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Intermediate depth ice core drilling support systems: power generators and shelters

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Abstract: Arctic and high altitude ice coring operations require lightweight and efficient equipment. Power sources, fuel and shelters in some cases compose up to 50% of the cargo delivered to a drilling site. Solar panels, two-stroke gasoline and air-cooled portable diesel generators have been used in Arctic and high altitude glaciers to power the drilling setup. On the summit of Mt. Kilimanjaro (5895 m above sea level) a portable air cooled diesel generator provided 1 kW of electricity for electro-mechanical drilling. The average fuel consumption was 0.66 liters of fuel per hour. More than 150 m of ice cores in three locations were drilled with this power source. For 150 m shallow ice coring a diesel generator and fuel was found to be 40% of the weight than 1.5 kW array of solar panels. Assembly and disassembly of diesel generator takes one tenth of the time necessary to assemble/disassemble the array of solar panels. However, solar power is environmentally friendly.

The purpose of the shelter is to protect personnel and equipment from the wind and blowing snow. At high altitude drilling sites the shelter provides a shadow to keep the drill and an ice core at temperatures below freezing. A set of lightweight shelters allowed flexible and weather independent ice coring operations in the Arctic and high altitude glaciers. Custom-built and commercially available lightweight geodesic domes have a 12 man/h setup time and provide comfortable working conditions during stormy days in Greenland and on the summit of Mt. Kilimanjaro. An additional reflective cover maintains the air temperature inside of the dome below the freezing point at 1200-1300 W/m^2 solar radiation. A portable, fast setup and commercially available shelter for the power generator was tested and demonstrated durableness during stormy days in Greenland.

This paper describes field-tested, lightweight, reliable and fuel-efficient power generators and lightweight shelters.

1. Introduction

Transportation of field gears, drilling equipment and fuel is often the most expensive part of the ice coring operation. For example, in the Russian Arctic the cost of shipping 1200-2000 kg of equipment from the closest airport to the drilling site was 10000-15000 US dollars. At high altitude mountains where, in most instances, only manpower can be used, equipment was delivered by porters in small (15–30 kg) pieces. Therefore, the use of lightweight and fuel-efficient equipment and support systems for ice coring permits safe and cost-efficient field operations. The use of lightweight components also requires less physical effort from the field crew during assembly and operation of the equipment.

Table 1 shows the weight of major components of an intermediate depth Arctic ice coring operation. Excluding the ice core storage boxes and transportation containers the weight of drilling equipment composed less than 10% of the total cargo delivered to the drilling site. The rest of the cargo is made up of support systems necessary to conduct field activity. Like most other ice coring operations drilling at high altitude requires power, weather protected working space, personal tents and food. In the Arctic up to 30% of ice coring operation logistics is dedicated to power system and fuel. On high altitude glaciers that fraction is usually bigger.

Setup time of a drilling system is a significant fraction of the drilling operation. Assembling the drilling setup after shipment takes 4 man-hours, assembling the geodesic dome shelter takes 12 man/h (disassembling takes 6 man/h). Assembling and disassembling the 1.5 kW array of solar panels requires about 12 man/h, while assembling/disassembling the diesel generator takes only 0.25 man/h. Two drillers and two core processors would spend 56 man/h to core down to 100 m. Maximum setup time of the BPRC portable drilling system (Zagorodnov *et al*., 2000), including a shelter and a 1.5 kW array of solar panels, is about 40% of the total drilling time down to 100 m. Drilling in open air and using a combustion engine generator instead of solar panels allows reduction of the setup time to 8% of the drilling time. In some cases, when good weather persists for a few days, open air drilling down to the depth of 100–150 m is a good option. However, drilling down to 200–300 m and deeper usually requires a shelter. The comfort of working inside a shelter always pays back in the form of more productive drilling.

In this paper, the merits of different power systems and shelters are investigated in

Table 1. Cargo list for Windy Dome ice coring.

Item	IN, kg/% of total weight	OUT, kg/% of total weight
6 person and personal staff	700/10.0	700/10.9
Food (18 man/month)	600/8.8	350/6.2
2 living tents and kitchen equipment	320/4.7	320/5.0
Propane (2×50 L bottles)	120/1.8	0/0
Heating stoves (2 each)	80/1.1	80/1.25
Heating fuel (3 drums)	600/8.8	0/0
Drilling shelter	350/5.2	350/5.5
Power generator (2 each)	250/3.7	250/3.9
Diesel fuel (6 drums)	1200/17.7	0/0
Snow machine	350/5.2	350/5.2
Gasoline (2 drums)	400/5.9	0/0
Drilling equipment	560/8.3	560/8.7
Ethanol (5 drums)	1000/14.7	0/0
Ice core (400 m)	0/0	3000/46.8
Automatic weather station	250/3.7	0/0
Total	6780	5960

conjunction with intermediate and shallow depth ice coring in Arctic and high elevation glaciers.

