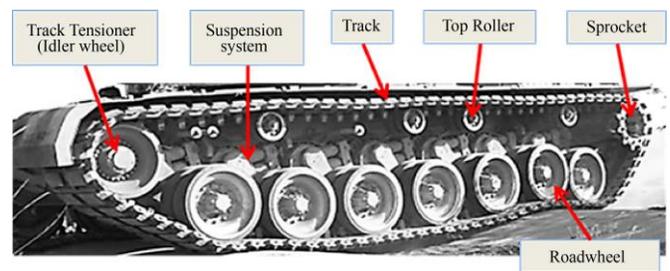
**Keywords** - Armoured fighting vehicle, Cross-country mobility, Hydraulic damper, Hydropneumatic dynamic track tensioner, Inbuilt damper, Running gear system.

## 1. Introduction

A tracked Armoured Fighting Vehicle (AFV) is a cross-country mobile platform and is designed for traversing the highly challenging off-road terrain conditions (Figure 1(a)). Its Running Gear Systems (RGS), which is an assemblage of six import elements, namely the sprocket, track, suspension system, track tensioner, top roller, and roadwheel (Figure 1(b)), is meant to provide mobility to the vehicle. In this, the track is made up of a series of individual links joined by means of hinge pins and connectors to form a chain-like system.



(a)



(b)

Fig. 1 A Track Armoured Fighting Vehicle and its running gear system

During the course of vehicle running, the pitch of the track is gradually increased due to wear and tear of the pin joints, resulting in slackness in the top run of the track, which is an undesirable factor since it leads to track shedding. However, a track tensioning mechanism, fitted at the opposite end of the sprocket location, is used for adjusting the track tension and thereby to reduce the sag. In general, a conventional fixed type of track tensioner is fitted on most of the tanks, which is operated manually by the tank crew



whenever tightening of the track is needed. However, if the existing system is replaced with a Hydropneumatic Dynamic Track Tensioner (HDTT), it would provide real-time tension to the track without manual intervention by virtue of its accumulator force.

In general, the HDTT has oil and gas as damping and spring media. The gas spring in the accumulator is meant to provide the required force for stretching the track continuously without any slackness occurring, while the damper is meant to attenuate the induced vibration due to track whipping under dynamic conditions.

Despite progress in hydropneumatic suspension and track tensioning technologies for tracked armoured vehicles, there remains a significant research gap in the integration of an in-built damping mechanism within a dynamic track tensioning system. Existing studies primarily focus on static or semi-active tension control without considering real-time coupling between track dynamics and vibration attenuation under rapidly changing terrain conditions.

Moreover, current one-dimensional flow models and AMESim simulations fail to capture complex multi-body interactions between the track, suspension, and hull, leading to limited prediction accuracy in dynamic environments. There is also inadequate experimental validation of compact, in-built damper configurations that can effectively dissipate vibrational energy while maintaining optimal track tension. Therefore, further research is required to develop a holistic hydropneumatic dynamic track tensioner that combines integrated damping, real-time control algorithms, and hardware-based validation to enhance the cross-country mobility and durability of tracked fighting vehicles.

## 2. Construction of Hydraulic Damper

Christopher Williamson et al. [7] developed an active damping with displacement control in which a variable displacement pump was connected to a single or double rod cylinder for having a higher efficiency and linear dynamic characteristics. The dynamic behaviour of the hydraulic shock absorber and its damping characteristics greatly influence the overall response of the suspension system to input signals. To achieve a satisfactory level of comfort and manoeuvrability, the shock absorbers must be designed and adjusted according to various criteria, such as force, maximum displacement, speed, etc., by Cao D t al. [1] and Farjoud A et al. [2].

This paper deals with the design and evaluation of a prototype hydraulic damper suitable for the HDTT application, and it is proposed to place the hydraulic damper between the accumulator and the actuator cylinders of the HDTT by using a proper interfacing arrangement. The Schematic diagram of the HDTT with a damper hydraulic circuit is shown in Figure 2.

