VIBROSEIS's Gentle Massage – How Gentle Can It Be?

by

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PRAKLA-SEISMOS AG

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Summary

Among the well known methods of improving the signal level in a seismogram the cheapest is the method of increasing the source output, but in most cases it is also the worst. Increasing the source output, that means increasing the ground force at the vibrator baseplate/soil interface, may lead to excessive damage without benefitting the seismic signal. On the contrary, the seismic efficiency may be greatly lowered by this measure. However, we do not want to obtain just a strong seismic signal, we also want to have a well defined seismic signal emitted into the ground. Therefore, this paper deals with theoretical considerations about what goes on under the vibrator baseplate and with some practical results to illustrate this. These results give some indications of how to operate a vibrator to achieve a strong and well defined source signal.

The Elastic Model

Geophysicists like to consider our earth as an elastic body (Fig. 1). A vibrator baseplate acts on the flat surface with a ground force F_G and has a velocity v_B. Both quantities are related to one another only by the elastic constants of the ground (Fig. 2). According to this theory the ground reacts like a spring characterized by its compliance, its mass, the so-called radiation mass, and the energy is transformed into heat through its radiation resistance.

The three quantities, radiation mass, compliance, and radiation resistance, vary depending upon the type of soil on which the baseplate rests. Soft soil, for instance, has a large compliance and a small resistance, hard soil has a small compliance and a large resistance, but a small radiation mass. There are reliable laboratory data available from which the ground impedance can be calculated.

In practice, either baseplate velocity or ground force is considered as a reference signal. They are related to each other only by the ground impedance. For Vibroseis, we deal with harmonic oscillations, so that we can write down the formula for the impedance in a complex form. From this formula we see that the imaginary components are a function of ω, that means a function of frequency as is the ground impedance itself.

We say the impedance is a complex quantity and we must deal with the phase shift between ground force and baseplate velocity, which is frequency dependent. Phase shift means time shift and as we measure time in seismics, we must decide if we refer to ground force or baseplate velocity. Some people unneccessarily recommend the use of baseplate acceleration as a reference. However, there is a constant phase shift of 90° between velocity and acceleration by definition,so that we need not worry too much about this.

If we put all the information in a polar diagram, we are able to see in principle the phase relation between acceleration, velocity and ground force (Fig. 3). The phase angle φ between acceleration and ground force is large for low frequencies and small for high frequencies. That means if baseplate acceleration ist used for vibrator phase compensation, ground force may change from out-of-phase to nearly in-phase in the course of upsweep emission.

As we have seen before, the variation of the phase angle depends upon the elastic constants and can be calculated as a function of frequency for different material, as has been done by several authors (Fig. 4). This diagram shows that the phase angle varies very little with frequency on hard material and very much on soft material. The phase angle reaches 90° for mud and sand, but not for chalk in the frequency range shown.

Measured Phase Characteristic

As is often the case, theory and reality are two different things (Fig. 5). We have measured, for example, the phase angle for a vibrator standing on a soft meadow, and this measured phase characteristic looks very similar to that given for mud. However, also the phase characteristic of a vibrator on hard asphalt does not look very much different (Fig. 6). You know how soft mud can be and you would never risk to drive on an asphalt road with these elastic properties.

Evidently there is something going on under the base plate which cannot be described by the above formula which describes the elastic soil.

For many years extensive discussions have been made about which quantity measured at a vibrator should be used for phase control in order to best adapt Vibroseis results to the results gained with impulsive sources, e.g. dynamite. There is a strong tendency to recommend ground force as the quantity which gives the most uniform results in this respect. From the phase characteristic shown it is then possible to derive the corrected values to be applied to the reflection signal when using baseplate acceleration or baseplate velocity instead of gound force for phase control.

