The Digipulse III Accelerated Weight Drop Seismic Source Systems Applications and Performance of the Series Model 1180 GC/TR

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Introduction

The Digipulse AWD III Model 1180 GC/TR is a vehicle mounted, high performance gas-charged accelerated (impact) weight drop energy source designed for use on seismic exploration surveys. Applications include: shallow and deep refraction surveys, 2D and 3D seismic reflection surveys, Vertical Seismic Profiling (VSP), and downhole seismic or LVL surveys. Where applicable, the Digipulse AWD III is an environmentally friendly, economical, and efficient alternative to using dynamite and vibrator seismic energy sources. For many 2D and 3D seismic surveys that use explosives or vibrators as the primary energy source in only a portion of the survey area, the Digipulse can also be used as an "infill" source to obtain near offset data in cultural zones that may prohibit drilling and the use of explosives and large vibrators. Deeper multi-layer refraction and LVL, and VSP surveys can be conducted without the requirement for costly shot hole drilling and dynamite, or vibrator seismic sources.

Used as an alternative to Vibroseis and explosive seismic sources, the Digipulse AWD III Model 1180 GC/TR has been used successfully on 2D and 3D surveys with geologic target imaging objectives in excess of 12,000 feet (4,000 meters). In many cases, the data acquisition production rate is at least five times faster with respect to source points per day than either the vibrator or explosive energy sources. In addition, maintenance and transportation requirements are a fraction of the cost and time when compared to vibrators.

The Digipulse AWD III Model 1180 is designed to work with almost any modern portable or large seismic data acquisition system. Configurations of the Digipulse AWD III systems can vary and are custom built to suit specific performance and operation requirements. Standard systems are mounted on Ford F450 and F550 diesel 4x4 trucks, or equivalent. Optional vehicle platforms include the Ford F750 Heavy Duty 4x4 trucks (or equivalent), and the IVI Minibuggy articulated all-terrain vehicle. For maximum traction in sandy and loose soil conditions, the Digipulse truck mounted systems can be equipped with wide-track wheels and tires. Optional base plate sizes are available for greater adaptability and improved performance in difficult terrain.

For accurate control and monitoring of source timing the Digipulse AWD III uses a radio link based on the Pelton Pro Encoder/Decoder Set. On 3D seismic surveys that require QC x,y shot location recording and monitoring the Digipulse can be equipped with a GPS/DGPS mobile receiver (Trimble 5700 RTK Series, or equivalent). The GPS system is interfaced with the radio link system to transmit real-time x,y,z coordinate information to the seismic recording system.

Theory of Operation - The Physics of Digipulse AWD III Sources

Unlike the explosive energy source, which is placed in shot holes below the ground, the Digipulse AWD III weight drop is a surface "impact" type seismic energy source. The energy produced by the Digipulse (approximately 70 to 100 K-joules) is derived from a large hardened steel hammer mass (1180 lbs) that impacts a ground coupled base plate. Mechanically, the Digipulse uses a hydraulic system to lift the hammer mass to a "mass loaded" position. In the loaded position, a nitrogen gas charged cylinder and piston assembly applies a downward force on the hammer mass. The approximate pressure applied to the hammer mass is a minimum 8,000 psi. When released, the hammer mass is propelled at high velocity to impact the base plate.

Energy Source Comparison (Digipulse versus 6 lb Dynamite Charge)

Based on the present model, the correct combination of base plate area, mass weight, and mass acceleration, the force generated by

the impacting hammer can be increased and the damping factor reduced while still maintaining a broad bandwidth in the seismic signal. Using this design criteria, the efficiency of transfer of the kinetic energy into the seismic wavelet can be increased from 5 - 10% to the 15 - 20% range. Combining the increased force levels, reduced damping, and increased efficiencies, the source energy model indicates that for an accelerated mass of 1200 - 3000 lb. with minimum kinetic energies of 30,000 to 35,000 ft lb. We should produce a wavelet equal to, or better than, 1 lb. of dynamite from a single impact. If we increase the acceleration component of the AWD operating model to achieve 70,000 ft lbs., the equivalence reaches 2.5 lb of a single dynamite charge.