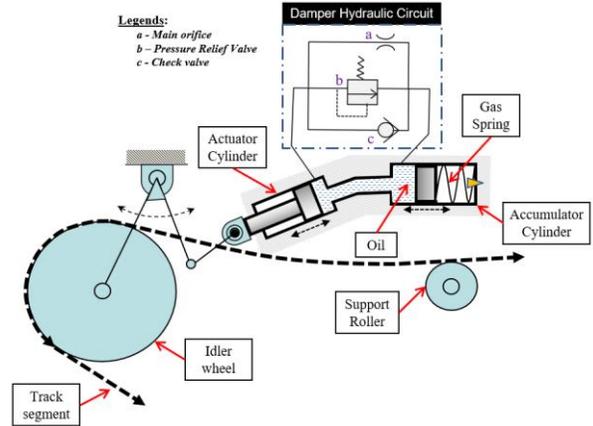
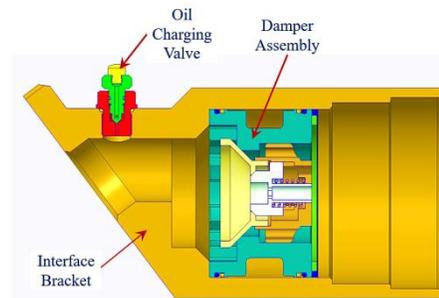
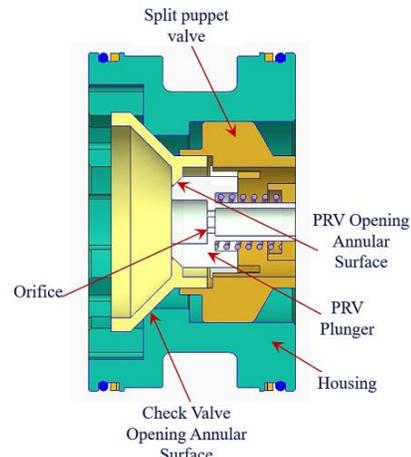


Fig. 2 Schematic diagram of the HDTT with a damper hydraulic circuit

The damper assembly consists of three main elements: a set of orifices, a Pressure Relief Valve (PRV), and a Check valve. The orifices are provided in a spring-loaded plunger, which is a part of the PRV assembly (Figure 3(a) & 3(b)). The whole assembly is confined in an interface bracket which has two open ends, such that one is connected with the neck of the actuator cylinder assembly, while the other end is connected with the accumulator cylinder assembly with proper fastening arrangements on both sides, as shown in Figure 2. On top of the interface arrangement, an oil charging valve has been fitted to fill the damper oil.



a) Interfacing arrangement



b) Damper assembly construction in detail

Fig. 3 Section view of the 3D model of the hydraulic damper

### 3. Working Principle of the Hydraulic Damper

Pingxin Wang et al. [3] developed an active track tensioning system in which a hydraulic servo system was selected as the track tension control actuator. The driving force generated by the hydraulic system was applied in the tensioner torsion arm to control the position of the idler.

Ramashanakar Paswan et al. [6] developed a new semi-active control device for displacement control by using an accumulated semi-active hydraulic damper to improve the function of the passive control system for seismic resistance.

In this research work, under the operational condition of the HDTT and depending upon the input force from the track segment, the gas in the accumulator cylinder would expand, causing movement of the floating piston, which in turn causes the oil flow to take place through the damper system, and accordingly, the track stretching occurs instantaneously. The different conditions of oil flow in the damper system are shown in Figure 4.

During the compression stroke of the actuator piston, the oil will flow through the direct orifice (①) provided in the PRV plunger (Figure 4(a)), causing required damping in the system. If the differential pressure ‘DP’ occurs before and after the direct orifice is exceeding the set value, the PRV gets opened, allowing a large quantity of fluid to rush through the annular passage of the plunger seating area (②) (Figure 4(b)) and the orifices as well. Once the differential pressure becomes zero, again the flow will take place as usually only through the orifices.

In the return stroke, that is, when the gas spring is expanding and allowing the floating piston to push the oil, the check valve gets opened and the flow will take place in the reverse direction through both the annular passage of the check valve seating area (③) (Figure (4)c) and the direct orifice (④). The larger flow rate in the return stroke ensures continuous contact of the idler wheel with the track without any separation.