Unfortunately it has not been proved up to now that ground force is just the right quantity to solve this problem under all circumstances. Ground force is a quantity which can be kept constant and fairly independent of the type of soil encountered along a seismic line, so that ground force does not exceed the preload of the baseplate. A specific force amplitude on soft ground, however, may cause great damage whilst on hard ground not even a single crack will be visible. The same force, therefore, can cause different active power, depending upon the velocity of the baseplate, the amplitude of the ground force and the phase angle between them.

Active Power Determination

If we follow the phase characteristic, it can be seen that the phase curve crosses the 90° line at relatively low frequencies (Fig. 5). A 90° phase shift between baseplate acceleration and ground force means that ground force and baseplate velocity are in phase. In this specific case all power emitted by the vibrator is **active power.** That means power which goes into the breaking up, particle motion, plastic deformation, air and pore fluid pumping. This active power depends upon the phase angle ψ between velocity and ground force (Fig. 7). A large angle ψ means relatively low active power, but high **reactive power,** a small angle ψ means low reactive power and rather high **active power.**

We have determined the active power and found that it reaches values far larger than the theoretical values (Fig. 8). For a broadband vibrator operating on sand, values of up to 30 kW have been reached. The maximum active power does not necessarily coincide with the 90° point.

Looking at the imprints of a vibrator on sand, it is clearly seen that much of the energy is transformed into displacement energy (Fig. 9). For sandy ground this means that the sand has flown radially from under the baseplate to form a small ridge at the baseplate edges, which means **plastic,** and **not elastic,** deformation has taken place.

Therefore, the baseplate soil model must be modified by introducing a ground resistance R_V which is dependent on the frequency and also upon the displacement ΔZ (Fig. 10). This resistance describes the visco-elastic properties of the soil in contact with the baseplate.

The space under the baseplate, which we call the visco-elastic pillow, is more or less moulded and extended depending upon the stiffness of the soil matrix. This pillow enables a good coupling to be formed between the baseplate and the ground. At first sight this seems to be a prerequisite for good seismic results in many areas, however, if this line of thought is continued when working on roads, we run into problems of considerable damage claims.

The question, therefore, is how can we control this pillow to achieve good seismic results and at the same time to avoid excessive damage. As a result we started concentrating not so much on the question of how to adapt Vibroseis results to impulse source results, but more on the question of how to run a Vibroseis broadband survey avoiding excessive damage. But when we evaluated the final results we found that we could make some remarks also about signature adaption.

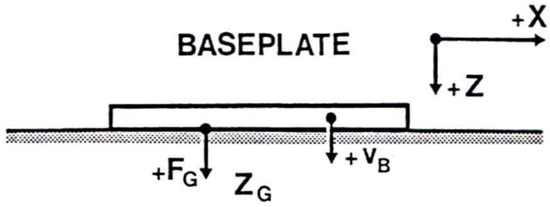
The Role of the Reactive Power

As geophysicists we are in a very good position because we are interested in achieving an elastic deformation. All plastic deformation, which is a synonym for surface damage, is of no use in our business. Consequently the **reactive** power should be as large as possible while high **active power** should be avoided.

As we have seen above, the ratio of reactive and active power is determined by the tangent of the phase angle ψ between the ground force and the baseplate velocity (Fig. 7). This ratio is very small in the range in which the phase angle between velocity and force is nearly zero (Fig. 11). In this range much of the power is active power with little reactive power, which is needed for stimulating seismic waves. Indeed this can be seen from the amplitude characteristic of a seismic signal measured with the vertical component of a borehole sonde at about 50 m below the vibrator baseplate. In a frequency range between 30 Hz and 40 Hz, where the phase angle is near 90°,the amplitudes of the spectral components of the seismic signal are strongly reduced (Fig. 12).

Conclusions

In conclusion it can be said that we must anticipate visco-elastic flow under a vibrator baseplate. This flow can be used in some areas for better coupling, but should be kept to a minimum in order to avoid large portions of the vibrator power being transformed into active power. Active power means heavy damage and little seismic effect. The vibrator output, therefore, should be controlled in such a way so that a large amount of **reactive power** is generated over the whole frequency range. Consequently little environmental damage is equivalent to good seismic results.