2. Power systems

Intermediate depth ice coring requires 1-5 kW of electric power. Specifically, electromechanical (EM) drills require 0.5-1.5 kW, while thermal drills need 2-5 kW. The BPRC EM drill and the portable winch need 0.6 kW and 1.0 kW of electricity, respectively. The BPRC high altitude ice coring operations were conducted either with an array of solar panels, two stroke gasoline engine generators (Koci, 1988) or a portable air-cooled diesel. All power systems have advantages and limitations that make them suitable for specific weather conditions and logistic support. Different power systems have been used during BPRC ice coring operations over the years. The specifications of these systems are presented in Table 2.

Table 2. Specifications of portable power systems.

Power system	Power, kW	Fuel, l/h	Weight*, kg	Total weight: 100 h or 300 m ice coring; kg
Solar	1.5 (3.0)	–	255 (510)	255 (510)
Gasoline, "Rotax" 20 hp	1.5 (5.0)	2.5 (4.3)	75	325 (500)
Diesel, "Yanmar" 7 hp	1.0	0.66**	63	129
Diesel, "Yanmar" 9 hp	1.5 (3.0)	1.65 (2.1)	125	290 (335)

* weight includes: engine, alternator, frame assembly; solar panels mounting and frames, electrical junction boxes.

** at 6000 m a.s.l., 80% load.

The estimates of fuel consumption are based on engines' factory rating. It is assumed that at 1.5 kW power EM drill maintains an average ICPR of 3 m/h; TD produces 2 m/h below 150-200 m depth at 3 kW.

2.1. *Solar panels*

Solar panels are the most environmentally friedly source of electric power. Along with the obvious advantages of this power source come the following limitations: 6-8 hours of day time operation; clouds and wind may restrict or stop power generation for hours or days. Conventional solar panels have an aluminum frame that supports a photosensitive media covered by glass. Such panels typically rated for 60 W and weigh 8.2 kg. Without directing them to the sun they are capable of producing 50-60 W of electricity (less on a cloudy day) at high elevation. Therefore, in order to have about 1.0 kW of power during a working day, including time when the sun is low or the air is hazy, an array of 30 solar panels (total weight 246 kg) is necessary. To make panels more stable in the wind they have to be assembled in groups of five and laid flat on the ground. Coupling brackets and electrical junction boxes with cables weigh 20-25 kg. Setting up and tearing down an array of solar panels requires about 6-8 man/h. This long setup time of conventional solar panels is a disadvantage for multiple drilling sites also. However, the environmental advantages of solar panels are still unsurpassed by combustion engine systems.

A new type of flexible panels is now commercially available. These panels weigh half as much as the conventional panels and are less vulnerable in windy conditions and damage during transportation. It may be possible to eliminate the frames and drastically cut the weight (40–60%) and assembly time (80%) of a 1.5 kW array of panels. The cost of a 1.5 kW array of flexible panels is about 12000 US dollars.

Note that the weight advantage of a conventional solar power system over a conventional combustion engine generator is feasible when the total depth of ice coring exceeds 500 m per drilling site. The same is true if an array of flexible panels is compared with a diesel engine generator equipped with a permanent magnet (PM) alternator described below.

2.2. *Combustion engine power generators*

At drilling sites with prevailing cloudy and windy weather the combustion engines are still the most convenient source of electric power. Two-cycle gasoline engines have a sufficient weight advantage over four-stroke gasoline and diesel engines. At the same time, diesel engines have better fuel efficiency than any gasoline engines. Therefore, in the long run a heavier diesel engine requires less fuel at the drilling site. The same is true about the four-stroke gasoline engines. Common perceptions are that a diesel engine is more robust, more reliable and creates fewer technical problems in the field. But experience shows that at low temperatures and at high altitudes it is very difficult or impossible to start the diesel engine.

Portable air-cooled diesel generators were used on the Franz Josef Land and Greenland ice coring operations at 600 m a.s.l. and 2750 m a.s.l., respectively. Engines demonstrate durability and good fuel efficiency. In most instances generators have been in use 24 hours a day for at least one week. At high altitude glaciers: Mt. Sajama (6548 m above sea level; a.s.l.) ice cap and Mt. Kilimanjaro (5895 m a.s.l.) ice fields electromechanical ice coring was conducted with solar panels and a modified air-cooled portable diesel. The basic principle of the diesel engine ignition is the compression of air in the combustion chamber up to the pressure when dispersed fuel ignites. At high altitude sites where the atmospheric pressure and oxygen content are low starting a diesel engine becomes a problem. In fact, it is almost impossible to start a conventional diesel engine above 4000 m a.s.l.