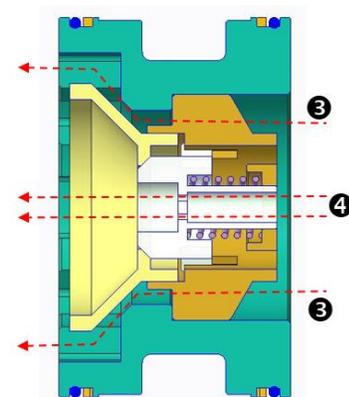
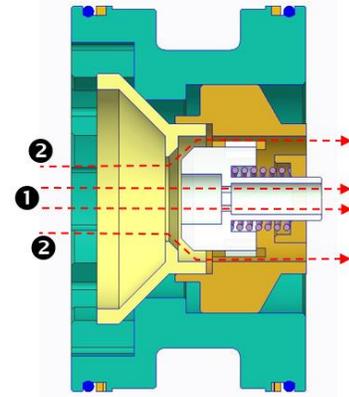
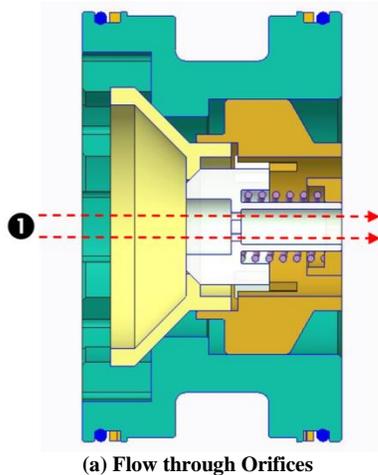


Fig. 4 Different flow conditions of the hydraulic damper

### 4. One-Dimensional Analysis on HDTT Damper Design

#### 4.1. Methodology, Modeling, and Input

As mentioned above, the damper assembly is interfaced between the actuator cylinder (referred to as C1) and the accumulator cylinder (referred to as C2). Also, there are three flow paths, namely a Direct Officer (DO), a Pressure Relief Value (PRV), and a Check Value (CV) for the bidirectional flow of oil. Hence, the modelling of the damper requires the modelling of subassemblies and components such as piston, C1, C2, DO, PRV, and CV, which are numbered from 1 to 6.

Farah Z.Rusli et al. [8] performed a simulation to study the effect of their hydraulic damper characteristics on a vehicle equipped with 3 different shock absorbers with 3 different tests, using the VeDyna software. Hailong Zou et al. [9] made a modelling of a hydraulic shock absorber and conducted a simulation to verify the influence of fluid compressibility characteristics in the AMESim simulation environment.

In this paper, the software used is AMESim, which is having multi-domain analytical capabilities and working based on 1-D scalar calculations. The actuating cylinder piston

input has been modelled as linear and with sinusoidal combinations. Output of the subsystem ‘Actuator cylinder assembly’ is directly connected to the inlet of the subsystem ‘PRV’, direct orifice, and to the rebound end of the subsystem ‘Conical Valve Assembly’. Then the inlet of the subsystem ‘Accumulator Assembly’ is directly connected with the subsystems ‘Conical Valve Assembly’ (bounce end) and

‘PRV’ (outlet) and direct orifice (Figure 5). After building the model, the dimensions and shapes of different elements were determined. In this analysis, the pressure has been taken as a limiting factor and piston velocity as a stability factor. Also, a bottom-up approach has been followed here, where the modelling starts with the direct orifice and then adds all other elements successively to reach the final assembly.

