

HARVESTING ENERGY WITH HAND-CRANK GENERATORS TO SUPPORT DISMOUNTED SOLDIER MISSIONS

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ABSTRACT

Dismounted soldier power needs have changed significantly since fielding of the G-67B/G, a portable DC hand crank generator. A developmental hand crank system, with the potential for both military and commercial application, is under development to meet existing and emerging dismounted soldier power needs. A comparison of this developmental system with the currently fielded hand crank generator is presented herein to gain an understanding of the feasibility and advantages of such a device.

KEYWORDS

Palm Power; hand crank; energy harvesting; battery charger; DC generator; G-67B/G; dismounted soldier

1. INTRODUCTION

Hand crank generators were developed by the military to provide a source of portable field power when traditional electrical sources were unavailable. In the early 1970s, the Communications-Electronics Command (CECOM) developed the 1C G-67 direct current hand crank generator which utilized permanent magnet alternator technology and a Harmonic Drive with a 100:1 step-up gear ratio to provide high rotational speeds for the alternator's rotor. During the late 1980s – early 1990s, the US Army Research Laboratory (ARL), developed the G-67B/G as a successor to the 1C G-67. This newer unit employed the same basic principles of operation used by its predecessor, but it also had some significant design differences. Most notably, the G-67B/G used an 80:1 Harmonic Drive in a slightly different arrangement with the alternator. Limited production runs of the G-67B/G were completed in 1991 and 1994, and this generator is still used as part of the OP-177(V)1/U Special Operations Power Supply Kit. (Allmon & Hopkins, 1994)

More recently, the Department of Defense initiated a Dual Use Science and Technology (DUS&T) Program in an effort aimed at conducting research necessary to

determine the most promising concepts for harvesting energy from ambient and human sources. DUS&T programs seek to develop new technologies that can be utilized for both military and commercial applications. The efforts were concentrated on high power density and high portability. In June 2000, High Tide Associates of Palo Alto, CA submitted a proposal entitled “Manually Cranked Battery Charger” in response to DUS&T Topic CECOM 01-12. This proposal led to the development of the Palm Power energy harvesting system in a cooperative effort between High Tide Associates and the US Army Communications-Electronics Research, Development, and Engineering Center (CERDEC) at Fort Belvoir, VA.

Initial DUS&T program funding facilitated the design, fabrication, and delivery of a Palm Power laboratory model to the CERDEC Power Generation Branch. Additional funding provided by US Special Operations Command (SOCOM) led to the development and delivery of 12 Palm Power HTE-425 model prototypes. Four of these units were the focus of system characterization tests at Fort Belvoir during the past year. (Moyers et al., 2004)

With some additional performance upgrades aimed at increasing operational capabilities, CERDEC hopes to establish a product that can ultimately be used as a replacement for the G-67B/G in a new power supply kit for dismounted soldiers. This paper discusses test results for the two generators, offers an objective comparison of the respective technologies, and addresses current efforts and future direction for the Palm Power energy-harvesting program.

2. SYSTEM DESCRIPTIONS

2.1 Design characteristics of the G-67B/G

The G-67B/G, as shown in Figures 1a and 1b, was designed and developed as a portable, hand-cranked device for converting mechanical energy to electrical energy that can ultimately be used to power military radios, coding equipment, rechargeable batteries, and

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other electronic equipment in the field. Utilizing a samarium-cobalt permanent magnet alternator nested in a Harmonic Drive, the generator produces three phase AC voltage that is rectified and filtered. Since cranking the unit faster produces greater unregulated voltage, a voltage regulator circuit was required to keep output voltages low enough to prevent damage to batteries and other equipment during charging. The regulated voltage can drift as high as 33 VDC as the electronic circuitry reaches higher temperatures.

