DESIGNING AND ANALYSING A HYDRO MECHANICAL CONTINUOUSLY VARIABLE TRANSMISSION SYSTEM FOR IMPROVING VEHICLE PERFORMANCE

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ABSTRACT

A new continuously variable transmission (CVT) system is proposed in this paper for the purpose of improving transmission efficiency in vehicles. The proposed system consists of a power-cycling hydro-mechanical transmission structure characterized by stepless speed regulation. In this paper, hydraulic Continuously Variable Transmission (CVT) pulley designs using Finite Element Analysis (FEA). Utilizing Solid Works for design 3D model of a hydro static CVT and ANSYS software for analysis, static structural assessments were conducted on both an Aluminum Alloy Flat Head Pulley for the proposed hydraulic CVT and a conventional conical-shaped pulley. Von Misses stresses (MPa), Equivalent elastic strains, and Total deformations were evaluated at speeds of 500 rpm, 1000 rpm, and 1500 rpm. Finally, the effect of the gear shift device, were analyzed at varying speeds which is in a different transmission path relative to the new CVT was analyzed, and appropriate transmission structures under different operating conditions were identified.

Keywords *– Continuously variable transmission system, CVT, Solid works, Static structural analysis*

I. INTRODUCTION

A hydraulic continuous variable transmission (CVT) system is a type of transmission that provides seamless and continuous variation of the gear ratio without discrete steps. Unlike traditional transmissions with fixed gear ratios, a CVT allows for an infinite number of gear ratios within a specified range, enabling the engine to operate more efficiently across a variety of driving conditions. Continuously variable transmission (CVT) is an ideal form of transmission, as it has been employed in vehicles set to operate under various working conditions. Accordingly, its use has considerably improved vehicle economy. Vehicles equipped with CVT have a wider range of speed ratios and can adapt to different environments compared with vehicles with a stepped drive. Moreover, the hydraulic pump-motor (P/M), which is representative of hydrostatic transmission, has gained wide interest owing to the small size of its hydraulic components, low weight, and the significant advantages it provides compared with other forms of stepless transmission. However, its low transmission efficiency and high cost compared with those of the stepped drive cannot be ignored. Accordingly, a hydro- mechanical CVT structure was proposed. In this transmission structure, a hydrostatic element is set parallel to a planetary gear (PG) train to improve the overall efficiency and reduce the difficulty of developing a high-power pure hydrostatic transmission. [1]

This paper presents the newly proposed transmission structure. The discussion includes the power-cycling hydro-mechanical transmission system, and its characteristics and advantages, which were obtained from an analysis of the transmission principle and basic characteristics of the system. A comparison of the proposed system with existing forms, such as pure mechanical transmission, pure hydraulic transmission, and power-split transmission (PST) is presented as well. Moreover, new ideas and directions for the current variable speed transmission structure are provided.

II. LITERATURE REVIEW

[1] Jianjun Hu et al., (2021), this study delves into the energy dissipation of hydraulic systems due to the fluctuating CVT speed ratio, aiming to enhance overall efficiency. Firstly, it examines various driving modes of PHEV equipped with CVT, analyzing transmission efficiency under each mode. Secondly, it presents a novel optimization approach utilizing genetic algorithms to optimize CVT gear count and speed ratio discretization, alongside shifting rules for diverse driving scenarios. Compared to conventional continuously variable transmission, the proposed DVROM-GA method reduces vehicle energy consumption by 2.2%.

[2] J. Wurm et al., (2016), With increasing engine performance, loads on the CVT components rise as well, leading to power loss and high thermal loads that reduce belt lifespan. New designs focusing on improving heat transfer and reducing high temperature zones are necessary. The presented work aims to develop a numerical model capable of computing heat transfer effects within an enclosed CVT, facilitating rapid evaluation of design changes and cost-effective experimental work. Utilizing the MRF approach supplemented by a novel method, the model achieves realistic temperature distributions on pulley surfaces with reduced computational time. Validation on an engine test stand demonstrates excellent agreement, enabling optimization of CVT components to enhance heat transfer and decrease peak temperatures efficiently.

