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16. Abstract

A study was undertaken on the performance of pile driving systems. First, analytical methods available for routine pile design and installation analysis were summarized (Main Report, V.I). Next, the existing technology for the measurement of performance parameters was reviewed (Main Report, V.II). Third, new measurement systems were evaluated and, finally, recommendations for the development of a new measurement were made (Main Report, V.III). Another facet of the project investigated the actual behavior of pile driving systems based on existing measurements. Depending on hammer type, average wave equation efficiencies were calculated and summarized (Main Report, V.IV).

The third group of results was an inspection manual for pile driving systems, i.e. for impact hammers as well as cushions, helmets, leads, etc. This inspection manual was illustrated by a tape slide show in five parts as a teaching aid for pile driving inspectors. A Saximeter was also delivered as an inspection tool.

This is the Second Volume of the Main Report which comprises four volumes. An Inspection Manual, the narrative of the Tape Slide Show, and a Summary Report were also issued.

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1. INTRODUCTION

This report was written with the intention of providing a comprehensive discussion of current measurement methods for the evaluation of pile driving hammer performance. The measurements may be rather simple observations, or they may be based on modern electronic technology. However, because of the speed of the impact phenomenon, electronic measurement techniques are superior to mere visual observations. Nevertheless, in order to provide information regarding different sources of hammer problems, as many observations as possible should be taken for a complete hammer evaluation. For example, even though a sophisticated ram velocity measurement is available, which can detect poor air/steam/hydraulic ASH hammer performance, the simply determined blow rate may be sufficient to show that the problem was caused by insufficient pressure.

Simple measurements have probably been taken as long as piles have been driven. On drop hammers (their performance evaluation may follow the recommendations for single-acting (S-A) air/steam/hydraulic (ASH) hammers), stroke is a prescribed value and the hammer operator must either check each hammer stroke visually, or be guided by a mechanical stop. The slackness of the hammer cable during impact is another important visual observation.

The ram stroke can also be observed visually for most S-A ASH hammers and open-end diesel (O-ED) hammers. Blows per minute and blows per foot (inch or meter) has been a standard inspection practice for a long time. Maximum pile displacement is also easily obtained. Since the advent of double-acting (D-A) hammers, air or bounce chamber pressure has been recorded for these hammers to assess proper performance.

Electronic measurement of hammer performance is a relatively new art. As far as it is known, the first electronic measurements were conducted by Glanville in 1938 (1).

Hammer performance may be evaluated by either direct or indirect measurement. Direct measurements are taken on the ram and they may determine

a) Ram Displacement vs Time
b) Ram Velocity vs Time
c) Ram Acceleration vs Time

Direct measurement of any one of the above ram motion quantities gives sufficient information to determine ram efficiency. However, if indirect performance measurements are made at locations in the total system below the ram, the performance of the intervening components is included in these measurements. In order to isolate the hammer performance, measurement of more than one quantity may be necessary.

Among the group of indirect hammer performance measurements are:

d) Cap Force and Motion
e) Pile Top Force and Motion

The term "cap" in (d) is meant to designate any location between pile top and ram. In general, a cap force will be different from pile top force because of the helmet mass, (see Rausche and Goble, 1972 (2)) while cap and pile top motions may be identical.

A third group of measurements only provides for performance indicators. They may establish necessary, but not sufficient, conditions for the rated output of a hammer. The most common indicator measurements are:

a) Ram stroke by visual observation of ASH hammers
b) Blow rate (e.g. blows/minute)
c) Bounce chamber pressure on closed-end diesel (C-ED) hammers
d) ASH hammer pressure
e) Combustion pressure on diesel hammers
f) Number of bounces of diesels after fuel input is terminated

g) Maxima of either pile top force, velocity or displacement

This report contains a discussion of both current and possible future measurement techniques. Results of conversations with representatives of firms involved in advanced measurement technologies relevant to hammer performance evaluations are in Appendix A. Appendix B contains brochures and/or technical descriptions of currently available systems.

2. DIRECT MEASUREMENT METHODS

As previously indicated, there are three basic types of ram motion measurements. They may be taken either in analog or in digital form and must be able to determine the ram maximum velocity immediately preceding impact.

Displacement measurements must be differentiated to obtain ram velocity, and, to be of value, must, therefore, be extremely accurate. Displacement measurements may be taken either in analog or digital form.

Direct measurements of ram velocity can be obtained from high frequency distance measurements (radar, ultrasonic). However, the associated electronic hardware for these devices, must be linear to obtain voltage signals which are proportional to the measured velocity. If a continuous record is required, it must be realized that radar devices cannot detect a very small velocity such as when the hammer is near the top of its stroke.

Measurement of acceleration can be obtained in analog form only. The signal must be accurately integrated to obtain velocity. This integration is probably only successful in digital form. Thus, an analog to digital conversion is a necessary part of the system.

2.1 Analog Ram Displacement

2.1.1 The Optical Transducer

Using an optical displacement transducer (similar to a video camera, see also Appendix B) and a black and white target on the ram, a continuous voltage signal proportional to ram displacement can be obtained. This system had been observed in actual use during a factory hammer performance test by MENCK (see Appendix A). The method is fairly accurate, and has the advantage that no attachment to the ram is necessary.

The discussion with users of this system (MENCK, TNO, see Appendix A) indicated, however, that it is often difficult to provide for a fixed reference due to soil vibrations caused by either the pile driving operation itself, or other construction activity. The target has to be well illuminated, and should not be obstructed by steam. Therefore, this instrument provides for an acceptable solution only for air and hydraulic hammers without enclosures. The cost of the transducer is approximately $10,000, with actual cost depending on the type of lens used. Because of this high cost, only one unit is generally used, although two measurements would be preferrable for the cancellation of non-axial motion effects. Set-up time is usually not more than one hour, including target preparation.

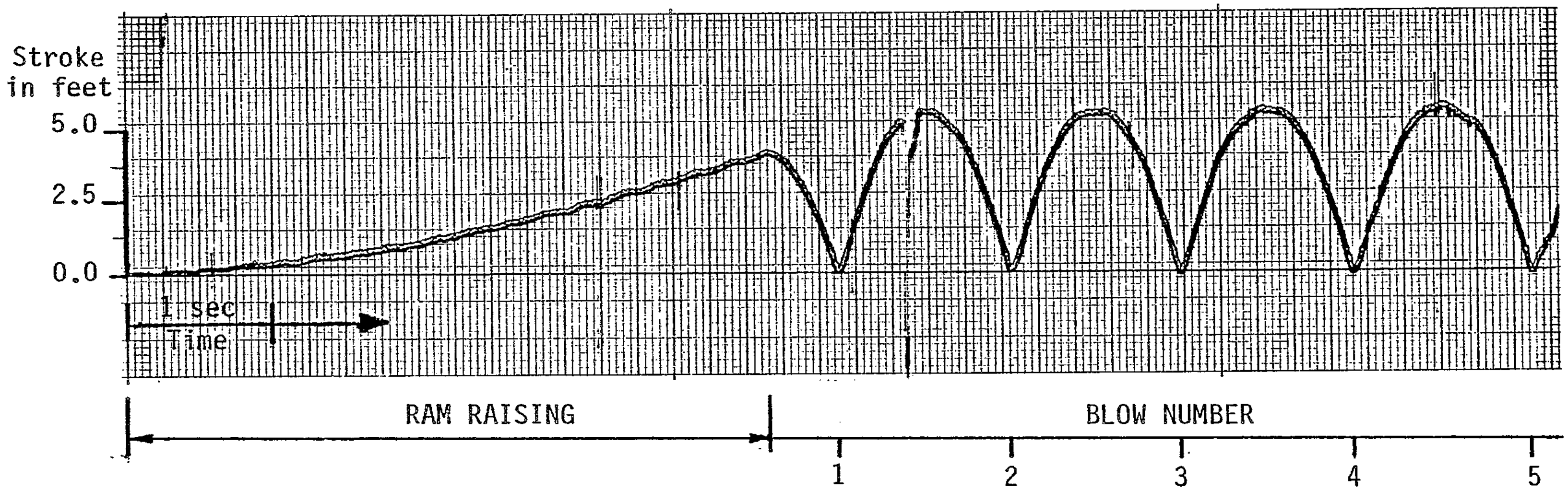
2.1.2 Potentiometer Type Transducer

Using a linear precision potentiometer together with an attachment at the ram top of an open-end diesel hammer, Goble and Associates, Inc. attempted such a ram displacement measurement in 1975 (Figure 2.1) for the Foundation Equipment Corporation of Dover, Ohio. The objective of the measurement was to determine the pressure-to-volume relationship for diesel combustion. Evaluation of the records was not satisfactory, since it was necessary to resolve the record over both a very limited time period, and a large ram displacement range with high accuracy. Figure 2.2 shows an example record. The test preparation had been difficult; the attachment of the potentiometer to the hammer cylinder, and the guide bar to the ram top (the ram usually rotates during driving) provided problems which caused the system to fail after the fifth impact. With all the disadvantages of an analog measurement system, such an electromechanical system does not seem to present a feasible solution. Its cost would, however, be much lower than the optical transducer (say $2000), but frequent breakdowns and replacements must be expected, and installation time may be several hours.

2.1.3 Force in Spring Type Transducer

By using a soft spring that is able to extend to the full range of ram stroke, measurement of the force in the spring could be used to determine ram

Figure 2.1: Attachment of a potentiometer type ram displacement gage to a Delmag D-12 Diesel hammer.



1 ft = .3048 m

Figure 2.2: Ram displacement versus time from potentiometer type transducer. (Courtesy of FEC)

position. If stress waves in the spring could be dampened out sufficiently, this system would be somewhat simpler than the potentiometer, since it requires less moving parts. A stiffer and shorter spring compressed during the last few inches of ram motion before impact would be an alternative. Cost and set-up time would be similar to that of a potentiometer type transducer.

2.1.4 General Discussion of Analog Displacement Devices

The goal of all measurements of ram displacement, u, is the determination of its derivative, du/dt, just before impact. This value is the ram impact velocity, v. This quantity is sufficient for wave equation analysis. However, in order to determine hammer energy (or efficiency), the following expression has to be evaluated:

$$E = 1/2\ M_r\ (\Delta u/\Delta t)^2 \qquad (1)$$

where M_r is the mass of the ram, and $\Delta u/\Delta t$ is the finite difference expression used to compute the ram impact velocity from the ram displacement record. The error in the energy, E_e, may occur in the displacement measurement itself, and in the determination of the derivative. Thus, after partial differentiation and with ∂u and ∂t designating the errors in displacement and time increment measurements, respectively, one obtains as a relative error:

$$E_e/E = 2(\partial u/\Delta u - \partial t/\Delta t) \qquad (2)$$

The energy computation, therefore, includes twice the error of the displacement and time increment measurements. For this reason, a 5% measurement accuracy may result in a 10% energy error. It should be observed that this error is 10% of full scale. Thus, if the energy losses are 50%, then the error in the actual energy computed may be as high as 20%. It is for this reason, that analog ram displacement measurements do not offer significant advantages over other, often simpler methods.

2.2 Digital Ram Displacement

There are several means of measuring displacement in digital form. The oldest form is high speed photography, and this system is still used occasionally. Among electronic methods, the simplest digital technique uses the time of passage of the ram between two locations. This measurement allows for the computation of an average ram velocity measurement at a certain point, such as immediately before impact. The most sophisticated device would determine the ram position-time history over the whole ram travel. As far as is known to the authors, there are only two such devices in routine usage, however, other general systems are available commercially.

2.2.1 High Speed Photography

Little has been published about this relatively simple method. Grasshoff in 1953 (3) used high speed photography for pile top measurements, and obtained remarkably conclusive results 30 years ago. Poskitt, in 1983 (4), utilized a polaroid camera with slot type shutter and obtained on one photograph, traces of ram position at constant time increments. Rather sophisticated cameras are available today, making such measurements relatively simple and inexpensive. However, data evaluation is always difficult and/or time consuming, since it is not easily automated. For this reason, high speed photography is not considered a viable alternative for routine use and evaluation.

2.2.2 The Fugro Device

This device (see also Appendices A and B) consists of a 3 inch (76 mm) wide vane that is mounted to the (moving) control rod of MENCK steam hammers. A U-shaped box is mounted to the hammer assembly. A light emitting diode installed on one side of the U is sensed on the other side. When the vane first interrupts the light beam, a pulse is generated; just before the ram reaches the point of impact, the vane passes the LED location, and a second pulse is produced. The duration between the pulses is printed, together with a blow number in a control box which is connected to the U-box at the hammer by cable. The unit has been in routine use on a number of jobs, but there are still problems of durability and secure attachment under repeated impacts.

For a free falling ram, the velocity, v, as a function of ram position, u, is

$$v = (2\ g\ u)^{1/2} \tag{3}$$

or the change of velocity is

$$dv/du = (g/2u)^{1/2} \tag{4}$$

where the displacement u is measured from the top of the stroke downwards. Thus, at a stroke of 36 inches(914 mm), the change of velocity over the bottom 3 inches (76 m/s) is 7 inches/sec (178 m/s) or 4% of the maximum velocity; because of averaging, an error of one half of this change of velocity is made. Assuming that no other errors occurred, such as inaccurate timing of pulses, this error is relatively minor, however, it would result in a 4% energy error.

One additional source of error may be caused by excessive compression or deterioration of the capblock material. If the capblock is too thin, then the ram may significantly slow down between the point of measurement (theoretical point of impact) and the actual impact. This ram speed decrease would occur because of the preadmission of the air/steam or hydraulic medium into the power cylinder, resulting in very significant losses of ram energy which would be undetected by this system.

The cost of the unit is not available, since it is only used on a rental basis. The attached device should not cost more than $1000. The control box may cost several thousand dollars. Up to 1000 blows have been recorded during continuous monitoring. Attachment time is between one-half and four hours.

In 1975, during the course of a research project at Case Western Reserve University, the authors had already measured ram velocity using a similar concept (see Figure 2.3,) by timing the ram between two sets of light sensors. Although results were reasonable, the unit survived less than 100 blows. In this case, the measurement was taken directly on the ram, and was referenced to the hammer base.

2.2.3 The MENCK Device

Details of the actual sensing device has not yet been published by MENCK. Company representatives indicated, however, that it is based on an inductive sensor and that pulses are generated over approximately 10 inches of the final ram travel. The distance between sensing points is apparently less than 1 inch. Thus, this device may be more accurate and, since it is factory installed, more rugged than the Fugro unit. On the other hand, since the unit has to be factory installed, it may not provide for an independent hammer performance check.

2.2.4 Visitrak

Visitrak (see Appendix B) is a commercially available device which is being used for high accuracy projectile position measurements. It consists of a virtually unlimited track length which contains grooves at intervals of .025 inches. Digital displacement measurements of high accuracy could be taken by installing the track on the ram, and the sensor on the hammer assembly. The difficulties will probably be in the attachment of the components to the hammer. The cost of the unit, including readout device is estimated at $2500.

2.2.5 Ultra Sound

Ultra sound transducers are used with increasing frequency in photography, and make distance measurement a simple task. Polaroid advertises a transducer plus signal conditioning unit at a rather low cost ($300). Apparently, the burst of ultrasound lasts for approximately 10 ms. For a 36 inch (914 mm) ram

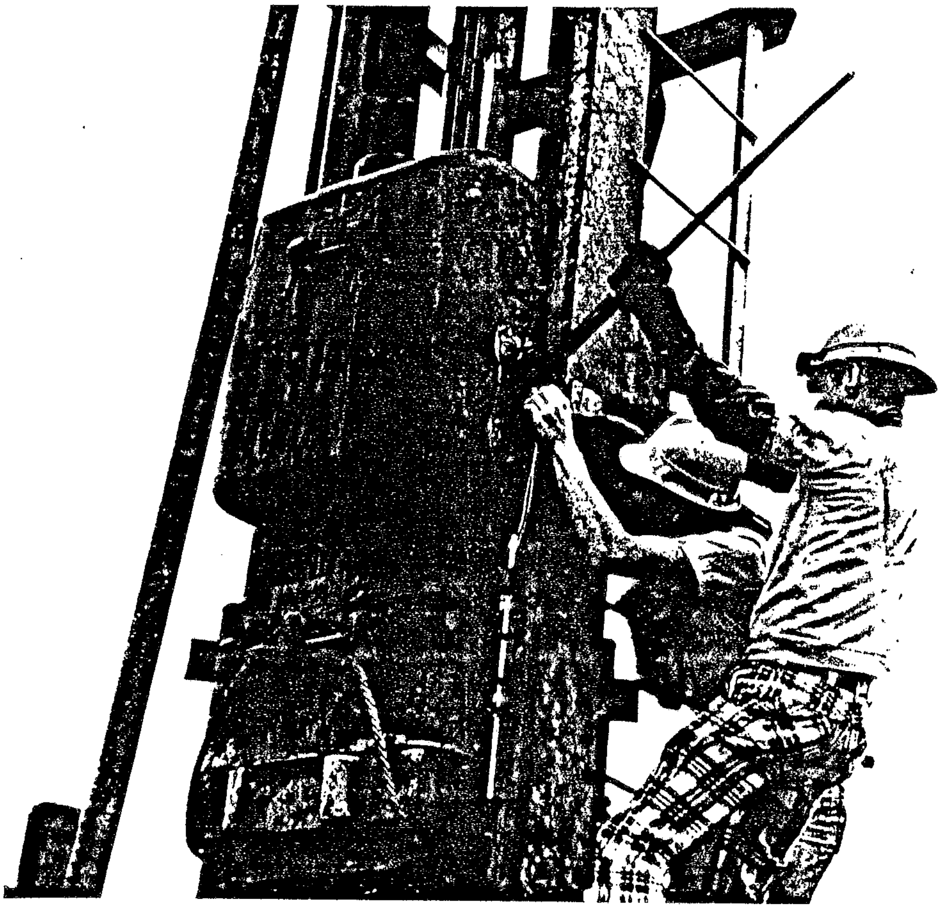


Figure 2.3: Installation of a device for the ram velocity measurements using light sensors at two locations.

stroke, the ram would travel 1.7 (43 mm) inches in this time. Unfortunately, these measurements are only repeated every 250 ms and therefore offer insufficient displacement resolution in the current form. Of course, attachment would again be the major problem of this device.

2.2.6 Other Solutions

A wide variety of emitters/receivers utilizing light, sound, ultrasound, infrared, magnetism, induction, capacitance etc. may be used for ram position determination. It does not seem important to discuss their individual differences, since their common drawback is the necessity of attaching sensors to the hammer. Conceivably, for diesels or the other enclosed hammers, the ram itself could produce the change of inductance, capacitance, etc. necessary for generating a position related pulse. The installation procedure would be different for each hammer model, and would, in general, require the drilling into, or other modification of the hammer which may be objectionable to contractors or manufacturers. (See also Section 8 on Safety Considerations.)

2.3 Ram Velocity

The only known device for direct measurement of ram velocity is in use, and is based on radar technology similar to that used in enforcement of vehicle speed limits. The RVM (Ram Velocity Monitor) was developed initially by Tera, Inc. and McClelland Engineers. A subsequent system, the HPA (Hammer Performance Analyzer), was developed by Pile Dynamics, Inc. A description of both units is contained in Appendix B. Notes on a meeting with Tera are reproduced in Appendix A. Actually, radar results may be considered a digital measurement technique, since it employs high frequency pulses. However, the device produces a continuous analog signal which is immediately plotted on a strip chart. The device definitely has major advantages over other solutions, the primary advantage being that it can measure the ram velocity remotely. Its accuracy seems adequate (5% error limit on velocity and therefore 10% possible error on energy).

