DESN2000 MECH Workshop

Week 8 – Power Transmission

Class overview

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Introduction

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Introduction

Power transmission is critical for a mechanical system to be feasible.

- ❑ Excessive power = cost, weight, breaking components.
- ❑ Insufficient power = inability for device to perform as intended.

Mathematically, the three primary forms of power for common engineering systems include:

- ❑ **Electrical:** $P = VI$, where $V =$ voltage and $I =$ current.
- ❑ **Mechanical linear:** $P = Fv$, where $F =$ Force and $v =$ linear velocity.
- ❑ **Mechanical rotational:** $P = T\omega$, where $T =$ torque and $\omega =$ angular velocity.

These are examples of instantaneous power, that is, power at any given moment in time. If you input variables which represent the system operating at its maximum capacity, then the instantaneous power you obtain is also the maximum power P_{max}. Average power is a more generalised formula,

$$P_{ave} = \frac{energy}{time}$$

Example 1: Braking Power

Example 1: Braking Power

❖ A $1300\ kg$ car is travelling at $120\ kmh^{-1}$. The driver suddenly applies full braking pressure, resulting in a deceleration of $0.65\ g$. How much power was exerted in bringing the vehicle to a complete halt?

Step 1: Assumptions

For this simplified example, we will ignore inefficiencies. Thus:

$$P_{in} = P_{out}$$

Step 2: Calculate Power

You should analyse both maximum and average power, P_{max} and P_{ave}.

- P_{max} informs you the maximum power the system requires and is useful for sizing components.
- P_{ave} informs you of the power required over a given time. This is useful for performance evaluation and for component sizing, if your use case does not expect high peaks and troughs in output requirement.

We will explore P_{ave} first, which is universally given by,

$$P_{ave} = \frac{energy}{time}$$

For our car, we can use rectilinear motion to find these two variables.

We can use the equation $\boldsymbol{v = u + at}$. In this case, $\mathrm{u} = 120\ kmh^{-1} = 33.33\ ms^{-1}, u = 0\ ms^{-1}, a = -0.65\times9.81\ ms^{-2}$. We want to know the time taken to stop the car. Substituting and rearranging to solve for t,

$$0 = 33.33 - 0.65\times9.81t$$

$$t = \frac{33.33}{0.65\times9.81} = 5.23\ s$$

We have time, now we want to know the energy. Since we are describing motion, we can use the kinetic energy formula.

$$E_k = \frac{1}{2}mv^2$$

$$= \frac{1}{2}1300\times33.33^2 = 722\times10^3\ J$$

Substituting these into the P_{ave} formula,

$$P_{ave} = \frac{energy}{time} = \frac{722\times10^3}{5.23} = \boldsymbol{138.06\ kW}$$

❖ If your project was a regenerative braking system for example, you could research what percentage of braking force is typically transformed into heat. Then you could apply that percentage to this average power to calculate how much energy you could harvest from a single braking application from a vehicle travelling at the speed set in the example.

Now, let's look at P_{max}.

Since we are dealing with mechanical linear motion (the car is moving along a ground plane in a linear fashion), we will use the formula,

$P = Fv$,

where $F =$ Force and $v =$ linear velocity.

We can use $F = ma$ to break it down further into,

$$P = mav.$$

Maximum power is simply the instantaneous power when the system is operating at its maximum. In this case, said maximum is just the information provided in the question. For your own analysis, you will have to research and discuss in your groups to determine what conditions your system might be operating at its max.

We have all the required variables. $\boldsymbol{m = 1300\ kg, a = \left|-0.65 \times 9.81\ ms^{-2}\right| = 6.38\ ms^{-1}, v = 33.33\ ms^{-1}}$. Thus,

$$P_{max} = 1300 \times 6.38 \times 33.33 = \boldsymbol{276.3\ kW}$$

❖ This means that if you were choosing what brakes to install on the car, you would need to choose ones that could output at least $276.3\ kW$ of braking power. In your reports, doing this analysis is a great way to prove that the components you have chosen will feasibly perform the tasks you intend your device to perform.

However, we have not been accounting for inefficiencies in our system (which there always is!). Next, we will show you how to account for them.

Example 2: Power Inefficiencies

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Example 2: Power Inefficiencies

❖An industrial fruit juicing machine requires an **average power of 3 kW** to drive the blades. This allows for the power fluctuation when blending a particular tough fruit. An electric motor is desired to run the juicer. A chain drive and belt drive transmit power between the motor and the blender blades.

- Assuming a power loss of **5% from the chain drive, 10% from the belt drive and 25% from the rest of the machine,** how much power should the motor provide?

