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Comprehensive Thermal Modeling of Power Split Hybrid Drive System

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ABSTRACT

Safety, performance and driving comforts are given high importance while developing modern day cars. All-Wheel Drive vehicles are exactly designed to fulfill such customer requirements. In modern times, human concern towards depleting fossil fuels and cognizance of ecological issues have led to new innovations in the field of Automotive engineering. One such outcome of the above process is the birth of electrical hybrid vehicles. The product under investigation is a combination of all wheel drive and hybrid system. A superior fuel economy can be achieved using hybrid system and optimized vehicle dynamic forces are accomplished by torque vectoring action which in turn provides All-Wheel Drive capabilities. The very basic definition of engineering is 'to optimize phenomena of physics for the improvement of human lives'. Ideally, Engineers don't like power losses. But heat generation is inevitable whenever there is a conversion of energy from one form into another. In this master thesis investigation, a thermal simulation model for the product is built using 1D simulation tool AMESim and validation is done against the vehicle driving test data. AMESim tool was chosen for its proven track record related to vehicle thermal management. The vehicle CAN data are handled in MATLAB. In a nutshell, Simulation model accounts for heat generation sources, oil flow paths, power loss modeling and heat transfer phenomena. The final simulation model should be able to predict the transient temperature evolution nin the rear drive when the speed and torque of motor is supplied as input. This simulation model can efficiently predict. Temperature patterns at various locations such as casing, motor inner parts as well as coolant at different places. Various driving cases were tried as input including harsh (high torque, low speed) ones. Simulation models like this helps Engineers in trying out new cooling strategies. Flow path optimization, flow rate, convection area, coolant pump controlling etc. are the few variables worth mentioning in this regard.

Keywords : Thermal Modeling, Power Split Hybrid Drive System, CAN, AMESim, Hydro Complex, THB, Hydro Electricity Generating Unit, UGB, LGB

I. INTRODUCTION

Hydro power contributes around 20% of the world electricity generation [1]. As a renewable source of energy it has become more important economical resource compared to other renewable sources as far as the scarcity of fossil petroleum fuel deposits, environmental threats, climate change due to greenhouse gas emissions, and acid rains global warming, etc. are concerned. Hydro power produces no direct waste and contribution to CO2, greenhouse gases compared to fossil fuel plants. The global installed capacity of Hydro-electrical power generation is approximately 777GW with a production of 2998TWh/year [1]. It is around 88% of the renewable sources [2]. In Sri Lanka about 40% of electricity is generated from hydroelectricity. At present almost all hydro potential available in the country has been utilized for electricity generation and few remaining are under construction. The deficit between electrical power generation and demand is met by thermal power generation.

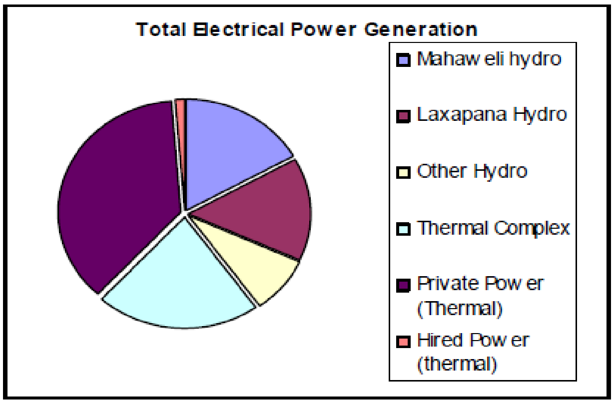

Figure 1. Hydroelectric contribution

The electricity power generation by different sources in the year 2009 is shown in Fig. 1.

Electricity generated in three major hydro power complexes.

Hydro Complex, Other Hydro Complex) in Sri Lanka, contributes 40% to the national energy supplywhile the rest is coming from thermal power generation. Hence, getting the maximum possible sharefrom hydro would be great saving to the national economy.Around 95% of the existing hydro power plants have passed the 25 year limit of their life span.