[3] Andrea Bedotti et al., (2018), This paper introduces and compares three system layouts (EFM, NFC, EPC) for a middle-sized excavator, contrasting them with the conventional LS system using mathematical analysis. The comparison focuses on trench digging and leveling cycles, assessing fuel consumption while maintaining desired movements and cycle times per JCMAS norms. An optimization methodology targeting meter-in, meter- out, and bypass flow areas has been devised to enhance energy efficiency by reducing valve losses without compromising excavator performance.

[4] Antonio Rossetti et al., (2019), this paper investigates the engine management of continuous hydro-mechanical transmission-equipped vehicles, aiming to establish on- board management protocols. Utilizing the minimum specific fuel consumption line for the entire power train, akin to conventional engine-only practices, offers simplicity to control systems while accommodating varied minimum lines. This approach is applied to an urban bus with a dual-stage hydro mechanical transmission, where simulation models derive minimum fuel consumption lines and evaluate two management criteria: one following engine-only lines and other minimizing power train losses. Results indicate that the latter criterion achieves a 2% reduction in consumption across congested urban and motorway routes.

[5] AAlarico Macor et al., (2013), The PSp transmission has emerged as a significant player in the agricultural machinery sector, prioritizing driving comfort. While acknowledged for its lower efficiency compared to conventional transmissions, its continuous nature enhances comfort and facilitates optimal engine management. This study explores the potential of PSp transmission in a city bus application, where comfort and performance are crucial despite intermittent driving conditions.

[6] C.A. Fahdzyana et al., (2019), In this study, a nested optimization framework was successfully implemented for the EMPACT CVT, aiming to achieve an integrated plant and control design optimized for the NEDC drive cycle.

[7] M. Lazarek et al., (2018), This paper presents a comprehensive experimental investigation of an inerter integrated with a specific CVT, forming part of a novel Tuned Mass Damper (TMD) designed to efficiently mitigate vibrations. The unique feature of the inerter lies in its capability for stepless changes in inertance, facilitated by the presence of the CVT.

[8] Antonio Rossetti et al., (2018), the paper introduces a mathematical formalization to represent various layouts of a planetary gear system in continuous form, yielding a polar plot that encapsulates both configuration and transmission ratio effects. Applied to an input- coupled hydro mechanical transmission for a 75-kW forklift, the plot facilitates comparison of design options and performance assessment.

[9] Wei Wu et al., (2020), The investigation into the design and performance of a hydro- mechanical continuously variable transmission (CVT) for an all-terrain vehicle (ATV) reveals several key findings. Firstly, the CVT offers a controllable and variable speed ratio, with the added capability of applying regenerative braking.

[10] Tie-Qiao Tang et al., (2018), This paper presents the development of a fuel-optimal driving model considering the transient coupling effect between the engine and CVT, accompanied by the design of an algorithm to search for fuel-optimal acceleration, uniform motion, and deceleration processes. Through numerical tests, the proposed fuel-optimal driving strategy's effectiveness in reducing fuel consumption across different driving distances is demonstrated, with driving behavior directly linked to distance traveled.

[11] Giallanza et al., (2016), in recent years, amid growing interest in renewable energy, innovative solutions have emerged to enhance the efficiency of wind turbines. Many of these solutions leverage permanent magnet generators tailored for low rotational speeds, making them ideal for direct-drive configurations. While cost-effective and straightforward, the mismatch between turbine and generator limits the wind speed range

[12] Roberto Paoluzzi et al., (2011), the minimum size paradigm, achieved through a search for the smallest displacement of the main units (pumps and motors), represents a potent tool in designing hydrostatic transmission systems for self-propelled machines.

[13] Yu Xia et al., (2020), this study introduces a novel design method for a PCHMCVT, with primary structural parameters determined based on required traction while maintaining a transmission efficiency above 80%. Observations during the design process highlighted lower efficiency in reverse gear mode, prompting modifications to enhance efficiency by altering power transmission direction, a unique improvement.