To determine the impact of power loss, **we write each source inefficiency as** $\boldsymbol{\eta = 1 - \%_{power\ loss}}$.

$$\eta_{drive} = 0.95, \eta_{belt} = 0.9, \eta_{machine} = 0.75.$$

The **system inefficiency** is the **product of every source.**

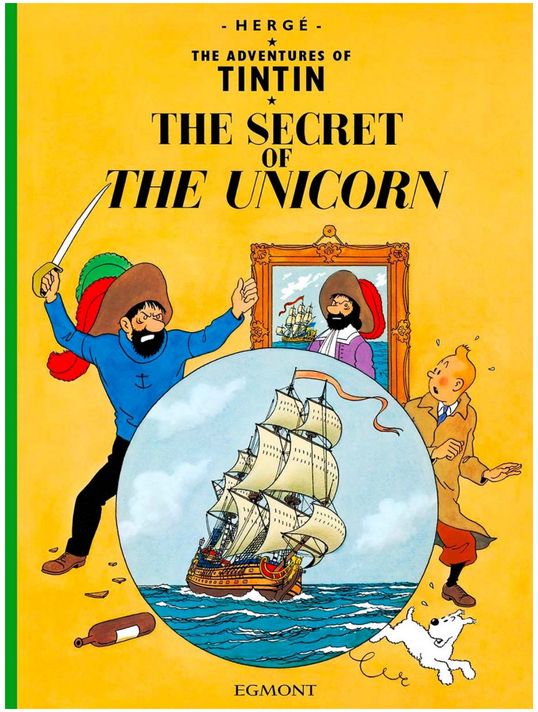
$$\eta_{system} = \eta_{drive} \times \eta_{belt} \times \eta_{machine} = 0.64$$

Since the machine requires $3\,kW$ of energy to drive, $P_{out} = 3\,kW$. To calculate our P_{in} while accounting for inefficiencies, we divide P_{out} by η_{system}. Thus,

$$P_{in} = \frac{P_{out}}{\eta_{systems}} = \frac{3}{0.64} = \mathbf{4.69\ kW}$$

❖You should always account for inefficiency when performing your power analysis for your report. Even if you are using a direct drive with no gearing/transmission, there's always friction losses!

Exercise: Treasure Recovery



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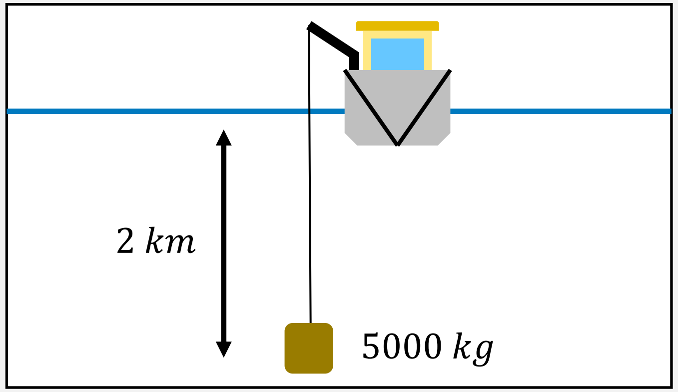
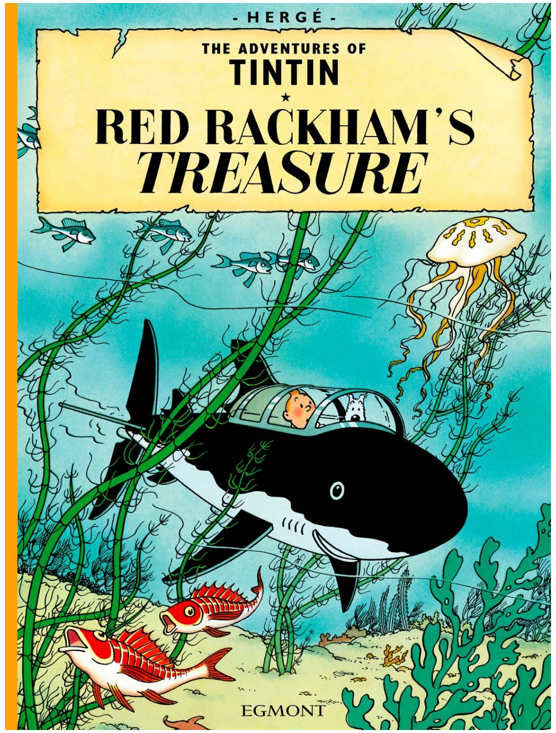
Exercise: Treasure Recovery

A $\mathbf{5000\ kg}$ treasure chest is $\mathbf{2\ km}$ deep under the ocean surface. Ignoring buoyancy forces and inefficiencies…

a) What is the minimum power your motor winch needs to be capable of if you want to recover it in 20 mins?