TABLE 1: Age analysis of Hydroelectric Plants in Sri Lanka

Name of the Station	Installed capacity / MW	Commissioned year	Age (Years)
Inginiyagala	11.25	1950	65
Norton	50	1950	65
Udawalawe	6	1955	60
Old Llaxapana	50	1955	60
Polpitiya	75	1960	50
Ukuwela	40	1976	34
Bowetenna	40	1981	29
New Laxapana	100	1984	26
Canyon	60	1984	26
Kothmale	201	1985	25
Victoria	210	1985	25
Samanalawewa	120	1985	25
Randenigala	122	1986	24
Nilambe	3.2	1988	22
Rantambe	50	1990	20
Kukule	70	2002	8

Therefore, it is essential to obtain the maximum capacity from the existing plants by minimizing the down time through proper operations. In that context predicting the availability of hydroelectric generating units for fault free operation is one of the crucial factors for achieving this. Bearing oil temperature plays a vital role in continues operation of hydro power plants. Stability of bearing temperatures in turbine and generators are essential for their successful continues operations. All hydraulic and lubricating fluids have practical limits on the acceptable higher operating temperatures. The machine loses its stability and experiences conditional failures whenever thesystem's fluid temperature violates this limits. Violations of the temperature limit could occur due to inadequate heat transfer rate, operating under higher ambient temperatures and longer duration of operation at higher mechanical loads. The power plant staff should closely monitor the bearing oil and metal temperatures in order to ensure a safe operation of the plant and the bearings life time.

TABLE 2: Bearing Metal/Oil Temperature Limits

Bearing Type	Temperature / Deg C (Alarm)	
	Metal	Oil
Upper Guide (UGB)	85	50
Lower Guide (LGB)	85	65
Thrust Bearing (THB)	85	65
Turbine Guide (TGB)	70	70

The aim of this research project is to model and simulate the dynamic variation of bearing(generator upper guide bearing UGB, generator Lower guide bearing LGB, turbine guide bearing TGB, thrust bearing THB) temperatures of a hydroelectric generating unit which depends on multiplevariables such as ambient air temperature, cooling water temperature, cooling water flow rate, initialbearing temperatures and generating unit electrical load and duration of operation etc.

1.1 The Hydro Electricity Generating Unit

Hydro electricity generating plant utilizes the potential energy of the water stored in a higherelevation and the turbine and the generator converts the potential energy in to kinetic energy andelectric energy respectively. [5].In this study real data is taken from the Kotmale hydro power generating system for simulating theproposed methodology. Kotmalehydro electric power generating unit consists of four main bearingsnamely upper guide bearing (UGB), lower guide bearing (LGB), thrust bearing (THB), and turbineguide bearing (TGB) as shown in Fig 2.

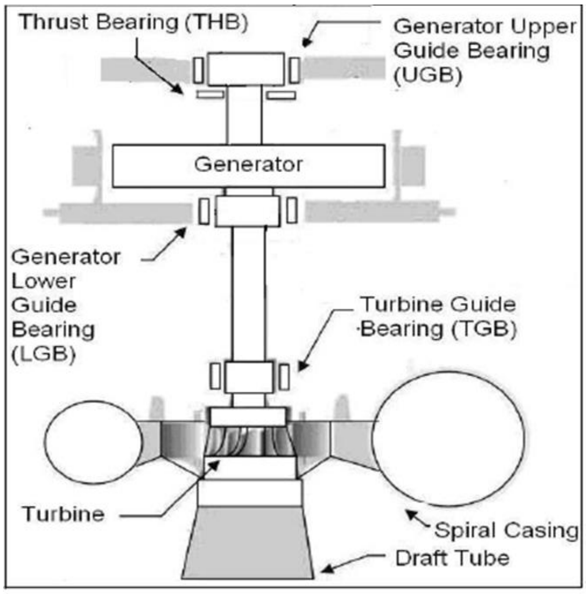

Figure 2. Bearing arrangement of the hydro-electric power generating unit

Problem Statement

The new HEV with its new key characteristic configurations (i.e. Mechanical complexity, Multiple driving modes, Multiple prime movers, … etc) inflicts an interference with the existed thermal management system of the conventional vehicles, which created new thermal issues that requires to be addressed to enhance the performance of the hybrid systems. According to the open literature there is no comprehensive 3-D thermal model exist for hybrid vehicle power train yet.Additionally, the current CFD simulations suffer from the lack of accuracy and theassumptions and approximations due to weak coupling and poor solution accuracy of CFD simulations: one simulation is applied as a boundary condition to the other; the boundary conditions for sub-models sometimes are taken from experimental data or experience.

Other thermal modeling based on Simulink were used to analyze thermal loads on the battery packs, however; these models did not take into consideration the interaction between the and has an extensive approximations and assumptions which used to either: couple the electro-chemistry phenomena of the battery cells to its thermal behavior, or reduce the running time of such models.