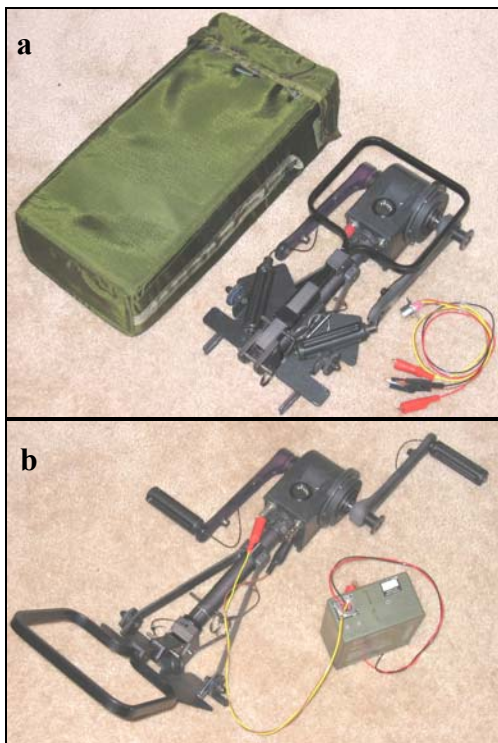


Figure 1. (a) The G-67B/G stowed configuration with carrying bag and battery cable. (b) Connected to BB-390 battery.

The entire G-67B/G, which also includes a folding stand for anchoring the device, weighs 6.5 lbs and occupies a 16 x 8 x 4 inch volume when in its stowed configuration. The two crank arms on the device are 6.63 inches in length. As part of the OP-177/ U Power Supply Assembly, the unit is packaged with a solar panel and various adapters and cables. The G-67B/G is primarily used to charge 24-volt batteries.

2.2 System characterization tests for the G-67B/G

In an October 1994 report (Allmon & Hopkins), ARL presented results of a series of tests that were conducted on the G-67B/G (and the 1C G-67) that compared the performance characteristics of the device when utilizing nine different rotor/stator configurations (including the configuration used during production). The performance of the configurations was determined through efficiency and acoustic noise testing. During efficiency testing, an

electric motor was used to vary the cranking speed of the generator, and a torque arm was rigidly connected to the generator and instrumented with a strain-gauge bridge to provide indirect torque measurements. Output voltage and current measurements were made with the generator connected to loads of 10 and 20 ohms. Values for input power, output power, and ultimately the efficiency were then obtained for the unit using measured data and Equations 1 through 3 shown below,

$$Power_{in} \text{ (mechanical)} = T \cdot \omega \quad (1)$$

$$Power_{out} \text{ (electrical)} = V \cdot I \quad (2)$$

$$Efficiency = \frac{Power_{out}}{Power_{in}} \quad (3)$$

where T is actual torque, ω is cranking speed, V is voltage, and I is current being supplied to the load.

Using the rotor/stator configuration incorporated on production units, a peak efficiency of 62% was observed with the generator cranked at 95 rpm while connected to a 10-ohm load. Approximately 73 watts of electrical output power were measured in this operating condition, but a peak output of approximately 88 watts was obtained at 105 rpm. Under a 20-ohm load, a cranking speed of 95 rpm yielded a maximum efficiency of 63.5% and an output of approximately 47 watts. A maximum output of 52 watts was obtained at 105 rpm with the 20-ohm load.

Acoustic noise measurements were recorded with a microphone directly in front of the generator head and 5 feet away for loads of 10 and 20 ohms. For the production rotor/stator configuration, sound pressure levels of 68.5 and 64.5 dBA were measured when operating the generator at 95 rpm under 10- and 20-ohm loads, respectively.

Another configuration consisting of a rotor with neodymium-iron-boron magnets and a different stator actually produced higher efficiencies and lower acoustic noise levels than the configuration used for production generators. Efficiencies as high as 69.5% were measured at 85 rpm with the 20-ohm load while sound pressure levels of 64 and 61.5 dBA were measured at 95 rpm under the two different loads. This developmental configuration likely would have been utilized for the generator had there been additional production runs.

The voltage regulator circuit of the G-67B/G proved to be its performance-limiting factor throughout testing. The electronics of the particular generator that was tested regulated voltage at 31.4 VDC. As cranking speeds were increased such that the unregulated output voltage was greater than 31.4 VDC, the efficiency of the device went down. Excess electrical energy was dissipated as heat in the regulator circuit, and correspondingly, data was not measured at speeds that caused the G-67B/G to limit

voltage in some cases. For the production rotor/stator configuration, 95 rpm was the maximum speed at which the unit could operate without limiting voltage during testing.