For theoretical comparison, a buried (20 meters) dynamite charge between 1/2 and 1 lb normally produces "enough energy" in most survey areas to delineate targets at 4 - 5 seconds (two-way travel time). With the ability to stack impacts, a wavelet from the Digipulse AWD that is equivalent in energy to a 1 lb. charge may require between 4 and 6 stacks to achieve the same S/N ratio. With a cycle time of 6-8 seconds the acquisition time at each shot point will be between 30 and 60 seconds.

In 1999, a field test was conducted to compare the amplitude-frequency performance between a Digipulse AWD 1180 gas-charged system, and a 6 lb dynamite charge placed in a shot hole 20 meters in depth. The test site was located in Northeast Texas, where near surface alluvial P wave velocities are about 850 meters per second. Near surface low velocity formations typically act as a strong attenuator of seismic signals (low Q values). The data are recorded from vertical geophone arrays cemented in boreholes, and the Digipulse occupied the dynamite test shot location. Figure 1 shows the raw records (unprocessed, no filters) from the dynamite shot. Figure 2 is the amplitude-frequency performance spectrum for the Digipulse AWD 1180. At 100 Hz, the relative amplitude level is –3 dB for the dynamite shot, and –12 dB for the Digipulse. AWD III 1180. Note that from 0 to 100 Hz, the amplitude-frequency spectrums are nearly the same, although the Digipulse is slightly richer in low frequencies at this test site.

From studies conducted for small charges of dynamite, only about 1 - 2 % of the chemical energy in the explosive is transformed into useful P wave energy over a band from 0 to 100 Hz. If these studies are correct, then the "efficiency rating" of dynamite in converting the primary energy to seismic energy in a properly tamped hole is less than 2%. As 1 lb. of dynamite is equivalent to 1,400,000 ft lb. of energy, the energy of the seismic wavelet from a 1 lb charge should be in the range of 14,000 to 28,000 ft lb. From this, we can infer that the minimum target range of an AWD source wavelet will therefore need to be at least 7,000 to 14,000 ft lb. As with all surface seismic sources, it is important to recognize that soil conditions can affect the downward transfer of energy and the overall spectral content of the wavelet signature. Attenuation and dispersion of seismic energy can be quite high in very loose low velocity surface soils, thus limiting the maximum depth of penetration. Stacking can overcome some of the energy losses due to near surface soil conditions, and on-site testing is always recommended for determination of the number of stacks.

Energy Source Comparison (Digipulse versus Vibroseis)

Comparison tests between the Digipulse AWD and Vibroseis similar to the dynamite source comparison have not yet been conducted. However, basic seismic signal theory indicates that the most ideal energy source signature for seismic exploration applications is a spike wavelet. Dynamite sources are the closest to this wavelet character and are therefore frequency rich for the bandwidth of interest. Although the Digipulse source signature (impulsive) shows a greater rate of signal attenuation with increasing frequency, its amplitude and phase characteristics are remarkably close to the dynamite signature, with nearly all of the energy generated over a very short time. Vibroseis sweep signals are quite different and should be compared to the Digipulse in a different manner. Since the Vibroseis system is also a surface source, it too suffers the same near surface signal attenuation as the Digipulse. To increase overall total energy, multiple Vibroseis sources are used simultaneously, and various sweep configurations can be used to optimize the cross-correlation process. While we cannot necessarily dispute the performance of Vibroseis in general, a clear disadvantage for using Vibroseis concerns cost, logistics, and environmental problems.

