Alternative Power Source for Dental Hygiene Device

Team 15

Francisco Health, Jiaqi Xie, Jin Niu,
Ningbao Jiang, Nizar Almansouri

Engineering Analysis

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Department of Mechanical Engineering
Northern Arizona University
Flagstaff, AZ 86011

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Introduction

The NAU Department of Dental Hygiene provides humanitarian services in some remote areas of the world. Sometimes, these areas have limited access to electricity.

In December, a team of students and professors of the Department of Dental Hygiene will be travelling to Mainpat in India to work on teeth. To get the work done, they will need to use the Wig-L-Bug, a device that can mix dental filling material.

The Wig-L-Bug requires electricity to run. Because there will not be electric power available, the team will need to bring a portable power source with them. This power source must be able to power the Wig-L-Bug ten hours a day for two weeks, without any downtime. It needs to be a convenient size and weight, so that it can be easily transported.

Wig-L-Bug Analysis

The dental hygiene device runs off of United States household electricity (110V 60Hz). To determine power usage, the device was tested in the CEFNS electronics lab. Table 1 shows the results at different power settings.

Power Setting	Peak Power Usage(W)	Continuous Power Usage(W)
Low	60	35
Medium	60	40
High	60	45

Table 1: Power Consumption

When set to run for 10 seconds, the power consumption would briefly spike at about 60 Watts and then settle down to the continuous power usage within one second. For our design, we will use the continuous power usage on the “High” setting to determine the necessary energy capacity of the storage device, and the peak power usage on the high setting for determining the necessary peak output of the storage device.

According to our Objectives/Constraints, the device will need to be run for a ten hour period. When used, the device will be loaded with a cartridge and run for 10 seconds. The cartridge will then be swapped out with a new one. It takes roughly ten seconds to swap out a cartridge, giving us an extreme case duty cycle of 50%.

The electricity stored in the power supply must be inverted from 12 VDC to 110 VAC. In order to do this, we must use an inverter. Using an inverter efficiency of 90%, we come up with the total energy capacity and peak power output of the storage device:

$$\frac{45\text{W}}{0.9} \times .5 \times 10\text{hr} = 250\ \text{Wh} \qquad \text{Eq. 1}$$

$$\frac{60\text{W}}{0.9} = 67\ \text{W} \qquad \text{Eq. 2}$$

Equation 1 is the minimum amount of energy the battery needs to store. Equation 2 is the minimum peak output of the battery.

Design Overview

Team 15 has decided to go with a battery design. The battery was chosen over the other options due to being lightweight, cheap, and reliable. The main components of the design are the battery, the inverter, the battery charger, and a plastic housing.

The charger can be powered by 110V US household current, or 220V current used in other countries. It is capable of charging the battery overnight. The battery is a lithium ion pack that is regulated at 12 volts and has a capacity of 296 Watt-hours. The inverter has a pure sine wave output form, and can continuously put out 180 watts. All of these components will be contained in a lightweight, durable plastic case.

1. Battery

Capacity	296 Wh
Nominal Voltage	14.8 V
Max Discharge Rate	8 A
Dimensions	787x4.72x2.95 in
Weight	4.0 lb
Grams Equivalent Lithium	~24 g

Table 2: Specification of Battery

The battery has to provide sufficient energy to the dental device and the overall energy consumption is 500Wh for continuous working for 10 hours. Thus, we need two batteries to provide enough energy. Another consideration is that the power source has to be carried on a flight. So it must satisfy the FAAA regulations for lithium batteries. Equivalent Lithium Content (ELC) is a measure by which lithium ion batteries are classified. 25g of equivalent lithium content are equal to about 300Wh. Passengers can carry Up to 2 spare lithium ion batteries, not installed in a device (between 8 and 25 grams aggregate). So two batteries of 24g equivalent lithium content are within the limitation and our client is allowed to take that on a flight.

