Name:_____

16.682 Technology in Transportation

Exam 1

April 5, 2011

Question 1: Internal Combustion Engine Technology (20 points)

Use the torque/RPM curve below to answer the following questions:

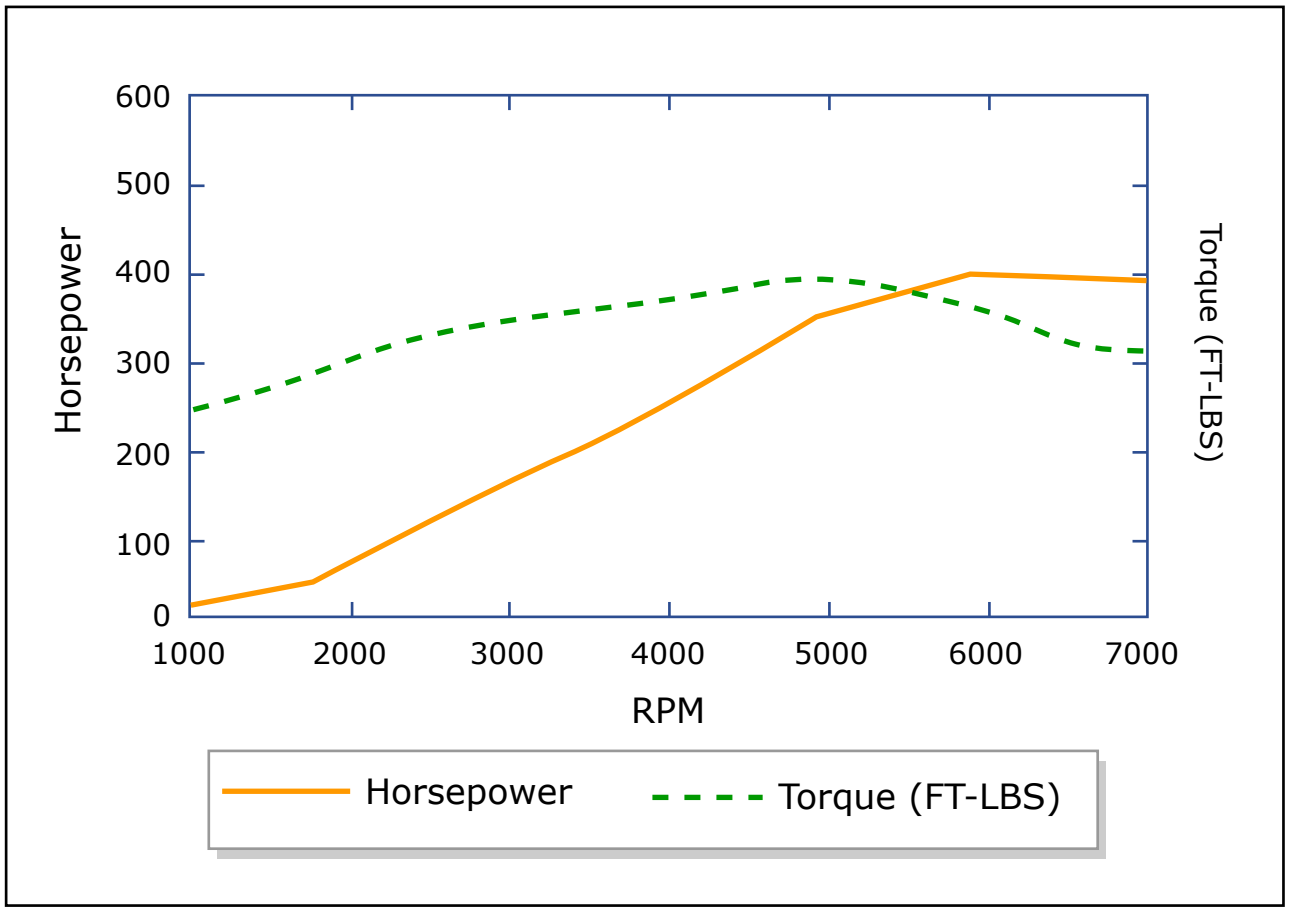

Image by MIT OpenCourseWare.

The relationship between engine displacement, power, speed and pressure is given below:

$$p_{mep} = \frac{Pn_c}{V_d N}$$

Where

P = power output in watts
p_{mep} = mean effective pressure in pascal
V_d = displacement volume in cubic metre
n_c = number of revolutions per cycle (for a 4-stroke engine n_c = 2)
N = number of revolutions per second

1. **(10 points)** Assume that you wanted to achieve the same power output (400 horsepower (HP)), but with an engine of the same displacement that can only spin up to 4,000 RPM. By what factor would the mean effective cylinder pressure have to increase over the values in this gasoline engine, which develops 400 HP at 6,000 RPM? Name two methods that are commonly used to achieve this.