A portable 7 hp (at sea level) Yanmar air-cooled diesel engine was modified in such a way that the combustion chamber was sized down by about 30% of its original volume and the cross-section of the air inlet was enlarged by about 20%. Also, a straight tube replaced the muffler. In such configuration the weight of the engine is 29 kg. The cost of engine modification is around 1000 US dollars.

A smaller combustion chamber helped to increase compression and made it possible to start (recoil starter) the engine at low atmospheric pressure. According to our estimations, modification of the combustion chamber should allow one to run the engine at an elevations from 4000 to 7000 m a.s.l. Power output of the modified engine is proportional to oxygen content in atmosphere. We experienced some difficulties starting a cold engine above 5000 m a.s.l. at temperatures slightly below freezing. Starting the engine at 6548 m a.s.l. at the temperature slightly above melting point was not a problem. At Mt. Kilimanjaro most of the ice coring was conducted with this generator. Modified diesel was easy to start, and average fuel consumption was 0.66 liter per hour. One person can assemble the engine and the generator in 15–30 min. The total amount of fuel used for drilling 150 m of ice core was about 20 liters.

The relatively simple modifications described above do not add either moving parts or weight to the engine and, most importantly, permit to start it at high altitude without additional special devices. In contrast, other modifications, such as addition of a super- or turbo-charger (SC or TC) require an air compressor mechanically or electrically coupled to the engine or to different power source. There is also a number of performance disadvantages of the generator with an SC or TC system. First of all, TC will not increase the air pressure in the combustion chamber without running the engine and, therefore, does not help start the engine at high elevation. Although, an electric SC with a battery could increase the air pressure at the air inlet and help to start the engine. Secondly, at an altitude above 3000 m a.s.l. an SC or a TC will consume most of the power gained. And thirdly, neither an SC nor a TC is efficient when used with one-piston engines. Aside from additional weight and increased fuel consumption, running of high-rpm devices (SC and TC are turbines) in a harsh environment increases the chances of a total power system malfunction. So far such devices have been developed only for engines larger than 30 hp.

The weight of any combustion engine generator set can be drastically reduced with a permanent magnet (PM) type alternator. A custom made 6.5 kW PM alternator weighs about 15 kg, is about 90% efficient, and costs 1450 US dollars; lighter (6 kg), more efficient (94%) and cheaper ($300 US dollars) PM alternators are in the development stage and will be available soon. A conventional alternator of that power weighs 45–80 kg and is 60–70% efficient on average. Another advantage of a PM-type alternator is the possibility of switching from 120 VDC to 280 VDC or to 400 VDC output. This eliminates the need for a heavy step-up transformer used for thermal drilling. Rectified (DC) output also allows for parallel connection of two, three or more generators. This option makes it possible to run the EM drill with only one (1.5–2 kW) generator, and use two or three such generators with the thermal drill, which requires more power. During the night, when there are no drilling activities just one generator can provide power and keep the other generators warm and ready for day usage. Therefore, the switch from the conventional alternator to a PM-type alternator will reduce the weight of the power system by about 40–55% and increase fuel efficiency by at least 20%.

A less common logistic problem with combustion engine power generators is the lack of certain kinds of fuel at remote sites. For instance, at Franz Jozef Land (Zagorodnov *et al*., 1998) only old and dirty diesel oil was available at the base site. It seems that the diesel oil is more common at remote places than gasoline, especially of high-octane grades. Finally, diesel oil has a higher flash point (~66°C) than gasoline (~50°C) that makes it safer for operation.

There is one problem associated with any type of portable combustion engine generators. An abrupt change of load, which is very common during ice coring, causes a long lasting (on the order of 0.5 s) surge of output voltage. In our experience, the surge is not strong enough to damage drilling controllers, but we have seen a few blown fuses in delicate electronics, such as electronic scales and radios. We have also found that conventional voltage suppressers were burned out by the first power surge. A possible explanation is that conventional devices are designed for very short peaks of power.

Therefore, a special voltage suppresser must be used if delicate electronics is to be powered from the drilling system power source.

2.3. Shelters

Maritime Arctic is known for its bad weather. Quite often wind and blizzards make it very difficult to drill or process ice cores without shelters. Ice coring inside a shelter allows continuous work in comfortable conditions. For some years Polar Ice Coring Office provided an aluminum frame shelter (geodesic dome) that was used in two high elevation ice coring operations (Koci, 1989; Koci and Zagorodnov, 1994). To supplement this shelter the BPRC ice core research group has acquired two geodesic dome shelters. The first one, commercially available for 3000 US dollars, has a steel frame (weight 135 kg) and a cover made of heavy canvas (70 kg). It is 6.2 m in diameter and 4.2 m high. The dome is equipped with 3 zipped doors and a PVC-laminated canvas bottom skirt. Three persons can set it up in 4–5 hours. This dome has been used in the Franz Jozef Land (Russian Arctic) and Raven (Greenland) ice core operations. It was field proven to be stable during storms. On the other hand, it is heavy and required a lot of effort to set up.