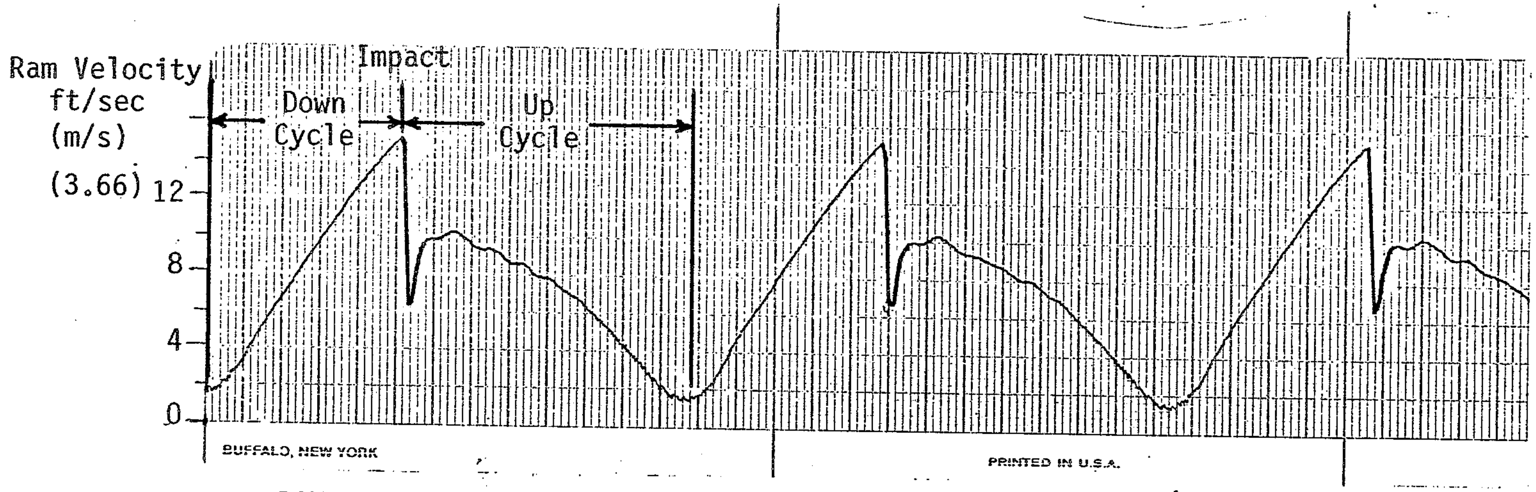
An actual radar record is shown in Figure 2.4. Both the RVM and HPA have compressed and expanded chart speed. The record was obtained during driving with an ASH hammer. Using a high chart speed, the individual phases of the ram motion can be clearly distinguished. For example, the velocity first increases linearly under the action of gravity to a maximum value, from which it drops sharply to zero. In the next phase, no clear signal is apparent since the ram was at a low speed. In the final phase, the upward velocity of the hammer in the lift part of the cycle is apparent. Only absolute velocities are displayed, so direction of motion is not indicated. Use of a fast chart speed allows determination of whether friction (slow gain of velocity) or preadmission (gain or loss of velocity just before impact) was responsible for poor hammer performance. The unit must be isolated from ground vibrations from impact as they produce relative velocity changes. Moving air hoses and large helmets or offshore type leads also pose additional sources of movement and must be minimized to produce acceptable results.

A change in hammer performance can very clearly be identified in the second record where the chart was run at a low speed of approximately 1 mm/sec. Thus, each Vulcan 560 (offshore) hammer blow caused a clearly visible peak value, and the total record shows a gradual change of ram impact velocity. This system has limitations for open-end diesel or cannot be used for enclosed hammers.

The cost of the system is less than $10,000. Installation time is less than one hour.

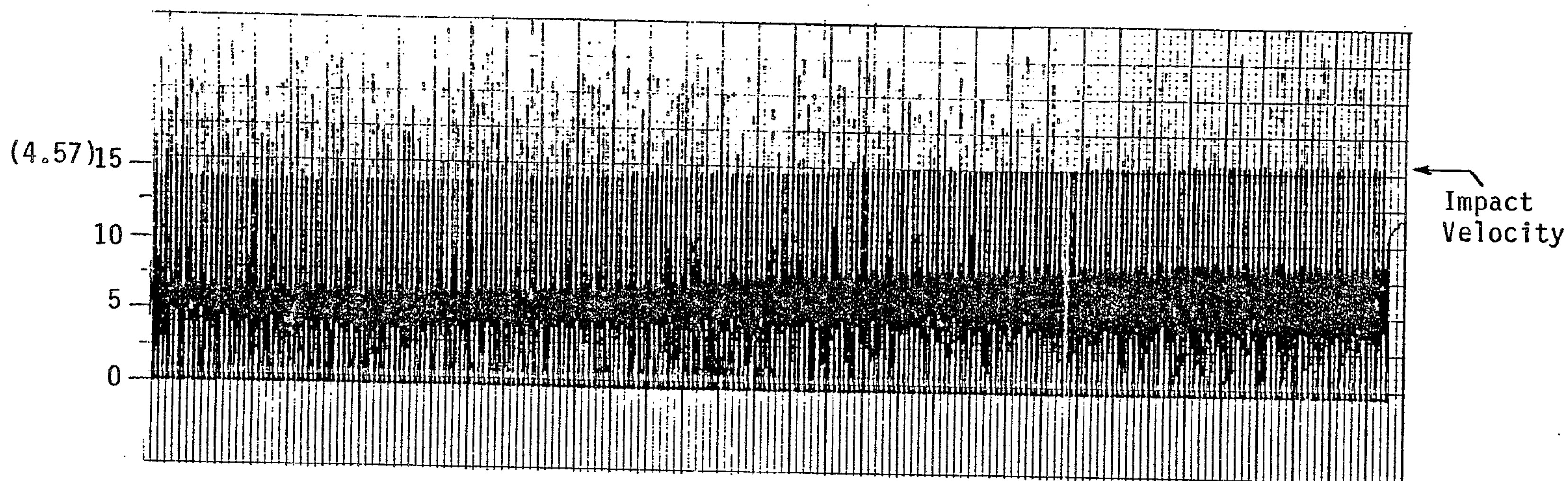
2.4 Ram Acceleration

Volume III of this report describes the efforts undertaken at the University of Colorado towards developing a sensitive accelerometer with overload protection. This device would have the disadvantage of requiring attachments to the ram. On the other hand, it is extremely small and light and therefore, does not cause any safety problems. Attachment to visible ram



RAM VELOCITY RECORD

Figure 2.4a: Ram Velocity Record from radar device, HPA (Courtesy of Pile Dynamics, Inc.)



COMPRESSED RAM VELOCITY RECORD

Figure 2.4b: Ram velocity record from radar device, RVM (Courtesy of McClelland Engineers)

ASH hammers is not a problem; attachment to other hammer types could be difficult.

3. INDIRECT MEASUREMENTS

3.1 Cap Force and Motion

3.1.1 Cap Motion

If ram efficiency needs to be determined, and measurements are taken below the hammer, then only combined force and motion measurements provide for unique solutions. Of course, the calculation of forces, compressions, velocities and other quantities of components located between transducers and ram is then also possible. When driving concrete piles, helmet motion must be measured because of the soft cushion response.

3.1.1.1 Acceleration

As for direct measurements, the goal of all measurement efforts is to determine the velocity of the components. The helmet velocity can be determined with standard accelerometers used for Case Method applications. Comparative measurements between pile top and helmet on steel piles show that the velocities are practically identical. Differences would occur at the time when a separation between the helmet and the pile top occurs, such as on the return of a tension wave. An example is given in Figure 3.1.

The helmet is usually easily accessible. Accelerometers may be mounted on the helmet while the hammer is near the ground, and cables can be easily secured without danger of damage. Two accelerometers have to be attached on diametrically opposite sides (e.g. using small bolts) to allow for the cancellation of rocking effects. Alternatively, an insert between capblock and helmet (like a force transducer) could be fitted with an accelerometer in the center of that device.

The acceleration measurement, and its integration to velocity has an accuracy within 5%. Integration after digital zero adjustment is, however, recommended. Since the hammer energy is transferred within a short time

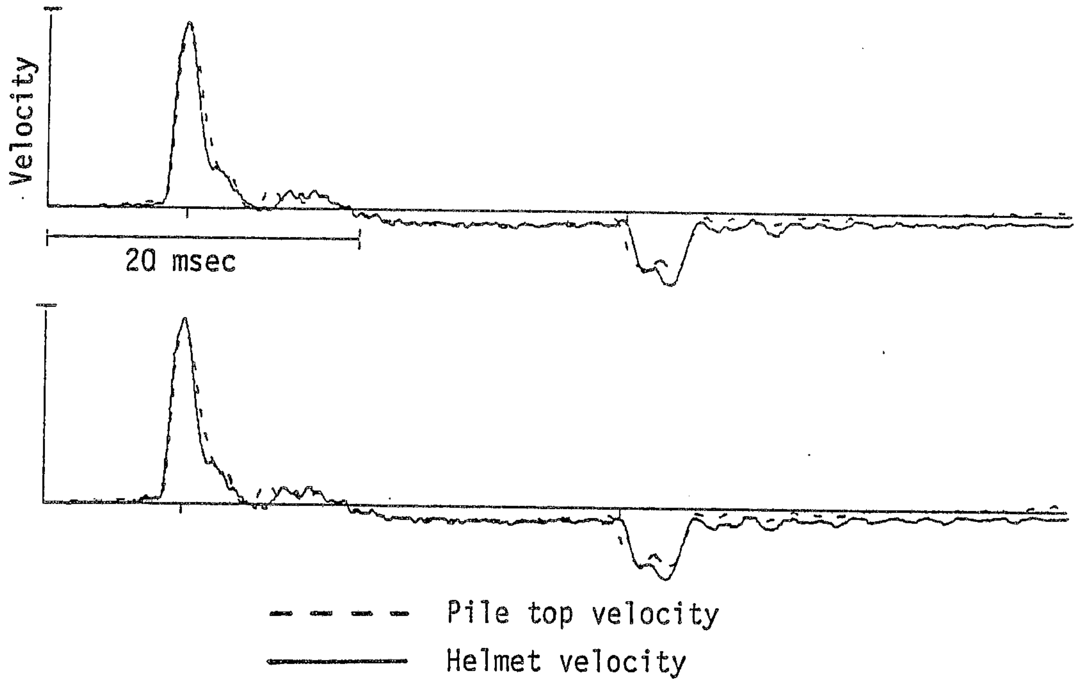


Figure 3.1 : Plots of pile top and helmet velocity taken under two consecutive blows of a diesel hammer on a steel pile.

integration errors due to an improperly determined accelerometer zero are generally small.

The cost of two accelerometers is less than $1000. However, additional instrumentation, like a power supply unit and integrator, would increase the cost of this method to a level that depends on the complexity of the data processing effort.

3.1.1.2 Velocity

No velocity measurement device suitable for helmet measurements is known to the authors.

3.1.1.3 Displacement

The optical transducer may be used, although it would have an advantage only if no force measurement was needed, as a cable connection for the force transducer would still be needed from pile to processing station unless telemetry were used. Advantages of helmet displacement over helmet acceleration measurements are insignificant.

3.1.2 Cap Force

The forces above and below the helmet differ by the helmet inertia. The force below the helmet is identical to the pile top force (as long as no additional masses are inserted between helmet and pile top). The force above the helmet is referred to as the "cap force" in this report.

The first large scale tests involving cap force measurements, were conducted by the Michigan Highway Commission (5). They designed and built a relatively heavy and sturdy force transducer which was installed between hammer and helmet. It was only realized later (see Rausche and Goble, 1972 (2)) that their transducer changed the measured force and added considerably to the maximum force values, because of the inertia of the large mass.

Ideal cap force transducers must be flat enough, and of such light weight they can be inserted into the driving system without significantly changing its mechanical behavior or efficiency. They must be capable of transferring loads of approximately 2000 kips (9 MN) under normal land application. For large diameter concrete piles, greater loads must be expected. An estimate for the load range would be the greater of the following two values:

$$F_{max} = (1/2)f_y(A_p) + M_c(a_{max}) \qquad (5)$$

and

$$F_{max} = f_y(A_p) \qquad (6)$$

where f_y is the yield or compressive strength of the pile material, A_p is the cross-sectional area of the pile, M_c is the mass of the cap and a_{max} is the maximum cap acceleration, which can roughly be estimated based on the hammer type.

a_{max} = 1000 g for hammers with no capblock
a_{max} = 500 g for diesel hammers
a_{max} = 200 g for air/steam hammers

The formulae for F_{max} have been based on the assumption that yield in the pile will be reached at a time when there is no significant acceleration, as the maximum pile-top force often occurs at the time of maximum pile-top velocity. It is then further assumed that the maximum acceleration occurs when the force reaches half of its maximum value. A wave equation analysis would be helpful in test preparations for actual cap force determination. Allowances need to be made for eccentric load applications.

There are many companies involved in the design and construction of transducers and there may be more products available than those discussed below. However, the following descriptions show the state of current technology.

3.1.2.1 The Sensotec "Pancake" Load Cell

Sensotec of Columbus, Ohio, offers "Pancake" load cells (Appendix B) with capacities up to 400 kips (1.8 MN). The largest unit has a 7 inch (17.8 mm) diameter and a 3 inch (76 mm) thickness. The load has to be applied through a 2.5 inch (6.4 mm) diameter center button. Eccentricities may reduce the stated 0.1% linearity of the unit. The 400 kip (1.8 MN) unit costs approximately $1200.

3.1.2.2 The A.L. Design Load Washer

A.L. Design is located in Niagara Falls, New York. Their literature (Appendix B) includes load washer offerings for loads up to 100 kips(0.45 MN). The "washer" has a thickness of .7 inches (18 mm) and an outside diameter of 2.25 inches (57 mm). The washer has a center hole into which a so-called load button should be fitted for load centering, in order to maintain a 0.15% linearity specification. Apparently, A.L. Design also makes custom designs. The small size of this transducer makes it a very attractive option. Whether or not a 1000+ kip (4.5 MN) unit can be built is not yet known. Currently, their largest unit has a 200 kip capacity, and costs approximately $800. High capacity transducers will probably be much more expensive.

3.1.2.3 The PCB Proposal

On February 22, 1983, Goble Rausche Likins and Associates engineers met with engineers of PCB (see Appendix B for a PCB brochure) and the possibility of designing a special purpose piezoelectric force transducer was discussed. Such a transducer would have to transmit the design load through a quartz crystal and would need a rather large surface area to avoid overstressing.

The weight of the unit would primarily depend on the load. High strength steel plates would be evenly machined and fitted to both sides of the transducer. Although this transducer would probably be very rugged, its potentially high cost (about $5/kip $1100/MN load transmitted) is a limitation.

3.1.2.4 The Fredericks Transducer

In personal communication, Mr. Leonard L. Frederick, Whippery, New Jersey, has described his development of a flat force transducer for use above or below the helmet. This unit is based on the changes in capacitance of the compressing transducer material. Unfortunately, a working prototype is not yet available.

3.2 Pile Top Measurements

This type of measurement is the basis of the Case Method and Pile Driving Analyzer. Its advantage is that the energy actually transmitted to the pile may be accurately determined. However, with the exception of transferred energy (determined from the integration of the product of force and velocity), the conclusions regarding hammer performance may only be obtained through additional computations. Also, because of the different pile sizes and shapes, direct measurement of force is not easily standardized. Strain measurements in the pile itself may be inaccurate when converted to force on piles other than steel, unless relatively complicated data checks are made.

Besides allowing for the determination of transferred energy, either pile top force or motion measurements may indicate the existence of severe preignition. As an example, consider Figure 3.2 which shows forces measured in the same situation (same pile type, same hammer) but at different times. Curve (a) was recorded in September, curve (b) in November, both on a 12 inch (305 mm) diameter pipe pile under the same, open-end diesel hammer. The strong rise before impact during the November test clearly indicates preignition. It should be added that cap measurements would similarly indicate preignition, however, example records are not available.

3.2.1 Pile Top Motion

Either displacement or acceleration of the pile top is currently measured on a routine basis. With continuous improvements in the technology of these

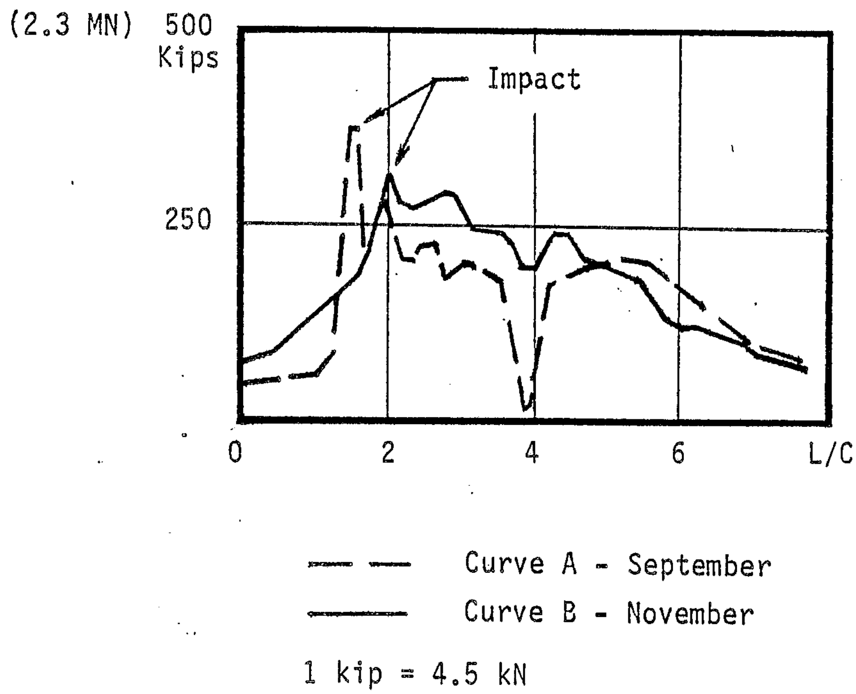


Figure 3.2 : Forces measured at different times on the pile-top for the same pile type and hammer.

devices, alternatives may not be necessary. The goal of the measurement is to obtain pile top velocity. The main techniques being used are outlined below:

3.2.1.1 Set-Rebound Curves

Pile top displacement has been measured for years without sophisticated equipment. The so-called set-rebound curve is obtained by passing a pencil or other suitable device along a reference fixed to the ground and drawn against the pile. As the pile moves, a relatively crude displacement vs time curve is obtained. This measurement is evaluated for maximum displacement and final set information that is required by some driving formulae. Also, the Kuemmel method (see Volume I report) sometimes utilizes maximum displacement as a measure of hammer momentum. Differentiation of set-rebound curves to velocity is impossible.

The person doing set-rebound measurements has to stand very close to the pile and underneath the hammer, and is, therefore, always in a dangerous location. Thus, because of both the inaccuracy and danger of this measurement, this method will be excluded from further discussions.

3.2.1.2 Pile Top Displacement

Two analog displacement devices have been used routinely to date. First, in 1971, the South Dakota Department of Transportation (6) reported on using a DCDT (DC current Displacement Transducer) with a 12 inch travel for pile top displacment measurements. Of course, such a device needs to be fixed both with respect to pile and soil. Once the range of the transducer is exceeded by the total pile penetration the transducer has to be reset, a distinct disadvantage.

This device suffers from a problem common to all analog devices with a large full scale value. The accuracy of a transducer is always stated as a percentage of its range. However, the maximum displacement of a pile is usually only a fraction of the range of a practical displacement transducer.

For example, for a 12-inch (305 mm) transducer range, and a transducer accuracy of 1%, a maximum displacement of 1/2 inch per blow, maximum displacement may be 24% in error. Differentiation to velocity will include additional uncertainties.

In addition to this inherent inaccuracy of an analog device whose full scale value is much greater than the quantity measured, the ground motions usually present at a construction site, and especially during impact, would further distort the signal. In this regard, all displacement or velocity devices suffer from the same shortcoming as the DCDT, although the optical transducer, which is the second device routinely used, probably suffers less from this effect as the distance of the device from the pile is large enough to avoid an interference from the impact-induced surface stress waves. Nevertheless, care has to be taken to isolate the device from other vibrations. Figure 3.3 shows an example of a pile top displacement - time history curve obtained from an optical transducer. Vibrations are clearly apparent in the record before impact. Their magnitudes reach 15% of the maximum displacement. A force record is also included in Figure 3.3 for a clear definition of impact.

For the DCDT, the displacement measurement may be completely meaningless if the ground motion near the pile is a large percentage of the pile motion. The soil motion will in many cases affect the measurement before maximum displacement is reached.

The DCDT including readout, would probably cost less than $2000. It can easily be installed in less than 1/2 hour.

It is conceivable that pile top displacement could be measured in digital form in the future. This would probably require that the pile is marked at small constant intervals. At present, such a process is not feasible.