2.3 Design characteristics of Palm Power HTE-425

The Palm Power HTE-425, shown in Figures 2a and 2b, is a lightweight, hand-held, electrical power source that extracts mechanical energy from human hand cranking and converts it to electrical energy that is conditioned and controlled in order to safely charge portable batteries and small electronic devices at high rates. The device utilizes neodymium-iron-boron permanent magnet generator technology for its main power source and digital microprocessor-based electronic circuitry and power converter to control all generator functions. The converter can also be used to recognize and regulate auxiliary inputs such as solar panels.

The user interacts with the Palm Power unit through an 8-character LED display that allows for monitoring of various system parameters such as cranking speed, current, voltage, power output, and cumulative energy in joules. When cranked or simply connected to a battery that has retained a small amount of charge, the device uses a relatively small amount of current to power the microprocessor and LED display. Controls are also provided such that the user can adjust the cranking resistance experienced during cranking. Greater power outputs are produced when the device is operated at faster speeds and higher crank drag torques. The output voltage of the device is dependent on the voltage of the battery being charged; it produces voltages near 8 VDC when charging an 8-volt battery and voltages near 12 VDC when charging a 12-volt battery.

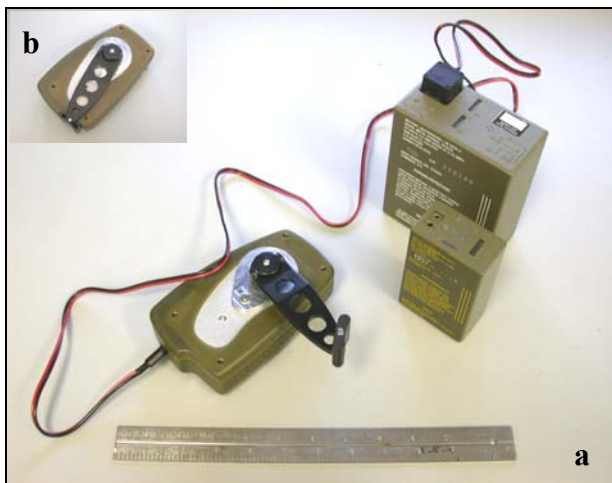


Figure 2. (a) Palm Power unit connected to a BB-390 battery. BB-2847 also shown. (b) Palm Power with hand crank stowed.

The Palm Power unit weighs 1.3 lbs and occupies a 2 x 3.5 x 6 inch volume with its hand crank in the stowed

configuration; the device has a 3.75-inch crank arm. Power outputs of 20+ watts are attainable with the unit, but the maximum output is dependent on the user's capabilities rather than device limitations.

2.3 System characterization tests for Palm Power

Test and evaluation efforts conducted on the Palm Power system during the past year were aimed at characterizing the system where specific requirements are not defined. The testing provided investigations of the battery charging capabilities and overall system performance of the units through a range of cranking speeds and input drag torques. Performance tests were designed to determine the overall efficiency of the units through various cranking speeds and torque settings, as well as the optimal cranking speeds and torques for operating at peak efficiency. In addition to basic power generation studies, other tests included a 50-hour endurance test, and a sound level test for aural non-detectability. Palm Power units were used to charge BB-390 and BB-2847 batteries throughout the tests.

The test setup utilized a 40-watt speed control motor and coupler to crank the removable unit at selectable speeds and torques. The CERDEC Power Generation Branch also modified the test stand to incorporate a 30 inch-pound in-line rotary torque sensor to measure the mechanical power input supplied by the motor. A non-contact RPM sensor (stroboscope) was consistently used to verify the cranking speed provided by the motor, and a data acquisition unit was used to obtain voltage & current data. Equations 1 through 3, as described previously, were used to calculate input power, output power, and efficiency. Ambient temperatures and internal temperatures of the Palm Power units were also logged during endurance testing.

Test results in Figure 3 indicated peak system efficiencies around 50% while Palm Power units were operated at mid-range torques and at a cranking speed of 120 rpm (2 revolutions per second). In this range of operating points, the device generates 8 to 11 watts of electrical power. The average male soldier can reasonably be expected to crank a Palm Power unit for about 5 minutes in this range.