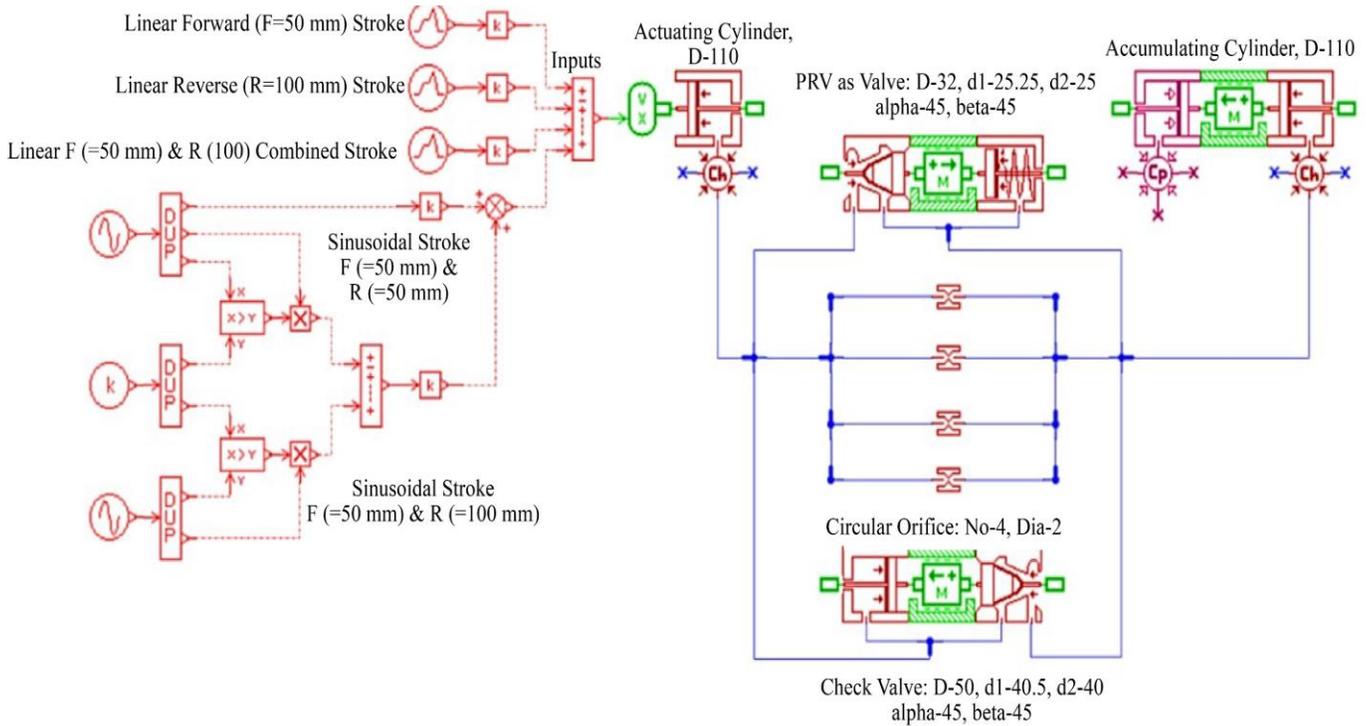


Fig. 5 Hydraulic Damper AMESim model of HDTT

#### 4.2. Direct Orifice

The operating pressure range considered for the damper system is 0 to 650 bar, as shown in Figure 6. Hence, the damper pressure at any point in time during the operation should not exceed the limiting pressure. The effect of adding orifices of different sizes is shown in Figure 7. It is worth to note that the floating piston is stable for the orifice sizes 5 mm or below, and the oscillation of the floating piston dies out within 0.15 to 0.20 s.

Hence, an orifice diameter of 4 mm or below would be a suitable only if the actuating cylinder pressure is within the limit. But pressure at the actuating cylinder for an orifice of 3 mm or below pressure is much beyond the limit. For the orifice size of 4 mm, the pressure crosses beyond the limit in the last phase. This dictates the selection of a direct orifice to be 4 mm. The shooting of pressure at the last phase is controlled by employing a PRV in the system. Also, during analysis it is observed that for the same flow rate through a direct orifice, if diameter of the orifice is reduced, then the flow is more stabilized. So that instead of one direct orifice of 4 mm, four direct orifices of 2 mm have been selected.