2. Inverter

Continuous Power	180 W
Output Voltage	120 V
Input Voltage	10-15 V
Output Frequency	60 Hz
Weight	1 lb
Efficiency	90%
THD	~3%
Dimensions	6.25×3.12×1.5

Table 3 Specification of Pure Sine Wave Inverter

Most of inverters on the market satisfy the size, weight, input voltage, output voltage, and power requirements. The only concerns left are cost and waveform. Inverters with the same specifications except the waveform have dramatically different prices. Alternative waveforms are shown in Figure 1. The price of a pure sine wave inverter is almost 3 times higher than a modified sine wave if the other specifications are identical. We want to analyze which output waveform is more suitable pure sine wave or modified sine wave. A main difference involved in our case with different waveform here is the harmonic. Harmonic is defined as the undesired wave at the frequencies which are integer multiples of desired frequency. For example, we want a sine wave at frequency of 60Hz and the harmonics are sine waves at 120Hz, 180Hz, etc. Harmonics are a distortion of the normal electrical current waveform, generally transmitted by nonlinear loads such as an inverter. A major disadvantage of harmonic distortion as shown in Figure 2 is that it will distort the waveform from the power source. Moreover, harmonic distortion will impact all loads in the circuit severely if the power of harmonics gets larger.

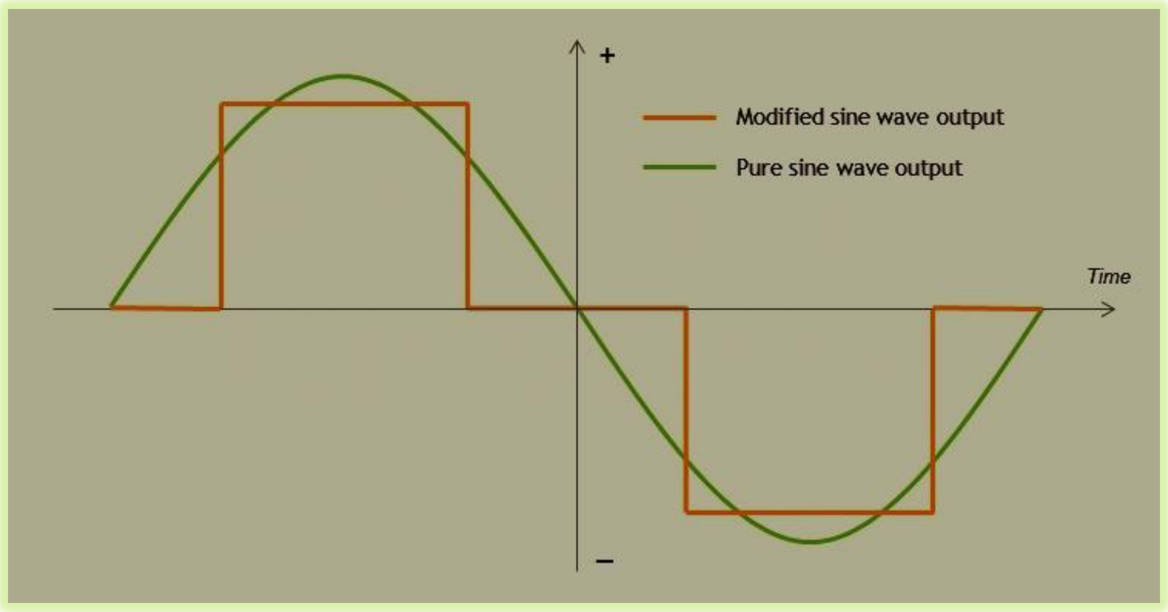

Figure 1 Pure sine wave and modified sine wave

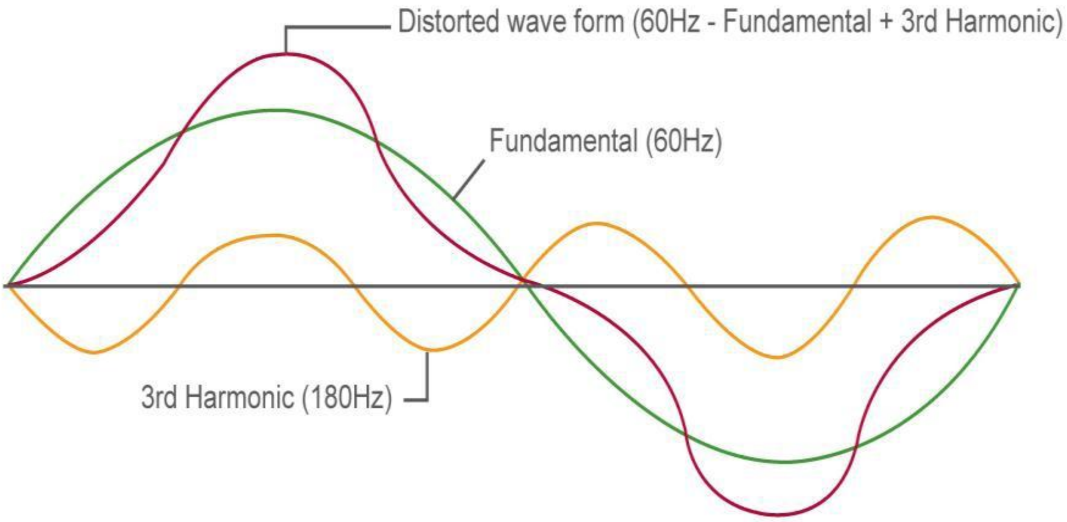

Figure 2 Harmonic distortion of the electrical current waveform

In order to account for the harmonics, an important criterion, total harmonic distortion (THD) is introduced to describe the performance of harmonic distortion of an inverter.

$$THD = \frac{\sqrt{\sum_{i=2}^{n} H_i^2}}{\sqrt{\sum_{i=1}^{n} H_i^2}} = \frac{\sqrt{H_2^2 + H_3^2 + \cdots + H_n^2}}{\sqrt{H_1^2 + H_2^2 + \cdots + H_n^2}}$$

H_i^2 is the power of wave at specific frequency

From the manufacturer’s specifications, THD of a pure sine wave inverter is less than 5% while a modified sine wave inverter is about 40%. Pure sine wave inverters are more expensive, but will run all AC loads, and are best for stereos, computers and other sensitive electronics. The Wig-L-Bug is a sensitive load and it is much more expensive comparing to the cost of inverters. To be conservative, a pure sine wave inverter is a better choice though it has higher cost.