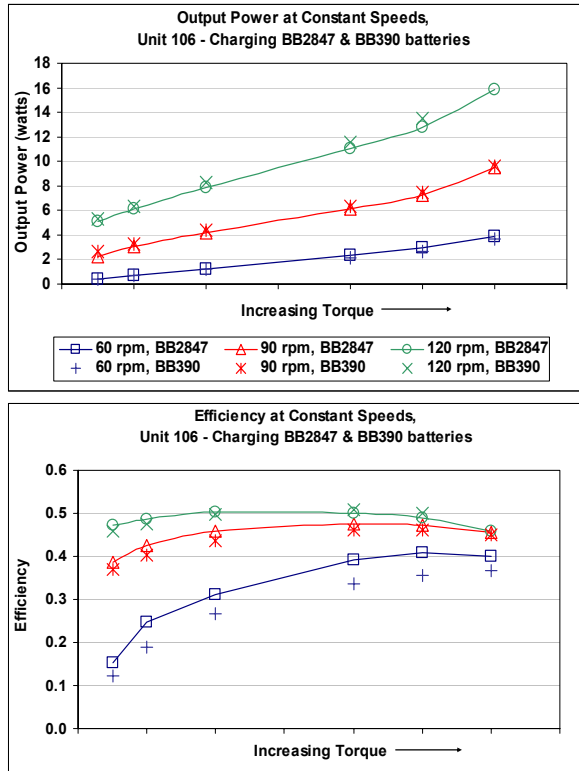


Figure 3. Performance test data for Palm Power units operated at constant speeds

A maximum output of 16 watts was measured when charging a BB-2847 at high torque and 120 rpm, but the output of the Palm Power unit was limited by the capabilities of the test stand rather than the device itself. Units tended to produce the same amount of electrical power regardless of whether a BB-390 or BB-2847 was charged but were more efficient at charging BB-2847 batteries, particularly at lower speeds. These same trends were also observed during tests in which the performance of the device was examined when maintaining constant power output by adjusting cranking speed at various crank drag torques. Power outputs of 3, 5, and 10 watts were investigated.

To characterize the endurance and reliability of the Palm Power system as a result of continued use, one of the units was subjected to 50 cumulative hours of operation during which batteries were charged at speeds of 90 or 120 rpm and low, medium, or high crank drag torques. Starting with discharged BB-390 and BB-2847 batteries, times were recorded at which a battery reached various states of charge (SOC) as per the battery's (SOC) indicator. As expected, charging occurred quickest during operation at higher torques and higher speed (120 rpm). In one particular test with a BB-2847, the battery reached 21% SOC within 28 minutes of accumulated cranking time and 83% after 127 minutes. Charging was also continued past 83% in this particular test scenario until the circuit opened after 156 minutes, implying a

fully charged battery. No failures were experienced and no significant degradations in performance were observed as a result of the 50-hour endurance and reliability run.

Throughout testing, two performance-limiting design issues were consistently encountered. Continuous operation at higher outputs (high torques & high cranking speeds) can result in an "Overtemp Alert" on the unit's LED display, but units have firmware logic that automatically reduces output at the onset of the alert to prevent damage to the unit. Additionally, units have an internally-set cutout threshold near 13.5 volts that limits the unit's effectiveness when charging higher voltage batteries such as the BB-390.

To examine acoustic noise levels produced during operation of Palm Power units, a sound level test for aural non-detectability test was conducted per MIL-STD-1474C. One-third octave sound pressure levels were measured at multiple locations in a 2-meter radius around the operator while the device was cranked at high torque and high speed (120 rpm). Ambient noise level readings were recorded, and the test was also repeated with measurements being taken at a 10-meter radius around the operator.

