DEMONSTRATION AND EVALUATION OF POTENTIAL HIGH LEVEL WASTE MELTER DECONTAMINATION TECHNOLOGIES FOR SAVANNAH RIVER SITE

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ABSTRACT

Four hand-held tools were tested for failed high-level waste melter decontamination and decommissioning (D&D). The forces felt by the tools during operation were measured using a tri-axial accelerometer since they will be operated by a remote manipulator. The efficiency of the tools was also recorded. Melter D&D consists of three parts: 1) glass fracturing: removing from the furnace the melted glass that can not be poured out through normal means, 2) glass cleaning: removing the thin layer of glass that has formed over the surface of the refractory material, and 3) K-3 refractory breakup: removing the K-3 refractory material.

Surrogate glass, from a formula provided by the Savannah River Site, was melted in a furnace and poured into steel containers. K-3 refractory material, the same material used in the Defense Waste Processing Facility, was utilized for the demonstrations. Four K-3 blocks were heated at 1150°C for two weeks with a glass layer on top to simulate the hardened glass layer on the refractory surface in the melter. Tools chosen for the demonstrations were commonly used D&D tools, which have not been tested specifically for the different aspects of melter D&D. A jack-hammer and a needle gun were tested for glass fracturing; a needle gun and a rotary grinder with a diamond face wheel (diamond grinder) were tested for glass cleaning; and a jackhammer, diamond grinder, and a circular saw with a diamond blade were tested for refractory breakup.

The needle gun was not capable of removing or fracturing the surrogate glass. The diamond grinder only had a removal rate of 3.0×10^{-4} kg/s for K-3 refractory breakup and needed to be held firmly against the material. However, the diamond grinder was effective for glass cleaning, with a removal rate of 3.9 cm^2/s. The jackhammer was successful in fracturing glass and breaking up the K-3 refractory block. The jackhammer had a glass-fracturing rate of 0.40 kg/s. The jackhammer split the K-3 refractory block into two pieces: one weighing 12.7 kg and the other 16.8 kg. However, it was not capable of fracturing smaller pieces off the block except when the chisel was applied at the edges of the block or at the fissure of the split. The circular saw successfully cut the K-3 refractory material at a rate of 0.29 cm^3/s or a line at 4.1 cm/s. A Fourier transform was performed on the acceleration data to obtain the frequency domain results.

INTRODUCTION

A primary, ongoing mission at the Savannah River Site (SRS) is to immobilize 35 million gallons of liquid high-level waste (HLW) produced over the past 45 years. Since March 1996 the Defense Waste Processing Facility (DWPF) has been using vitrification technology to treat and immobilize HLW by encapsulating it in glass. The HLW/glass frit melt pool is maintained at about 1150°C by controlling two pairs of submerged electrodes that pass current through the melt. The melt temperature has been decreasing primarily due to the settling of heavy metals from the HLW to the bottom of the melter. This increase in heavy metal concentration decreases the overall resistance of the melt, resulting in an increase in the current passed between the electrodes and a subsequent decrease in temperature. This temperature decrease could cause the melt to solidify if the temperature decreases to a sufficiently low temperature, which may prevent the melt from pouring or draining from the melter. This could potentially shut down HLW processing operations and cause extensive downtime attempting to remove this glass-waste compound from the melter interior. A single failed glass melter, for example, could contain as much HLW glass as five canisters. The current approach to dealing with this equipment is long-term storage in the canyon facilities, on regulated storage pads or in underground "Failed Equipment Storage Vaults." While storage is acceptable for the short term, technology must be developed to dispose of this equipment properly. This should include dismantling/size reduction of the equipment, decontamination and recyling of as much material as possible, disposal of the majority of the material as low-level waste (LLW), and disposal of remaining HLW materials in a controlled repository or as a recycle stream to tank farms and ultimately the DWPF.

To prepare for such decontamination and decommissioning (D&D) operations, technologies need to be demonstrated and/or developed that will assist in the removal of solidified glass from the melter tank. Furthermore, due to the high radiation field, these technologies will be deployed by a remote manipulator. Melter D&D consists of three parts: 1) glass fracturing: removing from the furnace the melted glass that can not be poured out through normal means, 2) glass cleaning: removing the thin layer of glass that has formed over the surface of the refractory material, and 3) K-3 refractory breakup: removing the K-3 refractory material. Commonly used D&D tools should first be tested on surrogate material to determine their capability in melter D&D. The Hemispheric Center for Environmental Technology (HCET) at Florida International University demonstrated and evaluated several commercially available hand-held tools: jackhammer and needle gun for glass fracturing; needle gun and rotary grinder with diamond face wheel (diamond grinder) for cleaning glass off the refractory surface; and jackhammer, diamond grinder, and circular saw with diamond cutting wheel for K-3 material breakup.