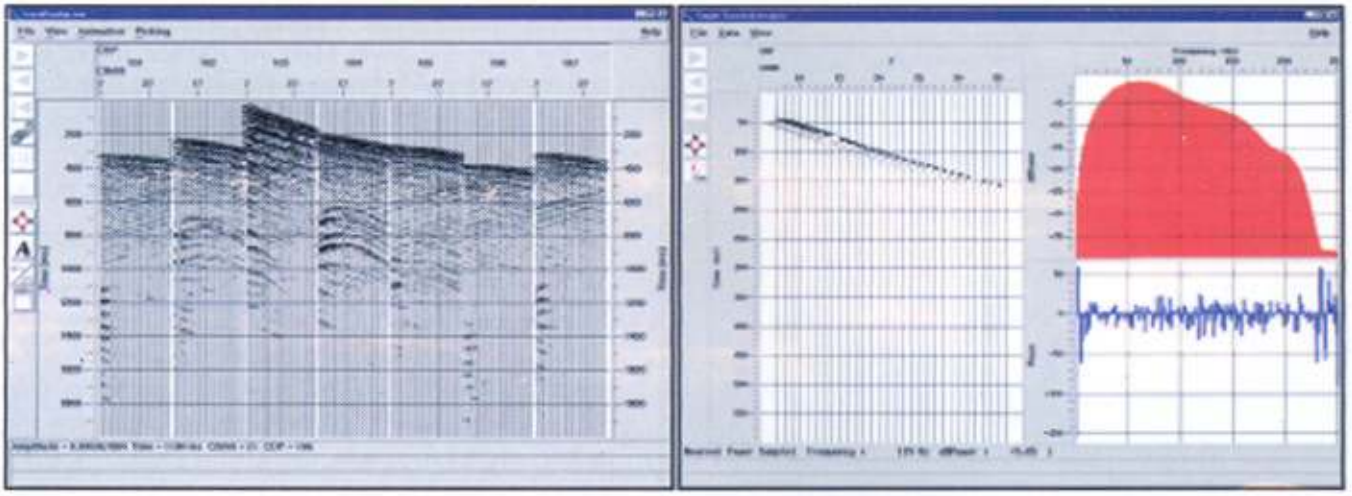

Figure 1. Single dynamite shot recorded by seven-station vertical geophone array and corresponding amplitude frequency spectrum.

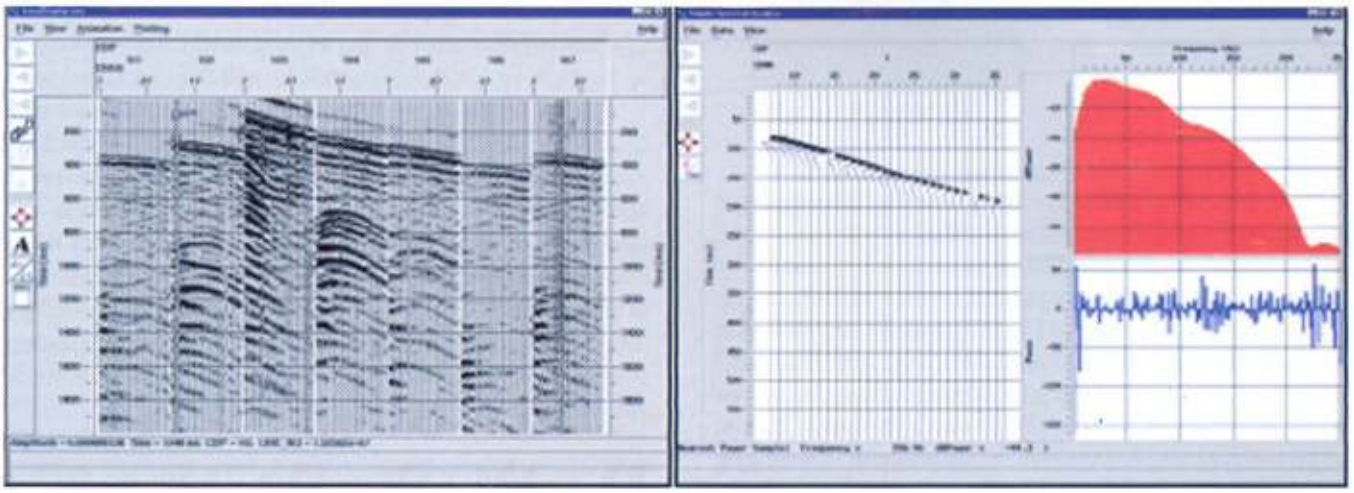

Figure 2. Digipulse record of 12 stacks and corresponding amplitude-frequency spectrum.

Digipulse AWD III Operation Advantages

The use of explosives and Vibroseis are currently the dominant energy source for most 2D and 3D land seismic exploration surveys. Approximately 40% of all seismic surveys conducted worldwide use dynamite, another 50% use Vibroseis, with 10% for the remaining other source types. For very deep geologic targets beyond 15,000 feet large size dynamite charges and groups of heavy vibrators will continue to dominate as the selected seismic source. These are the only seismic energy sources that currently produce sufficient energy to reach the deepest of geologic target objectives. However, there is a need for an alternative seismic energy source that is designed for handling shallow and intermediate target depths, or that can be used to provide supplemental shallow near-offset seismic data on 2D/3D seismic programs that include zones where dynamite and large vibrators have limited use because of environmental regulations and local area restrictions.