Figure 4 shows field measurements that were obtained in relation to the noise limits associated with non-detectability distances of 100 and 200 meters as per MIL-STD-1474C. The relatively high sound pressure levels measured in the 2000 to 4000 Hz range dictate that the Palm Power HTE-425 is non-detectable when an observer is at a distance between 100 and 200 meters away (and beyond) in a "rural area" environment. While this data suggests that the device has potentially undesirable noise levels for operation in a tactical environment, it should be noted that audible noise requirements have not yet been established. (Moyers et al., 2004)

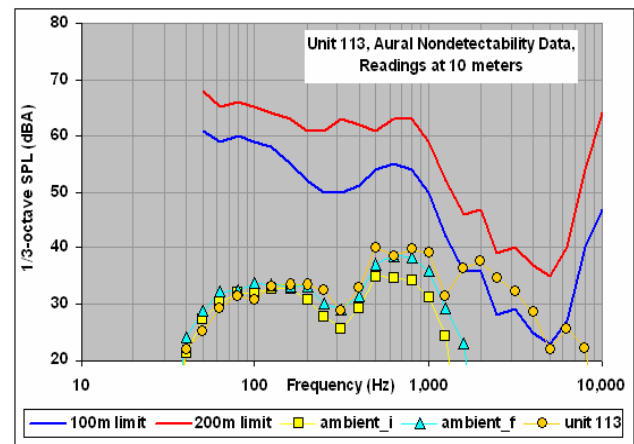


Figure 4. Palm Power noise levels in comparison to "rural area" limits for non-detectability at 100 & 200 meters.

3. SIDE-BY-SIDE COMPARISON

Results of system characterization tests obviously identified various strengths and weaknesses for both generators. This section aims to provide a direct comparison of the two technologies while identifying

other significant differences that are not necessarily performance-based. Table 1 shown below outlines several of the relevant considerations surrounding the G-67B/G and the Palm Power HTE-425 and is followed by brief, but more detailed synopses.

Table 1. Generator Characteristics Comparison

Generator	<i>G-67B/G</i>	<i>Palm Power HTE-425</i>
Weight	6.5 lbs	1.3 lbs
Volume	Stowed, 2 x 3.5 x 6 in. (42 cu. in.)	Stowed, 16 x 8 x 4 in. (512 cu. in.)
Alternator	Permanent Magnet, samarium-cobalt	Permanent Magnet, neodymium-iron-boron
Drive	Harmonic, 80:1 gearing	Spur gearing, 13:1
Max output	≈ 90 watts output obtained during testing	20+ watts attainable but dependent on user rather than device
Peak Efficiency	63.5% during testing at 95 rpm with 20 ohm load	50% at mid-range torques and high speed with mil-std batteries
Ruggedization	Extensive testing to assure compliance with requirements for extreme temps, vibration, shock, immersion, humidity & salt	No formal requirements established and otherwise no testing for verification
Reliability	Required Mean Time Between Operational Failure ≥ 790 hours	No formal reliability requirement, but no failures after 50 hrs endurance testing
User Interface & Feedback	Voltage meter	LED display indicates cranking speed, voltage, current, power, cumulative energy, temperature, peaks, and elapsed time; Control buttons set crank drag torque & data displays
Operation	Unit is anchored with stand and cranked with both hands in bicycle motion	Unit is held in one hand and cranked with the other
Noise	68.5 dBA at 5 ft with 10-ohm load	Non-detectable at a distance between 100 & 200 meters and beyond; 58.6 dBA max broadband reading at 2m (6.56 ft)
Variable input resistance	No adjustment provided	User-selectable crank drag torque
Voltage Regulation	Voltage varies with cranking speed; Voltage is regulated at 30 VDC	Regulation independent of speed - voltage regulated to match battery voltage; Cutout threshold exists at 13.5 volts
Commercial Application	Not feasible for commercial market	Inherently feasible for military & commercial apps
Cost per unit	≈ \$6,000/unit for lot of 1200 to 1300 units; (See <i>Cost & Commercialization</i> on p. 7)	Anticipate ≈ \$2,500/unit for lot of 1200 to 1300 units
Technology Readiness	Currently fielded as part of OP-177/U kit; No longer in production	Developmental; Under field evaluation by SOCOM
Device Limitations	Regulation reduces efficiency above certain speeds; Output is too high for smaller electronics; Primarily designed for 24 volt batteries	Internal cutout threshold at 13.5 VDC (to be removed); Output is too high for smaller electronics in existing config. Occasional over-temps during continued use at high outputs

Weight & size: The relatively small size and weight of the Palm Power system is one of its stronger characteristics considering the relative amount of power it provides. It has a volume 1/12 the size of the G-67B/G and weighs 5 lbs less, but it produces lower power levels than the G-67B/G (depending on user effort). Figure 5 on the following page shows the relative sizes of the two generators in their stowed configurations.