Fluent where dual-cell heat exchanger model used to simulate the non-uniform heatrejections at different ambient temperatures.However; such models assumed a uniform temperature at the surface tetra of the exhaust manifold, and on the exhaust pipes as a heat sources. On the other hand a –meshscheme was used to simulate the surface of the components of the complete model whichresulted in non-uniform element local heat conduction through such kind of meshingQuality.

II. LITERATURE REVIEW

In this chapter, a broad literature survey on hybrid electric and plug-in hybrid electric vehicle research is presented. The survey emphasis vehicle modeling and simulation, power and energy management, energy storage devices, propulsion systems and influence of driving cycle that affect the overall efficiency and fuel economy. The survey also focused on economic and emission analysis.

Karen et al (1999) presented a simulation and modeling package developed at Texas A&M University, V-Elph2.01. V-Elph was written in the Matlab/Simulink graphical simulation language and is portable to most computer platforms. They also discussed the methodology for designing vehicle drivetrains using the V-Elph package. An EV, a series HEV, a parallel HEV and a conventional internal combustion engine driven drivetrain have been designed using the simulation package. Simulation results such as fuel consumption, vehicle emissions, and complexity are compared and discussed for each vehicle.

Ma Xianmin (2002) developed a novel propulsion system design scheme for EVs requiring high power density. The theory analysis 21 mathematical models of EV are first set up based on the vehicle dynamic characteristics, then the whole system is divided into seven function blocks according to power flow, the simulation models are formed in the MATLAB language. The simulation results are verified in a PDM AC-AC converter, which shows that the suggested method is suitable for EV.

Brian (2007) created a model in MATLAB and ADAMS todemonstrate its fuel economy over the conventional vehicle. He used the Honda IMA (Integrated Motor Assistant) architecture, where the electric motor acts as a supplement to the engine torque. He showed that the motor unit acts as generator during the regenerative braking. He used a simple power management algorithm in the power management controller he designed for the vehicle.

Cuddy and Keith (2007) performed a parallel and series configured hybrid vehicles likely feasible in next decade are defined and evaluated using a flexible Advanced Vehicle Simulator (ADVISOR). Fuel economies of two diesel powered hybrid vehicles are compared to a comparable technologydiesel powered internal combustion engine vehicle. The fuel economy of the parallel hybrid defined is 24% better than the internal combustion engine vehicle and 4% better than the series hybrid.

Bauml and Simic (2008) discussed the importance of vehicle simulations in designing the hybrid electric vehicles. A series hybrid electric vehicle simulation with the simulation language Modelica was developed. They explained the simulation approach. They concluded with some of the simulation results emphasizing the simulation importance. Zhou and Chang (2008) established powertrain dynamic simulation model of an integrated starter/generator (ISG) hybrid electric vehicle (HEV) using Simulink. The parallel electric assist control strategy (PEACS) was 22 researched and designed. The analysis of dynamics performance and fuel economy of the model was carried out under the FTP drive cycle, which can provide a design reference for the setup of the powertrain test bench. The results show that the fuel consumption can be effectively reduced by using the designed PEACS with the state-of-charge of the battery maintaining in a certain scope. Kuen-Bao (2008) described the mathematical modelling, analysis and simulation of a novel hybrid powertrain used in a scooter. The primary feature of the proposed hybrid powertrain is the use of a split power-system that consists of a one-degree-of-freedom (dof) planetary gear-train (PGT) and a two-dof PGT to combine the power of two sources, a gasoline engine and an electric motor. Detailed component level models for the hybrid electric scooter are established using the Matlab/Simulink environment. The performance of the proposed hybrid powertrain is studied using the developed model under four driving cycles. The simulation results verify the operational capabilities of the proposed hybrid system.

III. METHODOLOGY

3.1 Model Analysis

It was common practice to build and test expensive prototypes to identify problems inthe design process; although; recently it becomes well-liked to build thermal models forthe vehicle in the early stages of the design process, in a way to avoid expensiveprototype build up; at the same time design changes take place during different level ofthe design process which leads to a manufacturing challenges. Therefore; identifyingsuch problems early in the design cycle, will assist providing a solutions to shorten thedesign time and cut down costs; hence; one can maximize engineering options in earlystages of development or to validate final product design.

Typically there are four steps involved in order for the thermal model to be success:

i. Generate a surface description and mesh the surface description
ii. Define the thermal model, properties and boundary conditions.
iii. Engage the analysis.
iv. Post processes the results.