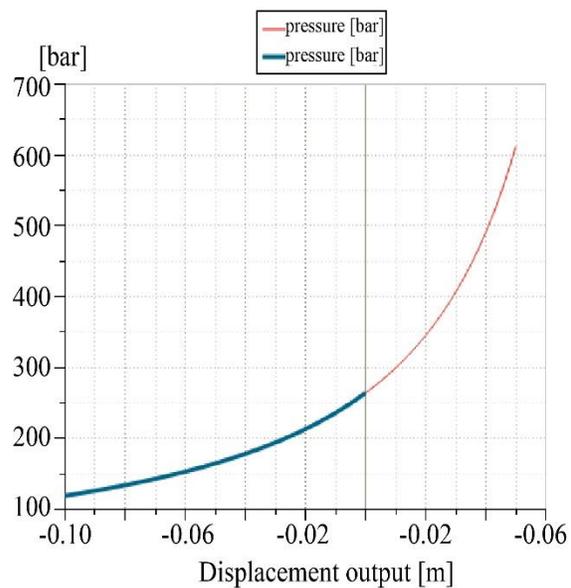


Fig. 6 Pressure Range

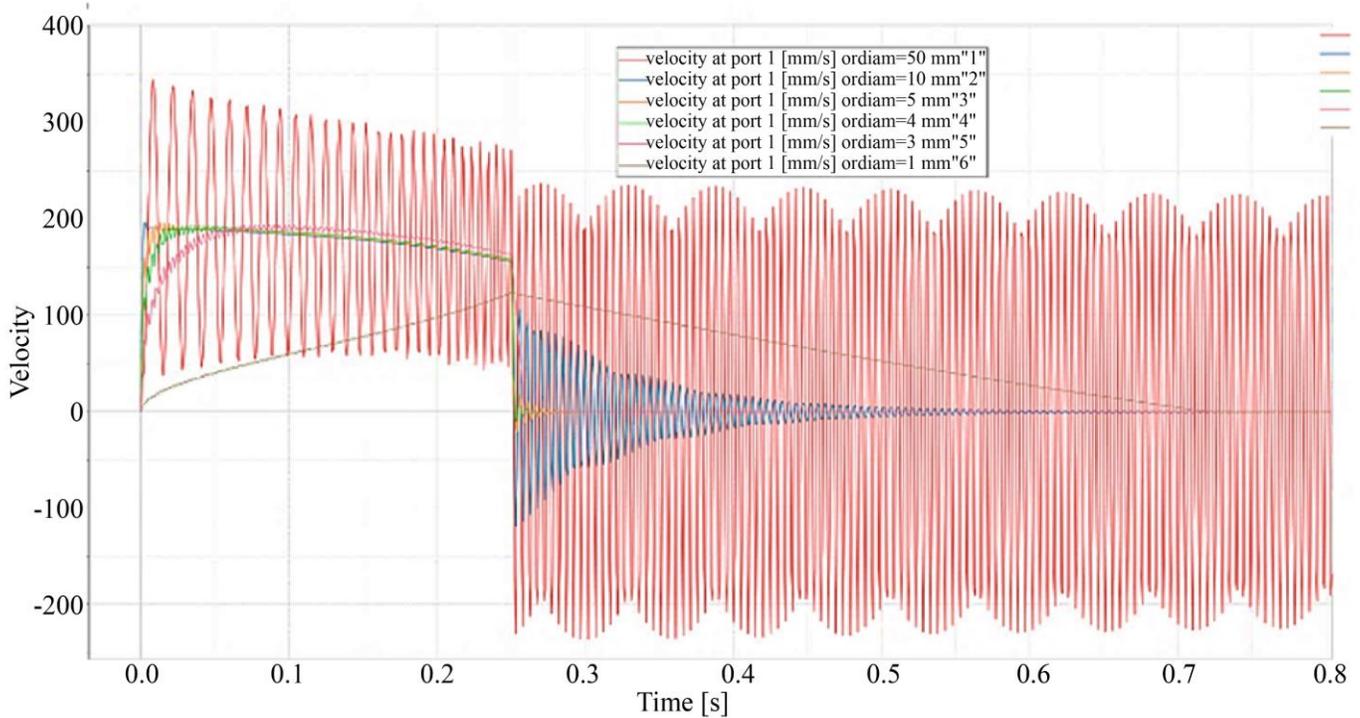


Fig. 7 Floating Piston Velocity

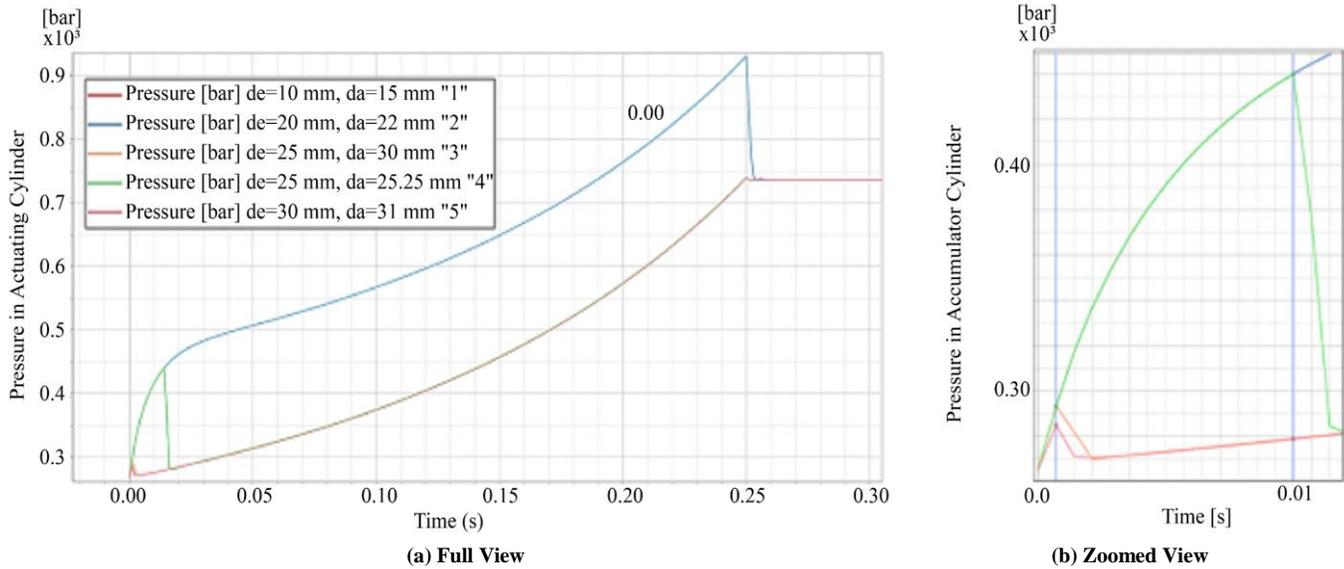


Fig. 8 PRV Pressure Variation

**4.3. Pressure Relief Valve (PRV)**

The PRV has the elements such as a spring, casing for the spring, and a poppet valve with conical orifices. The spring considered for the analysis has a spring constant as 2.2 kg/mm and a linear characteristic. The poppet valve, which is already drilled with the direct orifice, is connected to a spring. The weight of the poppet valve is adjusted to get the required characteristics.

Figure 8 shows the pressure variation in the actuating cylinder with different dimensions and settings of PRV

elements. Also, the poppet and actuator cylinder motions are stable. It can be seen that for even for 4mm orifice, the PRV cracks and pressure remains within the limiting pressure range.

The corresponding dimensions of PRV elements are worked out with 25 mm and 25.25 as initial and final dimensions, respectively. The size of the cone has been arrived at with 45 degrees after analysis with different angles. The cracking pressure is set at 160 bar.

#### 4.4. Check Valve (CV)

The CV has a poppet with conical orifices and a casing for it. The floating mass or poppet valve allows flow in one direction. The poppet shape dimension and mass determine the opening and response of the check valve.

The check valve considered is passive in nature. Contact surfaces are conical in shape. The CV poppet and PRV poppet are rigidly connected. Considering the damper only with PRV and direct orifice for reverse flow, it can be seen from Figure 9 that for orifice 4 mm, the actuator cylinder pressure would become zero and create a suction-like condition, which means HDTT is not responsive for track tension, which is the prime objective of the HDTT. Also, from Figure 10, it can be seen that the minimum orifice required is 10 mm. Hence, it calls for a valve which only operates in the reverse direction with a higher flow rate, and this is called a Check Valve (CV).