F_G = GROUND FORCE

v_B = BASEPLATE VELOCITY

Z_G = RADIATION IMPEDANCE OF THE GROUND

Fig. 1: VIBRATOR BASEPLATE ON ELASTIC GROUND

GROUND FORCE:

$$F_G = Z_G \cdot v_B$$

HARMONIC MOVEMENT:

$$Z_G = R_G + j\ (\omega m_G - 1/\omega C_G)$$

v_B = BASEPLATE VELOCITY

R_G = RADIATION RESISTANCE

m_G = RADIATION MASS

C_G = RADIATION COMPLIANCE

ω = ANGULAR FREQUENCY

Fig. 2: ELASTIC GROUND PARAMETERS

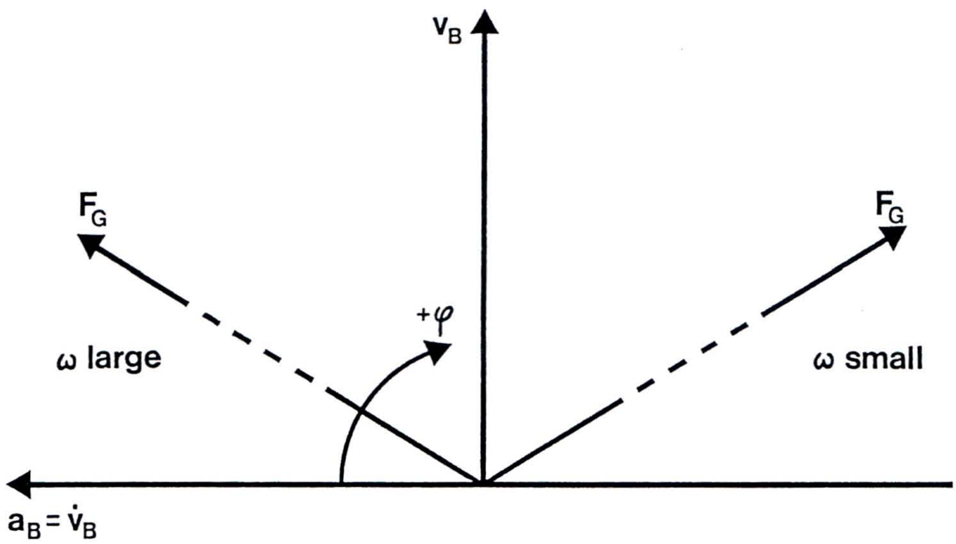


Fig. 3: SCHEMATIC POLAR DIAGRAM

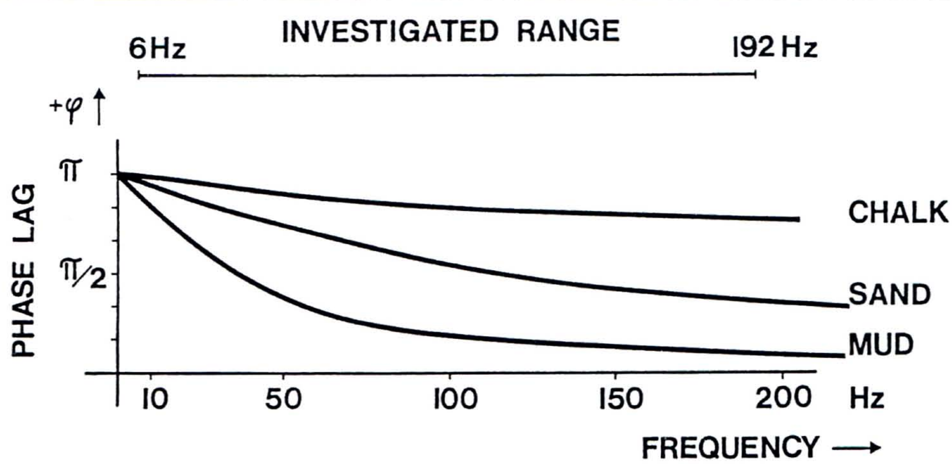


Fig. 4: PHASE OF GROUND FORCE REFERRED TO BASEPLATE ACCELERATION (CALCULATED AFTER SAFAR, 1984)