III. OBJECTIVES OF THE PROJECT:

Improving fuel efficiency in a hydraulic CVT system involves optimizing the transmission's operation to ensure that the engine operates at its most efficient speed and load conditions across a wide range of driving situations. Here are some strategies to achieve improved fuel efficiency in a hydraulic CVT: [10], [11]

- Optimized Gear Ratios: Adjust the hydraulic CVT's gear ratios dynamically to match the engine's speed and load requirements efficiently. By continuously varying the gear ratio, the engine can operate closer to its optimal efficiency point, reducing fuel consumption.
- Smooth Power Delivery: Ensure smooth and seamless power delivery from the engine to the wheels by minimizing friction losses within the hydraulic CVT system. This includes optimizing the design of hydraulic actuators, pulleys, and belts to reduce energy losses during power transmission.
- Adaptive Control Algorithms: Implement adaptive control algorithms that can adaptively adjust the hydraulic CVT's gear ratios based on real-time feedback from sensors measuring vehicle speed, engine load, throttle position, and road conditions. These algorithms can optimize the transmission's operation for maximum fuel efficiency under varying driving conditions.
- Low Friction Components: Use low-friction materials and coatings for the hydraulic CVT components to minimize friction losses and improve overall efficiency. This includes employing advanced bearing designs, surface treatments, and lubrication systems to reduce energy losses due to friction.
- Integrated Engine Control: Integrate the control systems of the hydraulic CVT and the engine to optimize their operation collectively. By coordinating the engine's operating parameters with the transmission's gear ratios, it's possible to achieve greater fuel efficiency by maintaining the engine within its optimal operating range more consistently.

IV. METHODOLOGY:

- **Literature Survey:** Conduct a comprehensive review of existing research, patents, and technical literature related to hydro-mechanical CVT systems, vehicle performance optimization, and transmission design principles.
- **Conceptual Design:** Develop a conceptual design for the hydro-mechanical CVT system, considering factors such as power requirements, torque capacity, packaging constraints, and manufacturability. Explore different configurations, such as variable-diameter pulleys, hydraulic actuators, and mechanical linkages, to achieve the desired performance objectives.
- **Modeling and Simulation:** Utilize computer-aided design (CAD) software to create detailed 3D models of the CVT components, including pulleys, belts, hydraulic actuators, and control systems. Employ multi-body dynamics (MBD) simulation software to simulate the operation of the CVT system under various driving conditions, including steady-state cruising, acceleration, and deceleration. Validate the simulation results against theoretical calculations and empirical data to ensure accuracy and reliability.
- **Analysis and Optimization:** Perform performance analysis of the CVT system using simulation results to evaluate its efficiency, power transfer characteristics, and response time. Identify areas for optimization, such as minimizing power losses, reducing inertia, or improving control algorithms. Validate the final design of the hydro-mechanical CVT system through comprehensive testing and analysis. [10], [11]