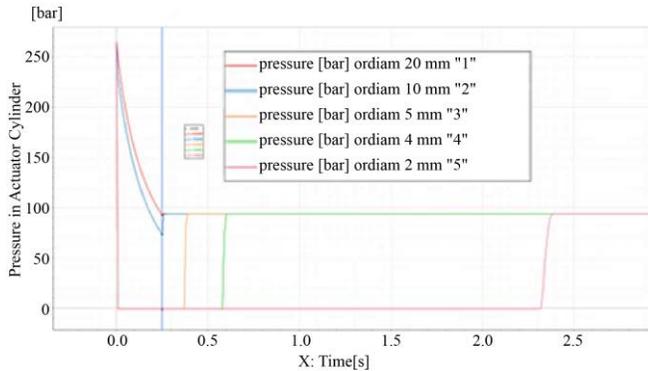


Fig. 9 Actuating cylinder pressure without CV

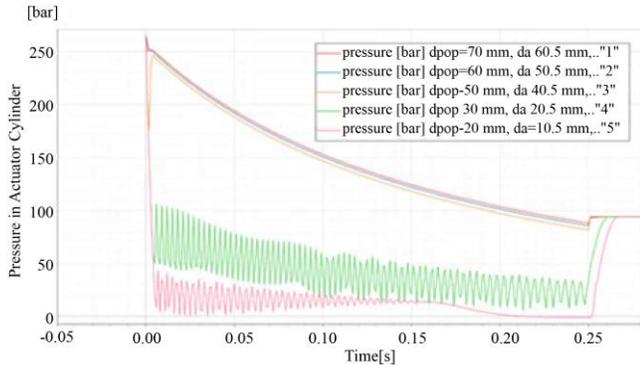


Fig. 10 Actuating cylinder pressure without CV

#### 4.5. Damper Assembly

A full-fledged damper assembly model was arrived at after properly arranging all the elements, namely the Direct Orifice, PRV, CV, and both Actuator and Accumulator Cylinder assemblies (consisting of pistons). The damper pressure in the actuator cylinder and accumulator cylinder is shown in Figures 9 & 10. The effect of PRV and CV is clearly visible. The pressure in the actuator is limited by PRV for forward direction flow, and the pressure in the actuator cylinder is maintained above the minimum limit in reverse

flow. Figure 11 shows the response of the sinusoidal movement of the actuating piston, and the pressure values shown for the actuating cylinder and accumulator cylinders are as required. Figure 12 shows the velocity of the floating piston, and its behavior is also as expected.

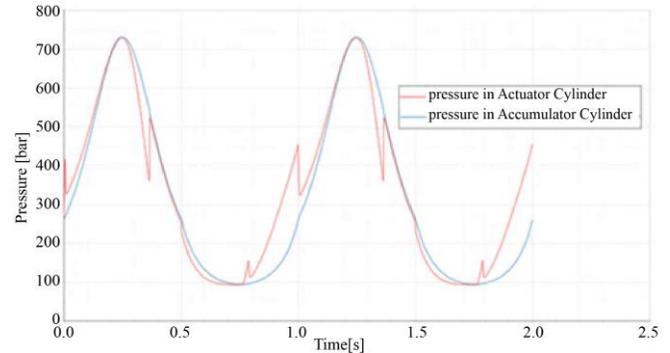


Fig. 11 Pressure Variation

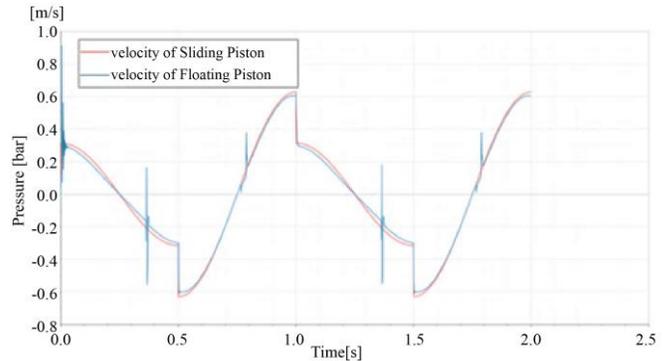


Fig. 12 Floating piston velocity

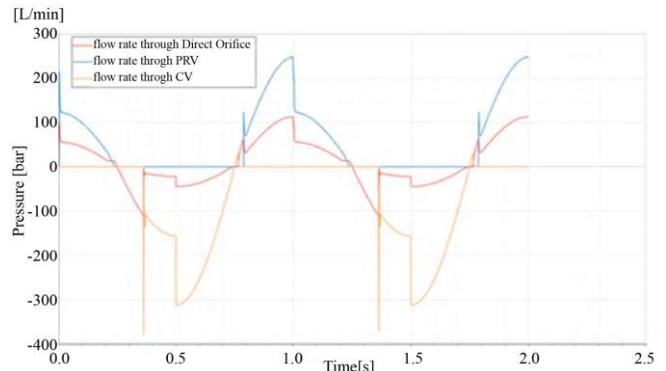


Fig. 13 Flow rate through PRV, DO, and CV

Figure 13 shows the individual flow rate through direct orifice, PRV, and CV, as well as cumulative flow rate through the damper, and it can be seen that initially in the forward flow, only the direct orifice is open, and then PRV opens. The CV flow rate is 0 litres/min. Similarly, as the forward flow closes, the PRV flow rate is 0 litre/min, and then only the direct orifice is open with a reversed direction of flow. After some time, the CV opens. The cumulative flow (of PRV, Do, and CV) shows a sudden jump in flow rate at a few points. It

is an indication of the opening and closing of PRV and CV. The jump can be reduced, and flow smoothness can be improved by further understanding and experimenting.