These techniques and tools have not been specifically applied to a HLW melter, so the effectiveness of each technology is unknown. Testing on a non-radioactive surrogate glass will assist in determining the most cost-effective and efficient technology for cleaning the HLW melters. Additionally, the forces generated by these technologies during use were measured with a tri-axial accelerometer to determine the suitability and requirements of a remote manipulator for using these tools.

EXPERIMENTAL SETUP

Surrogate glass, formulated at SRS to simulate the glass matrix used at the DWPF, was placed in the melter at HCET, heated, poured into steel containers, and allowed to cool into a solid matrix. The surrogate glass has a density of 2.5 g/ml and a composition (by weight percentage) of 52.0% SiO_2, 10.6% Na_2O, 10.2% Fe_2O_3, 8.3% B_2O_3, 6.0% Al_2O_3, 3.8% Li_2O, 3.1% K_2O, 3.0% MnO, 2.0% MgO, and 1.0% ZrO_2 (1). The HCET melter consists of an inconel crucible or tank installed inside a furnace. The tank is heated from all sides by the enclosing furnace, melting the glass. A vertical riser, connected to the bottom of the tank and extending horizontally to the pour spout, provides a delivery path for the molten glass to be poured to an external canister, pushed by applying pressure to the melter plenum using a nitrogen gas pressurization control system.

Surplus K-3 refractory blocks (the same material used in the DWPF melter) from SRS were purchased. These K-3 blocks were archived sample blocks from the vendor when the first melter refractory material was purchased and were never put into service. Each block is 30.5 cm by 20.3 cm by 15.2 cm and has a measured density of 3,385 kg/m^3. The composition of the refractory blocks is 58.2% Al_2O_3, 27.2% Cr_2O_3, 6.2% Fe_2O_3, 1.9% SiO_2, 0.3% Na_2O, and 6.2% other (1).

Glass powder was placed onto the surface of four K-3 refractory blocks to form a thin layer and heated for two weeks at 1150˚C to simulate the chemical reactions that have occurred in the melter between the glass and refractory material during melting operations. An electric kiln (DaVinci model) with 7.6 cm of fireblock from L&L Kilns was used to heat the blocks and glass. A "power bottom" was installed to ensure even heating for dense refractory blocks and to decrease the time to achieve this temperature. The K-3 blocks were heated up to the final temperature at a rate of 20˚C/hr and then cooled down at a rate of 17˚C/hr to avoid thermal shock to the K-3 blocks since higher heating rates could fracture the K-3 refractory material due to its low thermal impact property (1). The glass layer, after heating, varied from 0.33 mm to 0.89 mm, with an average value of 0.64 mm.

Tools chosen for the demonstrations were commonly used D&D tools that have not been tested specifically for the different aspects of HLW melter D&D. The tools chosen were jackhammer, needle gun, diamond grinder, and circular saw with a diamond blade. A plasma torch was not tested because previous D&D operations did not allow the use of plasma torches if air ventilates through HEPA filters. A paper concerning D&D of a HLW melter in Belgium was reviewed, in which ceramic blocks of the type ER 2161 RT required the use of a hydraulic jack with a capacity of 31 t and a stroke of 155 mm. The refractory material resisted to a pressure of 3,500 kg/cm^2 at room temperature. The use of a saw with a diamond blade was planned, but the installation and operation of the saw on a remote manipulator arm was more demanding than for a simple hydraulic jack (2).

The jackhammer used was a 35# Paving Breaker from Ingersoll-Rand with a piston stroke of 15.9 cm, 1250 blows per minute (bpm), and weight of 19.5 kg (3). Two chisels were tested: a narrow chisel (2.22 x 8.26 cm) and a wide chisel (8.26 x 10.8 cm). The portable compressor was set at 689.5 kPa.

A needle gun contains a bundle of needles that are struck by a piston driven by compressed air. The needles then strike the surface and are able to follow the contours of an uneven surface. Needle guns are utilized for removing coatings, such as paint, or for profiling a surface. The Corner-Cutter needle gun from Pentek was used. It weighs 5.3 kg and was equipped with 28 needles at 3 mm width, recommended for concrete, or 65 needles at 2 mm, recommended for steel. This tool had a rate of 3,500 bpm.