3.2.1.3 Pile Top Velocity

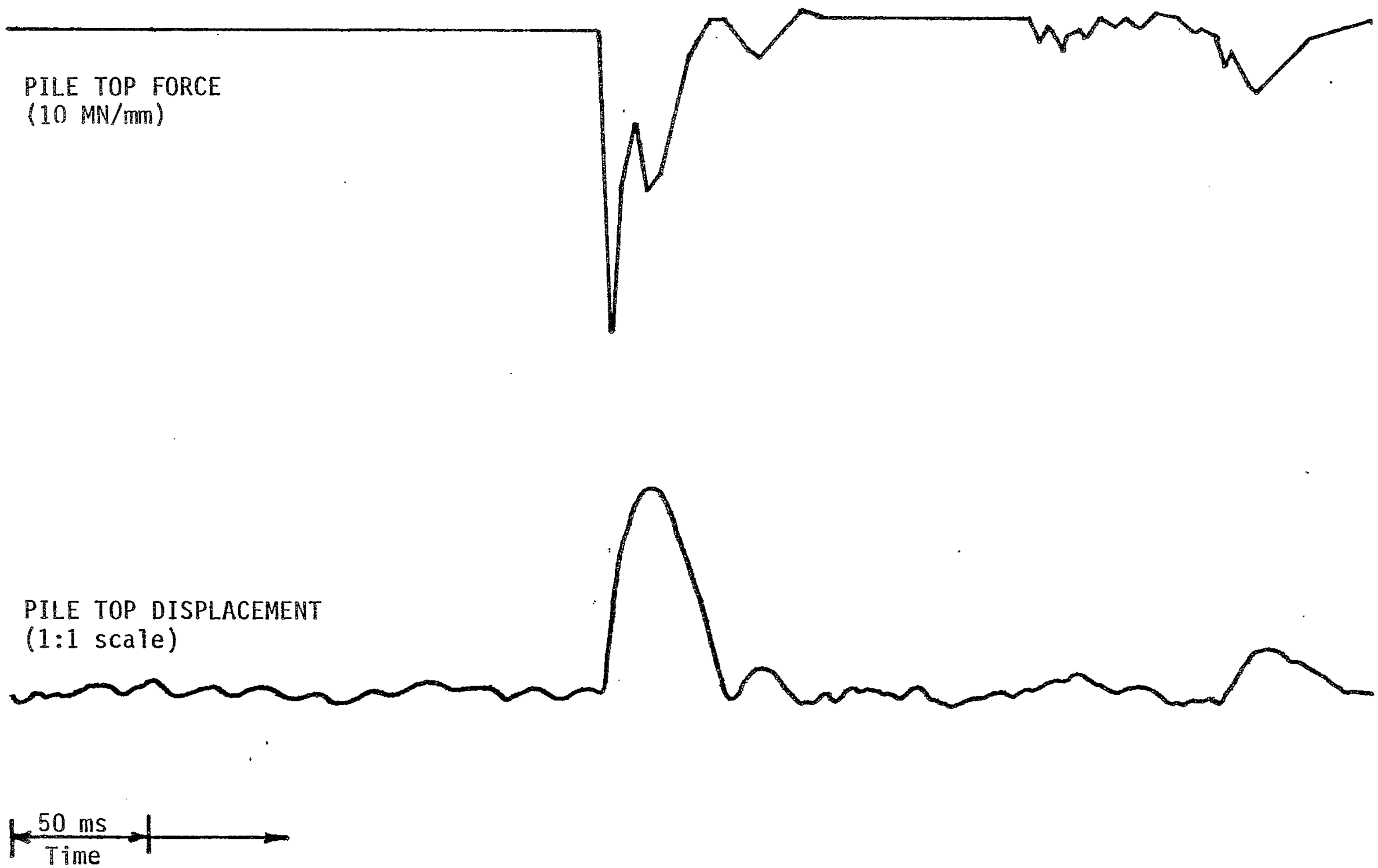


Figure 3.3 : Pile top displacement from optical transducer and pile top force.
(Courtesy of MENCK)

The major drawback to the direct measurement of pile-top velocity is the same as for pile top displacement - it is very difficult to provide a stable reference point for the measurement. At present, there are no routinely used pile velocity measurement systems.

3.2.1.4 Pile Top Acceleration

Acceleration measurements have the advantage that they do not require a reference. They require, instead, an accurate determination of the acceleration zero line if velocity is to be determined from acceleration. Today, using digital integration techniques, this problem can be easily overcome. An accelerometer with a 5000g range cannot resolve its zero line better than within a few g's. Thus, without correction, the error over a 100 msec time interval for a zero error of 1g would be 3.2 ft/sec (1m/s), or approximately 25% of a typical maximum velocity. Further integration to obtain energy compounds this error. Digital correction by an appropriate zero shift of the acceleration curve can reduce this error almost to zero. On the other hand, over the first 10 msec, which is the most important period as far as hammer performance is concerned, the error becomes only 0.3 ft/sec (91 m/s), even without correction, acceptably small if only maximum velocity is to be measured.

There is no significant difference between helmet or pile instrumentation as far as acceleration is concerned. Two units should always be used on opposite sides of either the pile or helmet.

Two accelerometers plus power supply cost less than $1000. Additional cost must be expected for signal conditioning. Installation time is at most 1/2 hour.

3.2.2 Pile Top Force

Pile top force may be measured in either of two ways. The first method is to place a force transducer between helmet and pile top, which measures the force directly. The second method is to measure the strain in the pile top, thus obtaining an indirect force result. Of course, the strain measurements require that the elastic and geometric properties of the pile top are known.

3.2.2.1 Force Transducers

A force transducer is a unit which transfers the total force; the resulting signal, is therefore, independent of the material properties of the pile. A good force transducer should be insensitive to eccentrically or nonuniformly applied loads.

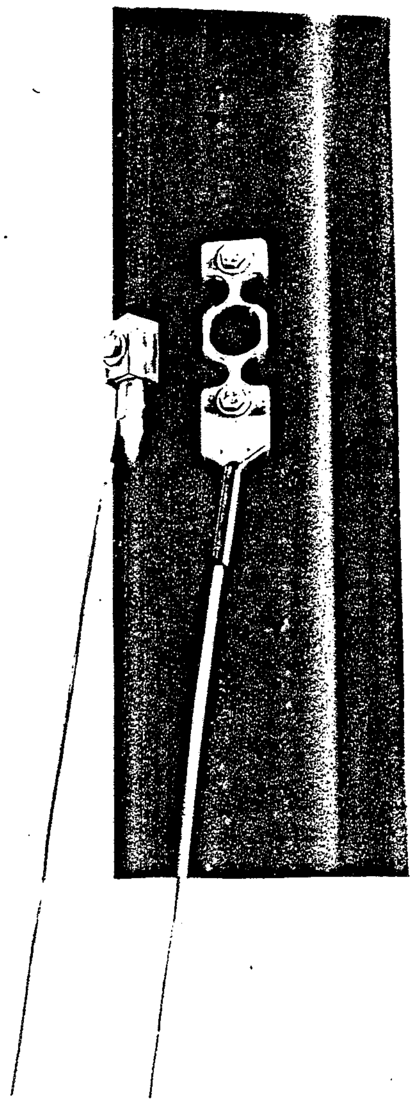
Force transducers which are acceptable for cap measurements would also be suited for pile top measurements. In general, however, since they are not placed above a large mass, they can be designed for the forces given by Equation 6 of Section 3.1.2.

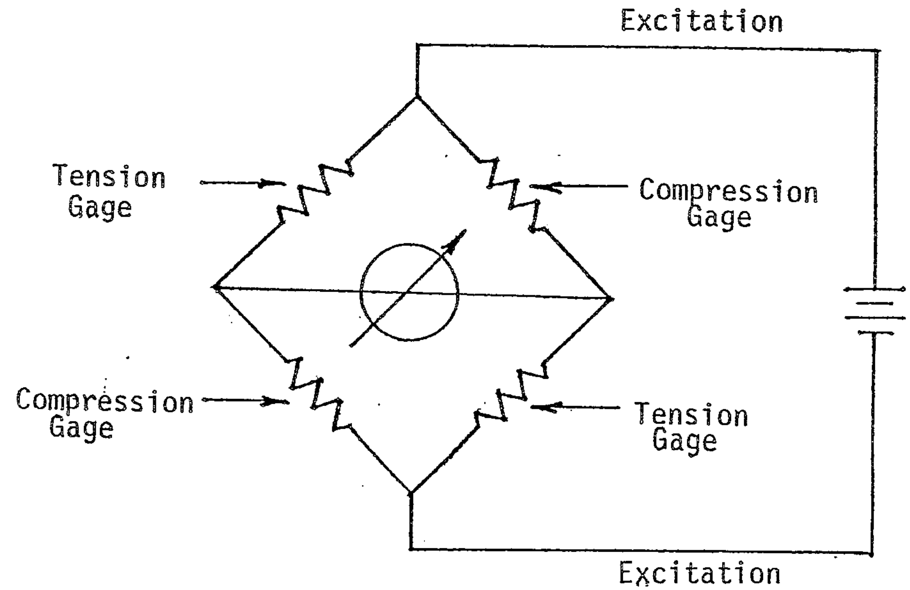
During the late 1960's, researchers at Case Institute of Technology (7) built and used several such transducers successfully, primarily for pipe piles. A similar version was used on H-piles (8) but placement on the pile was more difficult. The concept did not prove economical on concrete piles, because of the large weight of the unit. "Pancake" load cells or "Load Washers" (see Appendix B) would provide preferable solutions.

3.2.2.2 Strain Transducers

Starting with the studies at Case Institute of Technology (7), great progress has been made in the development of strain transducers for pile driving applications. Routinely used approaches include glue-on (9) and bolt-on transducers. Weld-on units are less common.

Strain transducers consist of a reusable piece of metal to which strain gages are attached. Glue-on transducers are thin metal strips with foil gages and wires attached. Bolt-on transducers, in the most common form, are flexible aluminum frames with foil gages attached to points of stress concentration (Figure 3.4).





Typical Wheatstone Bridge Stain Transducer

Figure 3.4.: Strain Transducer (a) attached to pile and (b) schematic of gage attachment.

Actually, foil strain gages themselves glued to the pile are a good solution. However, their installation especially in winter is difficult and time consuming. Weldable gages are installed with relative ease (say 1-1/2 hours per set). They range as an intermediate solution between foil gage and strain transducer. After a single use they are lost, often at a cost in excess of $100 per set.

Strain transducers have the following disadvantages in comparison with force transducers:

(a) The elastic modulus of the pile material and the pile area at the point of measurement must be known.

(b) The strain distribution should be linear at the point of measurement. To achieve this, a distance of at least one (equivalent) circumference must be maintained between the pile top and strain transducer. If this cannot be satisfied, then more than two strain transducers must be attached and their signals averaged.

(c) The strain transducer must be light and flexible, and, therefore, may be damaged or may change calibration if handled without care.

These disadvantages make determinations of force from strain transducers less accurate than those from force transducers. Accuracy can be maintained if simultaneous velocity measurements provide information about the force peak through application of the proportionality requirement. This is, however, not possible for non-uniform piles, or piles with skin friction soil effects close to the pile-top.

Strain transducers have a great advantage in that they are portable and of relatively low cost. They usually require that holes be drilled into the pile for bolting or anchoring. Attachment is much faster than that of foil or weldable gages. If epoxy glue is used, then attachment problems can arise in cold weather.

4. INDICATOR MEASUREMENTS

4.1 Observation of Ram Stroke

The ram of many hammer types can be observed during their full working cycle. On open-end diesel hammers, the ram top usually becomes visible at the top of its stroke. Using a so-called jumpstick (see Figure 4.1), it is relatively easy to determine the stroke of these hammers. Some manufacturers suggest observing the position of reference rings to estimate stroke.

Visual measurement of stroke while the hammer is operating, may be accurate to within 3 inches depending on the experience of the observer. Furthermore, the distance of the observer from the ram and the angle under which he has to make his "measurement" can influence the accuracy of the result.

On some air hammers, it is also possible to check the grease marks of the ram on the ram guides. However, this method only gives the maximum stroke obtained during a driving sequence.

4.2 Hammer Speed

Hammer speed (blow rate, striking rate, etc.) is a common, easy to perform, and low cost measurement. It is recommended as a first check on hammer performance by almost all hammer manufacturers. Depending on the hammer type, different conclusions may be drawn from the rate of ram operation. Note that hammer speed can easily be determined from any type of direct or indirect and from some indicator measurements by merely timing the duration between consecutive events. The Pile Driving Analyzer, for example, determines the blow rate (blows/minute) from either force or acceleration measurements.

4.2.1 Single-Acting ASH Hammers

Typically, for single-acting (S-A) ASH hammers, the hammer speed varies only within small margins. For example, the speed of a small Vulcan hammer

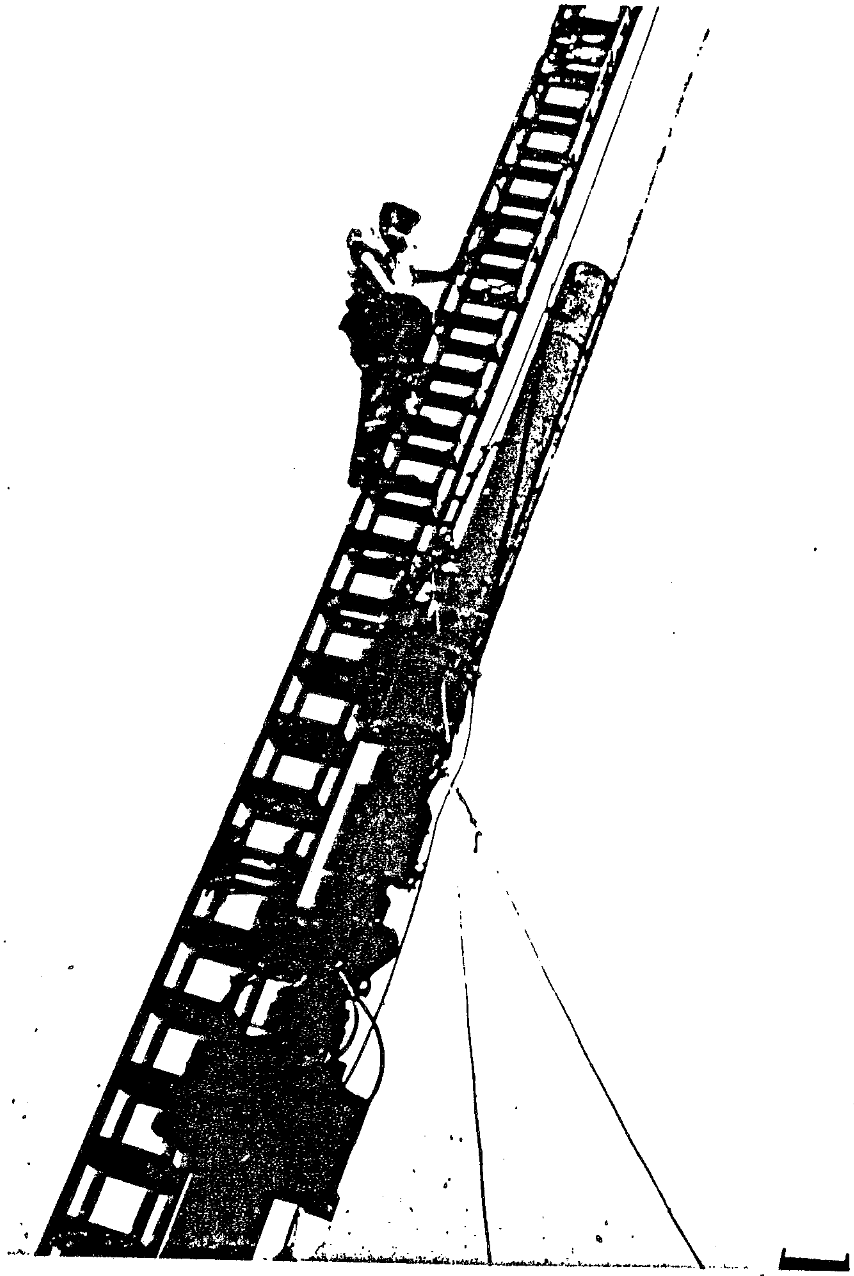


Figure 4.1 : Ram stroke measurements on an open-end diesel hammer with a jump stick

should be 60 blows per minute. A low value like 55 blows per minute could already indicate a severe problem with pressure supply or friction. Timing for only 15 seconds results in an accuracy of ± 4 blows per minute, and it is, therefore, recommended that a full minute's operation be recorded, or a device such as the Saximeter (see Section 4.2.3.2) should be used.

4.2.2 Double-Acting ASH Hammers

For double-acting (D-A) ASH hammers, the blow rate is even more important than for S-A hammers since pressure supply is directly related to the energy in the ram. Unfortunately, a deviation of the blow rate from the rated value may not always be an indication of a malfunctioning D-A ASH hammer. The main reason is that in hard driving, lift-off occurs which must be compensated by a reduction in pressure. Thus, the hammer may not perform at its fullest potential, and the blow rate may decrease.

4.2.3 Open-End Diesels

For open-end diesel (O-ED) hammers, it is obvious from observation of the ram, that the ram stroke changes with the driving resistance. Most manufacturers suggest rating their hammers by the available potential energy, Wh, (i.e., ram weight, W, times actual stroke, h).

The O-ED ram is subjected to only gravity and some friction throughout most of its travel, and the stroke height is, therefore, directly related to the time T (in seconds) between two successive impacts. Thus,

$$\text{Stroke[ft]} = 4.01(T)^2 - 0.3 \text{ [ft]} \qquad (7)$$

$$(\text{Stroke [m]} = 1.22\ (T)^2 - 0.009)$$

This expression was empirically derived through both measurements and wave equation simulation by correcting the equation governing perfect free-fall ($h = 4.01\ (T)^2$) with a loss term (0.3 ft. or .009 m) which accounts for friction, gas compression, and other losses in the cycle. The time interval, T, should be measured electronically for individual strokes, as an average over 10 strokes if a stop watch is used, or as an average over at least 30 strokes using a regular watch.

4.2.3.1 Watch Method

Start timing at impact 1 and stop with impact 11. The time thus measured is the time for 10 strokes. The time T in the above equation is therefore one-tenth of the measured time. The Foundation Equipment Corporation of Dover, Ohio, uses this measurement regularly. Using a regular watch, the time T can also be obtained from 60/BPM where BPM is the number of blows per minute.

4.2.3.2 Saximeter

Pile Dynamics, Inc. manufactures an electronic instrument which accurately determines the time T between two consecutive blows and converts this value to blows per minute, BPM. It can also compute the stroke, or potential energy (O-ED hammers only), counts blows and provides average values as printout as per operator request. Since the unit determines impact by sound pressure change, no actual hook-up to the pile is necessary.

The Saximeter outputs BPM or strokes for individual blows. Thus, hammer performance irregularities can be identified. The cost is approximately $1500

4.2.4 Closed-End Diesels

Hammer speed may be used as an indirect measurement of the equivalent stroke of closed-end diesel (C-ED) hammers. This measurement is, however, not as sensitive as for O-ED hammers. Either counting for a whole minute, or using the stop watch method may provide the answer. International Construction Equipment Corporation (ICE) does not recommend this measurement as a reliable hammer performance check.

4.3 Bounce Chamber Pressure of Closed End Diesels

There are only two manufacturers of closed end diesel hammers in the United States. They are Linkbelt/ICE and MKT. Both hammer types offer a bounce chamber pressure indicator. The indicators differ substantially in their design, and will be discussed independently in Sections 4.3.1 and 4.3.2.

Electronic measurement of the bounce chamber pressure is an obvious alternative to the mechanical or pneumatic systems provided by the manufacturers, and are possibly more accurate than those admittedly rugged devices. However, there is no need to record pressure history, since the only value of interest is the maximum pressure. Unfortunately, the pressure-stroke relationship is different for each hammer model. This stroke may be related to the available hammer energy, assuming certain energy losses as the compressed air pushes the ram downwards (manufacturers generally assume zero energy losses). Thus, bounce chamber pressure for C-ED hammers is a replacement for the hammer speed measurement on O-ED hammers.

It is not known whether any electronic bounce chamber pressure measurements have been made. It seems that the limited value of a high accuracy measurement does not justify the cost associated with a reliable and rugged electronic system.

4.3.1 Linkbelt/ICE Hammers

These hammers are fitted with a connector on their bounce chamber which allows for the attachment of a pneumatic gage through a hose. Depending on the condition of hose and gage, and the length of the hose, this measurement is more or less accurate. As a simple check, the maximum bounce pressure should be measured when the hammer lifts off in hard driving, and compared with the manufacturer's listed lift-off pressure.

4.3.2 MKT Hammers

MKT hammers have a mechanical, spring loaded gage installed at the lower side of the bounce chamber. This gage distinguishes only between low, medium and high stroke and is, therefore, not sensitive to small changes in stroke. Note, that the relationship between stroke and pressure is nonlinear, and that relatively small pressure errors may cause large errors in equivalent stroke. The gage is very small, and often difficult to read from a distance. Lately, better, hose connected gages have been made available by MKT. Again, the best check of the built-in gage is a reading at lift-off.

4.4 Pressure of ASH Power Medium

One hammer manufacturer (MENCK) indicated that they took such pressure measurements during hammer development. Another manufacturer (Vulcan) intends to develop a measurement system for routine applications. All manufacturers of ASH hammers agree that the pressure of the medium at the hammer inlet valve is one of the most important parameters regarding hammer performance of these hammers.

This pressure measurement is not simple, because of the gage attachment difficulties. Often, needle gages are recommended for a peak reading of pressure at some location in the pressure hose. However, it is questionable whether either a peak or an average value is valid or sufficient. The necessity for measurement at the hammer inlet valve is highlighted by one manufacturer's estimate that as much as 25% of pressure is lost between the source and the hammer.

Electronic measurement of pressure with time would be more sophisticated. This would be difficult because of the lack of a reference pressure at a known time. In other words, a long time static measurement is necessary with very good stability in an environment of variable temperatures (hot steam makes this measurement even more difficult).