Clue: Since winches usually operate at a constant RPM (i.e., $P_{max} \approx P_{ave}$), we can use $P_{ave} = \frac{energy}{time}$ to determine our P_{in}. We want to bring a weight up vertically, requiring a change in height. Think about what kind of energy we are changing and find the equation which best describes it.

Exercise: Treasure Recovery – Solution

A $\mathbf{5000}\ \boldsymbol{kg}$ treasure chest is $\mathbf{2}\ \boldsymbol{km}$ deep under the ocean surface. Ignoring buoyancy forces and inefficiencies…

a) What is the minimum power your motor winch needs to be capable of if you want to recover it in 20 mins?

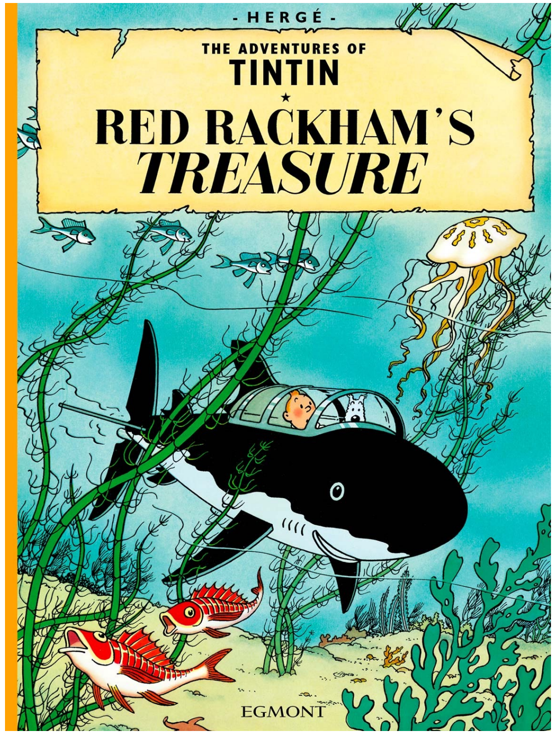
Solution: Since we are hoisting the mass vertically, the main energy we are concerned with is a change in **gravitational potential energy.** Thus,

$$E_p = mgh = 5000 \times 9.81 \times 2000 = 98.1 \times 10^6 J$$

We know we want to get the job done in 20 min. We ignored inefficiencies, and our system operates at a relatively constant manner, so $P_{in} = P_{out} = P_{ave}$. Hence,

$$P_{in} = P_{ave} = \frac{energy}{time} = 98.1 \times \frac{10^6}{20 \times 60} = \mathbf{81.75}\ \boldsymbol{kW}$$

Thus, our motor needs to be **at least $\mathbf{81.75}\ \boldsymbol{kW}$** to achieve our mission!



General Workflow and Report Tips

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General Workflow

- ❖ To assist in making your analysis more straightforward, try working using this sequence of events. This is also how you might want to structure your writing to make your calculations easy to read and understand. After describing what you are analysing,

1. **State your assumptions:** This helps you to lay all the information out on the table, so you don't forget to account for them later.

2. **Determine what it is that you want to analyse:** Am I sizing for a component or trying to find out the performance over time? This will dictate the equations you use.

   - ❖ The equations for P_{max} are quite straightforward, the equations for P_{ave} will require some work from you to find what best represents the energy that you are analysing. If you struggle, try to think what action you are performing and what energy is being altered. In the car example it was a change in kinetic energy, while the treasure example was about gravitational potential energy, for instance.

3. **Calculate the power in question and apply it to your analysis**

   - ❖ You might perform steps 2 and 3 multiple times if you are analysing multiple components. You may also need to research some data using databases, component specifications sheet etc.

Tips for Report

- **It is ok to make assumptions!** Real world analysis is extremely complex, and it is ok to simplify your calculations for this assignment. However, make sure to tell us what you have assumed.
- **Analyse more than one component if possible:** As you saw, the analysis we performed were relatively short. Thus, it is a good idea to select a few mechanical components in your device to analyse. It’s not an absolute rule, however. If you are performing a very in-depth analysis that takes up more space (or if your device only has very few mechanical parts), then looking at fewer components is fine too.
- **Account for inefficiencies where possible:** As mentioned, no engineering system is 100% efficient (we wish though!). Thus, accounting for inefficiencies will make your analysis much more efficient. This is an area where broad assumptions are ok, though tell us and cite where you obtained the information from to determine the amount of power loss in your system.

Project Time!