The diamond grinder is a rotary grinding tool that employs a diamond wheel. Diamond wheels utilize diamond dust as the cutting abrasive and are able to cut hard surfaces. A high specific normal force for grinders indicates that resistance has increased. A concrete grinder from CSUnitec, Model EBS 125 D, was utilized with a 12.7 cm Thermo-Jet Diamond Wheel, which is designed for thermoplastics and hard coatings. The wheel rotation rate is 10,000 rotations per minute (rpm). It weighs 5.8 kg.

At Monofrax, the K-3 refractory material is cut with a saw using a diamond cutting wheel (4). The circular saw used for the demonstration was a Porter-Cable 18.4 cm circular saw with a 17.8 cm diameter diamond cutting wheel from Dixie Diamond Manufacturing, Inc. that is designed for both dry and wet cutting. The blade speed is 5800 rpm. The saw and diamond cutting wheel together weigh 4.7 kg.

A tri-axial accelerometer (model 2258-10 Isotron accelerometer from Endevco) was used to measure the acceleration on the x, y, and z axes simultaneously. It weighs 15 grams, so any weight effect on measured acceleration is insignificant. This model has a range from –500 to 500 g, where g is the gravitational force. A battery-powered isotron conditioner model 4416B was used for powering and conditioning the signal of the accelerometer. The accelerometer was placed on or near the handle and was attached by adhesives. The acceleration data was recorded and stored on a computer.

RESULTS AND DISCUSSION

To design the remote manipulator arm that will hold the D&D tools for HLW melter D&D, one needs to know the upper values of the live and dead loads of the tools. Dead loads can be determined by the weight of the tool; therefore, each tool was weighed before the demonstration. Live loads (the load required to hold the tool against the work piece, which changes during operation) can be determined by measuring the forces generated during the demonstration with a tri-axial accelerometer. All data shown in the figures were recorded at a rate of 500 data points per second. The acceleration data were first graphed in the time domain (acceleration vs. time). The zero points were then removed, which was when the tool was not in operation but acceleration data were still being collected. A Fast Fourier Transform (FFT) was then performed on the data to convert them to the frequency domain (acceleration vs. frequency) and plotted as a power spectral density (PSD) spectrum, which is the square of the acceleration divided by frequency (g^2/Hz) vs. frequency (Hz).

The accelerometer was positioned so that each axis was consistent for each tool. The x-axis was positive away from the front of the operator, negative away from the back of the operator. The y –axis was positive to the left of the operator, negative to the right of the operator. The z-axis was positive upwards along the tool, negative downwards along the tool. However, it should be noted that the axes are consistent with the tool, not the operator nor the test bed. For example, if the jackhammer is held at a slant (angle other than 90° to the surface), the z-axis does not correspond to the upward direction from the earth's surface. The angle of the tool to the test bed moved frequently during testing. Therefore, only the average acceleration is plotted in the frequency domain. Clear peaks were seen in the PSD for the average acceleration and only occasionally for the x-, y- and z-acceleration.

Glass Fracturing

The needle gun with 3 mm needles installed did not have any noticeable effect on fracturing the glass. During the demonstration, the operator felt a significant amount of kickback from the instrument, more than any other instrument that was demonstrated.

The jackhammer was tested with two different chisels: a wide flat chisel and a narrow chisel. Glass fragments were removed from the canister to allow further testing. The wide flat chisel fractured glass at a rate of 0.57 kg/s but became stuck in the glass matrix several times. The chisel was loosened from the glass matrix by operating the jackhammer while moving it in a circular motion. The narrow chisel had a rate of 0.40 kg/s but never became stuck in the glass matrix. The operator held the jackhammer vertically against the glass or at a small angle away from the vertical. The pieces of the fractured glass were removed and placed in a separate empty steel container (one container for flat chisel and another container for the narrow chisel). A steel mesh was placed over a vacuum hose to allow only dust and very small particles into the vacuum. The dust was vacuumed from the container (and weighed), and the glass pieces were then sorted by size (see Table I) using a ruler and sieves. Each size category was weighed.

Table I. Size Segregation of Glass Fragments Generated by Using a Jackhammer to Fracture Surrogate Glass

Size Category	Weight (kg)		Percentage (%)	
(in cm)	Flat Chisel	Pointed Chisel	Flat Chisel	Pointed Chisel
Dust	0.35	0.25	0.006	0.005
< 0.635	12.5	5.7	19.9	11.2
0.635 to 2.54	25.0	15.0	39.8	29.6
2.54 to 7.62	20.0	17.3	31.8	34.1
7.62 to 15.24	5.0	12.5	8.0	24.6
Total	62.85	50.75	99.6*	99.6*

* Percentages do not add to 100% due to rounding.