In summary, needle gage measurements of pressure are very inexpensive, although not always conclusive. Pressure histories recorded electronically would be both difficult and expensive. Thus, although the value of such measurements has been universally agreed on, a recommendation for routine usage cannot be made.

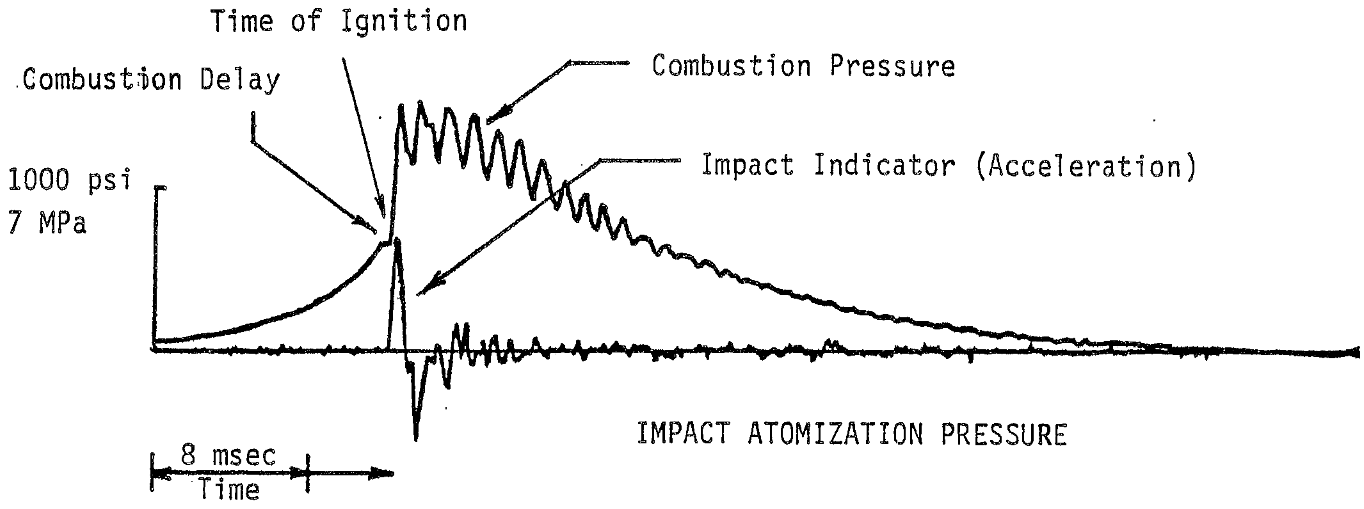
4.5 Combustion Pressure of Diesels

During the past years, and in particular during the course of this project, a large number of combustion pressure measurements were taken. The measurement system in all cases consisted of a piezoelectric pressure transducer with high temperature electronics capable of handling a 2500 psi pressure range.

The combustion pressure measurement is simplified by the venting of the chamber shortly before compression starts. Thus, a reference atmospheric pressure level is always established, and a simple dynamic measurement system can be used. Care must be taken, however, that both the transducer and the signal conditioning system have a time constant in excess of 10 seconds. If not, the low frequency pressure components which occur during the initial compression and later expansion phase may be lost. Such errors would be indicated by negative values late in the record.

Two different pressure time histories are shown in Figure 4.2 together with pile acceleration or velocity. The onset of the steep velocity (acceleration) increase is an accurate indicator of the arrival of the stress wave in the pile top, approximately one-quarter of a millisecond after impact.

The two pressure plots clearly indicate different behavior both before and during impact. In the first case, a combustion delay exists between the time of impact and the time of ignition. It is this case that had been used as a model for the WEAP thermodynamic computation. In the second case, the occurrence of preignition is identified by high pressures before impact. The second pressure history, which was obtained on an atomized fuel injection ham-



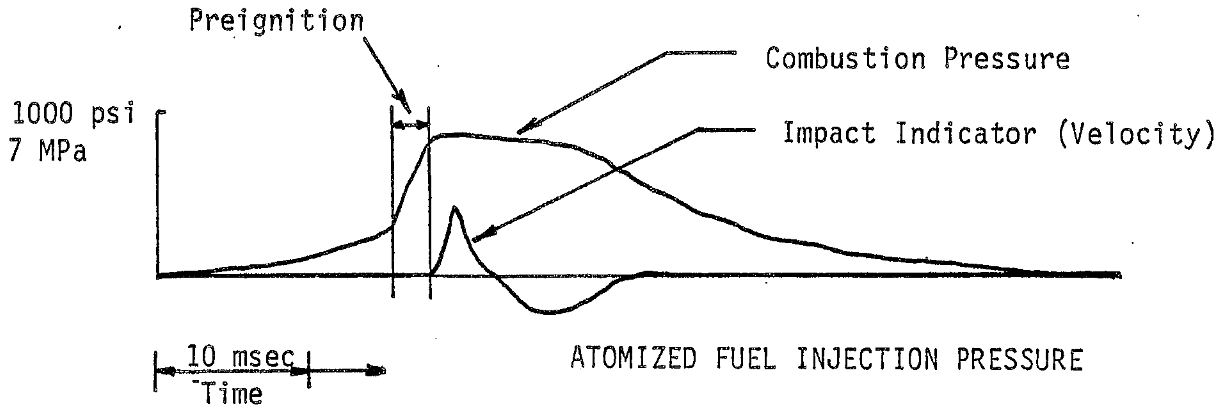


Figure 4.2 : Pressure time records, (a) from impact and (b) from atomized fuel injection

mer, is not similar to the WEAP thermodynamic model. The two curves clearly indicate differences in hammer performance. It is, therefore, possible to compare the pressure histories of a cold and a hot hammer to see if unwanted preignition occurred.

Preignition can, however, also be detected by direct or indirect measurements as discussed in the previous sections. Maximum pressure may also be back-calculated from the observation of stroke and a wave equation simulation. Thus, combustion pressure measurements do not add information regarding hammer performance that cannot be derived from simpler measurements, unless a pressure time history is needed for the formulation of a mathematical model.

The cost of a pressure transducer is less than $500. Attachment is relatively simple since hammers usually contain a clean-out plug in the combustion chamber area which can be utilized. The electronic signal conditioning is also rather inexpensive. However, since the measurement is only of value if the total history is recorded, it is necessary to provide an oscilloscope and, preferrably, a tape recorder. The cost of the system then exceeds $5000. There is probably no simple automated evaluation technique for combustion pressure which would clearly distinguish between a normally and a poorly performing hammer.

4.6 Subsets of Direct Measurements

4.6.1 Maximum Helmet/Pile Velocity

The maximum helmet or pile velocity may be obtained from displacement time measurements (e.g. optical transducer), from acceleration time measurements or from an LVDT (Linear Velocity/Displacement Transducer). In the latter application, the LVDT coil is mounted to pile or helmet and a small mass is attached to the core which rests on the coil. When a hammer blow suddenly moves the core; the coil is temporarily unsupported and starts to fall under its own weight. For short times, the difference between the core and coil velocities is nearly identical to the pile or helmet velocity. For longer times, the free fall velocity of the coil may be computed and added. Thus, a very simple measurement system may be obtained that has no need for a reference and yet provides a velocity value.

Marchetti (10) has proposed this measurement system for a check of wave equation input parameters. From theoretical considerations, it is known, however, that only a maximum value is insufficient to determine the hammer efficiency, since other parameters, like capblock stiffness, have an influence. Other disadvantages of this measurement system are:

(a) The LVDT may be too sensitive for long term applications. A study performed in 1974 by Goble & Associates in trying to design a maximum pile displacement transducer using a DCDT, in a manner similar to Marchetti, was primarily unsuccessful because of the high failure rate of the transducer.

(b) Friction between coil and core may make the system highly inaccurate. It is not believed that an accuracy better than 10% on the velocity maximum can be obtained under routine field conditions.

The cost of the LVDT device, including readout, is probably rather modest. The transducer itself costs approximately $500. Once modifications and read-out device are included, a cost of $2000 should not be exceeded. However, the cost of accelerometers and read-out would be similar, and have the dual advantages of being much more accurate and rugged.

4.6.2 Maximum Cap/Pile Force

As with velocity measurements, maximum pile top force is not necessarily sufficient to solve for hammer efficiency. In contrast to maximum velocity measurements, however, maximum force measurements are more difficult and expensive. If maximum force can be measured, then the total force history may also be determined, giving much more complete information, at practically the same cost. Furthermore, as discussed in Chapter 3, the additional measurement of motion provides for complete data at little additional cost.

5. COMPARISON OF DIRECT AND INDIRECT MEASUREMENTS

For a fair comparison of available or future measurement systems or techniques, the performance of the systems in the most general piling situations, for instance, where a nonuniform pile with unknown material properties and skin friction is being driven, should be considered. In this case, a ram velocity measurement at impact is the most desirable parameter for wave equation analysis input. This parameter removes the greatest source of error inherent to hammer simulation. For ASH hammers, it takes into account any preadmission, friction, reduced stroke or any other influences on the ram motion before impact. For diesel hammers, determination of ram velocity at impact allows for inclusion of any preignition, friction and stroke effects that might be present. Ram velocity measurements also allow determination of available kinetic energy immediately before impact.

The studies in the Volume IV report have shown that there is a rather large difference between potential energy, actually available kinetic hammer energy, and energy ultimately doing work on pile and soil. Thus, even though ram velocity is known, the additional energy losses must be estimated. These losses may easily be 50% of the actual hammer losses.

For this reason, it seems reasonable to take advantage of indirect measurements, in conjunction with computational techniques, so that both hammer energy and driving system losses can be simultaneously determined. The ideal indirect measurement system would measure velocity at the helmet. Using these measurements, it would be possible to compute both capblock stiffness and coefficient of restitution. Measurement of force underneath the helmet or at the pile top would be beneficial for concrete piles, the pile top acceleraton could also be recorded directly, allowing determination of the pile cushion's stress-strain curve. Further studies (see Volume III) will investigate the details of such a system.

The indirect measurement systems need to be complemented by computational techniques. With force and acceleration measurements available, it is a relatively simple task, in the case of ASH hammers, to calculate the ram impact velocity, capblock stiffness and coefficient of restitution using a direct approach based on the momentum and energy theorems. For diesel hammers, similar computations can be made, although these computations are more complex, because the precomression phase must be taken into account.

6. VALUE OF INDICATOR MEASUREMENTS

Most indicator measurements are easily taken. The measurement of combustion or air pressure as a function of time are exceptions. The value of the most commmon indicator measurements is discussed below:

(a) A visual observation of the ASH hammer stroke is valuable for qualitative hammer performance observations but is too inaccurate for actual quantitative assessment. It is recommended that ASH hammer stroke observations be recorded.

(b) Hammer speed is easily observed and is very valuable for hammer performance evaluation. It can be determined from any continuously recorded direct or indirect measurements, or if lacking this sophistication, by using a stopwatch. The recording of blow rate (blows per minute) is therefore strongly recommended.

(c) Bounce chamber pressure should always be recorded when using closed end diesel hammers. However, measurement of this pressure does not eliminate the need for other measurements, as it is generally inaccurate. This parameter should be used as a complement to the observations in (a) and (b).

(d) The inlet pressure of ASH power media is not easily or accurately measured. This measurement does not indicate if a hammer is actually functioning as rated. It only indicates inadequate power medium performance which will, of course, result in poor hammer performance. Simple measurement of blows per minute should detect this problem without the complexity of this pressure measurement.

(e) Diesel combustion pressure can be simply measured. However, it does not provide any information that cannot be determined from indirect measurements. Measurement of this pressure is necessary only to allow improvement of mathematical thermodynamic models.

(f) Subsets of indirect measurements do not provide for any particular advantages.

7. TELEMETRY

Telemetry is the term generally used to describe the transmission of data from a remote source to data analysis equipment. In order to avoid the use of cables linking the transducers and data analysis equipment, it would be desirable to use telemetry techniques in pile driving analysis. The telemetry system would have to include signal conditioning, data (signal) encoding, radio transmission, antenna, power supplies, radio receiver with antenna and data decoding sections.

The advantage of telemetry would be the simplification of measurement operations, since no cables would be necessary from pile or hammer to the recording station. This would be of major advantage for systems with sensors on the hammer or driving system as it would make the testing of several piles extremely simple. However, if measurements are taken directly on a pile, then the advantage of telemetry would be minor.

The major disadvantage of telemetry is the need to attach a relatively large package of electronics to either pile or hammer, and to isolate the electronics from the shock of driving. Another disadvantage is its very high cost compared to a cable system. As will be pointed out in Chapter 8, a heavy package attached to the driving system is a safety hazard.

Technically, the system would require signal conditioning for the transducers, including auto-balancing and resetting. The voltage of each conditioned signal would be input to a set of high performance voltage to frequency converters. The frequency converter output would be directed to a commercially available wideband FM transmitter and transmitted through a small antenna.

The signal would be received by a ground antenna attached to a commercial wideband receiver. The signal taken from the discriminator of the receiver would pass through filters separating the individual channels of data. The signal from each channel would then be converted back to a voltage, using high performance frequency to voltage circuits.

The approximate cost of such a telemetry system would be \$4500. Of course, some minor savings in the data analysis system may result, since signal conditioning would already be included in the telemetry package.

8. SAFETY CONSIDERATIONS

Pile driving involves high energies, with heavy equipment often operating at great heights, and the continuous danger of the fatiguing of attachments to the hammer-pile system. Thus, any equipment attached to hammer, helmet or pile may fall off and become a hazard.

The use of set rebound measurements which require a person to be directly beneath the hammer are particularly dangerous and should be avoided. The risk to life is too large to offset the small gain in knowledge, which can be easily and safely obtained with modern electronics.

Any attachment or measurement component with substantial weight would be dangerous if it is hard or sharp-edged. In addition, any monitoring equipment that potentially interferes with the operation of the hammer, may require repair work or modification of the hammer or other driving system components while they are at a great height, and be an indirect danger.

For safety reasons, the optimum system should be installed near the ground and consist of light attachments or components that cannot possibly fall. Cables are not necessarily a disadvantage if they can be kept out of the way.

Attachments to the hammer should be very light, and should not require extensive drilling into or welding to hammer parts subject to fatigue. The system should always be monitored at a safe distance from the driving system.

9. SUMMARY OF CURRENTLY USED METHODS AND EQUIPMENT

In this chapter, a summary will be given of present methods for both the evaluation of hammer performance, and regular pile stress measurements. The advantages and disadvantages of these systems with regard to hammer performance checks will be discussed. A summary table (Table 1) indicates the quantities that are measured or that can be derived from each system.

9.1 The Pile Driving Analyzer (PDA) from Pile Dynamics, Inc.

Measurements by the PDA are based on pile top force (from force or strain transducers) and acceleration. A schematic of the system is shown in Figure 9.1. The PDA conditions and processes the signals, and calculates bearing capacity, pile stresses and pile integrity. For hammer performance, four outputs are of particular importance.

a) The energy transferred to the pile.

b) The maximum force at impact or the maximum downward wave at impact.

c) The impulse at the pile top at the time of pile top zero velocity.

d) The speed of the hammer (blows per minute).

These four quantities may be used directly by the momentum method to determine driving system parameters, or indirectly by matching wave equation results. For relative comparisons of the total driving system, the transferred energy is the most important parameter. However, it does not distinguish between losses in the driving system and in the hammer. For that reason, additional analyses are necessary.

9.1.1 Disadvantages

a) For concrete piles, the pile cushion adds another unknown which makes

Table 1: Direct and Indirect Hammer Performance Measurement Systems

Section	System	Measured Quantity							Derived Quantity				Direct Indirect
		RAM V	RAM D	CAP F	CAP AVD	PILE F	PILE AVD	BPM	RAM E	CAP k	CAP e_c	PILE E	
9.1	PDA	–	–	–	–	X	X	X	X	X	X	X	I
9.2	GPT	–	–	–	–	X	X	–	–	–	–	X	I
9.3	DMS*	–	–	–	–	X	–	–	X	X	X	–	I
9.4	TNO	–	–	–	–	X	X	–	–	–	–	–	I
9.5	MENCK*	–	X	–	–	X	–	–	X	X	X	–	D
9.6	QMC	–	–	–	–	X	X	–	X	X	X	–	I
9.7	RVM	X	–	–	–	–	–	–	X	–	–	–	D
9.8	PDR	–	X	–	–	–	–	–	X	–	–	–	D
9.9	Saximeter	–	–	–	–	–	–	X	X	–	–	–	D
9.10	Marchetti	–	–	–	–	–	X	–	–	–	–	–	I
9.11	SPT	–	–	–	–	X	–	–	–	–	–	–	I

*ASH – Offshore Piles (Steel)

X indicates obtainable quantities

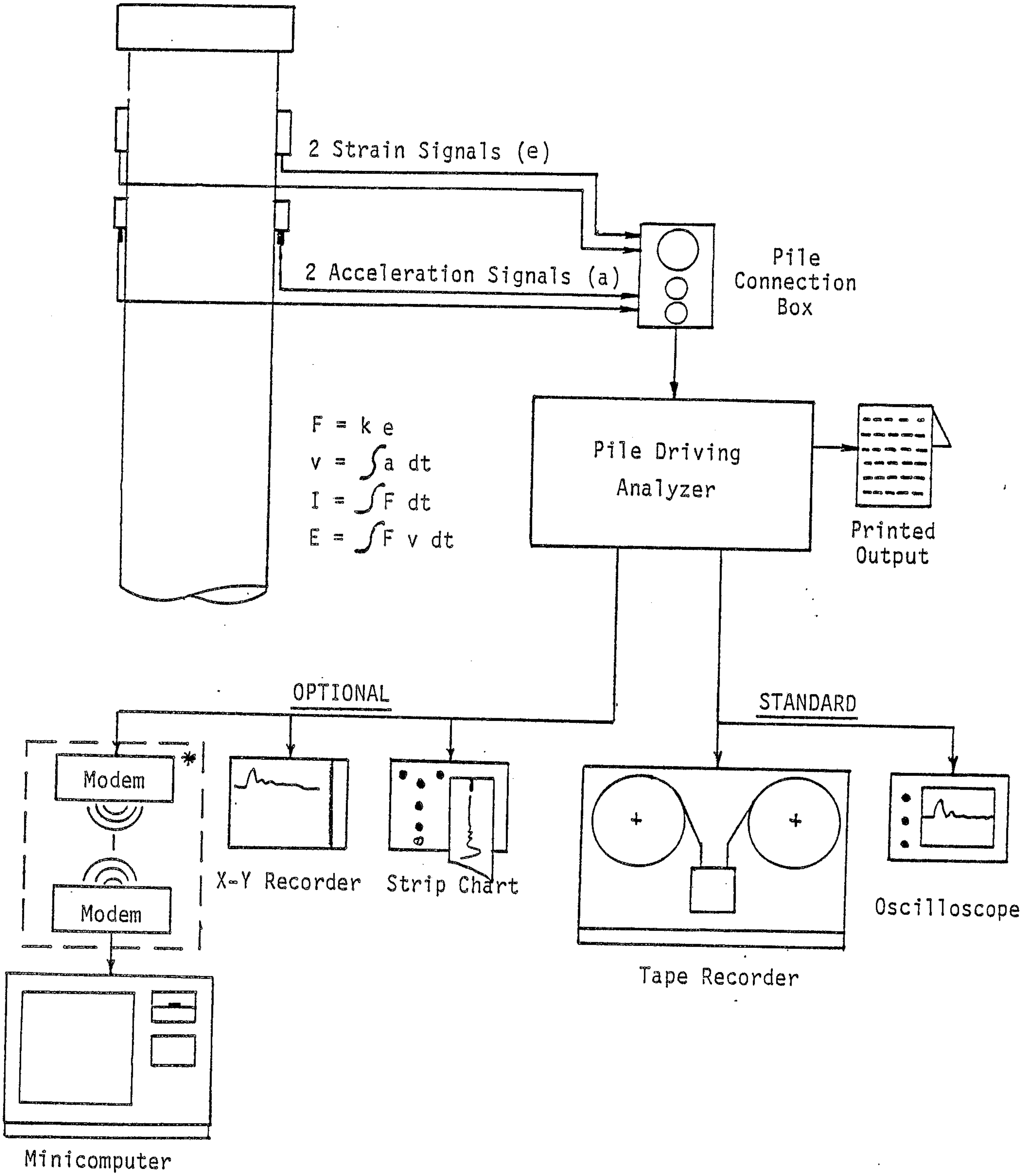


Figure 9.1 : Pile Driving Analyzer System and its hammer performance outputs.

driving system parameter determinations difficult, or requires that helmet acceleration measurements be made.

b) If the PDA is used with strain transducers on concrete or timber piles, the strain to force conversion is not always accurate or easy, and usually requires wave speed measurements and data checks. This is not a simple task.

c) The PDA performs additional tasks which are not needed for hammer evaluations. Some hammer performance evaluations are not performed automatically in the present form of the PDA.