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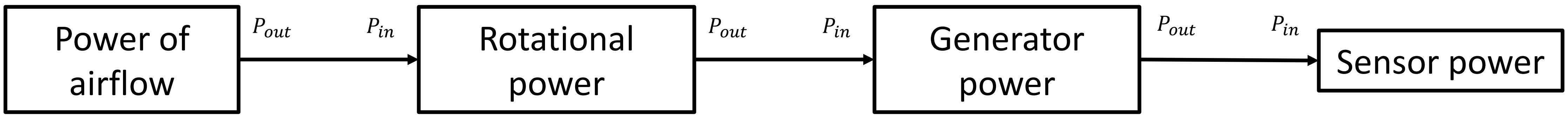
Mechanical design with power in mind

- Purpose of power transmission calculations is to understand how much input and output power we can have.
  - We want to understand how much output power we need to drive something or power some electronics.
  - We want to understand how we can change our mechanical design to accommodate input/output power constraints.
- Process
  1. Think high-level, what is the chain of power? How is power being converted with each step within the system?
  2. How much output power is required?
  3. What variables can be changed in the system?
     1. Adjust these variables to suit your design. THIS CAN BE AN ITERATIVE PROCESS.
     2. Don’t forget to factor in efficiency, there will be power lost somewhere in the chain.
  4. What is the range and average input power that can be obtained?

Can do steps 2, 3, 4 OR steps 4, 3, 2. Any order is fine – we just need to start from a place where we have more complete information.

Example: Turbine

Powering a turbine with airflow



Power lost between airflow and turbine blade

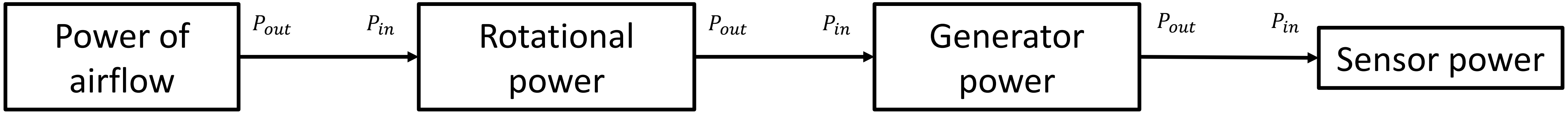
Power lost inherent generator efficiency

Power lost assumed negligible

The ends of the chain is usually where we have the most information. It will be easy to start placing constraints at the ends of the chain then work towards the middle.

Example: Turbine

More about power loss



Power lost between airflow and turbine blade

$$\eta = \frac{P_{out}}{P_{in}}$$

How to figure out η? Can get from research data, datasheets, laws, assumptions.

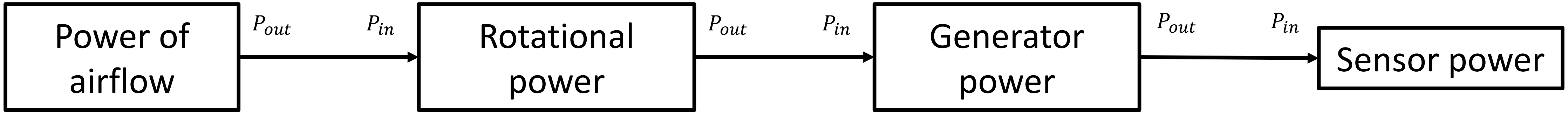
Power lost inherent generator efficiency

Difficult to calculate. Can use motor efficiency curves or empirical data or assume 1:1 power transfer

Power lost assumed negligible

Example: Turbine

What variables can change?



- Fluid velocity
- Fluid pressure

- Cross-sectional area
- Turbine size
- Turbine blade shape
- Number of blades

- Motor selection

- Sensor selection

For stuff that is too hard to calculate - just make assumptions or find research data.

Example: Turbine

Can have more complex chains

Summary

- Basic equations:
  - **Electrical:** $P = VI$, where V = voltage and I = current.
  - **Mechanical linear:** $P = Fv$, where F = Force and v = linear velocity.
  - **Mechanical rotational:** $P = T\omega$, where T = torque and ω = angular velocity.
  - **Efficiency:** $\eta = \frac{P_{out}}{P_{in}}$, where η = efficiency.
  - **Average:** $P_{avg} = \frac{\Delta E}{t}$, where ΔE = change in energy and t = time/duration.
- Find or derive power equations more appropriate for your application, maybe P can be better expressed in terms of other variables in your system.
- Refer to Shigley's textbook.

Summary

Today we covered:

- Power Selection

Next week:

- Open consultation!
  - There will be no formal content for Week 9, the purpose of the workshop will be purely for you to finalise your presentations, work on your reports and ask any question you might have.
  - Which groups want to do trial runs with feedback?