IV. 2D MODEL OF HYDRO-MECHANICAL CVT

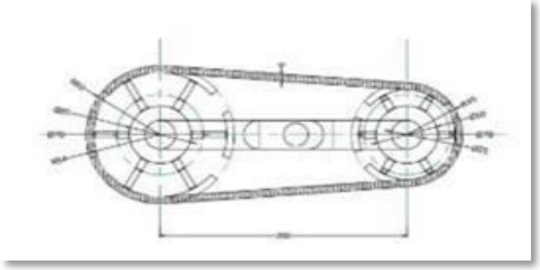


Fig.1 2D Drafting of Hydro-Mechanical CVT

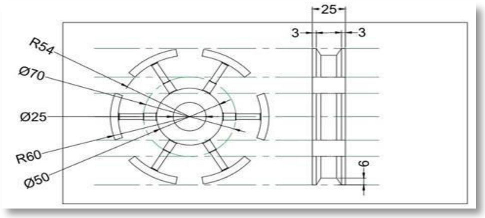


Fig.2 2D Drafting of Expended Pulley

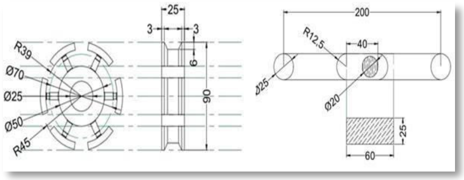


Fig.3 Contracted Pulley and Hydraulic Shell

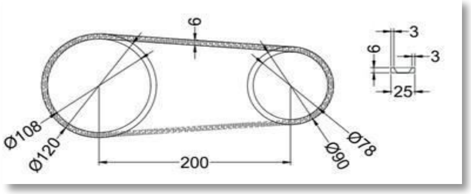


Fig.4 Drafting of Belt

V. 3D MODELLING IN SOLIDWORKS:

Utilizing Solid Works to create detailed 3D models of each CVT component, incorporating features such as fillets, chamfers, and threads. Assemble the individual components into a complete CVT assembly within Solid Works, ensuring proper mating and alignment between parts. [12] Assemble the designed components to create a 3D model of the entire CVT system, ensuring proper fit and alignment.

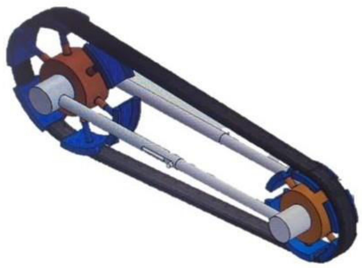


Fig.5 Assembly Design of Hydro-Mechanical CVT

VI. STATIC STRUCTURAL ANALKYSIS IN ANSYS:

Advanced FEA Analysis: Utilize ANSYS for more advanced finite element analysis (FEA) of the CVT system, including nonlinear material behavior, contact analysis, and dynamic simulations. [13] A static analysis can be either linear or nonlinear. All types of nonlinearities are allowed - large deformations, plasticity, creep, stress stiffening, contact (gap) elements, hyper elastic elements, and so on. This analysis gives a clear idea whether the structure or component will withstand for the applied maximum forces.

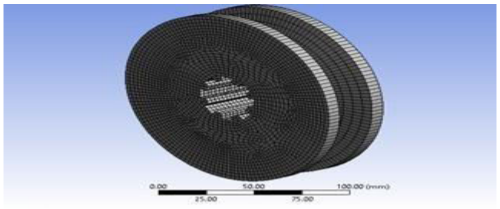
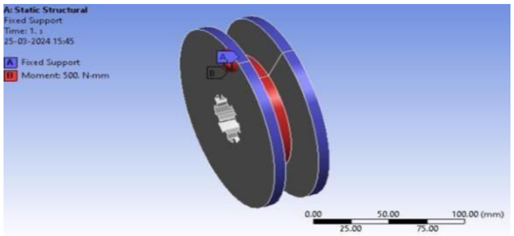


Fig.6 Mesh

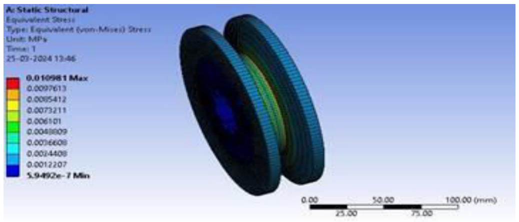


A: Static Structural
Fixed Support
Time: 1. s
25-03-2024 15:45

A Fixed Support
B Moment: 500. N-mm

Fig.7 boundary conditions

STATIC STRUCTURAL FOR PROPOSED FLAT PULLEY AT VARIATION OF SPEEDS 500, 1000 AND 1500 RPM

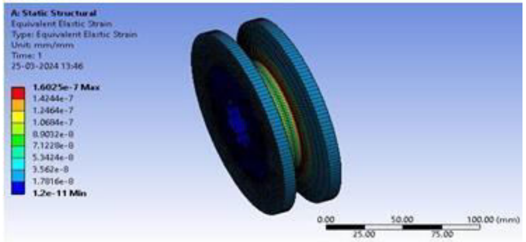


A: Static Structural
Equivalent Stress
Type: Equivalent (von-Mises) Stress
Unit: MPa
Time: 1
25-03-2024 13:46

Fig.8 Von misses stresses at 500rpm

A: Static Structural
Total Deformation
Type: Total Deformation
Unit: mm
Time: 1
25-03-2024 13:57