9.1.2 Advantages

a) The PDA is fast, and provides for an immediate output of the above mentioned important parameters.

b) Since it does provide for a check on two independent measurements, gross errors can easily be avoided.

c) The PDA system includes recording capabilities, thus providing for reanalysis of the data.

d) The PDA results can be interpreted to determine the reasons for a hammer malfunction (e.g. soft cushion, preignition).

e) It is a single component system.

9.1.3 Accuracy

The PDA used with proportionality and wave speed data checks allows for signal accuracies of 5%, which in the worst case, gives a 10% accuracy on transferred energy.

9.2 The General Pile Testing System (GPT)

Basically, this system is modeled after the Pile Driving Analyzer except that it uses commercially available components for data processing rather than the PDA (Figure 9.2). Thus, strain and acceleration are measured near the pile top and acceleration is usually integrated to velocity. Both signals are then displayed by a transient recorder which may also store the data on floppy disk.

Computations are performed by a desk top computer. It is not known that particular hammer performance parameters are investigated by any of the users, which include the Technical University in Uppsala, The Technical University in Braunschweig, McClelland and Fugro among others. The system would, however, be capable of performing a hammer analysis.

9.2.1 Disadvantages

a) All disadvantages of Pile Driving Analyzer.

b) Speed of Operation: Computations can only be performed sometime after pile driving.

c) Multi-component system.

9.2.2 Advantages

a) System components commercially available.

b) Advantages of PDA as in 9.1.2 b), c) and d) above.

9.2.3 Accuracy

Since this system is basically similar to the PDA, accuracy should be similar.

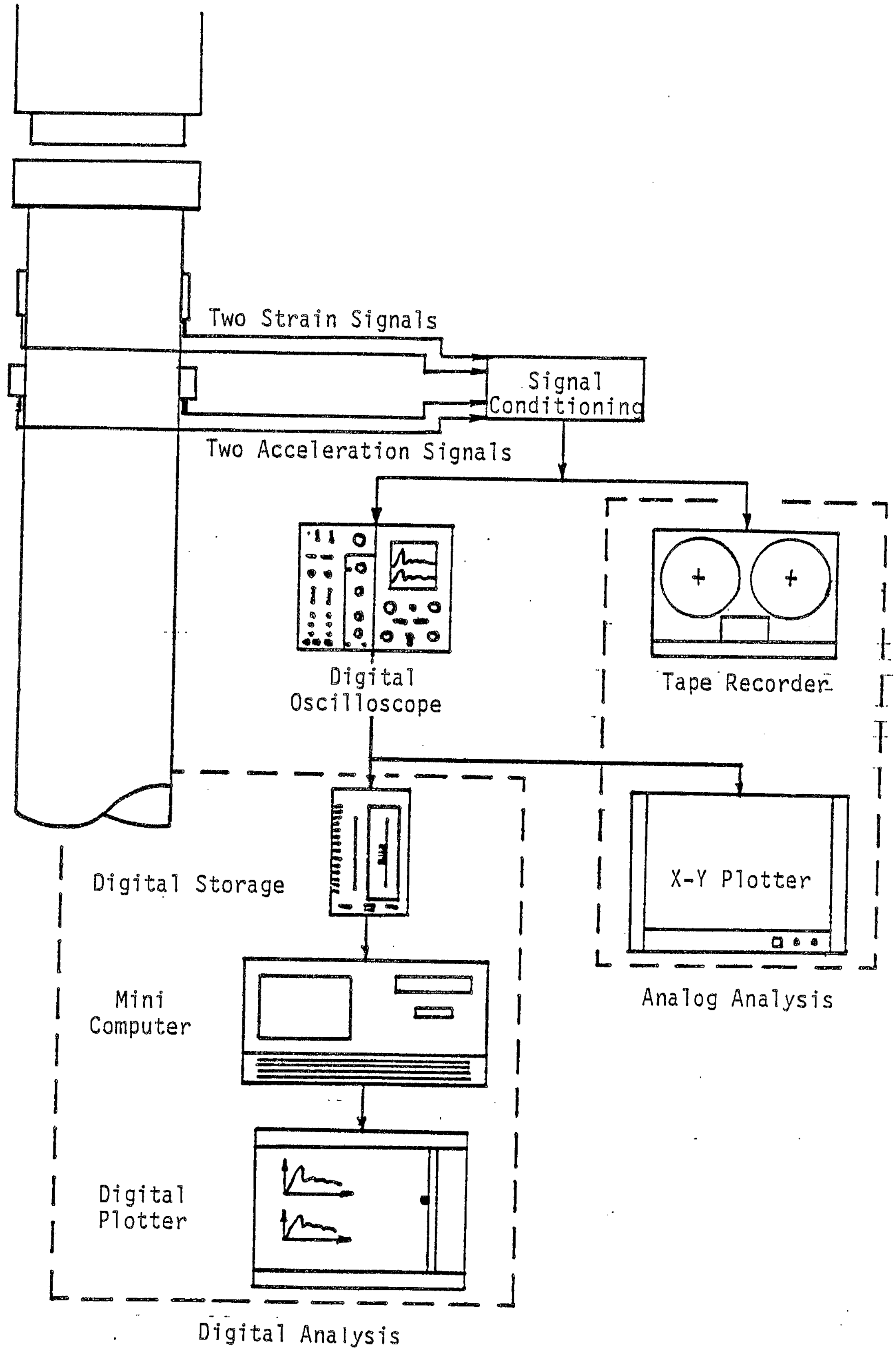


Figure 9.2: General Pile Testing System

9.3 McClelland DMS System

A schematic of this system is shown in Figure 9.3. Force is measured in the pile either using weldable gages or strain transducers. After signal conditioning, which may include temporary storage and a peak force display, a force curve is drawn on a strip chart recorder. This force curve is then investigated to determine rise time, T_1, time of occurrence of a second peak, T_2, and maximum force.

Since DMS is applied offshore, these three quantities are, generally, independent of soil effects because of the long distance from gages to soil. Thus, it is possible to perform an array of wave equation analyses by variation of e_{rc}, hammer efficiency; k, capblock stiffness, and e_k, coefficient of restitution, and to plot a nomogram with dependent variables T_1 and T_2. The three quantities k, e_k, and e_{rc} are obtained from the results of the measurements in combination with the nomogram.

9.3.1 Disadvantages

a) Single measurement quantity does not provide for data check.

b) System only applicable to offshore piles with air/steam hammers.

c) Many wave equation analyses are necessary to provide for a nomogram which is only applicable to one specific case.

9.3.2 Advantages

a) Simple, relatively inexpensive measurement system.

b) Complete driving system evaluation.

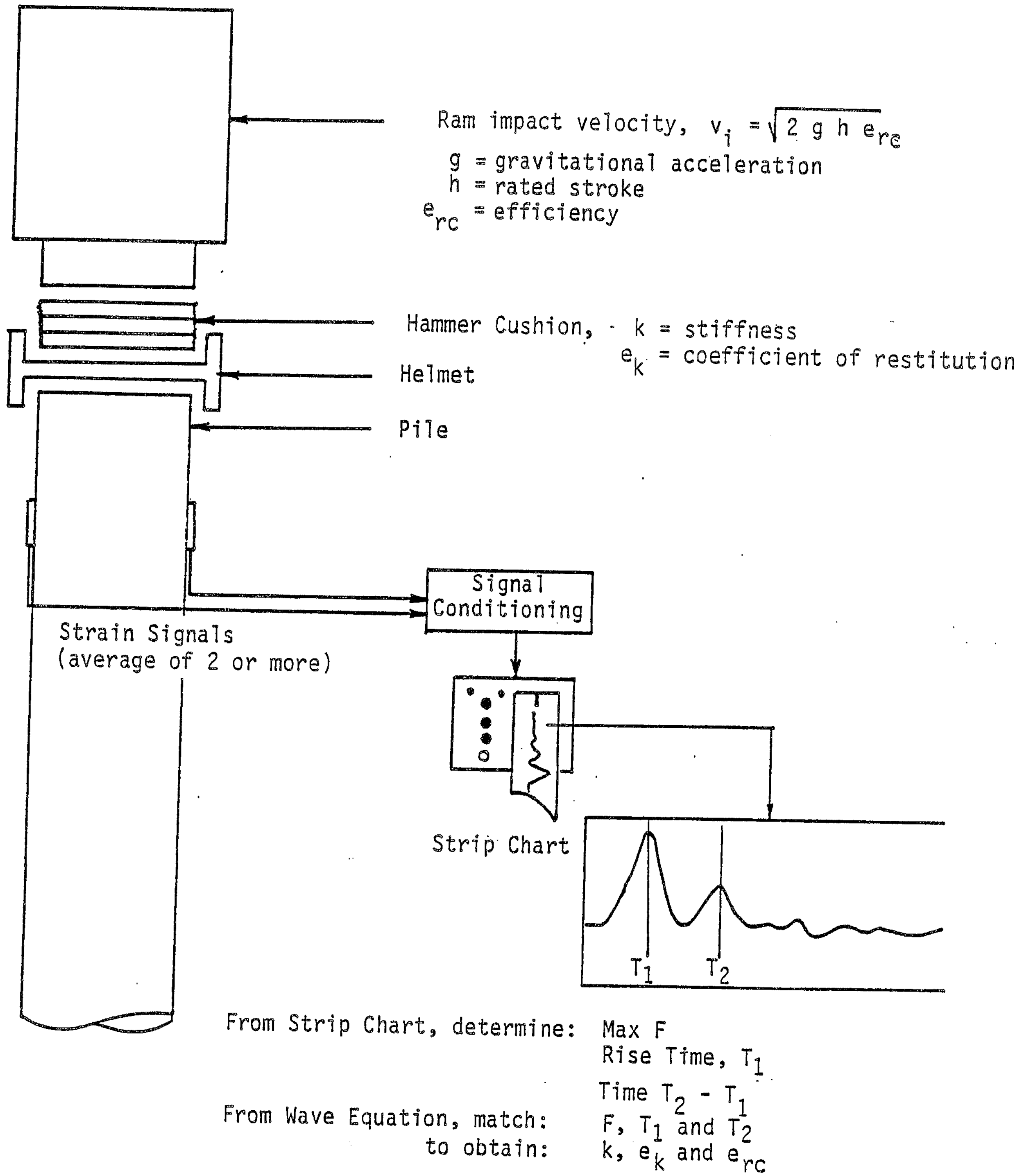


Figure 9.3: Tera/McClelland DMS System

9.3.3 Accuracy

McClelland claims a 5% accuracy on hammer impact velocity with DMS.

9.3.4 Additonal Remarks

It should be mentioned that McClelland sometimes also measures acceleration. Their system is then very similar to the General Dynamic Pile Testing System discussed in Section 9.2.

9.4 The TNO System

TNO (see Appendix A) developed its system based on similar concepts as were researched at Case Institute of Technology and which led to the development of the PDA. TNO, however, uses components similar to the general Pile Testing System (see Figure 9.4). The primary difference between TNO and both PDA and GPT is the use of an optical displacement transducer rather than accelerometers. Furthermore, TNO uses glue-on rather than bolt-on strain transducers.

TNO does not routinely derive hammer performance parameters from its measurements, although it does have the necessary tools available.

9.4.1 Disadvantages

a) Relatively complicated set-up, including difficulty in providing light to target area on the pile.

b) Displacement measurements affected by ground motion.

c) Displacement measured only on one side, thus nonaxial pile motion will produce errors.

d) Resetting of displacement transducer necessary for piles moving

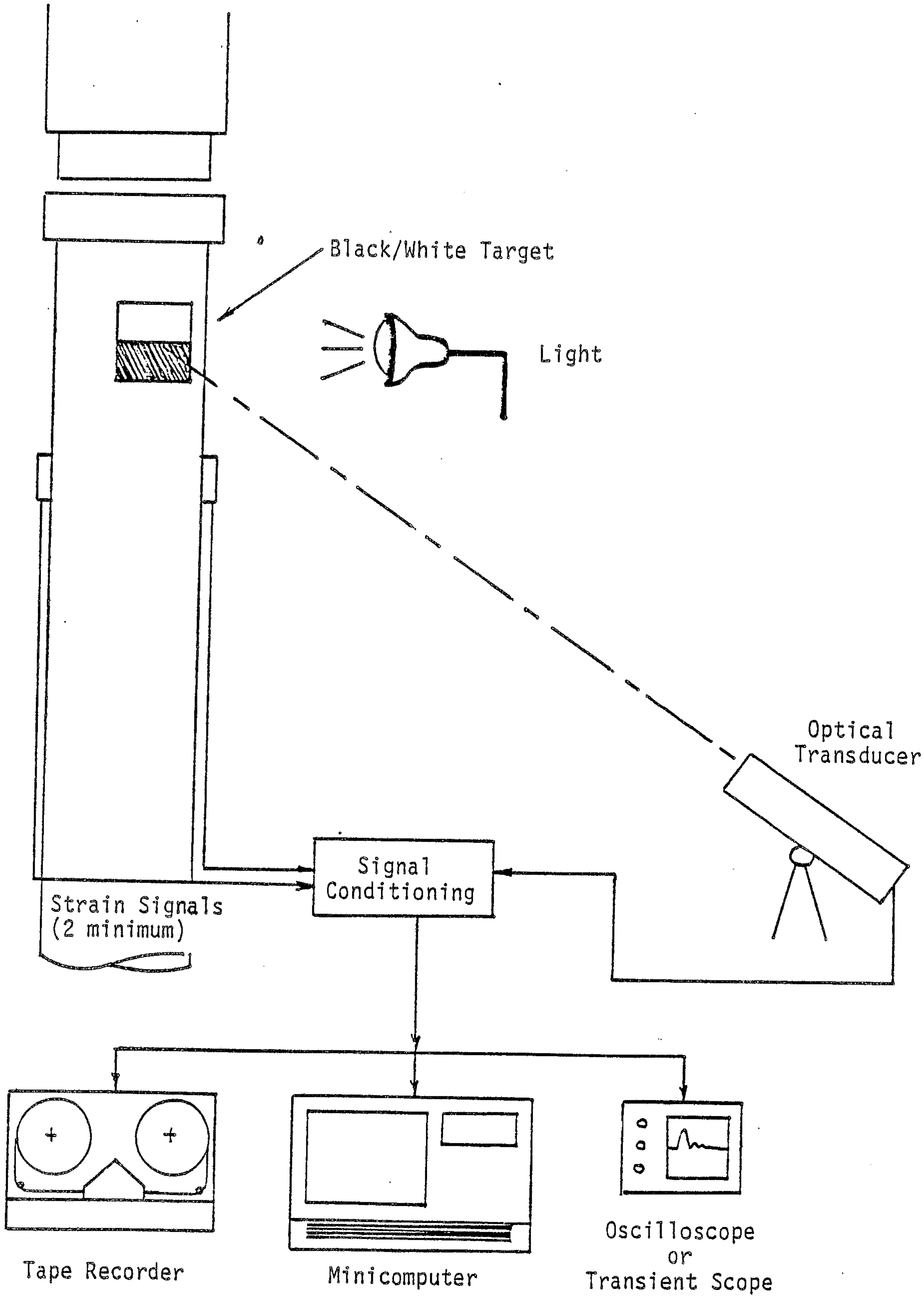


Figure 9.4: TNO Pile Testing System

distances greater than range.

e) Glue-on strain transducers are slow to set in cold weather.

f) All disadvantages of GPT.

9.4.2 Advantages

a) No integration correction necessary (as opposed to acceleration measurements).

b) All advantages of GPT.

9.4.3 Accuracy

The displacement measurements will, in general, yield less accurate velocities than accelerometers, because of ground motion, differentiation problems and non-cancellation of bending effects. Of course, this statement is only true if integration or zero shift errors are corrected when accelerometers are used. One great advantage of displacement measurements is the possibility of accurate final transferred energy determination. Double integration of acceleration will not lead to satisfactory final energies (or final pile displacements). If care is used, and the range over which measurements are made is not too large, then the displacement measurement probably has an accuracy comparable to that of acceleration measurements, i.e., approximately 5%. Thus, this system's accuracy should be comparable to the PDA.

9.5 The MENCK System

MENCK occasionally performs hammer performance tests. They use an optical transducer (see Figure 9.5) for a direct determination of ram motion. MENCK also uses strain measurements (using weldable strain gages) on the pile. As discussed by Glanville et al (1) the stiffness and coefficient of restitu-

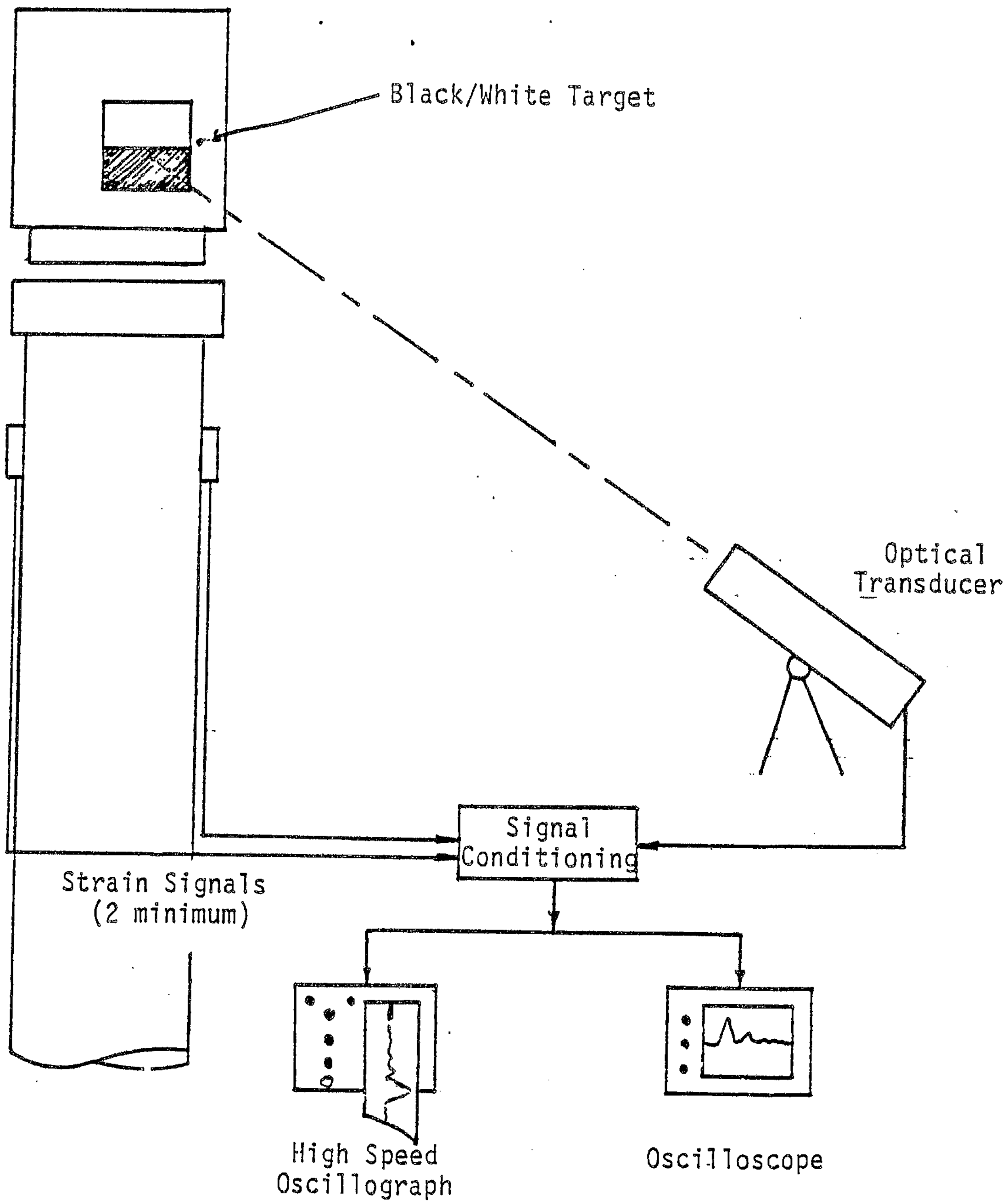


Figure 9.5: Menck System

tion of the capblock are derived from the force measurements, given the impact velocity of the system. With displacements from the optical transducer plus pile force in the measurements, the following evaluation may be given.

9.5.1 Disadvantages

a) Relatively complicated set up.

b) Displacement measurement can not be performed on all hammer types.

c) Long preparation time for weldable gages.

d) For concrete piles, force in pile may not be sufficient to obtain capblock parameters.

e) Driving system parameter computation from pile force restricted to offshore piles.

9.5.2 Advantages

a) Independent measurement of ram velocity and driving system parameters.

b) No attachments to hammer, direct measurement results are obtained.

c) Weldable gages possibly more accurate than strain transducers.

9.5.3 Accuracy

Regarding impact velocity, see discussion of analog ram displacment measurement. It is expected that hammer energies from the displacement measurements are not more accurate than 10%.