Electrical performance: During testing with 10- and 20-ohm loads, the G-67B/G operated at a peak efficiency of 63.5% and produced power outputs of nearly 90 watts. Palm Power was tested with military standard batteries and yielded maximum efficiencies of 50% at mid-range crank drag torques and high cranking speeds; higher levels of user input resulted in maximum power outputs above 20 watts. Further testing with more similar procedures and loads is required to arrive at a more representative comparison for the electrical performance of the two generators.



Figure 5. The G-67B/G and Palm Power HTE-425 in stowed configurations.

System Design: Both systems use permanent magnet alternator technology. Electronic circuitry converts the output of the alternator from AC to DC. The G-67B/G is essentially a “fixed” voltage device since it produces up to 30 VDC output regardless of the type of battery it is charging. The maximum speed at which the generator can be cranked is limited by the voltage regulation circuitry since faster cranking speeds produce greater unregulated output voltages. The Palm Power HTE-425, however, operates at a regulated output voltage that is dependent on the voltage of the battery to which it is connected. Output power for the unit is only limited by the user’s capabilities. Additionally, the G-67B/G utilizes a Harmonic Drive with an 80:1 gear ratio for its mechanical drive mechanism while Palm Power has traditional spur gearing with a much smaller ratio giving lower gear stresses.

User Interface & Feedback: The Palm Power unit’s user interface is another characteristic that distinguishes it from other energy harvesting technologies. When cranked or simply connected to a battery that has retained a small amount of charge, the device draws a small amount of power for its microprocessor and LED display. The user is given feedback regarding various output performance parameters including cranking speed, voltage, current, power, and cumulative joules of energy produced. The user can manipulate which parameters are displayed using two control buttons on the unit. These buttons also allow the user to adjust the amount of resistance that is experienced while cranking; greater resistances produce higher power outputs at a given cranking speed. The G-67B/G has a voltage meter for user feedback, but it provides no means of adjusting input resistance or determining charging progress. The user feedback features of the two generators are shown below in Figures 6a and 6b.

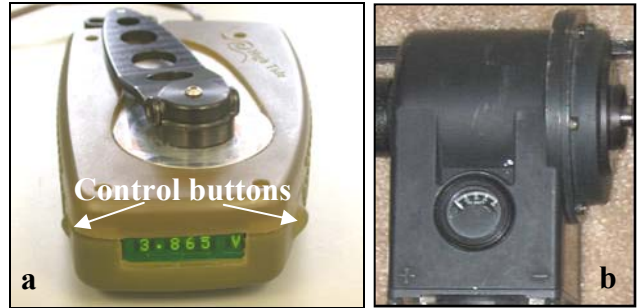


Figure 6. (a) Palm Power LED display with user controls highlighted (b) G-67B/G voltage meter

Operation & Ergonomics: To operate the Palm Power HTE-425, the user holds the unit in one hand and cranks with the other. While much emphasis was placed on ergonomics during the development of the unit, some aspects of the design can be further refined to accommodate user comfort. For example, depending on the size of the operator’s hand and the grip applied to the unit, it is possible to “scrape” one’s fingertips with the crank. Ergonomics issues are currently being addressed in an on-going contract effort with High Tide Associates. Conversely, the G-67B/G has a two-handed cranking arrangement in which the device is anchored by the user sitting, kneeling, or standing on the folding stand while cranking the device in a bicycle fashion. Figures 7a and 7b show the G-67B/G configured for seated and standing operation, respectively, in comparison with the operational configuration for the Palm Power unit.