There is increasing pressure from government and environmental regulations, private and commercial land owners for limiting, or prohibiting, the use of dynamite and/or Vibroseis in the United States, and in many other regions worldwide. As a result, the geophysical industry has experienced increasing operation difficulty and higher costs associated with using explosives or vibroseis, and it is likely that some seismic projects in some areas around the world may never be completed. With respect to environmental and increasing cost factors, the Digipulse AWD source can be a good alternative seismic source. Where applicable, the Digipulse AWD does have several distinct operational and cost advantages compared to dynamite and Vibroseis.

1. Dynamite seismic surveys require drilling of shot holes. On 3D surveys this can mean thousand of shot holes. In the United States, the average cost per loaded (5.5 lb Pentolite) shot hole drilled to a depth of 20 meters ranges from $165 USD.

   For every 1,000 shot holes, the average cost is $165,000, not including permits, insurance bonds, and post survey cleanup. In some cases dynamite is now simply not permitted at all. In some foreign nations where labor

and drilling costs are much lower, another problem arises that affects the use of dynamite. Foreign seismic operations can present special safety and security problems with shipping and transport to the field.

For the same 1,000 shot holes (USA average shot hole costs), the Digipulse 1180 is about 1/10th the shot hole drilling and loading costs. Although the actual time for data acquisition may be the same, projects using the Digipulse are completed faster because the time for permitting, drilling, and loading of shot holes is eliminated. As soon as a layout crew completes setting of geophones and seismic cables, the data acquisition operations can commence. A second advantage for using the Digipulse is safety and security.

The Digipulse AWD seismic source is benign in terms of safety hazards, and there are no-security issues with regard to its use. Unlike dynamite surveys that may require post acquisition cleanup, the Digipulse is also environmentally friendly, causing little or no damage within the survey area.

2. Vibroseis surveys are extremely costly, especially for surveys located in remote areas, or those that require multiple vibrators, along with a sizable complement of spare equipment and operation support resources. Factors that contribute to the cost of using vibrators include, but are not limited to, land permitting and clearing, shipping and transportation to the site, field tests, fuel and support equipment costs, operator and mechanic costs, land or structural damage and cleanup costs. In addition to the basic operation costs, the vibrator has relatively fixed data acquisition costs in terms of sweep time, listen time, and move-up time.

The cost per Digipulse unit is far less than the operation cost of a large vibrator unit. The Digipulse AWD 1180 is smaller, consumes less fuel, does not require the same level of equipment and personnel support, and it is far less damaging to the environment. Moreover, the cycle rate per shot is 8 seconds as opposed to a typical 12 to 16 second sweep time for a single vibrator sweep. For the Digipulse operating in the stacking mode using 8 impacts per source location, the total time per source station is 64 seconds, plus move-up time. For a vibrator