Fig.9 Total deformation at 500rpm



A: Static Structural
Equivalent Elastic Strain
Type: Equivalent Elastic Strain
Unit: mm/mm
Time: 1
25-03-2024 13:46

Fig.10 Strain at 500rpm

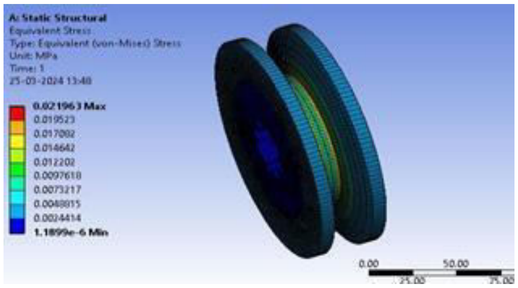


Fig.11 Von misses stresses at 1000rpm

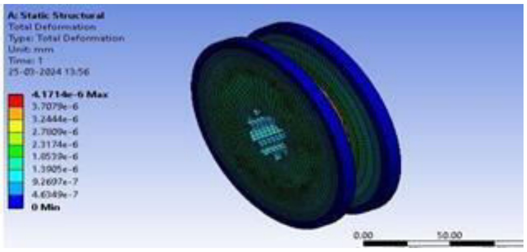


Fig.12 Total deformation at1000rpm

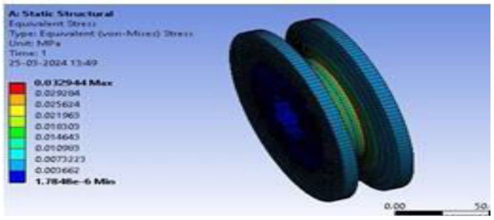


Fig.13 Von misses stresses at 1500rpm

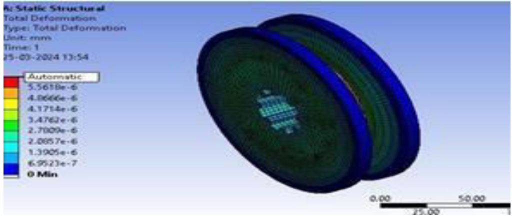
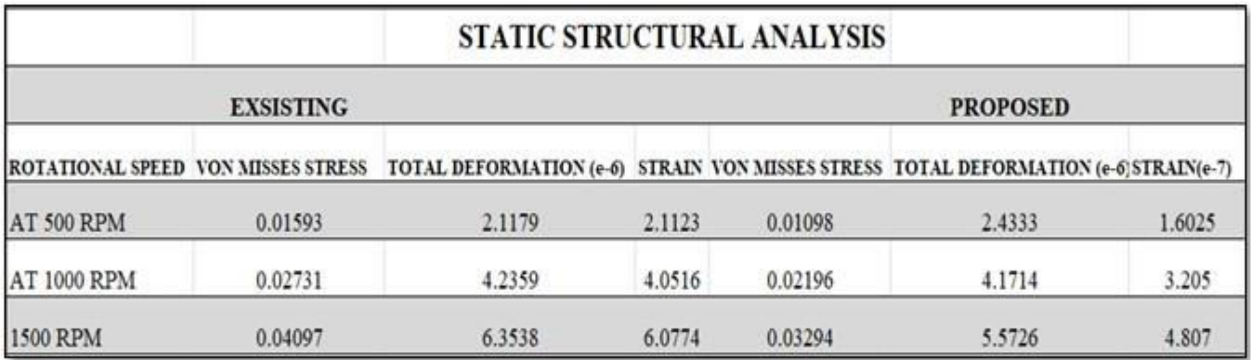


Fig.14 Total deformation at1500rpm

Like the same way conducting von misses stresses, total deformations and strains to existing conical pulley and their results are given below.