A statement regarding the accuracy of their driving system parameters cannot be made, since independent measurements are not available.

9.6 The QMC System

At the Queen Mary College (QMC), England, a measurement system for offshore driven piles has also been assembled. Weldable gages and piezo-electric accelerometers are attached near the pile top. The total system as described by Cuthbert, et al (12) is very elaborate, however, there seems, in essence, to be no real difference between DMS and QMC. QMC uses the data of the first force pulse, and matches it with computed values based on a wave equation analysis. The matching technique is automated by use of nonlinear programming techniques. The primary disadvantage of this system seems to be its costliness and size. Also, large amounts of computer time apparently need to be expended. The use of both acceleration and strain measurements should be sufficient to assure data quality.

9.7 McClelland RVM and Pile Dynamics HPA Radar Systems

Figure 9.6 shows a schematic of the RVM (Ram Velocity Monitor) and HPA (Hammer Performance Analyzer) systems. This system was discussed in Section (2.3), ram velocity measurement.

9.7.1 Disadvantages

a) Limited to piles with visibly moving ram, otherwise a target would need to be attached to the ram which could be difficult and possibly hazardous.

b) Ground motion may influence velocity readings and therefore must be minimized.

c) Additional measurements are needed to determine driving system parameters.

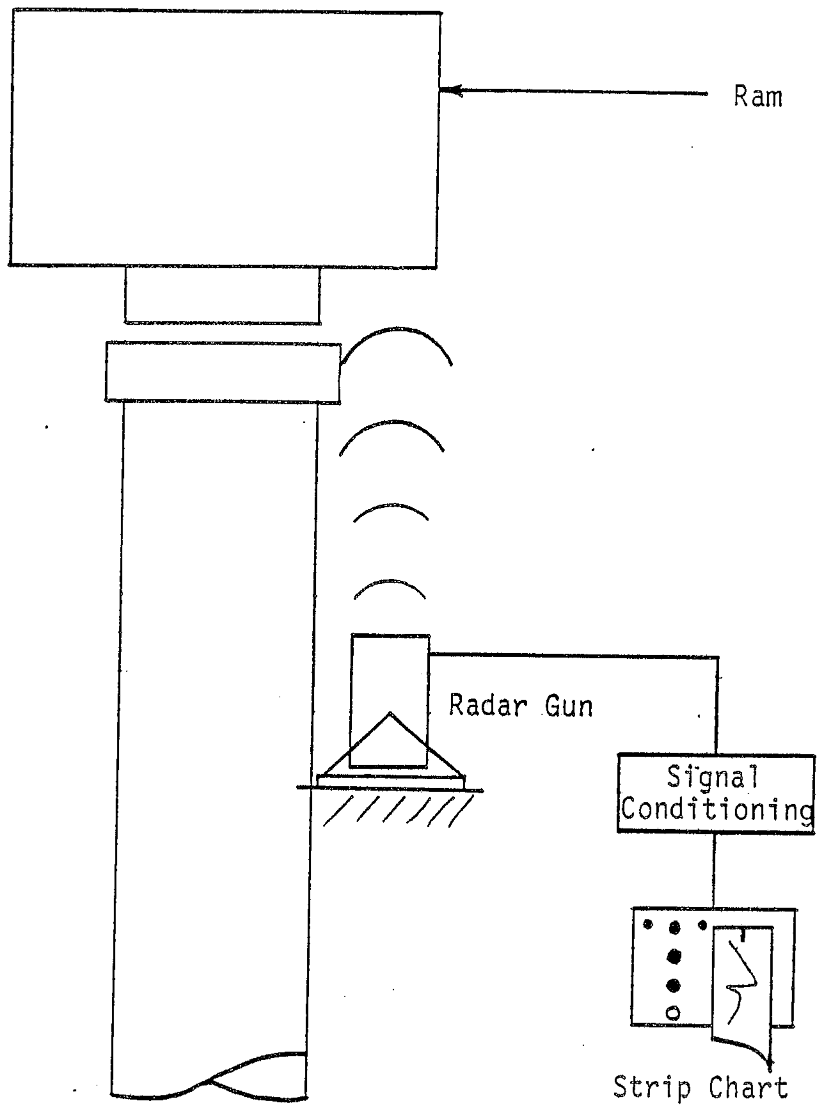


Figure 9.6: McClelland RMV System
Pile Dynamics HPA System

9.7.2 Advantages

a) Very simple to use.

b) Probably most accurate device for determining impact velocity.

c) Velocity time record may indicate type of hammer problem.

9.7.3 Accuracy

The developers estimate 5% accuracy on velocity measurements and, therefore, 10% on kinetic energy determinations.

9.8 The Fugro PDR Device

A schematic of the PDR (Pile Driving Recorder) system is shown in Figure 9.7. The system was thoroughly discussed in Section 2.2.2. Although used only on MENCK air/steam hammers thus far, the basic idea of a momentarily blocked light beam may be adaptable to other air/steam hammers.

9.8.1 Disadvantages

a) Not always easily installed; requires cable connection to hammer.

b) Different arrangements need to be designed for different hammer types.

c) Breakdowns are common.

d) Only average result, possibly from location above actual impact. It is not possible to interpret result for reason of poor hammer performance.

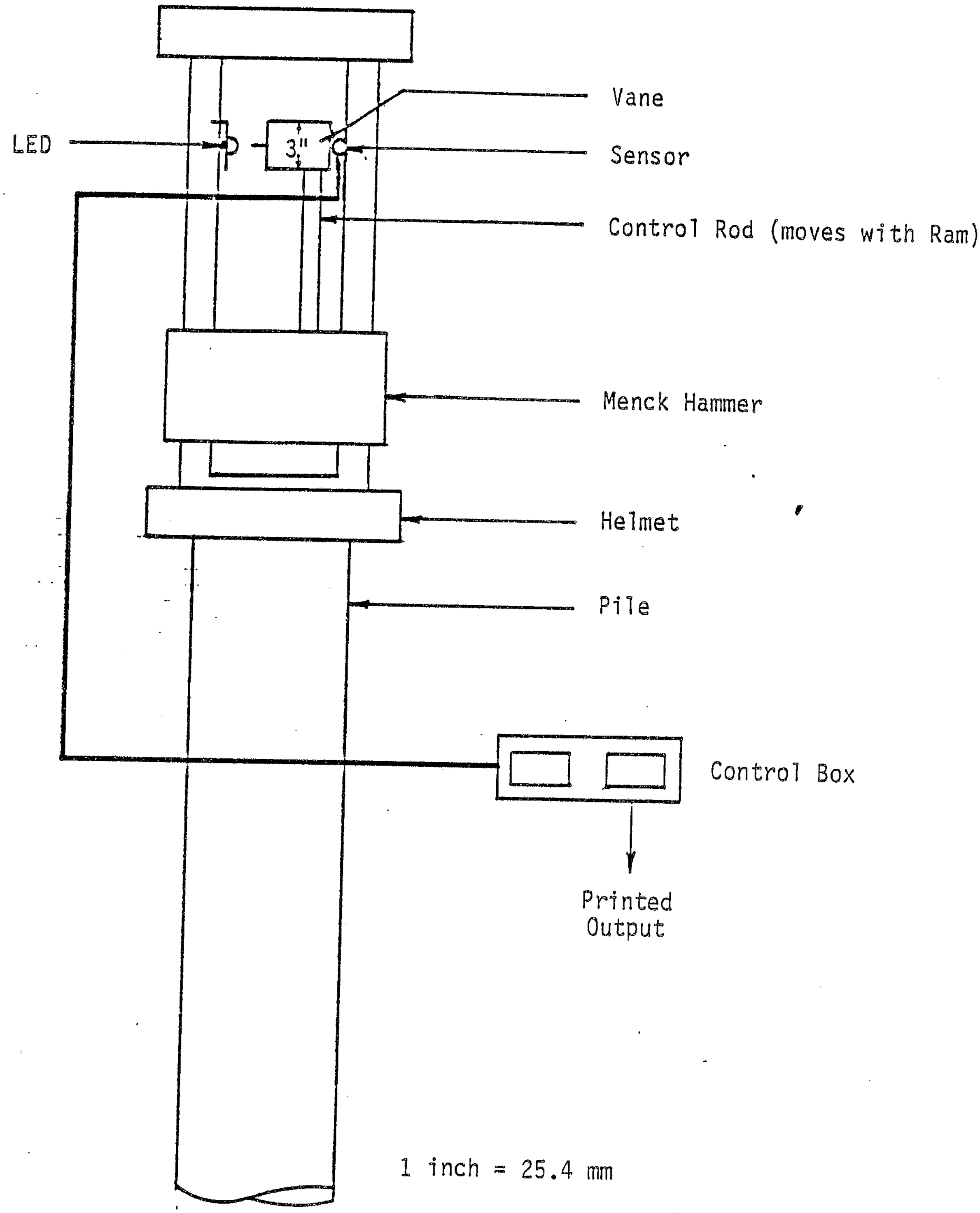


Figure 9.7: Fugro PDR System

9.8.2 Advantages

a) Relatively accurate results.

b) Simple equipment with digitally printed results.

9.8.3 Accuracy

Assuming the hammer assembly does not move (reference), the obtained average velocity may be as accurate as 2%. However, if the capblock is too low then errors of unknown magnitude of the actual impact velocity may result. Thus, without further comparisons, the routine results of the system cannot be guaranteed.

9.9 Saximeter™ from Pile Dynamics, Inc.

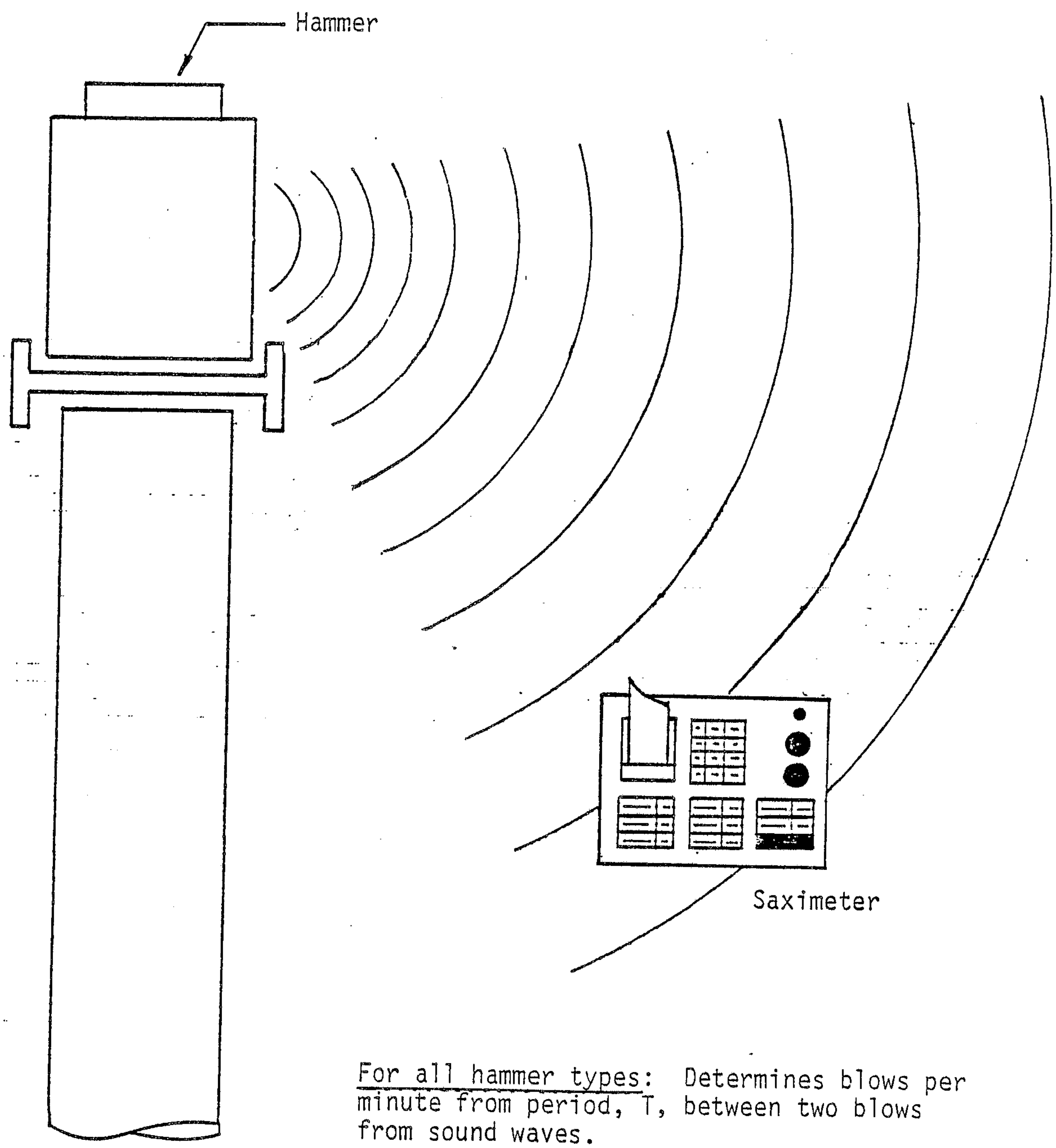
The Saximeter (see Section 4.2.3.2 and Figure 9.8) determines blows per minute and blow count. Stroke and potential energy can also be obtained for open-end diesel hammers. It shows digital results on liquid crystal displays and on a built-in printer.

For open-end diesel hammers the Saximeter is often used together with a blow count vs stroke curve for a given capacity, obtained from wave equation simulations. However, if the cause for high strokes is preignition, then this process will not lead to a satisfactorily driven pile. Similarly, in cases of extreme friction loss in the hammer, an overprediction of stroke would result.

9.9.1 Disadvantages

a) No direct indications of why hammer speed changes.

b) No driving system performance results.



For all hammer types: Determines blows per minute from period, T, between two blows from sound waves.

For Open-end Diesels: Determines actual stroke, h_a, where

$$h_a = 4.01\ (T)^2 - 0.3\ (ft)$$
$$= 1.2\ (T)^2 - 0.009\ (m)$$

Figure 9.8 : Saximeter

9.9.2 Advantages

a) Simple operation, no wires or other installations.

b) Hardcopy output can be used for recording blows per minute and blows per foot.

c) Can be used with all impact hammers.

d) May effectively be used where stresses in concrete piles must be limited by stroke control.

9.9.3 Accuracy

The time period determined between blows is accurate to within 5 milliseconds; at a blow rate of 60 blows per minute this represents a potential difference of 0.3 blows per minute for any individual blow. In its usual mode, for the average of a series of blows this error would be reduced by the number of blows averaged (i.e., for 10 blows the error would be at most 0.03 blows per minute).

For open-end diesel hammers with normal friction, the accuracy of the stroke prediction is within 0.3 feet (0.009 mm). For hammers with high frictions, stroke results may be too high. For batter piles, conversions of Saximeter to real strokes must be made, however, their conversions may not be based on correct friction assumptions, and may, therefore, be unreliable.

9.10 Marchetti's Device

Marchetti developed this device to measure a pile peak velocity (see Section 4.6.1). The device only acts as a performance indicator and should be used together with wave equation analyses. Proper application would, however, require that an accurate skin friction estimate for the pile is used in the wave equation analysis, since skin friction will tend to lower the maximum pile top velocity.

9.10.1 Disadvantages

a) Limited accuracy and applicability results.

b) Questionable ruggedness of equipment.

9.10.2 Advantages

a) Simple use and installation.

9.10.3 Accuracy

The accuracy of the device under routine field conditions of friction and wear is questionable. The accuracy of the results when used in conjunction with wave equation analyses is dependent on the accuracy of hammer, pile and soil modeling.

9.11 Schmertmann's SPT System

This system is indirectly related to hammer performance evaluations. It utilizes force measurements near the top of an SPT drill string, and, by integration of the square of this force, determines the energy transferred to the drill string. The integration is only carried out until the force becomes zero or the wave returns from the pile tip. The force is measured by a piezo-electric force transducer. Although not intented for pile measurements, extensions to pile driving system performance are possible for end bearing piles. However, more accuracy and generality would be obtained when combined with motion measurements. Thus, the Schmertmann system only provides for a subset of indirect measurements and is therefore only an indicator of hammer performance in specific cases.

9.11.1 Disadvantages

a) Single measurement with no verification.

b) Limited application for land piles.

9.11.2 Advantages

a) Simple operation using a force transducer that matches the drill string.

b) Ruggedness of the piezoelectric device.

9.11.3 Accuracy

The accuracy of force measurements at the pile top is probably much better (say 5%) than the conclusions on performance drawn from the single measurement. However, without modification to include motion measurements the method is theoretically in error for most land piles.

10. DETERMINATION OF WAVE EQUATION PARAMETERS FROM HAMMER AND DRIVING SYSTEM SYSTEM SPECIFICATIONS

Ideally, measurements of hammer performance should be unnecessary. With proper specifications, and some experience, accurate modeling of a hammer should be possible. The material properties of man-made cushioning materials in the driving system are known, and vary little during the cushion's life. Wood cushions have more variability by nature and also as a function of the number of hammer blows absorbed.

The efficiency of hammers of all types with respect to their rated energy varies between 0 and maybe 110%. The higher bound occurs in an overstroke situation. The reason for energy variations occurs primarily in the way these machines are handled and maintained. Difference in output may also stem from manufacturing tolerances and material selection.

For diesel hammers, even in normal opertion, a significant amount of energy is required to compress the air before combustion. This energy loss is the only one of the three major loss types that can be predicted from specifications. However, preignition may result from overheating, which is not necessarily predictable, and may cause significantly higher losses than normal.

In many cases, the hammer energy available also depends upon the pile stiffness and soil response.

There has been progress in the area of hammer performance prediction from specifications, primarily with the development of WEAP (13). Of course, additional work can and should be done, and a number of specific factors which can be better modeled will be discussed in the following sections.

10.1 Specifications for Single-Acting ASH Hammers

The most important and most accurately known quantity is the ram weight.

Using the rated energy, E_r, a rated stroke may be computed. Any loss of energy occurring before the ram reaches zero velocity after impact is included in the efficiency, e_k. Thus

$$E_a = E_r e_k$$

where E_a is the energy available to do work on driving system, pile and soil.

Hammer manufacturers usually estimate efficiencies between 0.8 and 0.9. These efficiencies can be obtained when proper adjustments have been made to valves and bushings. Field adjustments to valves, or bushing replacements by untrained personnel, may cause 'e_k' to become as low as zero (friction may actually prevent the ram from falling).

Measurements and computations have shown, for S-A ASH hammers, an efficiency e = 0.67. The 67% efficiency can only be expected if the hammer is well greased, and if the power medium contains sufficient lubrication and is kept at the specified pressure, and if the hammer attains the specified operating speed (implying that the air/steam/oil volume delivered is adequate).

Of course, wave equation analysis of ASH hammer could be expanded to simulate effects like low stroking in easy driving, power medium expansion and losses, friction, preadmission due to low capblocks or poor valve timing throughout the rise and fall of the ram. This process would then allow for a more detailed investigation of the causes of low efficiency, however, a large number of hammer parameters would be needed to describe these effects. These parameters would only be known when detailed measurements are performed. With the exception of the capblock thickness and power medium pressure, these parameters would be difficult to determine.

10.2 Specifications for (D-A) Double-Acting ASH Hammers

There are actually three types of D-A hammers. MKT builds the normal D-A type. Vulcan builds differential-acting hammers, and a third type is the so-called compound hammer (14). The first two hammer types utilize pressure directly from the source (considered constant) to drive the ram downwards. The compound hammer allows the air/steam medium to expand, driving the downward stroke starting with full pressure in the top position. (Compound hammers are rare, and have never been encountered by the authors on a construction site involving bearing piles.)

Specifications for D-A ASH hammers include the effective areas on which pressure acts during the downstroke in addition to the ram weight and rated energy. It is usually sufficient to compute an equivalent rated stroke for a wave equation simulation. Then, with an appropriate efficiency, the impact velocity can be computed for wave equation purposes.

Valve settings and friction are even more important for D-A than for S-A ASH hammers. Improper valve timing may cause both preadmission, and late application of downward pressure. The greatest detrimental influence, however, results from inadequate pressure during the downstroke. In fact, this pressure must be reduced if the ram rebounds heavily in hard driving so that hammer uplifting is reduced. This pressure reduction directly causes a decrease of downward ram velocity.

Hammer uplifting could be directly simulated in a wave equation analysis, similar to the WEAP diesel analysis, which determines stroke from the pile response. Of course, hammer problems like faulty valves or friction are most effectively modeled by a single efficiency value.

The Volume IV report presented a limited amount of data from D-A hammers. The back-computed efficiencies indicated a significant difference between the efficiencies of S-A and D-A ASH hammers. It is recommended that an efficiency, e = 0.5 be used for the D-A ASH hammer type.