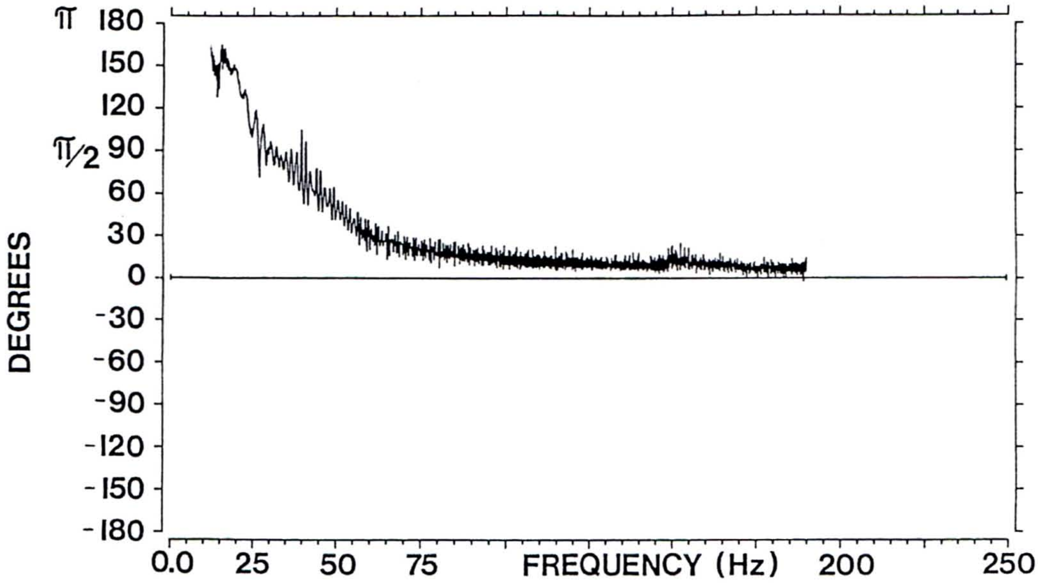


Fig. 5 : PHASE OF GROUND FORCE REFERRED TO BASEPLATE ACCELERATION (MEASURED ON MEADOW)