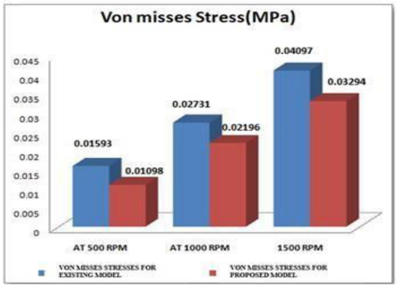
STATIC STRUCTURAL ANALYSIS						
	EXSISTING			PROPOSED		
ROTATIONAL SPEED	VON MISSES STRESS	TOTAL DEFORMATION (e-6)	STRAIN	VON MISSES STRESS	TOTAL DEFORMATION (e-6)	STRAIN(e-7)
AT 500 RPM	0.01593	2.1179	2.1123	0.01098	2.4333	1.6025
AT 1000 RPM	0.02731	4.2359	4.0516	0.02196	4.1714	3.205
1500 RPM	0.04097	6.3538	6.0774	0.03294	5.5726	4.807

Table Static Structural Analysis at Different Speeds

VII.GRAPHS

VON MISSES STRESSES GRAPH

The below von misses graph results for static structural analysis conducted on both flat proposed CVT pulley and existing conical pulley at variation of rotational velocities of 500 rpm,1000 rpm and 1500 rpm respectively.

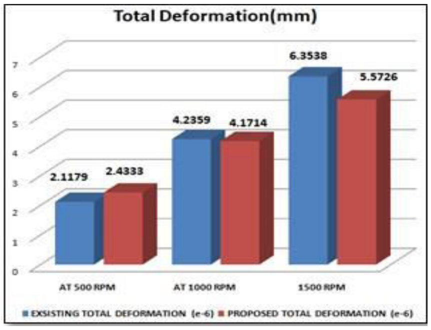


Graph 1 Von Misses Stresses

The von-misses stresses of proposed exposed tolower stresses to comparing with existing model. The highest stresses are obtained at 1500 rpm about 0.04097 MPa and lower values are recorded at 0.03294 MPa. So favorable lesser stresses are exbhited when top load given to proposed model. Is shown at Graph. 5.5 Von Misses Stresses

TOTAL DEFORMATION GRAPH

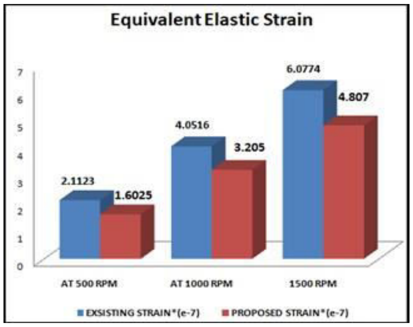
The below total deformation graph results for static structural analysis conducted on both flat proposed CVT pulley and existing conical pulley at variation of rotational velocities of 500 rpm,1000 rpm and 1500 rpm respectively. The total deformation of proposed exposed to lower deformation to comparing with existing model. The highest total deformation is obtained at 1500 rpm about 6.3538*e-6 mm and lower values are recorded at 5.5726*e-6 mm. So favorable lesser deformations are exbhited when top load given to proposed model.



Graph 2 Total Deformation

EQUIVALENT ELASTIC STRAIN GRAPH

The below Equivalent elastic strain graph results for static structural analysis conducted on both flat proposed CVT pulley and existing conical pulley at variation of rotational velocities of 500 rpm,1000 rpm and 1500 rpm respectively. The strain of proposed exposedto comparing with existing model. The highest strain is obtained at 1500 rpm about 6.0774*e-7 and lower values are recorded at 4.807*e-7. So favorable lesser strain is exbhited when top load given to proposed model.



Graph 3 Equivalent Elastic Strain

VIII. CONCLUSION

In this study concerning Metal Matrix Composite The hydraulic continuously variable transmission (CVT) was developed using Solid Works. Analysis tests were conducted using ANSYS software to perform static structural analysis and determine Von Misses stresses (MPa), Equivalent elastic strains, and Total deformations at varying speeds of 500 rpm, 1000 rpm, and 1500 rpm, respectively. The analysis was performed on both an Aluminum Alloy Flat Head Pulley for the proposed hydraulic CVT and an existing conical-shaped pulley for the CVT. Results indicate that at speeds of 500 rpm, 1000 rpm, and 1500 rpm, the flat head pulley of the proposed hydraulic CVT exhibits more favorable Von Misses stresses (MPa), Equivalent elastic strains, and Total deformations compared to the existing conical-shaped pulley for the CVT.

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