The surface geometry for the model under consideration forms the foundation ofthermal model [3]; hence finite element model for the surface geometry for a completevehicle should be properly constructed, repaired and meshed for warpage andunconnected vertices. However; thermal modeling requires finite element models with acertain mesh quality to provide a precise thermal analysis.

The mesh size is crucial, hence; it is necessary to reduce the mesh size to reduce therunning time in order to obtain better thermal results, The FE model for this research wasgenerated by laser scanning for real objects, 3D scans have an advantage over the reverseengineering which is usually voluminous and leads to larger simulation times.

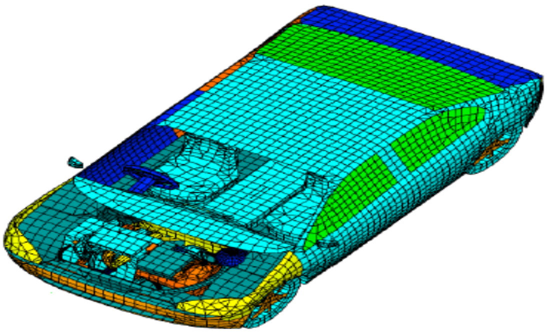

Figure 3.1. FE model of a complete vehicle

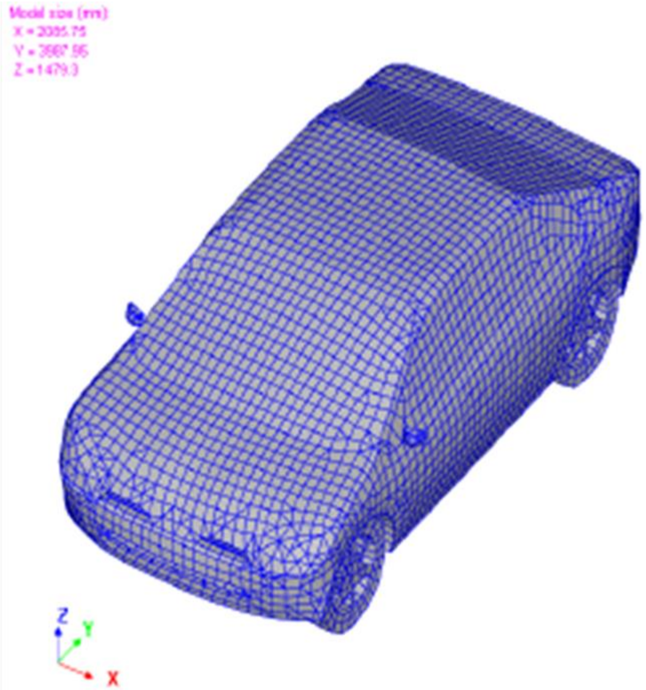

Figure 3.2 Rad Therm Graphical User Interface

Table 3.1 Automotive BiW panels material replacement

Part	Current design	New design
Under Body	Steel	Aluminum, Magnesium
Engine Cylinder Block	Steel	Aluminum & Magnesium
Splash Wall	Steel	Titanium, Aluminum

Problem Description

This is a modal analysis of a wing of a model plane. The wing is of uniform configuration along its length, and its cross-sectional area is defined to be a straight line and a spline, as shown. It is held fixed to the body on one end and hangs freely at the other. The objective of the problem is to demonstrate the wing's modal degrees of freedom**.**

