AN EVALUATION OF ELECTRICAL SYSTEMS FOR HYBRID VEHICLES

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ABSTRACT

I. INTRODUCTION

In the hybrid concept, the source of power is a combination of heat engine and batteries (in essence, the heat engine supplies steady state power and the batteries supply transient power demands). This paper contains limited results of a study aimed at determining the feasibility of using a hybrid heat engine/electric propulsion system as a means of reducing exhaust emissions from street-operated vehicles. It covers the electric motor/generator and their control systems but excludes the heat engine, emissions and the battery portion of the study.

Several classes of vehicles as well as several design configurations were considered in the study. Following a review of associated technologies, requirements for electrical components were determined. Based on these results recommendations were formulated to ensure early demonstration of prototype vehicles.

The purpose of this paper is to present information, results of studies and general recommendations on the electrical features of the system. An earlier paper presented at the 1971 Intersociety Energy Conversion Engineering Conference in Boston gave data on the mechanical features of the studies and also estimates of the pollution levels to be expected from the use of various types of heat engines.

II. SYSTEM SYNTHESIS

There are many different design approaches to the development of an electrical system for the hybrid vehicle. The major catagories are as follows:

1. Series Configuration
2. Parallel Configuration
   (a) Single Electric Motor
   (b) Dual Electric Motor

Electric motors can be smaller in the parallel configuration, due to the fact that they are used only during peak loading situations. The parallel arrangement appears to have the potential of greater efficiency because a large portion of the energy does not flow through the electrical system but is channeled directly to the wheels. The principal loss is friction in the mechanical system, and the electrical loss is reduced below the series configuration.

III. SUBSYSTEM TECHNOLOGY

MOTOR CHARACTERISTICS AND CONTROL

Designs for electric motor drive systems should have the following goals for performance characteristics:

(a) High starting torque
(b) Sufficient accelerating torque over the specified speed range
(c) High overall operating efficiency
(d) Simple, inexpensive speed control
(e) Simple, inexpensive, efficient re-generative braking

The most common approach to the design of electrically propelled vehicles in the United States has been to use DC series motors utilizing chopper circuits for their control, either pulse frequency or pulse duration. Although this approach appears reasonable for some classes of vehicles and driving cycles, it is not optimum for all types. The motor induced voltage varies with speed; it is very small at low speed and increases as the motor speed increases. Exceeding this voltage results in high current leading to overheating of the motor. The armature applied voltage must be varied to match the induced voltage of the motor at all speeds. This can be achieved in several ways:

1. Chopper circuit
2. Variable resistance in armature circuit
3. Step voltage change and field control

The chopper circuit provides an efficient means of transforming a fixed battery voltage to a smoothly variable effective voltage matching the requirements of the motor at all speeds of operation. The main disadvantage of the chopper is the high cost of power switching components and the associated control circuitry.

The use of variable resistance in the armature circuit introduces high losses associated with the voltage drop in the resistance, and is an inefficient method of voltage control for a vehicle required to operate over a wide speed range.

Motor voltage control can also be achieved by step voltage switching of the battery cell groups from parallel to series as the vehicle speed is increased. However, to provide adequate voltage matching over a wide speed range several stages of voltage switching are required to obtain a reasonable motor efficiency and avoid excessive loading of the battery. The number of voltage steps may be reduced by combining field control with voltage switching.

IV. SUBSYSTEM EVALUATION AND COMPARISON

A comparison of electric motor systems must include:

a. Operating characteristics and suitability to demand requirements.
b. Control system complexity and cost.

c. Operating limits including:
   1. Surge currents
   2. Commutating current limit
   3. Temperature rise limit
   4. Velocity limit set by centripetal strength and commutation speed
d. Power density (lb/hp) and efficiency
e. Motor cost and availability
f. System weight
g. Reliability and maintainability

Series, separately excited, compound and brushless DC motors as well as AC induction types were evaluated on the bases of the above mentioned parameters. Details of these evaluations are contained in the full length paper.

V. DESIGN GOALS

Electric motors, particularly DC motors have not been developed to optimize efficiency, weight, size and cost for vehicle propulsion. It is believed that DC electric motors can be designed with higher efficiencies and lighter weights than those on the market today, with equal reliability and lifetimes. Power densitites of from 5.5 to 3 lb/hp should be available at reasonable cost by merely optimizing the design for the particular application and utilizing light-weight materials where possible. The corresponding efficiencies would range between 90 and 94% at design load depending on the size of the motor. Part load efficiency is also very important because during a typical driving cycle, the motor operates at part load most of the time.

VI. RECOMMENDED SUBSYSTEM DEVELOPMENT

As already discussed to some extent in this paper certain areas require further development effort in the electrical system. These efforts consist of the following:

a. Develop lightweight, efficient DC motors optimized for efficiency and weight for the automotive application. Both separately excited and series types are required.

b. Develop lightweight, efficient controllers for shunt type motors. Very little development appears necessary in the area of choppers.

c. Develop small and compact, vehicle-borne logic and control circuits to optimize electrical/heat engine performance. Inputs to the logic circuit would be generator current, battery charge current, motor armature current, engine speed, battery voltage, and accelerator pedal position. Based on these inputs the logic circuit would determine the desired optimum heat engine power setting.

d. Determine and compare the efficiencies and heat rejection systems of DC and AC motors and associated control systems, particularly for the large vehicles.

e. Compare in more detail the cost of various approaches.