3. Charger

Input Voltage	100-240V AC
Output Voltage	14.8 V
Charging Current	3.0 A
Dimension	6.1×3.3×1.9 in
Weight	0.8125 lb

Table 4 Specification of Charger

Since the charger has to be compatible with the batteries the team decides to buy a compatible charger for battery packs from the manufacturer of the battery. In order to make sure they are compatible, the team will test whether they work well or not as soon as we have the batteries and charger.

4. Package

Size	9×8×8 in
Weight	1.2 lb
Cost	$ 20

Table 5 Specification of Package

The major concern for packaging is cost and weight. Since the specification of package depends on the actual size and weight of the other components and how circuit is connected it may change its specifications. The table above shows our team desired specification of the package.

Test Procedure

In the test procedure, team members going to connect the battery to the inverter and the inverter to the wig-L-bug. We will run it for 10 hours simulating working conditions. We will continue running the wig-l-bug until we completely drain the battery, then we will charge the battery until full. We will contact the sponsor and demonstrate to them how it works. If the sponsor has issues with the power supply, we will address those issues as necessary.

Conclusion

We have finished the analysis of Wig-L-Bug and the design. Our design can be divided into four main parts: battery, inverter, charger and package. The selection of battery depends on FAA regulations, energy capacity and portability. For inverter, we have a detailed consideration on invert rate, total harmonic distortion (THD) and portability. Charger is determined by input voltage of power supply in India. Package depends on the actual size and weight of the other components and how circuit is connected it may change its specifications. For our design, we primarily consider battery capacity and portability of the whole system. Table 6 shows the overall specifications of the system. The remaining task for us is to build this design and insure that our design can meet our client’s requirements and works successfully.

Total Cost	$500
Total Weight	9 lb
Package Size	9×8×8 in
Energy Capacity	500 Wh

Table 6 Specification of Overall System

Reference

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