IV. RESULTS

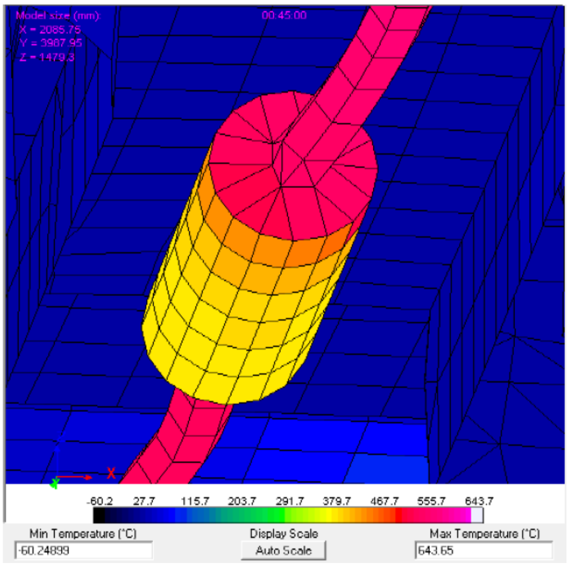

Figure 4.1. Model size of shielded drive system

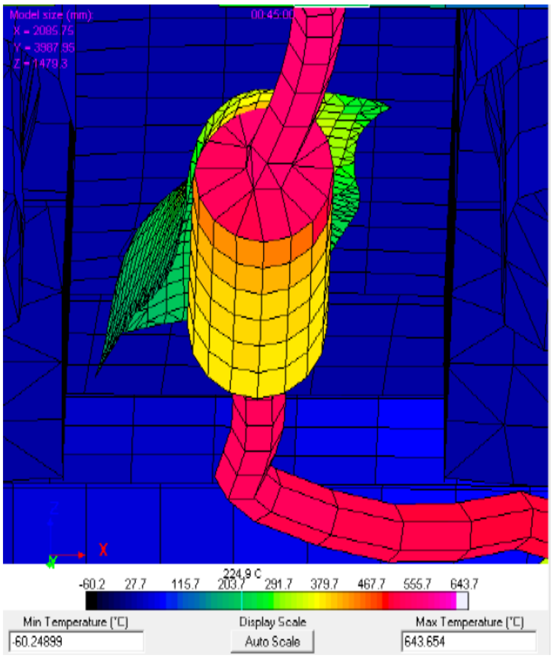

Figure 4.2. Model size of un-shielded

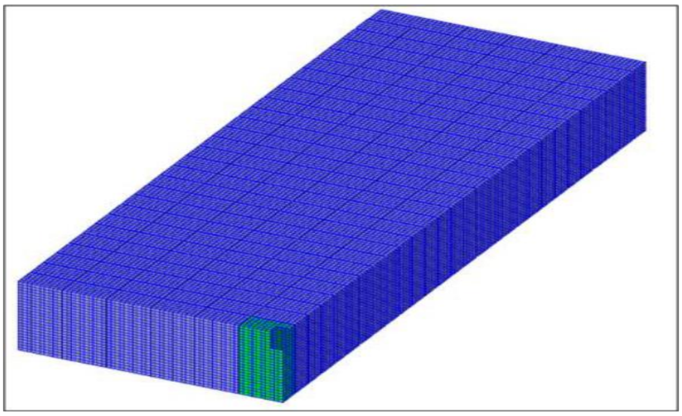

Figure 4.3. Battery cell surface geometry with one cell unit highlighted

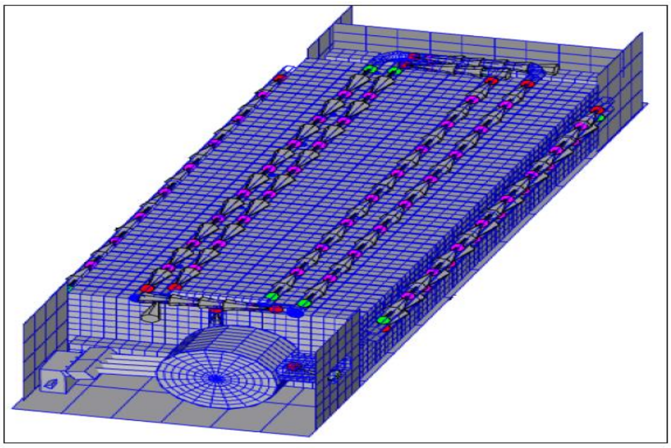

Figure 4.4. Battery pack cooling system with the fluid stream

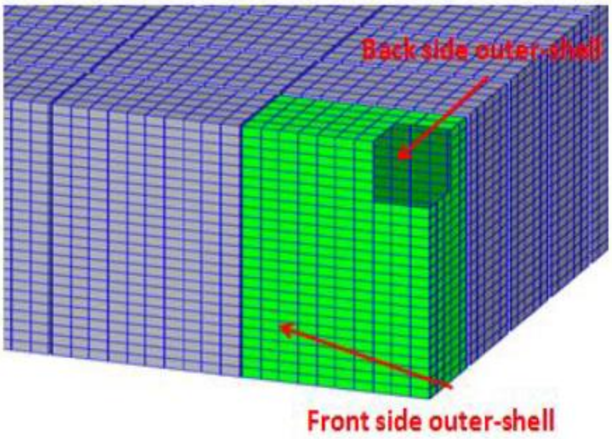

Figure 4.5 The inner side of battery cell

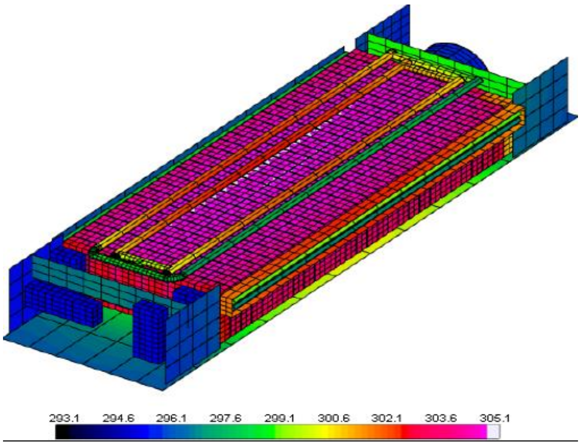

Figure 4.6 Net heat flux for the battery cells for FHDS

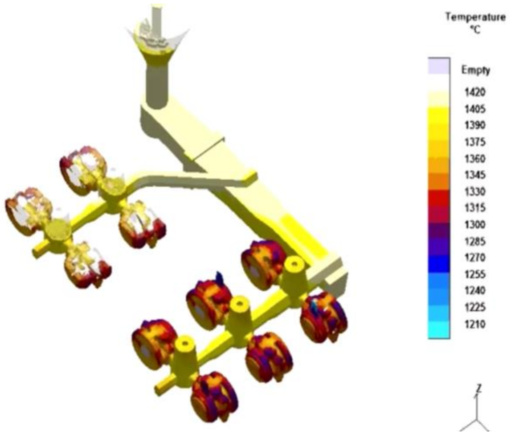

Figure 4.7Hybrid drive temperature system

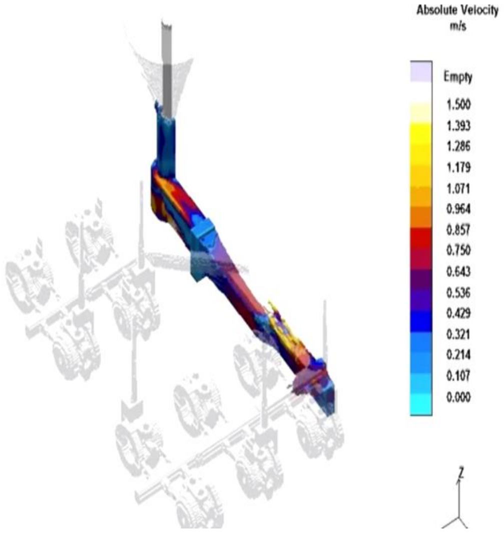

Figure 4.8 Absolute velocity system

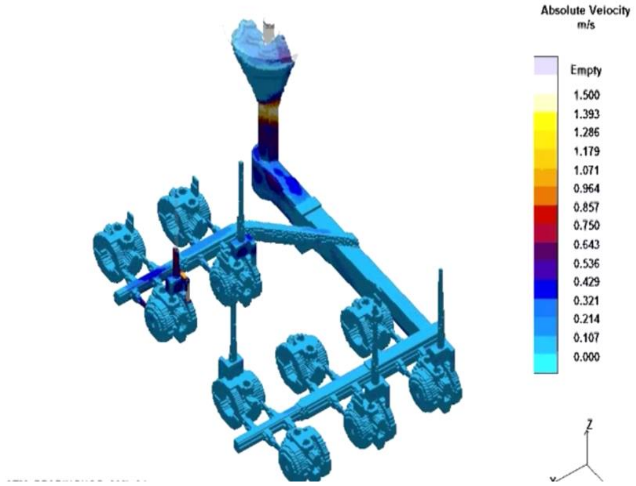

Figure 4.9 Absolute velocity system final view

V. CONCLUSIONS

This dissertation presented a comprehensive 3D thermal model for simulating thethermal behavior of both conventional and hybrid electric vehicles' power trains, wherethe temperature measurements using the thermography forms the basis for thermalmodeling; yet; an inclusive extraction process for the boundary conditions for differentmodule in the power train was conducted, where a real time transient and spatialtemperature profiles using infrared detector were acquired, a hybrid powertrain thermalperformance was monitored for peak and steady state power demands while applying astandard driving cycles (FHDS, FUDS, US06, JAPAN 10-15, ECE), in addition to anewly invented artificial driving schedules.

The model developed in this research to simulate bearing temperatures of a bearing heat exchanger system was successful giving promising results. Initially a static model was developed and it was extended to simulate the dynamic behavior of the system. According to these results, neural network models are more capable of modeling non-linear, multi-dimensional MIMO systems rather than using conventional methodologies using first principles. The model developed and methodology used provides and serves as a good initiative for others for modeling problems of this nature.

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