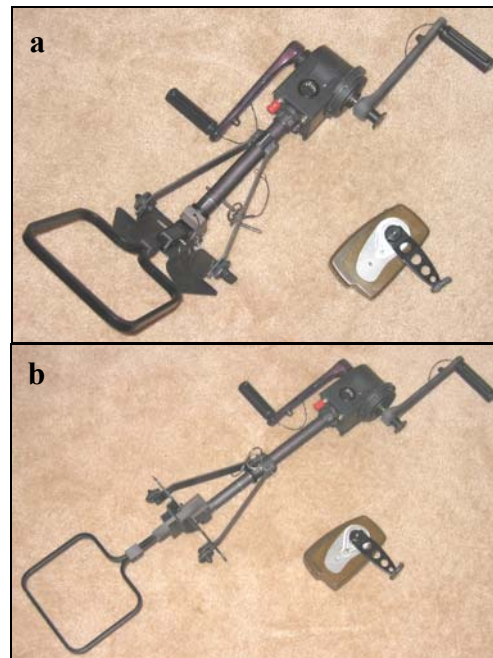


Figure 7. (a) G-67B/G configured for seated operation. (b) G-67B/G configured for operation while standing. Palm Power operational configuration also shown.

Performance limitations: As stated previously, the output and efficiency of the G-67B/G are limited by its design. Efficiency is limited by the voltage regulation at higher cranking speeds, and the output voltage is also dependent on the speed at which the device is being cranked. In its basic configuration, the unit is primarily used to charge 24-volt rechargeable batteries such as the BB-390. Auxiliary circuitry would be required for the device to accommodate batteries of different voltages since its output is inherently too high for batteries such as the 8-volt BB-2847 and those of lesser voltage.

Similarly, the Palm Power HTE-425 also has some limitations associated with voltage output. While the unit effectively charges BB-2847 batteries, its power output is currently too high to be compatible with lesser power requirements of smaller electronics. On the other end of the spectrum, the cutout threshold near 13.5 volts limits the unit's effectiveness at charging higher voltage batteries such as the BB-390. This issue was encountered throughout testing even though the pins for the connector to the battery were arranged such that the battery's two 12-volt cells could be charged in parallel. Both of these issues are being addressed under a new contract effort. Additionally, while the Palm Power units had the previously-mentioned issues with overheating, thermal management is not expected to be a performance limiting issue during normal operation where human strength and endurance are a factor.

Reliability: The G-67B/G is currently fielded and is subject to military specifications described in MIL-G-49469(HD). In regards to reliability, the device is required to demonstrate a Mean Time Between Operational Mission Failure of no less than 790 hours. Reliability testing involves operating a generator for one hour at a time at a cranking speed of 68 rpm while connected to 15-ohm load followed by 1 hour of rest. This procedure is repeated until the generator has accumulated a total of 87 operating hours, and a sample of 10 generators is tested for reliability with this procedure. (US Dept. of Defense, 1991)

The Palm Power unit is still a proof-of-concept, and in the absence of formal requirements, the 50-hour endurance test was conducted to investigate the reliability of the device. The device was used to charge BB-390 and BB-2847 batteries at different cranking speeds and crank drag torques. No failures were observed and the performance of the unit was not compromised as a result of the accumulated operational time.

Ruggedization: As per MIL-G-49469(HD), the G-67B/G was subjected to extensive product assurance testing. Units were required to meet operability and performance requirements at operating temperatures from -50°F to 120°F, after vibration and shock, after prolonged

exposure to humid conditions, after immersion in water, and after exposure to salt atmospheres characteristic of coastal areas. (US Dept. of Defense, 1991) No formal requirements for ruggedization have been established for the Palm Power unit since it is still in developmental stages.

Cost & Commercial Application: The G-67B/G was developed by ARL for other Department of Defense agencies and was therefore never intended for the commercialization. The cost per unit was approximately \$6,000, but this cost covered various aspects of the program including program management, production, production support, and design changes. (Personal communication with John Hopkins of ARL.) As part of a Dual Use Science & Technology program, Palm Power was inherently developed as a technology with both commercial and military applications. The materials and processes used were taken from the high-volume commercial electromagnetics market.

Audible Noise Levels: Two entirely different procedures were used for noise testing of the G-67B/G and Palm Power HTE-425. The G-67B/G produced broadband sound pressure levels of 68.5 and 64.5 dBA at 5 feet from the head of the generator while the generator was cranked at 95 rpm and connected to 10- and 20-ohm loads, respectively.