10.3 Specifications for Diesel Hammers

10.3.1 Fuel Injection and Combustion

Fuel injection type and the combustion process are the factors most heavily affecting hammer performance for both open-end (O-E) and closed-end (C-E) diesel hammers. Specifications for compression ratio and fuel injection type may usually be obtained from manufacturers. Unfortunately, modifications to a hammer, either to improve a model or in the process of maintenance, may significantly change the specifications. (It was noticed that some manufacturers were not even aware of the actual compression ratio of their hammers, since they had arrived at the best value more or less by trial and error).

Fuel injection is either by impact atomization or atomized injection. Impact atomization, combustion starts at or shortly after impact except for a malfunctioning hammer. With atomized fuel injection, atomized fuel is injected when the ram is a certain short distance, d_i, above the impact block and continues for a pre-determined time, t_i. Combustion occurs at the time of injection, or after the compressed air has become sufficiently hot.

During the WEAP development work, the program authors noticed that the specifications for the distance, d_i, and duration t_i could not be successfully used to simulate hammer performance; different values were required to obtain agreement between analysis and measurement value. It was therefore concluded that these specifications were of no practical use. It was also noticed that hammers of the same model may behave differently depending on fuel pump adjustments, ambient temperature, cooling periods between consecutive piles, etc.

Preignition is difficult to quantify whether designed (atomized fuel injection) or accidental (impact atomization). For example, in a well lubricated hammer, preignition may be result from the burning of lubrication oils. Water cooling does not seem to significantly improve hammer performance or reduce preignition.

The second factor of particular importance is the amount of energy released during combustion, since it relates to the maximum combustion pressure. Since the amount of energy released is not only dependent on fuel and air quantities, but also on a hammer's temperature, lubrication, scavenging conditions, pile response and other details, exact prediction of combustion energy from specifications is difficult at best. It has been noticed that even the relatively simple liquid fuel pumps may vary slightly and change their output depending on the severity of use.

In general, however, the average behavior of diesel hammers is quite easily modeled using manufacturer's specifications. Experience has indicated that a hammer efficiency of 0.72 must be used to bring measurement results and analysis predictions into agreement. This efficiency relates the actual ram energy at port closure to that computed from free-fall. Energy losses in the compression zone not due to precompression are assumed to be accounted for by the reduced velocity at the time of port closure.

10.3.2 Bounce Chamber

The closed-end diesel (C-ED) hammer has an air cushion on top of the ram, which stores energy. A shorter stroke and faster blow rate is therefore obtained. Energy losses associated with this energy storage are easily approximated by an appropriate choice of the air's expansion/compression exponent.

It should be mentioned that analysis of C-ED hammers does not need to involve the complete bounce chamber cycle; computation of equivalent stroke is sufficient. The only additional result of this extra computation is the blow rate.

A problem similar to that of D-A ASH hammers occurs with C-ED hammers in hard driving when hammer lift-off occurs. Thus, fuel amounts must be reduced in hard driving. This reduction can be modeled in WEAP such that the hammer runs at an ideal high level with lift-off imminent. However, in the reality of typical construction practice, the fuel setting is usually reduced more than required.

10.4 Friction Modeling

An alternative approach to wave equation modeling of friction using an overall efficiency value, would be to actually model friction from manufacturer's specifications in combination with some safety factor. This would be particularly applicable to the analysis of diesel hammers where a long period of the analysis models the rise and fall of the ram in the cylinder. Driving of battered piles could possibly be more realistically modeled using this approach. In general, however, the results would not be very different, and use of an overall efficiency value is both convenient, and allows losses other than friction to be accounted for.

10.5 Driving System

The driving system consists of strike plate, capblock, helmet, adaptors and pile top cushion. For all cushion materials, elastic moduli, E_c, and coefficients of restitution, e_{rc}, typical values may be found in the literature. Unfortunately, these properties are often variable, in particular for wood, and uncertainties exist. These listed parameters are in general obtained from static tests. Since materials behave differently in dynamic applications, it would be better to derive these constants from in-situ measurements. This capability now exists°.

Energy losses must be expected at all driving system component interfaces. For example, a well-fitting helmet/pile top interface transfers more energy than a rough cut pile top under a bent helmet. Thus, there are site-dependent, and driving system-dependent differences that may be accounted for by means of coefficients of restitution less than one.

11. CONCLUSIONS AND RECOMMENDATIONS

Major causes for poor hammer performance are

a) Friction

b) Insufficient stroke

c) Preadmission or preignition

d) Driving system losses

It is possible and beneficial to provide a system which determines the major causes of poor hammer output.

The discussions with engineers from several countries have shown that advances are still possible in measurement of hammer performance. Existing methods are capable, however, of directly measuring hammer impact velocity for some hammers and indirectly determining hammer cushion parameters. All techniques either use indirect measurements or, for air steam hammers with a visible ram, direct radar measurements. Most methods can determine ram kinetic energy just before impact with less than 10% error.

It has been found that even with accurate hammer specifications, great variations in hammer output should be expected. Thus, predictions of hammer performance will always include uncertainties about the state of maintenance of a machine. The differing conditions of hammers is considered the primary reason for great variations in hammer output.

A great amount of information can be extracted from indirect measurements of acceleration of the various hammer system components. When monitoring the driving of concrete piles, helmet motion should be measured in addition to the pile top motion so that pile cushion parameters may be determined. To minimize interference in the driving system, force, if desired should be measured at the pile top. It is believed that the necessary equipment together with appropriate and available algorithms, will provide for a quick, safe, accurate and complete hammer and driving system performance test.

As envisaged, the system's signal conditioning and processing unit would have preset input values and would check data quality automatically. The processor would be programmed to print ram impact velocity, both pile cushion and capblock stiffnesses, and coefficient of restitution(s). In addition, blow rate in blows per minute and the energy transferred (if force measurements are included) to the point of measurement would be printed.

Once the hammer and driving system efficiency is known, wave equation predictions will have a much greater precision than is currently possible. This equipment should also allow easy determination of the reasons for unexpected driving behavior.

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APPENDIX A

NOTES ON MEETINGS WITH REPRESENTATIVES OF FIRMS INVOLVED IN HAMMER/PILE MEASUREMENTS

VOLUME II

APPENDIX A

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Meeting with Fugro
Mr. Roy van Hooydonk
November 3, 1982

Fugro is an engineering consulting firm with primary interests in geo-technical fields. Their headquarters are near Den Hague, Holland. They have become known through their work with penetrometers which identify skin friction and end bearing values during exploration. Most of their work is done offshore, and includes, besides exploration and analysis (also wave equation), Case-Method type measurements during pile driving and hammer peformance monitoring. On land, Fugro also performs impact integrity testing of piles and caissons (low strain method). Their electronic laboratory includes several electronic engineers, and has a total of 15 staff members. Their equipment includes analog and digital instrumentation, one of which is the PDR (Pile Dynamic Recorder) whose function is primarily the determination of the impact velocity of MENCK offshore hammers. It also counts blows and gives printed output of depth, blow number and, indirectly, impact velocity.

Fugro has a 30 inch diameter test pile in their yard and experiments with various types of soil, pile and hammer monitoring equipment. They say that they have experimented with a variety of devices. However, they feel the PDR to be the most practical unit. They have used it in the field applications approximately 20 times.

A description of this hammer performance monitor is given in Sections 2.2.2 and 9.8 of this report. A brochure is reproduced in Appendix B.

The PDR consists of three components:

(a) A vane attached to the control bar of the hammer which moves up and down together with the ram.

(b) An LED light source and receiver mounted on the hammer so that the vane first blocks and then clears the path of the light beam a short distance before the ram reaches the bottom of its travel. Since the vane has a 3 inch width, the timing of blocked and readmitted light provides for an average ram velocity shortly before impact.

(c) A control box with printer which is triggered by the sequence of light beam interruptions. The control instrument prints the duration of light blockage together with the blow number and depth. The depth value is initialized at the start of driving and is incremented by manual control.

Both power and the pulses from the light receiver are transmitted through a cable which is attached to the steam hose of the hammer.

The writer has had, on a previous occasion, an opportunity to observe the device in field use. At that time, Pile Driving Analyzer measurements were also taken. Unfortuantely, correlations were never attempted.

Meeting with TNO
Mr. H. von Koten
November 4, 1982

TNO (Nuverheidsorganisatie voor Toegepast-Natuurwetenschappelijk Onderzoek) is a large research organization partially financed by the Dutch government. Their work is concentrated on the improvement of construction methods and materials.

Their dynamics group has 15 members and is primarily involved in piling research, particularly, the integrity testing of both driven and cast in place concrete piles by the low strain method. They also perform dynamic bearing capacity tests using minicomputers, optical displacement transducers and strain transducers.

A wind tunnel, MTS dynamic test equipment, a large computing center and other sophisticated facilities allow for advanced research.

TNO has used the optical transducer on its high strain dynamic pile tests, and have a wide range of experience from small model to large field tests. They have not been involved in hammer testing. However, since the optical displacement transducer appeared to be a viable solution for simple hammer performance observation, their experience seemed valuable.

The unit consists of a video camera and, depending on the distance from the target, a more or less powerful telephoto lens. The target is painted or attached to the pile and consists of a contrasting black and white area. A control instrument converts the moving black and white image to a displacement-proportional voltage signal. It is apparently important to direct a strong light against the target area. Immediate analog differentiation yields a velocity signal.

The writer had opportunities on previous occasions to observe field operations both when the target was painted on a MENCK ram and when TNO attached a target on a pile. At that time, no results were shown to the writer.

Not including the target attachment, camera preparation usually took half an hour. The location of the camera had to be changed several times during the testing.

Meeting with MENCK

Mr. Pieter van Luipen

November 5, 1982

MENCK produces air, steam and hydraulically powered impact hammers both for land and offshore use. They are represented in the USA by ICE in Matthews, North Carolina. The rated energies of their hammers range from 34.8 to 1582.2 ft-kips (50 tp 2200 kj). Their hydraulic hammers may be used under water.

The firm's engineering department has experience both in the design and testing of hammers. Their measurements of (a) strains at sensitive points of the hammer, (b) pressures of the power medium and (c) ram motions are outstanding. Thus, two purposes were served by talking with their engineers, first, with regard to hammer maintenance and trouble-shooting and second, as far as the measurement of hammer performance is concerned.

The most important recommendation arising from the meeting was the measurement of ram motion by optical transducer. This was discussed in the "TNO" summary. It may be repeated here that MENCK did not recommend this instrument for routine hammer performance checks. MENCK also installs an impact velocity and ram position sensor in their underwater hammer. Technical details of this device have not yet been published. Discussion of this device is, therefore, not included in this report.

Meeting with Delmag

Mr. F. Kuemmel

November 8, 1982

Delmag is one of the largest diesel hammer manufacturers worldwide and is represented by Pileco, Inc. in the USA. Their hammers range in size from a 1.1 kip (5 kn) (ram weight) D-5, to a 17.6 kip (80 kn) D-80 model. The company tests prototypes on a test stand which consists of a heavy pipe driven to rock. Measurements of force are taken in a relatively heavy transducer. These measurements are used as a relative indicator of hammer performance. Through Pileco, Delmag has indirectly supported the development of the SAXIMETER.

This unit identifies the occurrence of a blow by its characteristic sound pressure behavior and determines the duration between blows. Under the assumption of a free fall, the time between blows is converted to a fall height and corrected for losses through friction and gas compression by subtraction of 0.3 feet (0.009 m). The Saximeter is in routine use on a number of sites in the U.S. Mr. Kuemmel suggested wider acceptance if the instrument would display not only the stroke but also the potential energy (i.e., the product of stroke and ram weight). Of course, the stroke of a diesel hammer is only a necessary, but not a sufficient indicator of hammer performance.

Mr. Kuemmel mentioned attempts of measuring the ram impact velocity by means of radar, however, he felt the results were inaccurate. He instead recommended measurement of the maximum displacement of the pile top (see momentum approach - Likins' Method) or the force. Measurements, in his opinion should always be taken on the pile.

Meeting with Tera

Mr. W. Vines

May 6, 1982

Tera is a firm involved in the design and installation of offshore platforms. Part of this work is pile driving monitoring. Tera, now independent, used to be a subsidiary of McCelland Engineers which is primarily concerned with geotechnical investigation, soil testing and analysis. Tera and McClelland used to cooperate in the development of electronic equipment.

In the past, Tera has been using the Texas A&M approach of pile installation monitoring. This approach requires the measurement of pile top force, and by matching wave equation impact forces with measured forces, hammer performance variables are accounted for. The method is referred to as DMS (Dynamic Measurement System). Tera has used weldable gages but now makes strain transducers and attaches these together with accelerometers. Thus, they are now using an approach rather similar to the Case Method. In fact they compute, as an option, transferred energy.

Their preferred analytical method requires the determation of the following parameters:

(a) hammer efficiency or impact velocity,

(b) capblock (hammer cushion) stiffness and

(c) capblock coefficient of restitution.

Assumptions are made for these quantities and wave equation analyses are performed. A nomogram is then constructed that relates the three driving system parameters to the following three force record quantities.

(a) Rise time, i.e. the time that the pile top force requires to reach its maximum at time of impact. This quantity is primarily related to capblock stiffness.

(b) Peak to peak time, i.e. the time between the first major force peak and a second lower one which typically occurs a short time after the first peak, and which is, apparently, an indication of the coefficient of restitution of the capblock.

(c) Maximum force at impact. This quantity is mainly related to impact velocity.

The method works most reliably when impact and soil response are separable, as for long offshore piles. For shorter piles, soil resistance assumptions affect the trial results. The method is, of course, restricted to air/steam or hydraulic hammers where the ram strikes the capblock directly and where there are no pile top cushions. Thus, for diesel hammers or concrete piles, this approach cannot be adopted without modification.

Tera engineers feel that the DMS approach yields impact velocity results with a 5% accuracy. Hammer energy would, therefore, be predicted with a 10% accuracy.

Of course, DMS involves a significant amount of computer and engineering work. For this reason, Tera, in cooperation with McCalland Engineers, developed a device for the direct measurement of hammer impact velocity. Their device is based on radar and produces a strip chart output of ram velocities with time. A fast (100 m/s) and a slow (0.5 m/s) chart speed allows for detailed or comprehensive output. The slow mode shows very clearly changes of hammer performance with time.

For Air/steam or hydraulic hammers, the radar gun is usually installed near ground level so that the radar beam which extends as a cone from the gun can detect the ram. For open-end diesel hammers, the radar is installed on the leaders above the hammer, and detects the ram top. This approach is not applicable to enclosed hammers.

Tera expects 5% accuracies in the determination of impact velocities from this device. They refer to this device as RVM (Ram Velocity Monitor). RVM has two major advantages over other existing methods.

(a) Velocity is directly determined and no errors are introudced by either integration or differentation procedures.

(b) For air/steam/hydraulic hammers with no enclosure, i.e. where the ram is easily visible, no attachments to the ram are necessary (it should be mentioned that any object within the beam cone of the radar moving with a speed greater than 2 ft/s (.61 m/s) may be mistaken by the device as the target).

APPENDIX B

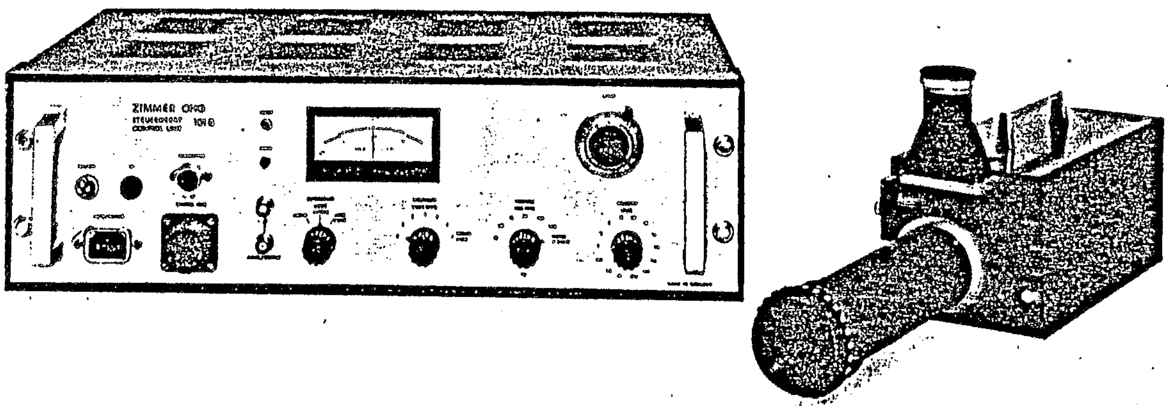
REPRODUCTIONS OF BROCHURES WHICH DESCRIBE DEVICES APPLICABLE TO HAMMER EFFICIENCY MEASUREMENTS

VOLUME II

APPENDIX B

Table of Contents

Elektro Optischer Wegmesser
Electro Optical Displacement Transducer
100 B



Der Elektro Optische Wegmesser 100 B wandelt die Linearbewegung einer Schwarz-Weiß-Kante in eine wegproportionale Spannung.

Das berührungsfreie Meßprinzip ermöglicht die Aufzeichnung von Bewegungsvorgängen im Frequenzbereich von 0 bis 400 kHz.

Zweiachsenbewegungen, Winkelbewegungen sowie Geschwindigkeit und Beschleunigung können mit Zusatzgeräten gemessen werden.

The Electro Optical Displacement Transducer Model 100 B converts the linear motion of a black and white edge into a voltage proportional to displacement.

The non-contacting principle permits reproduction of displacement in the frequency range from 0 to 400 kHz.

Dual axis motions, angular displacement as well as velocity and acceleration can be measured with optional accessories.

ZIMMER OHG

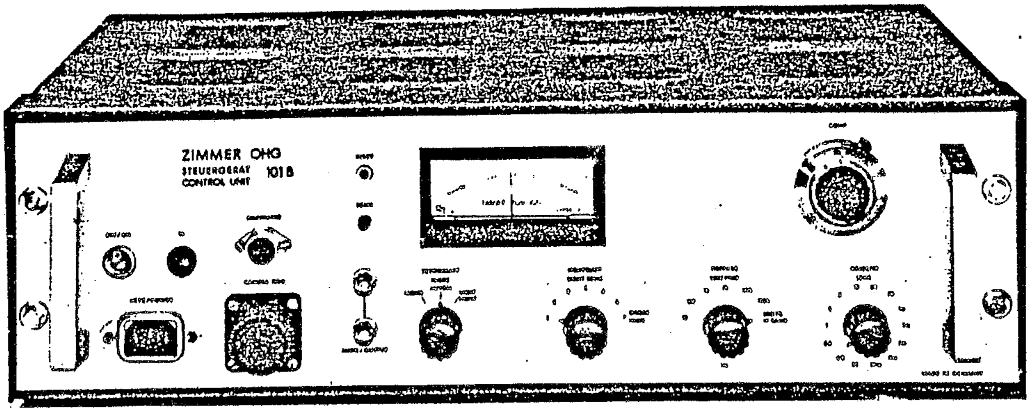
BERÜHRUNGSFREIES MESSEN MECHANISCHER GRÖSSEN
NON-CONTACTING MEASUREMENTS OF MECHANICAL QUANTITIES