The Fourier transform of the data for the jackhammer with a narrow chisel is plotted in Figure 1. The main peak is at 1.95 Hz, but the other, smaller peaks are at 15.65, 29.30, 44.92, 60.55, 76.17, 89.84, 105.47, 121.09, 134.76, and 150.39 Hz. The smaller, higher frequency peaks appear to be resonance peaks of 15.65 Hz, not of 1.95 Hz. Acceleration data recorded at 4 data points per second showed that the initial shock of the jackhammer starting was greater than the shock of continual operation of the jackhammer. During the testing, the jackhammer often had to be stopped, picked up, and moved to another spot before testing could resume. Therefore, the main peak at 1.95 Hz may be an artifact of the higher initial shock of having to stop, move, and restart the jackhammer often.

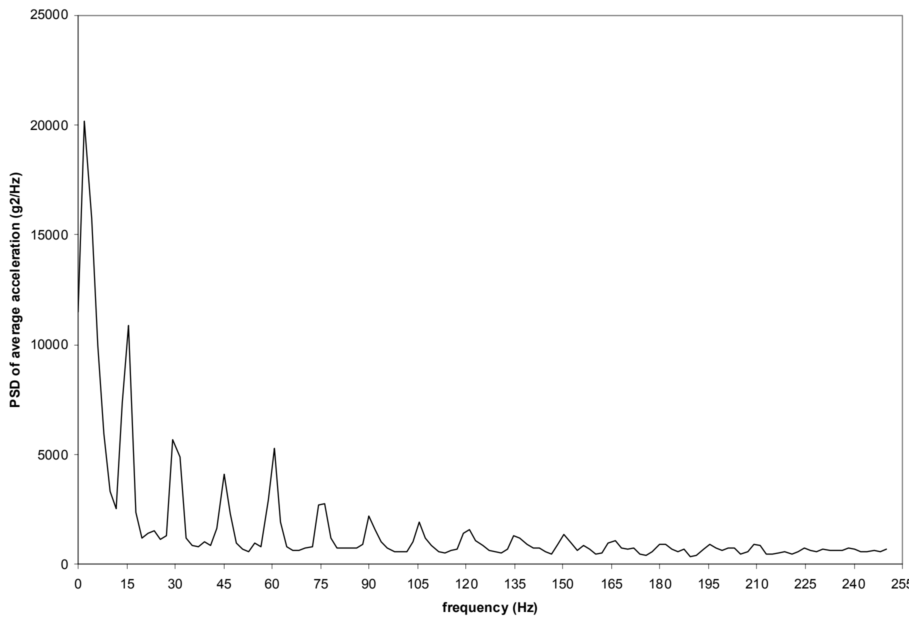

Fig. 1. PSD for total average acceleration for the jackhammer with narrow chisel fracturing glass, measured at 500 dps. The peaks are at 1.95, 15.62, 29.30, 44.92, 60.55, 76.17, 89.84, 105.47, 121.09, 134.76, and 150.39 Hz. The PSD values are expressed as dB/Hz.

Cleaning Glass from K-3 Refractory

The needle gun with 2 mm needles installed did not remove any glass from the surface of the K-3 material. The operator felt significant kickback from the tool, more than from any other tool demonstrated. The Fourier transform of the average total acceleration is shown in Figure 2.