Digipulse AWD III Model 1180 GC/TR General Specifications

Item	Specification
Energy Source Type	Digipulse AWD III Series Model 1180 Accelerated Weight Drop – Truck mounted P-wave surface impact seismic source. Uses ground coupled impact base plate.
Mass Acceleration	Single piston nitrogen gas charged cylinder *Maximum Pressure: 15,000 psi Minimum Pressure: 2,000 psi*
Mass Weight	1180 lbs (535 Kg) *Optional 3,000 lb (1360 Kg) mass available with IVI Minibuggy*
Mass/Base Plate Control	Dual hydraulic piston (1000/2000 psi operating pressure)
Hydraulic Motor Type	Hatz 20 HP "Silent Pack" Diesel Motor *Installed on Ford F450 and F750 only*
Standard Vehicle Platforms	Ford F450/550 HD Diesel Powered V8/4x4 Ford F750 HD Diesel Powered V8 IVI Minibuggy All Terrain Articulated Vehicle
Digipulse Source Weight	6,200 lbs (2807 Kg) *Mercedes Unimog: 10,200 lbs (5,987) Ford F450 Weight: 7,200 lbs (3,260 Kg) Ford F750 Weight: 8,900 lbs (4,030 Kg) IVI Minibuggy Weight: 9,600 lbs (4,347 Kg)*
Stacking Cycle Rate	Minimum 8 seconds
Impact Force	40,000 – 60,000 ft/lbs (20,000 g-force)
Operator Controls	Master Control Unit Interface with Remote "Hand Held" Controller *Hand held controller operates hydraulic system for mass lift and movement of tower/base plate assembly*
Source Fire Control	Pelton Encoder/Decoder Remote "Source" Controller System with optional PC Based Command Controller I/F. *The Pelton controller system offers dual mode operation for fire command from the Digipulse, or from the seismic recording station (doghouse). Supply Voltage : 9-36 Volts DC Internal Time Break Accuracy : 40 microseconds +/- Sensing Threshold : 1.2 Volts Input/Outputs : Opto-isolated*
"Zero" Time Trigger Sensor	Base Plate mounted accelerometer *The trigger pulse is detected with mass impact on the base plate, and transmitted to the recording system via the Pelton UHF radio link. Time break pulse accuracy is 8.85 milliseconds.*
GPS/DGPS Interface	Trimble 5700 RTK Receiver System (or equivalent) with Pelton Map32 for x,y,z coordinate recording and source position mapping.
Summary of Applications	The Digipulse AWD III Model 1180 can be used for a variety of engineering, environmental, and petroleum seismic investigation projects. Seismic Reflection – On 2D and 3D seismic reflection surveys with geologic target depths of 1,000 feet to 10,000 feet. The Digipulse can also be used as an "infill source" to obtain near offset data in areas where dynamite or vibrators cannot be used. Seismic Refraction – The Digipulse is an economical and safer alternative source for deep refraction or LVL surveys. Vertical Seismic Profiling – Efficient and safe seismic source for 2D and 3D VSP surveys to delineate reservoir characteristics, or to map thin bed coal seams.

using a 12 second sweep, plus 4 seconds listen time, and 8 sweeps per station, it would take a total of 128 seconds for each source location (not including move-up time). In general, with the Digipulse 1180 AWD truck mounted system, we should experience an increased production rate by a factor of 3 to 5 times faster than the Vibroseis.

Although the Digipulse is smaller and may therefore be more maneuverable over rugged hilly terrain, both the Vibroseis and Digipulse have limitations across mountainous and steep slope terrain. However, Digipulse can have the option of getting fitted at the back of a crawler which is now the case for allowing it to work in moderately sloping areas and undulating terrain as may be the case in the Himalayan foothills of India. But this cannot be done in the case of vibrators, which then limits the owner to opt for costly shot hole drilling and blasting.

Conclusions

The concept of using weight drop, or accelerated weight drop technology, is not new to the seismic exploration industry. Several forms of weight drop systems have been in use for seismic exploration during the last 40 years. Currently, the Digipulse AWD III system is the only latest version of high performance accelerated weight drop systems in production. Depending on surface soil conditions, the source signature characteristics and energy levels of the Digipulse are usually sufficient for acquiring up to 4-6 second records (two-way travel time). Current users of the Digipulse AWD III report reaching target depths of up to 10,000 feet under ideal conditions. Typical seismic target objectives range from 2,000 to 15,000 feet.

Integrity Geosciences Pvt. Ltd. does not advocate the complete replacement of explosives and Vibroseis with Digipulse, particularly on 2D and 3D surveys with very deep seismic imaging objectives. However, where applicable, and if it can deliver sufficient energy to reach shallow geologic target objectives, the Digipulse AWD III 1180 gas charged system is a more economical alternative in almost every aspect. A new Digipulse AWD IV with a 3,000 lb mass mounted on an IVI Minibuggy platform is now available. These larger Digipulse systems will deliver more than twice the downgoing energy of the Digipulse AWD III Model 1180 units, and will likely reach the deeper seismic targets while still offering the same economical and production efficiency benefits.

The Digipulse AWD is also a more suitable source alternative in areas with sensitive cultural and environmental issues. In some cases, the Digipulse AWD can be combined with dynamite or vibrator operations to acquire only near-offset data within areas that restrict or prohibit using energy sources that are hazardous or damaging to the environment.

Moreover, the production rate in terms of completing a survey can be much higher, and the overall operating costs associated with the Digipulse is much less than with seismic surveys using dynamite or Vibroseis.