2. **(10 points)** Assume that the car whose torque/power curve is shown above requires 40 HP to maintain 60mph. At which RPM does this engine most efficiently produce 40 HP? How would you design the transmission's gear ratios to achieve best fuel economy on the highway?

Question 2: Electric Motors (20 points)

1. **(10 points)** Estimate the torque produced by a brushed DC electric motor with the following operating characteristics:

    - Mean air-gap flux density under the pole face = 0.4 T
    - Pole-Arc as % of total circumference = 75%
    - Active Rotor Length = 50 cm
    - Rotor Diameter = 30 cm
    - Total Number of Rotor Conductors = 120
    - Current in Each Rotor Conductor = 50 A

2. **(10 points)** A brushed DC motor with an armature resistance of 0.5 Ohms is being operated in steady state at 140 V and 5,000 RPM. The motor constant (for both torque and back emf) is 0.25 Nm/A. If the operating voltage is suddenly dropped to zero in an effort to use regenerative braking, what are the new current and torque outputs of the motor?

Question 3: Energy in Transportation (30 points)

Will electric airplanes ever be feasible? You're designing an electric Boeing 747; below are the specifications of a normal 747 to use as baseline estimates in your planning.

- Empty Weight: 178,756 kg
- Maximum Takeoff Weight: 396,890 kg
- Fuel Capacity (216,840 L = 172,800 kg)
- Power (ballpark 100,000 HP – 75 MW - on takeoff; uses about ¼ of that on cruising).
- Each engine = 4,000 kg (there are 4).

You'll no longer need fuel tanks or engines, as you're replacing them with batteries, motors and motor controllers. You want to keep the same passenger capacity, so consider the available mass for the conversion to be equal to the weight of the existing engines and fuel capacity.

- State-of-the-art EV drive power density: 2.5 kW/kg (for motor and inverter)
- State-of-the-art battery energy density: 200 Wh/kg

Consider that the plane will be running at 75 MW for the first 15 minutes to reach altitude, and then at 19 MW during cruising. For how many hours can an electric 747 fly?

Question 4: Multiple Choice / Short Answer Questions (30 Points, each question equal)
Each short response should be a maximum of 2 sentences.

1) In order to achieve the same overall vehicle performance characteristics, which hybrid powertrain architecture would need to have the most powerful electric motor?

   A) Series
   B) Parallel
   C) Series Parallel
   D) Mild Hybrid

2) Given the chart on the attached page, what would the electrode potential of a lithium copper battery be?

   _____

3) What are the primary energy efficiency advantage(s) of modern trains over road vehicle mass transport options like city busses or long-haul trucks (circle all that apply)

   A) Rolling Resistance
   B) Aerodynamic Drag
   C) Inertial Acceleration
   D) Power Plant Efficiency
   E) None of the Above

4) What is a fundamental limiting factor to a propeller's speed in water?

5) The large, slow-spinning diesel engines on container ships can achieve efficiencies greater than 45%. Cite one reason that aids in raising this efficiency figure.

6) What is the point of supercharging a vehicle, and how does this work?

7) How does variable valve timing work to improve engine efficiency for a vehicle that's driving in the city, where the engine RPM fluctuates during driving?

8) Why do the number of gears in automatic transmissions on newer cars keep increasing? In the '60's, automatic transmissions typically had 3 speeds, now most have at least 5.

9) What is a fundamental advantage of fuel over batteries that allow it to achieve such high gravimetric (by mass) energy density?

10) What technological advances in the electrical engineering field fundamentally enabled long-distance electric rail? Circle all that apply:
    A. Commercialization of high strength rare-earth magnets used in DC motors
    B. Silicone carbide rectifier circuits
    C. High strength materials for wrapping motor rotors, allowing them to reach higher RPMs
    D. AC power distribution

11) You're designing an international shipping port: name 3 logistical concerns that arise in moving cargo from ships to further land-based distribution.

12) A guy at the auto parts store is trying to sell you a huge wing for your Honda Civic that looks like this. Why is it a bad idea to put this on a front-wheel-drive car?

13) (Vehicle Dynamics). What is a fundamental advantage that allows a rear-wheel drive car to move more quickly off the starting line in a drag race?

Reference: Material:, Table 13.

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