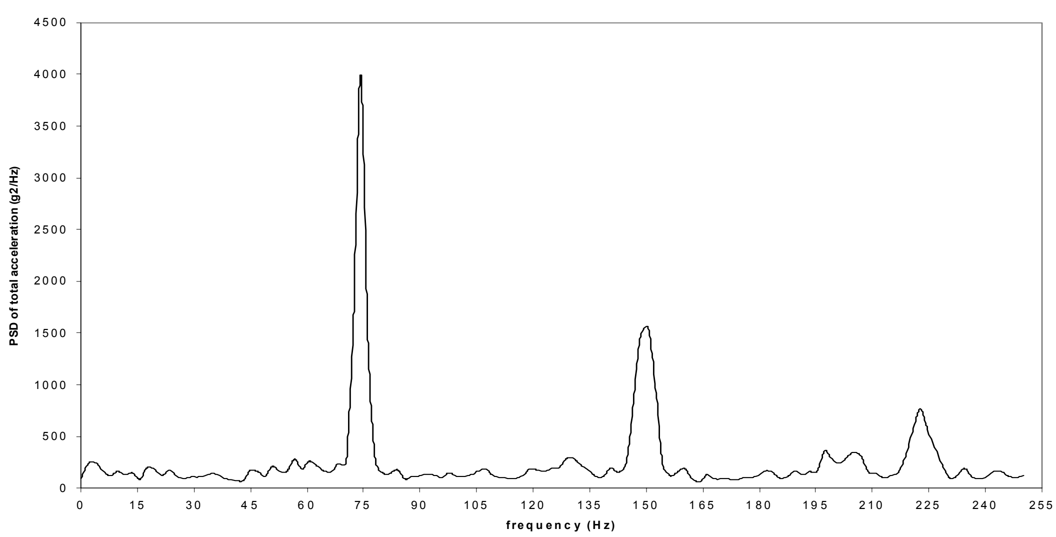

Fig. 2. PSD for total average acceleration for the needle gun with 2 mm needles cleaning glass off the refractory surface, measured at 500 dps. The peaks are at 74.22, 150.39, and 222.66 Hz. The PSD values are expressed as dB/Hz.

The diamond grinder was sucessful in removing the glass from the surface of the K-3 material. The operator did not have to hold the grinder hard against the brick as was the case during the K-3 refractory breakup demonstration using the same tool. The grinder was moved over the surface in a sweeping motion. The glass often required three to four sweeps to be fully removed. The glass was black, but partially removed glass was brown and then a lighter tan color when more glass was removed from that area. The K-3 refractory surface was grey. These colors could provide a method of determining when the glass has been fully removed from the refractory surface using a remote camera. The removal rate of the glass was 3.9 cm^2/s (partially removed spots were given a weighting factor of 0.5 in the calculations). The Fourier transform of the acceleration data is shown in Figure 3.

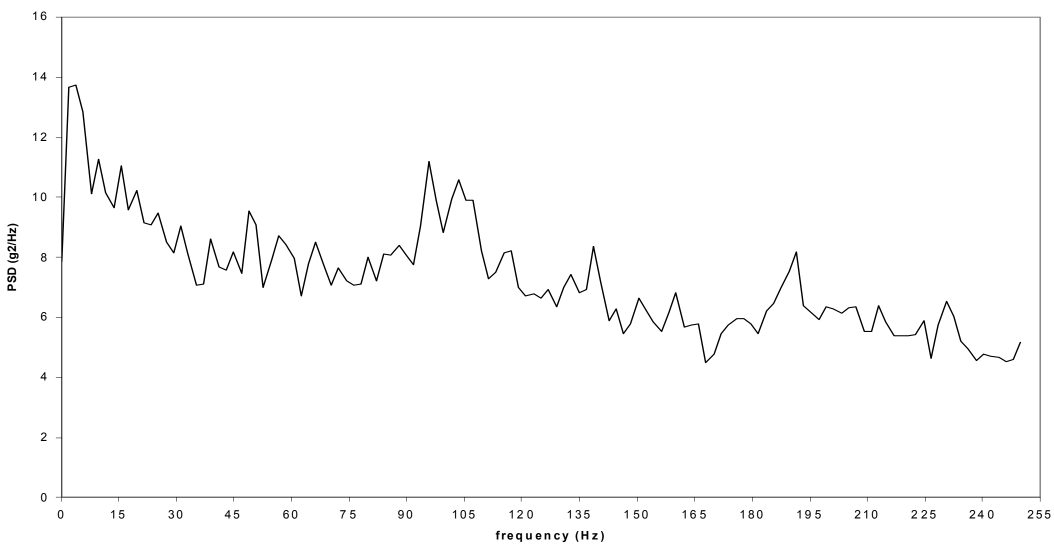

Fig. 3. PSD for total average acceleration for the diamond grinder cleaning glass off the refractory surface, measured at 500 dps. The main peaks are at 3.91, 95.70, and 103.52 Hz. The PSD values are expressed as dB/Hz.

K-3 Refractory Breakup

The jackhammer with the narrow chisel was tested on the K-3 refractory block. The operator tried to hold the jackhammer vertical (90° angle) to the surface of the block but was not able to prevent the chisel from dancing around the surface of the K-3 block and moving off the block. When the jackhammer and chisel moved off the block, the operator picked it up and repositioned it on the surface of the block. The impact of the chisel on the K-3 material produced sparks. The chisel was blunted at the end of the demonstration, and the chisel was shorter by 1.90 cm. The block was split into two pieces after 30 seconds (not including the time spent picking up and replacing the jackhammer after it jumped off the K-3 block) of striking it. The two pieces weighed 12.7 and 16.8 kg. Smaller pieces (approximately smaller than 4 cm) were also fractured from the block, but only when the chisel was applied to the edges of the K-3 refractory block or to the fissure of the split block. The rate of fracturing for the small pieces was 10.4 g/s.