For Palm Power, MIL-STD-1474 aural non-detectability testing involved measuring 1/3-octave noise sound pressure levels at multiple locations in a 2 meter (and also 10 meter) radius around the operator and device. Broadband measurements at 2 and 10 meters were also included in the data acquisition. The maximum broadband reading for Palm Power at 2 meters (6.56 ft) was 58.6 dBA while the unit was connected to a BB-2847 and cranked at 120 rpm with high crank drag torque. Further testing with more similar procedures and operating conditions is required to arrive at a more representative comparison of noise levels.

4. ON-GOING IMPROVEMENTS TO THE PALM POWER UNIT

Based on test findings and user feedback, SOCOM has provided additional program funding under a new contract in FY04 for the development of retrofit upgrades to existing Palm Power HTE-425 units. The upgrades will ultimately improve functionality and enhance operational capabilities by incorporating provisions such that the units are compatible with a wider range of electronic devices. Performance limitations associated with the internal cutout threshold will be addressed, and firmware and circuitry changes will be made to improve instrumentation for sensing voltage, cranking speed, and

current to provide more accurate feedback to the user. Units will also be modified to incorporate an energy buffer or energy storage device such that the units can accommodate electronics devices with small power consumption such as personal data assistants (PDA), cell phones, and global positioning system (GPS) receivers; Palm Power in its existing configuration likely produces too much power for these devices, even at lower output levels. Refinement of the ergonomics is also planned in an effort to further accommodate user comfort. Figure 8 shows various concepts that are being considered as ergonomic enhancements for the grip and crank.

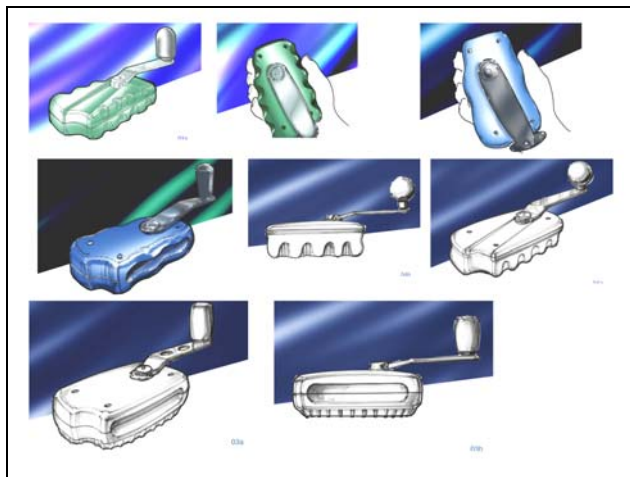


Figure 8. New Palm Power grip & crank concepts under consideration

Although it is not included under the current contract effort, improved sound attenuation will likely need to be addressed at some point for Palm Power, whether through system design modifications or improvements to the manufacturing and assembly process. Formal noise requirements have not been established, but low observability is a relevant consideration for this technology since the device is intended for use in dismounted soldier missions. (Army CERDEC, 2004)

5. CONCLUSIONS

Based on user requirements and feedback during the early 1990's, the G-67B/G was primarily designed to recharge 24-volt batteries and provide power to radios and other electronic equipment with similar voltage requirements; the power output of the device makes it a feasible option for completely recharging a higher voltage/larger capacity battery in 1.5 to 2.5 hours. During the 10+ years since the G-67B/G was first produced, the equipment inventory and associated power requirements for outfitting dismounted soldiers have changed. Department of Defense organizations such as SOCOM are opting for smaller, lighter equipment, and technological advancements in electronics and computers

have resulted in devices that require smaller amounts and greater varieties of power to operate. Accordingly, Palm Power is being developed as a small, flexible, lightweight emergency power source that can be used to "top off" or restore a charge to larger capacity batteries while also providing power levels appropriate for completely charging smaller batteries such as those found in cell phones, PDAs, and other small electronics.

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ADDITIONAL INFORMATION

To learn more about the Palm Power energy harvesting program, please contact the corporate and government program representatives shown below.

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