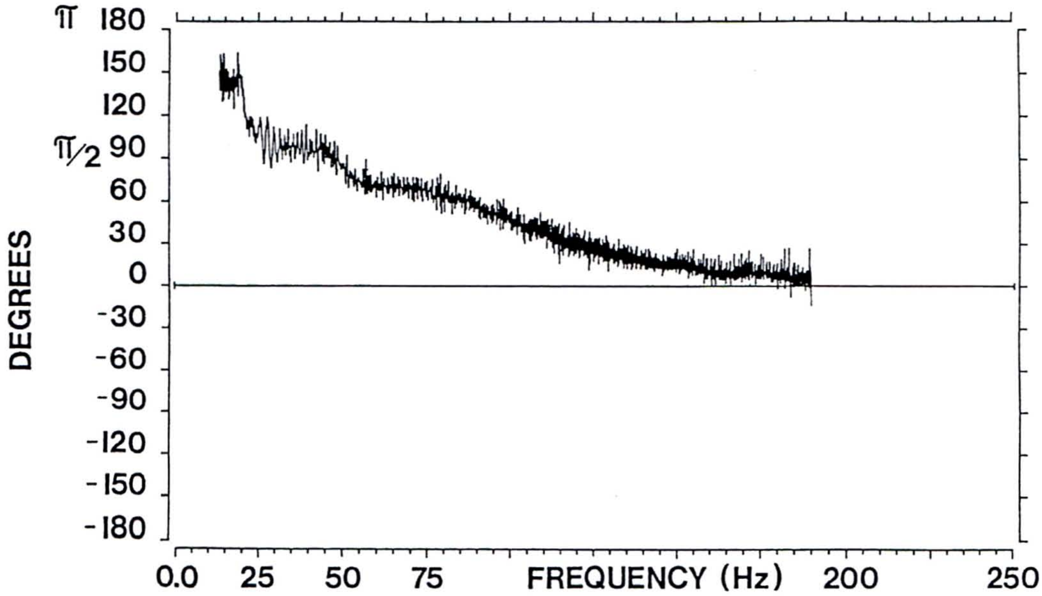


Fig. 6 : PHASE OF GROUND FORCE REFERRED TO BASEPLATE ACCELERATION (MEASURED ON ASPHALT ROAD)