The diamond grinder only had a removal rate of 3.0 x 10^{-4} kg/s. Initially, the grinder was moved in a sweeping motion over the surface of the K-3 block and then held in one place. A circular groove with a depth of 0.36 to 1.0 mm was etched into the K-3 block by holding it in one place. The operator had to hold the grinder down forcefully to remove any K-3 material. Acceleration values exceeded 500 and –500 g during the demonstration, which is expected since a high specific normal force for grinders indicates that resistance has increased.

Since a circular saw with a diamond blade is used by Monofrax to cut K-3 material, it was expected to cut the K-3 block successfully during this demonstration. At Monofrax, they flood the saw with water for cooling purposes (4), which was not done for the demonstration. Therefore, cutting times for the demonstration were short, and a diamond blade designed for dry cutting was utilized. Sparks formed during cutting. The operator had no handling problems with the saw during the demonstration. The removal rate of K-3 material was 0.29 cm^3/s or a line at 4.1 cm/s. The Fourier transform of the acceleration data is shown in Figure 4.

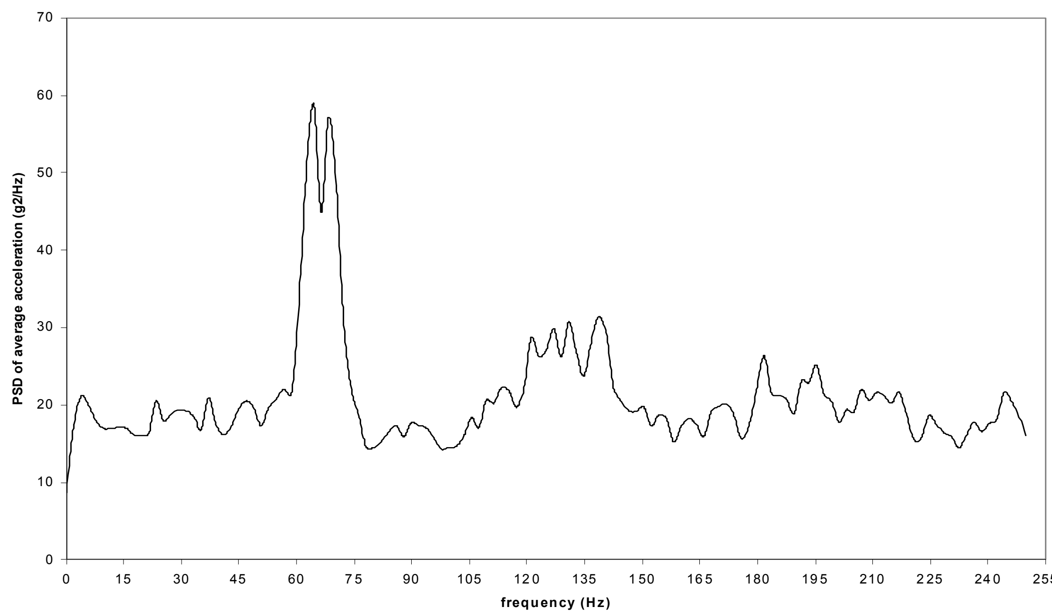

Fig. 4. PSD for total average acceleration for the circular saw with diamond cutting blade cutting K-3 material, measured at 500 dps. Main peaks are at 64.45, 68.36, 121.09, 126.95, 130.86, and 138.67 Hz. The PSD values are expressed as dB/Hz.

Final Analysis

The frequencies with peak acceleration were expected to correspond to the blows or rotations per minute of the tools. However, this was not observed for any of the tools. The most effective tools are clearly the jackhammer with a narrow chisel for glass fracturing, the diamond grinder for glass cleaning, and the jackhammer or circular saw for K-3 material breakup. The circular saw has lower acceleration values than the jackhammer but is considered more complicated to control remotely (2). A saw must be controlled to follow a straight line with little variation or may become stuck, which is easy for an operator but not a remotely controlled manipulator to perform. Therefore, of the tools tested, only the diamond grinder and the jackhammer should be considered for further use in remote D&D of failed melters.

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