A custom made geodesic dome of the same size has been built and used in Greenland and Mt. Kilimanjaro field operations. Its aluminum frame with quick connectors to the assembly rings allowed setup time of 10 man/h. The cover of this dome was made of Spectra® Nylon (registered trademark of AlliedSignal Performance Fibers). Spectra® is a high molecular weight polyethylene (HMWPE) and the strongest and lightest manmade fiber. Spectra fiber exhibits superior resistance to chemicals, water and ultra-violet light. The cover is extremely elastic at low temperatures, and permits fast and effortless placement. Total weight of the shelter is about 200 kg of which the shell is about 35 kg and the rest are studs and connecting rings. As an alternative, it may be possible to use a commercially available steel frame, which costs only 400 US dollars and is slightly lighter than the aluminum one. Heavy canvas currently could be replaced with a lighter fabric such as Spectra®.

A common problem with shelters is greenhouse heating, when air temperature inside the shelter rises well above the ambient temperature. In Greenland, at -6°C, with strong wind on partly cloudy day the air temperature inside the dome was 2–4°C above the melting point. At high altitude in the tropics this effect is much stronger. To reduce green house heating, a cap made of aluminized fabric was placed on top of the geodesic dome used at Mt. Kilimanjaro. At an ambient air temperature about -6°C, solar radiation of 1200–1300 W/m^2, and 8–10 m/s wind the air temperature inside the dome was slightly ($-1 \sim -2^\circ$C) below freezing.

To protect the diesel generator during ice coring at three drilling sites in Central Greenland, a commercially available (300 US dollars) winter fisherman shelter has been used. This shelter comes with polyethylene floor, which forms a shipping box when folded. It is equipped with two zipped doors, two plastic covered windows and can be installed in 15 min by one person. The shelter is $1.5 \times 1.5 \times 1.8$ m, and has a shipping weight of about 40 kg. Sheet metal plates were attached to the side of the shelter to terminate the exhaust pipe of the diesel generator. Two sheets of plywood provided floor insulation. In order to sustain strong winds a top cap was added. The cap has 8 grommets, allowing the shelter to be tied down to the snow. The shelter held up in severe storms over the course of 3 weeks. The diesel generator was run for 24 hours a day in this shelter. Temperature-sensitive products have been stored there. The footwear was placed there to dry overnight. A portable toilet was also installed inside that shelter. Note that if the shelter is to be used for longer than 1 week, then floor insulation must be added. Otherwise, the shelter needs to be relocated in order to avoid it sinking down into the hole melted underneath.

A typical high altitude ice coring operation lasts for 4–6 weeks. For such long-term operations, it is imperative to have comfortable conditions to rest during the night. Availability of electricity makes it possible to have a low-power (25 W) illumination for personal tents and electrical heating (25–100 W) for sleeping bags. Therefore, a 1 kW generator can make nights more comfortable for 8–10 persons. A diesel generator can be in use for 24 hours a day during a few weeks to provide power as well as a place for sanitary needs, for storage of temperature-sensitive products, drying footwear, and keeping a spare generator warm. That option requires only 8.5 liters of diesel oil per night (12 hours).

3. Conclusions

The key advantage of solar power is environmental safety and reliability. Practical daytime usage limit of solar panels in the mountains is about 8 hours. Wind, clouds and blowing snow may interrupt a drilling operation for hours or even days. The total weight of a 1.5 kW array of conventional solar panels is about 255 kg. Assembly and disassembly of conventional solar panels required 4–6 man/h. As an alternative, flexible panels are also commercially available. The weight of a 1.5 kW array of these panels can be as low as 100–120 kg, the assembly time can be 1 man/h. The cost of these panels is estimated at 12000 US dollars.

The most weight- and cost efficient power system for EM drilling is a modified 7 hp air-cooled diesel engine. Sizing down the combustion chamber allowed using it at high altitude glaciers. Production EM drilling at three drilling sites at 5895 m a.s.l. required 0.66 *l*/h of fuel; the total consumption of fuel to drill a 150 m ice core was about 20 liters. Weight advantage of the solar power system over the combustion engine is feasible when total ice coring exceeds 500 m.

In harsh environments, a commercial geodesic dome shelter can be used to provide comfortable working conditions for drilling and ice core processing. Additional light-reflective cover reduces green house heating inside the dome and keeps air temperature below freezing. Assembling and tearing down of the geodesic dome requires 12 and 6 man/h, respectively.

A portable, self-contained and commercially available shelter can be used to protect the combustion engine power generator from the snow. Such shelter additionally provides a warm place for storage, drying clothes and sanitary use.

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