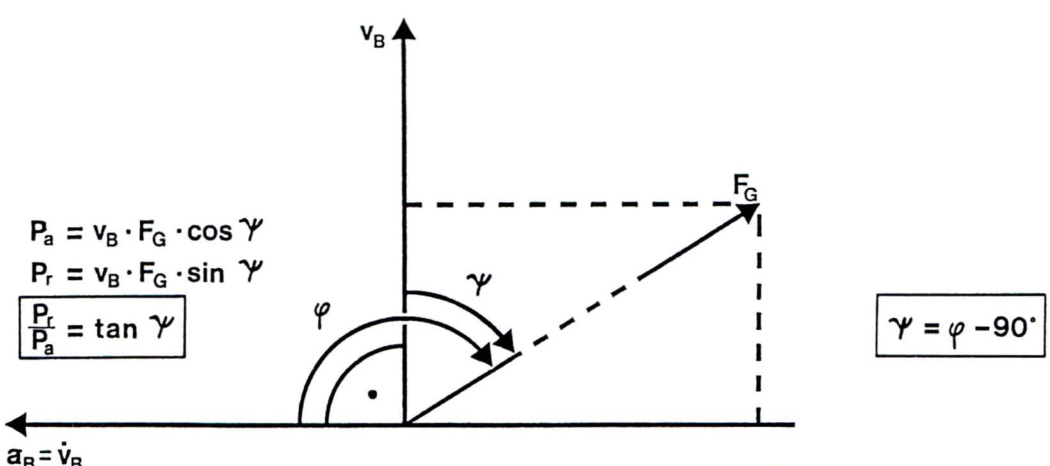


Fig. 7: ACTIVE (Pa) AND REACTIVE (Pr) POWER

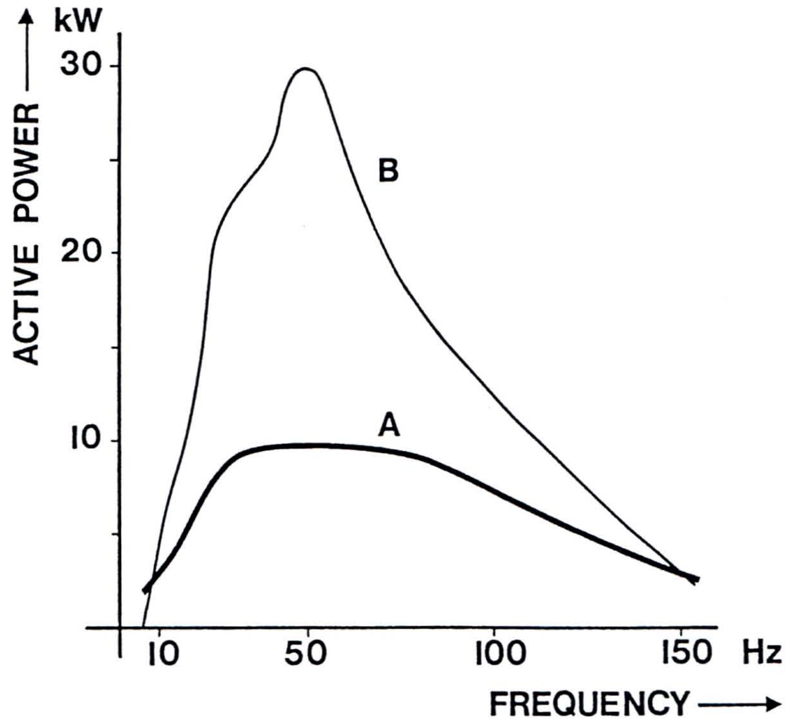
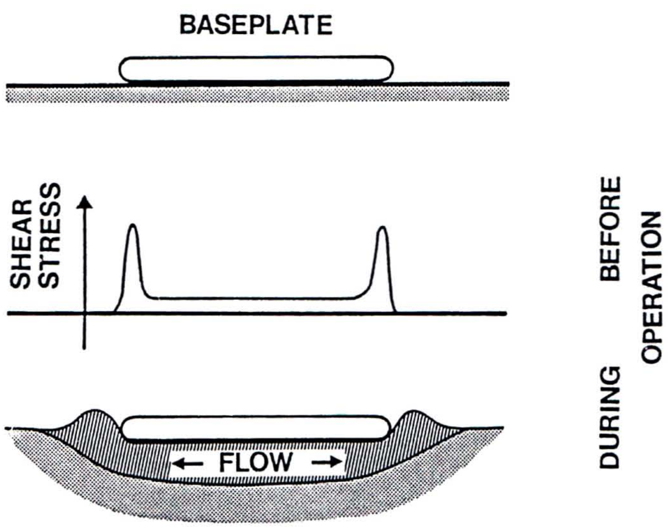
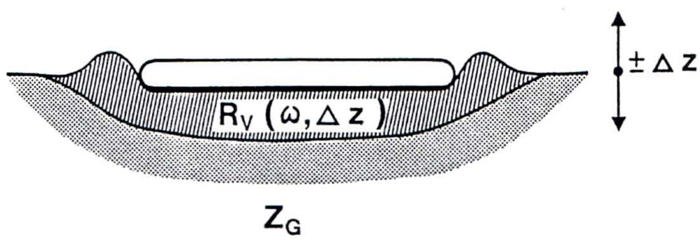


Fig. 8: EMITTED ACTIVE POWER OF A VIBRATOR ON SAND AS A FUNCTION OF FREQUENCY.
A: CALCULATED FROM LERWILL, 1981;
B: MEASURED



