Power Calculation

Updated 25 March 2020

This page provides an estimate of the maximum power required by a motor used to compress an Ambu bag using a double gripper design, actuated from the bottom. Different designs, with other actuation methods, will change motor specifications, but the power should stay approximately the same.

Caution: Many designs circulating on the internet significantly underestimate the pressures needed to inflate a subject's lungs. There is a reason why the diaphragm is a large muscle. However, adding more power without great care is equally dangerous. In addition, COVID-19 compromised patients may require more aggressive motion profiles, i.e. short, quick breaths and longer inspiration times. In specific, clinicians are reporting I:E ratios of 1:4 in COVID-19 patients. (Our estimate uses 1:3.)

Theoretical Power Requirement

Independent of the mechanical design of the gripper, the required power output can be computed from the worst-case values of the following variables:

- Maximum pressure at airway: $P_{\text{airway,max}}$ = 40 cm H_2O (pop off cracking pressure)
- Maximum respiration rate: $RR_{\max}$ = 30 bpm
- Minimum inhale/exhale ratio of 1:3: $\text{IE}_{\text{ratio, min}}$ = 0.25
- Maximum volume output: $V_{\max}$ = 800 cm^3

That is, in the worst case the device needs to squeeze of air at a pressure of 40 cm H_2O, in half a second (60 sec / 30 * 0.25).

The volume flow rate needed in the worst-case (peak) scenario is, then:

$$Q_{\text{airway}} = \frac{V_{\max} \cdot RR_{\max}}{IE_{\text{ratio, min}}} = 0.0016 \frac{\text{m}^3}{s}$$

The power output (in the form of pressurized volume flow in the airway) is:

$$P_{\text{airway}} = p_{\text{airway, max}} \cdot Q_{\text{airway}} = 6.27\ \text{W}$$

However, some of the power used for squeezing the bag is lost (bag deformation, friction, etc.) and let's estimate that 50% is converted to pressurized volume flow. Taking this efficiency into account, the power required at the gripper is:

$$P_{\text{gripper}} = \frac{1}{0.5} P_{\text{airway}} = 12.5\ \text{W}$$

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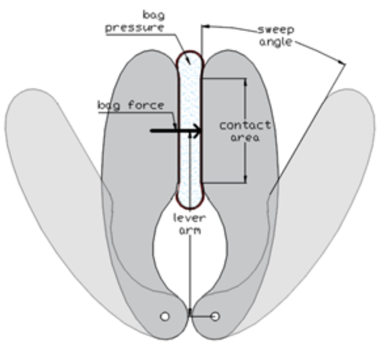
The actual power needed from the motor will be higher, how much higher depends on the mechanical design. Assuming half the power output of the motor is lost to mechanical inefficiencies (gears etc.), the power output required from the motor is given by:

$$P_{\text{motor}} = \frac{1}{0.5} P_{\text{gripper}} = 25.1\ \text{W}$$

Power requirement for 2-finger design

This is an alternative approach to calculating power.

The following is an illustration of a 2-finger gripper design:



A more direct approach can be used for this design provided the following quantities can be measured:

- Finger-bag contact area
- Finger lever arm length
- Sweep angle

For one particular prototype, we have:

- Finger-bag max contact area: A_{bag} = 80 mm^2
- Finger lever arm length: l_{finger} = 12 cm
- Sweep angle: α_{sweep} = 30°

The maximum force of the bag on one finger (when fully squeezed) is, using the same 50% pressure transmission efficiency as before:

$$F_{\text{finger}} = A_{\text{bag}} \cdot \frac{p_{\text{airway, max}}}{0.5} = 50.2\ \text{N}$$

The maximum torque needed on each finger is then:

$$\tau_{\text{finger}} = F_{\text{finger}} \cdot l_{\text{finger}} = 6.02\ \text{N} \cdot \text{m}$$

Now we can compute the power required on each finger using the sweep angular rate (in half a second):

$$P_{\text{finger}} = \tau_{\text{finger}} \cdot \omega_{\text{finger}} = 6.31\ \text{W}$$

The total power for the motor (assuming a single motor) is twice that:

$$P_{\text{motor}} = 2 \cdot P_{\text{finger}} = 12.6\text{W}$$

which is similar to the result from the calculation based on volume flow rate. Applying the same 50% motor and gearbox efficiency, we arrive at a similar estimate of 26.2 W.

Recommendation

Therefore, a power supply at 12 V should be specified with a minimum of a 2.5 A capability for safety. Allowing another safety factor of 2 we recommend a 5 A supply.

Benchtop Validation

During testing of a 2-finger gripper design, E-Vent Unit 002, equipped with an Andy Mark motor am-3656 (188:1 gearbox) we observed a peak current of under 3 A at 12V or 36 W.