### 5. Testing of Damper

K. Huh et al. [4] developed a track tensioning experimental set-up which consists of a track tensioner, idler, road wheel, hydraulic suspension unit, and track links with a load cell, in a laboratory to evaluate the performance of their proposed monitoring system. Kunsoo Huh et al. [5] developed a hydraulic unit with double-acting folded actuators, which was meant to provide good control characteristics for their proposed track tension control system. Łukasz Konieczny et al. [10] developed a hydropneumatic strut for determining damping characteristics in conjunction with a gas spring, so it was necessary to pressurize the fluid in the strut. Author conducted an experiment on a hydrogas suspension unit of an armoured fighting vehicle towards optimisation of damping characteristics by subjecting the unit to various test conditions in line with the duty cycle.

In this research work, a prototype HDTT Damper was developed as shown in Figure 14, which was subjected to a flow characteristic study. The hydraulic circuit of the test bench incorporated with the test sample (HDTT Damper) is shown in the Figure 15. As indicated in the diagram, the setup is comprising of a flow control valve, a pressure relief valve, a motor with a pump, and gauges for pressure and flow measurements. The actual testing of the prototype HDTT Damper mounted on the hydraulic test bench is shown in Figure 16.

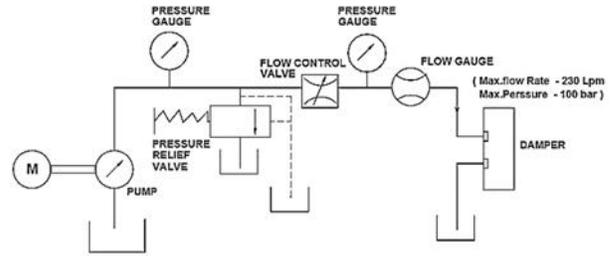


Fig. 15 The hydraulic circuit diagram of the damper assembly test bench

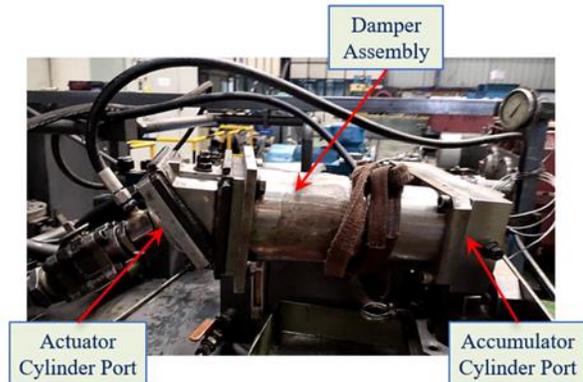


Fig. 16 The HDTT Damper is under flow characterisation testing.



(a) Damper Assembly inside interface housing



(b) Inner detail of Damper Assembly

Fig. 14 The Damper Assembly mounted on HDTT

In the lab test, the HDTT was connected with oil supply at its actuator cylinder and accumulator cylinder ports, and then a bi-directional flow characteristic study was conducted first in bounce direction by pumping the oil from the actuator cylinder port to the accumulator cylinder port through the main orifice, and then the flow was reversed in rebound direction. The flow characteristic was recorded for differential pressure Vs oil flow rate, and the opening of PRV was ensured at the designed cracking pressure. The damper performance was in line with the designed parameters.

### 6. Summary and Conclusion

A concept of a suitable in-built hydraulic damping system for a hydropneumatic dynamic track tensioning system of an Armoured Fighting Vehicle was arrived at and modelled using AMESim software for doing an 1D analysis. All the components of the damper, including a main orifice, a Pressure relief valve, and a Non return valve, were modelled, interfacing between actuator and accumulator cylinders in a bottom-up approach.

A rigorous bidirectional flow simulation was carried out in the AMESim software for different sizes of the oil flow passages and arrived at the optimized sizes of the main orifice, check valve opening, and the PRV opening of the damper. Also, a design validation was taken up by developing a prototype hydraulic damper, subjecting it to flow characteristic test on a hydraulic test bench, and the performance was evaluated.

## Nomenclature

AFV: Armoured fighting vehicle  
RGS: Running gear systems  
HDTT: Hydropneumatic dynamic track tensioner  
PRV: Pressure relief valve  
C<sub>1</sub> : Actuator cylinder

C<sub>2</sub>: Accumulator cylinder  
DO : Direct orifice  
CV : Check valve

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