VISCOUS FLOW ZONE, PRESSURIZED

Fig. 9: ACTIVE - REACTIVE POWER TRANSFORMATION



R_V = VISCOUS DAMPING RESISTANCE
Z_G = RADIATION IMPEDANCE

Fig. 10: IMPROVED BASE PLATE - GROUND MODEL

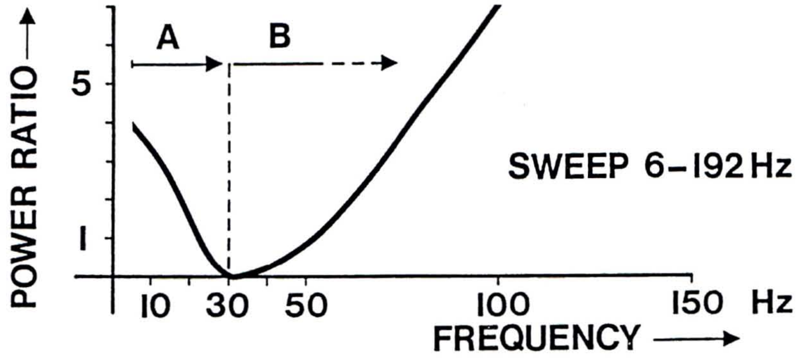
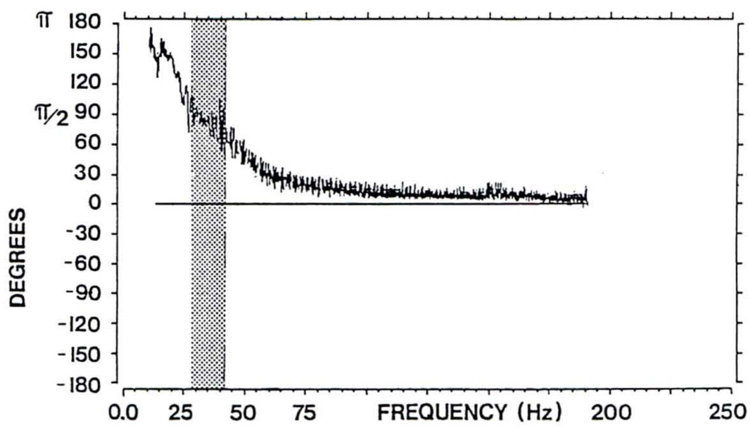
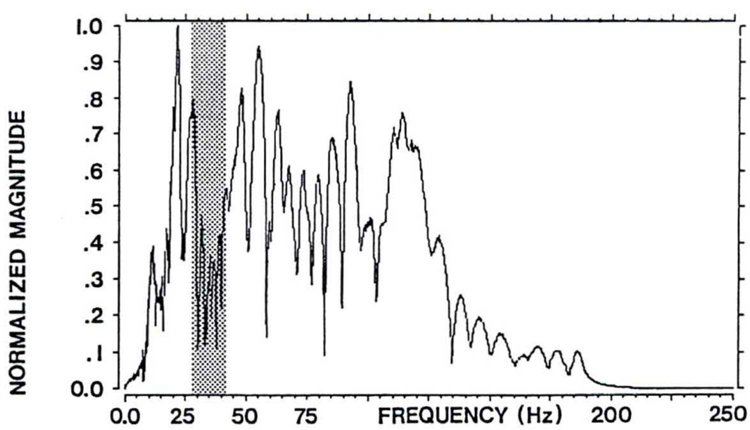


Fig. 11: RATIO OF REACTIVE AND ACTIVE POWER
A: INCREASING FLOW
B: DECREASING FLOW



PHASE SHIFT BETWEEN F_G AND a_B (ON MEADOW)



VERTICAL COMPONENT SPECTRUM AT 50 M DEPTH

Fig. 12: RANGE OF LOW REACTIVE POWER

VIBRATOR-SYSTEM VVCA

Vibrator Specifications

Type	PC 8 S
Weight on baseplate	122 500 N
Peak force	84 500 N
Actuator mass	1600 kg
Piston area	40.25 cm^2
Usable stroke	82 mm
Baseplate area	2.14 m^2
Lift system	One cylinder lever-arm system (PRAKLA-SEISMOS patent)
Vibrator isolation	air bags
Lift stroke	800 mm
Pump model	Rexroth Hydromatik A 6 V 117
Pump output	250 l/min

Vehicle Specifications

Vehicle type	4 x 4 crab tractor
Engine type	KHD F 6 L 413 F
Engine power (DIN 6270)	107 kW at 2150 rpm
Vehicle dimensions (L x W x H) (without winch)	7200 mm x 2500 mm x 2750 mm
Wheelbase	4000 mm
Tires	20.5 x 25 Continental E 58
Power transmission	hydrostatic, power regulated
Max. Speed	35 km/h (22 mph)
Engine fuel tank capacity	480 l
Hydraulic reservoir capacity	120 l
Turning diameter	13.5 m
Total weight *)	144 000 N

*) varies with equipment

Standard Equipment

Automatic air bag pressure fill system
Hydraulic monitor system on front panel
Separate hydraulic system for steering

Lighting system, brake system, hydraulic system conform to european regulations

Optional Equipment

Separate electric systems for vehicle and electronics
Front winch
Brush-guard for cabin and fuel tank

Air conditioner
Cabin heating (fuel)
Sound proofing

Further accessories on request
Technical changes without notice

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