Beschreibung

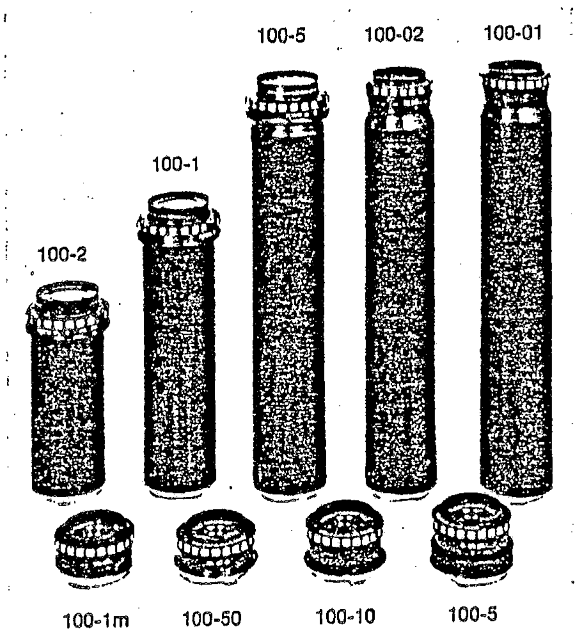
Der Elektro Optische Wegmesser 100 B wandelt die Linearbewegung einer Schwarz-Weiß-Kante (Meßfläche) berührungsfrei in eine wegproportionale Spannung im Frequenzbereich zwischen 0 und 400 kHz um.
Das auf der Frontseite dieser Broschüre abgebildete betriebsfertige Meßsystem besteht aus der Camera 100 B, dem Steuergerät 101 B, einer Meßflächenleuchte und einem Objektiv sowie einem kunstlederbespannten Transportkoffer für das gesamte System.
Die Meßflächenleuchte enthält eine 10 W Halogenlampe langer Lebensdauer, die von einer im Steuergerät eingebauten, geregelten Stromversorgung gespeist wird. Ein zweilinsiges Kondensorsystem gewährleistet hohen Wirkungsgrad.
Das Verbindungskabel zwischen Camera und Steuergerät ist mit robusten, schwingungsfesten Steckern ausgerüstet. Verlängerungskabel werden auf Anfrage geliefert.
Die Camera mißt Vertikalbewegungen, kann jedoch durch Verdrehen der integralen Aufnahmeeinheit auf jeden beliebigen Raumwinkel eingestellt werden, ohne daß hierbei die eigentliche Position der Camera verändert wird.
Eine Dosenlibelle auf der Camera erleichtert das Ausrichten. Das Einrichten der Camera auf die Meßfläche erfolgt mit Hilfe der angebauten Fokussiereinrichtung. Der serienmäßige Objektivhalter sorgt für einen festen Sitz von langen Objektivrohren. Eine Vielzahl von Objektiven steht zur Verfügung. Sie bestreichen einen Meßbereich von 0,2 mm bis 20 m in Bereichsschritten von 1-2-5 wie z. B. 10 mm, 20 mm oder 50 mm. Nähere Angaben über die Objektive sind in Abschnitt „Technische Daten" gemacht.
Jedes Objektiv wird individuell graviert mit der Typennummer, die gleichzeitig Aufschluß über den Meßbereich gibt, der Seriennummer und dem Meßabstand. Alle Objektive werden werkseitig so eingestellt, daß der volle Meßbereich eine Ausgangsspannung von 10 V erzeugt (± 5 V).
Nachträglich bestellte Objektive werden bereits mit den entsprechenden Eichkomponenten geliefert, so daß eine nachträgliche Eichung beim Kunden entfallen kann. Sonderobjektive können rasch geliefert werden.
Das Gerät kann auf Netzspannungen zwischen 100 und 240 V, 50–60 Hz geschaltet werden. Werden keine besonderen Angaben gemacht, wird das Gerät in der 220 V-Ausführung geliefert. Wechselrichter können auf Anfrage geliefert werden.
Das Gerät ist nach den neuesten Erkenntnissen aufgebaut. Die fast ausschließliche Verwendung integrierter Schaltungen gewährleistet hohe Betriebssicherheit. Die Ausgänge sind kurzschlußsicher gegen Masse. Die Elektronik wurde in 5 Steckkarten aufgegliedert. Für den seltenen Fall einer Störung kann diese durch einfaches Auswechseln der defekten Steckkarte beseitigt werden.
Das Meßinstrument auf der Frontplatte des Steuergerätes zeigt die relative Position der Meßfläche zur optischen Achse statisch an. Außerdem dient es zur Messung der relativen Leuchtdichten der Meßfläche. Für den Fall, daß der Lichtpfad zur Camera unterbrochen wurde, wird das Meßsystem sofort nach Freigabe des Lichtpfades wieder funktionsfähig durch eine automatische Abtasteinrichtung. Zur Aufzeichnung einmaliger Vorgänge kann diese abgeschaltet werden. Hierdurch werden Zweideutigkeiten in der Anzeige vermieden.
Ein Reset-Knopf ermöglicht das manuelle Einleiten eines einmaligen Suchvorgangs.
Die Lichtempfindlichkeit kann in 6 Stufen erhöht werden und gestattet störungsfreies Arbeiten auch bei extrem schlechten Beleuchtungsverhältnissen.
Ein dem Signalausgang vorgeschalteter 6stufiger Tiefpassfilter erster Ordnung sorgt für optimales Signal/Rauschverhältnis bei den jeweiligen Meßaufgaben.
Zwei parallel geschaltete BNC Ausgangsbuchsen erlauben den gleichzeitigen Anschluß verschiedener Geräte.
Verschiedene Zusatzgeräte ermöglichen die Erweiterung des Einsatzgerätes wie z. B. Winkelmessungen, Geschwindigkeits- und Beschleunigungsmessungen sowie Schwingungsanalysen.
Das Steuergerät 101 B kann aus dem mitgelieferten Gehäuse entfernt und in ein Rack montiert werden. Eine innere Abschirmung dient als Berührungsschutz und hält Streufelder fern.

Description

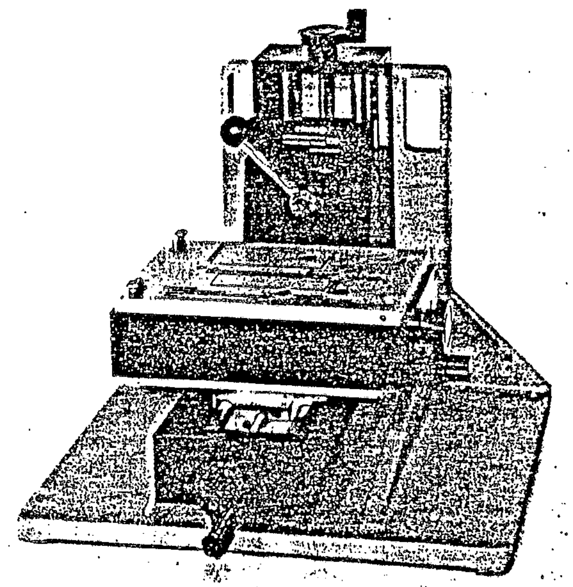
The Electro Optical Displacement Transducer Model 100 B converts the linear motion of a black and white edge (target) into a voltage proportional to displacement, without any contact, in the frequency range from 0 to 400 kHz.
The operational system is illustrated on the front of this brochure. It consists of the Camera Model 100 B; the Control Unit Model 101 B; a Target Illuminator, a Lens, and a Vinyl Carry Case for the entire system.
The Target Illuminator comprises a 10 W halogen source with a dual condensing lens system driven by a regulated Power Supply in the Control Unit Model 101 B.
An interconnecting cable between the Camera and the Control Unit is fitted with vibration proof heavy duty connectors. Extension cables are supplied upon request.
Normally the Camera detects vertical displacements but it can be rotated through ± 100° to measure displacements at other angles.
A circular spirit level on top of the Camera enables precise alignment to be made easily. Rapid adjustments of the optics are made by a focusing control provided on the Camera. A Lens Support which is part of the standard system adds to rigidity when lenses with long barrels are being used.
A variety of Lenses are available to measure displacement which range from 0.2 mm to 20 m full scale. The range steps are 1-2-5 e. g. 10 mm – 20 mm – 50 mm. Detailed information on the lenses available is listed in the specification.
Each Lens is individually engraved with the Model No. which indicates the displacement range, the Serial No., and the working distance. All Lenses are factory calibrated so that the full scale displacement generates an output voltage of 10 V (± 5 V).
Further Lenses may be purchased after the system is delivered and no alterations to the calibration will be required. Special Lenses can be provided on short delivery.
Mains supply required is 100 to 240 V, 50 to 60 Hz. When the mains supply available is not specified in the order the equipment will be despatched set for 220 V operation. Static inverters are available as an optional accessory.
Only the most up to date techniques have been used in the design of the electronics. Monolithic integrated circuits are employed to provide outstanding reliability.
The outputs are protected against the accidental application of short circuits against ground.
The electronic system has been functionally divided into 5 different plug-in printed circuit cards. In the rare event of service work becoming necessary it has been reduced to the point where the user only has to replace a faulty plug-in card.
The meter on the front-panel measures the DC output level which is an indication of the target position. In addition the meter can be used during the setting up procedure for measuring target brightness and contrast ratio.
In the event of the optical path between the Camera and target being obscured an automatic scan facility will initiate a search sequence. When the optical path is cleared the Camera will "lock on" within microseconds. Where the user only wishes to record single events this facility could provide misleading information and can therefore be switched out. A reset button permits manual re-lock.
A light sensitivity switch is provided so that the instrument will perform satisfactorily for a variety of different light levels.
Also incorporated is a low pass filter which has 6 selectable upper frequency limits to provide a reduction in high frequency shot noise produced at the photo cathode of the image converter. Two parallel outputs are available via BNC sockets so that two instruments can be connected easily. Various accessories can be purchased for expanding the range of applications e. g. angular measurement, target velocity and acceleration, vibration analysis and dual axis measurement. For full details see "Special Accessories" section.
The Control Unit 101 B can be removed from its cabinet and put into a rack. An internal shield provides protection against electric shocks and stray fields from the outside.



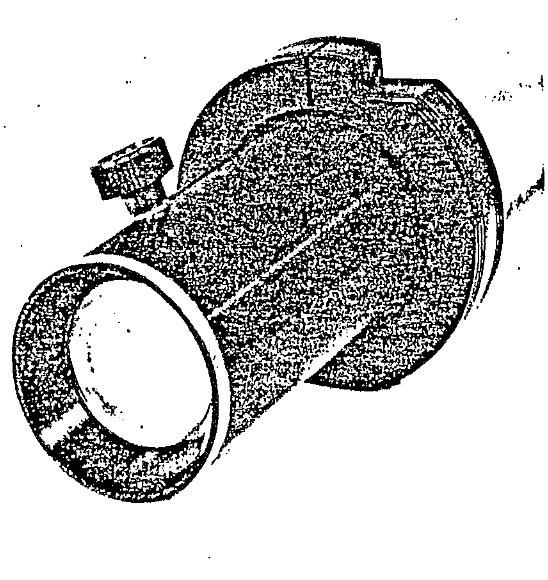
① Steuergerät 101 B – Control Unit 101 B



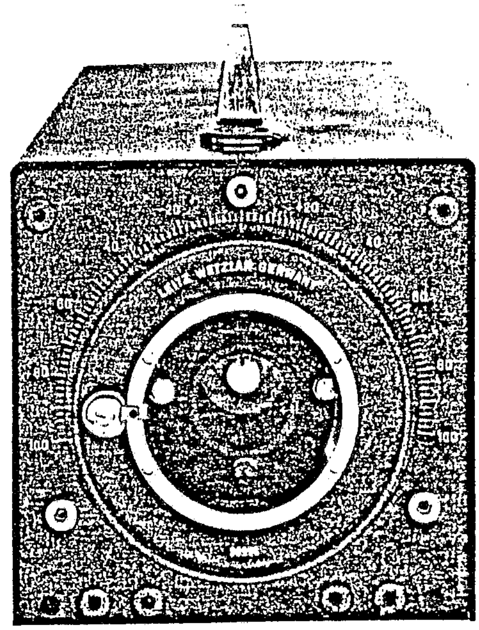
② Verschiedene Objektive – Various Lenses



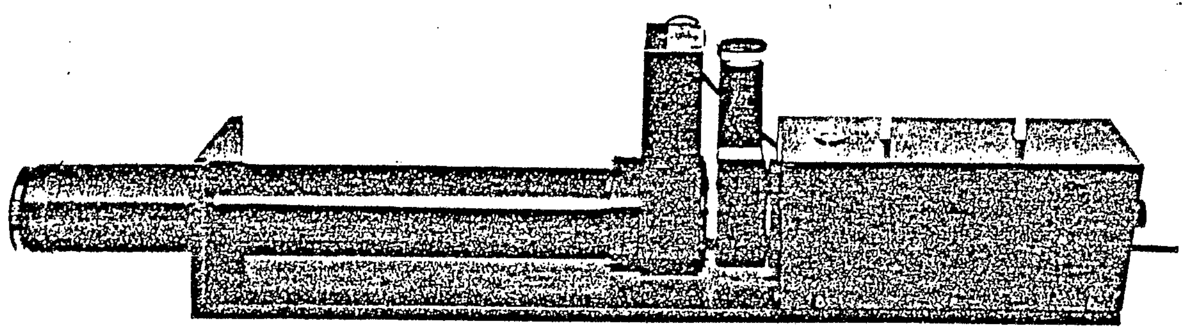
③ Dreiachsentisch 105 – Three Axis Table 105



④ Meßflächenleuchte – Target Illuminator



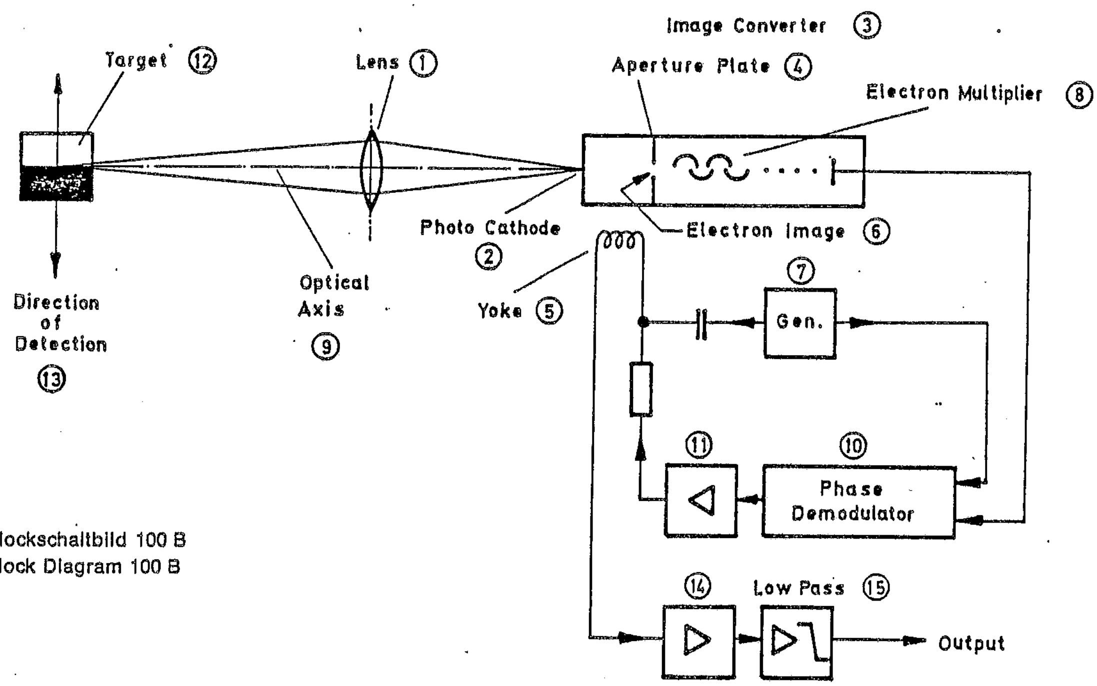
⑤ Frontansicht Camera 100 B – Front View Camera 100 B



⑥ Autocollimator 140 an Camera 100 B – Autocollimator 140 with Camera 100 B

Wirkungsweise

Principle of Operation



⑦ Blockschaltbild 100 B
Block Diagram 100 B

Ein Objektiv (1) projiziert ein Bild auf die Fotokatode (2) des Bildwandlers (3) der Camera 100 B. Das optische Bild wird durch die Fotokatode (2) in ein Elektronenbild (6) umgewandelt, das auf einer Lochblende (4) fokussiert wird.
Eine Ablenkeinheit (5) zwischen Fotokatode (2) und Lochblende (4) ermöglicht schnelle, trägheitslose Ablenkung des Elektronenbildes (6).
Die Ablenkeinheit (5) wird durch einen Generator (7) angesteuert. Hierdurch entstehen am Ausgang des Elektronenvervielfachers (8) Impulse. Diese sind mit dem Generatorsignal gleichphasig, sofern die Kontrastlinie der Meßfläche (12) auf der Optischen Achse (9) liegt.
Ein Phasendemodulator (10) erzeugt eine der Phasendifferenz beider Signale proportionale Spannung. Diese ist null bei Phasengleichheit.
Ein Verstärker (11), der mit dem Ausgang des Phasendemodulators verbunden ist, führt das Regelsignal zur Ablenkeinheit (5). Hierdurch entsteht ein geschlossener Regelkreis mit Hilfsabtastung.
Das Elektronenbild (6) bleibt auf der Lochblende (4) stets in der gleichen Position, auch wenn sich die Meßfläche (12) in Richtung der Meßachse (13) bewegt.
Der Korrekturstrom durch die Ablenkeinheit (5), der das Elektronenbild (6) in gleicher Position hält, ist proportional zur Lage der Meßfläche (12). Ein Strom/Spannungswandler (14) mit nachgeschaltetem Tiefpassfilter (15) erzeugt ein wegproportionales Ausgangssignal.

A Lens (1) projects an image on the photo cathode (2) of the image converter (3) of the Camera 100 B. The optical image is converted into an electron image (6) by the photo cathode (2). It is then projected on an aperture plate (4).
A deflection yoke (5) between photo cathode (2) and aperture plate (4) permits fast deflection of the electron image (6) without inertia.
The deflection yoke (5) is driven by a generator (7). This causes the output of the electron multiplier (8) to generate pulses. These pulses are in phase with the generator signal if the target center line is located on the optical axis (9).
A phase demodulator (10) converts the phase relationship between both signals into an analog voltage which is zero at zero phase shift.
An amplifier (11) connected to the output of the phase demodulator applies the control signal to the deflection yoke (5). This results in a closed loop scanning system.
The electron image is always kept in position even if the target (12) moves in the direction of detection (13).
The correcting current in the deflection yoke (5) keeps the electron image (6) in a fixed position and is proportional to the target deflection. A current to voltage converter (14) with a low pass filter (15) in the output generates the signal proportional to displacement.

Technische Daten

Meßbereich: 0,2 mm bis 20 m Vollausschlag[1]
Meßabstand: 5 mm bis 200 m[1]
Auflösung: 0,008 % des Meßbereichs[2]
Frequenzgang: 0 bis 400 kHz (−3dB), linear innerhalb 1 % von 0 bis 200 kHz
Anstiegszeit: < 1 µs von 0 auf 63 %
Tiefpassfilter: Verzögerungsglied 1. Ordnung, 100 kHz, 20 kHz, 5 kHz, 1 kHz, 100 Hz, 10 Hz
Ausgangsrauschen:

Tiefpass (Hz)	Rauschen (mV ptp)[3]
Breitband	45
100 k	30
20 k	15
5 k	7
1 k	3
100	1,5
10	0,8

Mono Scan: Aufz. einmaliger Vorgänge, mit Reset Taste
Blindzeit Autom.: < 2 µs
Meßfehler, Linearität: ± 0,2 % des Meßbereichs[1]
Beleuchtung Meßfläche: > 500 Lux
Abtastbreite: 3,3 % des Meßbereichs[1]
Spektralempfindlichkeit: 400 nm bis 650 nm
Meßachse: verstellbar um ± 100° aus der Vertikalen, Einstellgenauigkeit ± 0,5°
Ausgangsspannung: ± 5,0 V für Vollausschlag[1]
Ausgangsimpedanz: 50 Ohm
Ausgangsbelastung: ± 10 mA, kurzschlußfest gegen Masse
Ausgangsbuchsen: 2 BNC Buchsen parallel
Ausgangsdrift: < ± 5 mV (0,05 %) pro 24 Stunden[3]
Arbeitstemperatur: + 10° C bis + 50° C
Abmessungen Camera: 103 × 101,5 × 269 mm (B, H, L)
Gewicht Camera: 3,5 kg ohne Objektiv
Max. Beschleunigung Camera: 10 g in 3 Achsen
Abmessungen Steuergerät: 19″ Einschub, 132,5 mm hoch in Gehäuse 280 mm tief
Gewicht Steuergerät: ohne Gehäuse: 5 kg
mit Gehäuse: 9 kg
Meßflächenleuchte: 6 V DC, 10 W Halogen-Punktlichtlampe mit 2fachem Kondensorsystem, kurzschlußfeste Versorgung aus Steuergerät, Kabellänge 5 m mit Steckverbindungen
Lebensdauer Lampe: 2000 Stunden Dauerbetrieb
Kabel 101 B – 100 B: 3 m lang mit Steckverbindungen
Verlängerungskabel auf Anfrage
Netzanschluß: 100–240 V, 50–60 Hz, max. 32 VA umschaltbar, Kabel 2 m lang
Batteriebetrieb auf Anfrage
Netzspannungsänderungen: bei ± 10 %: Drift und Meßfehler < 0,01 %
Lieferumfang: Ein betriebsbereites System 100 B besteht aus:
- 1 Camera 100 B mit Fokussiereinheit und Staubschutzhaube
- 1 Steuergerät 101 B mit Staubschutzhaube
- 1 Netzkabel, Schuko, 2 m lang
- 1 Verbindungskabel 101 B – 100 B, 3 m lang
- 1 Meßflächenleuchte 6 V/10 W
- 1 Dreifuß mit Stange und Kreuzmuffe
- 1 Objektivhalter mit Montageschlüssel und Schrauben
- 1 Ersatzlampe für Meßflächenleuchte
- 1 Bedienungsanleitung
- 1 Objektiv gemäß Kundenangaben[4]
- 1 Transportkoffer

[1] Je nach verwendetem Objektiv
[2] In Filterstellung 10 Hz
[3] Typische Werte, die um ± 30 % streuen können, gemessen mit 100–1
[4] Muß getrennt bestellt werden

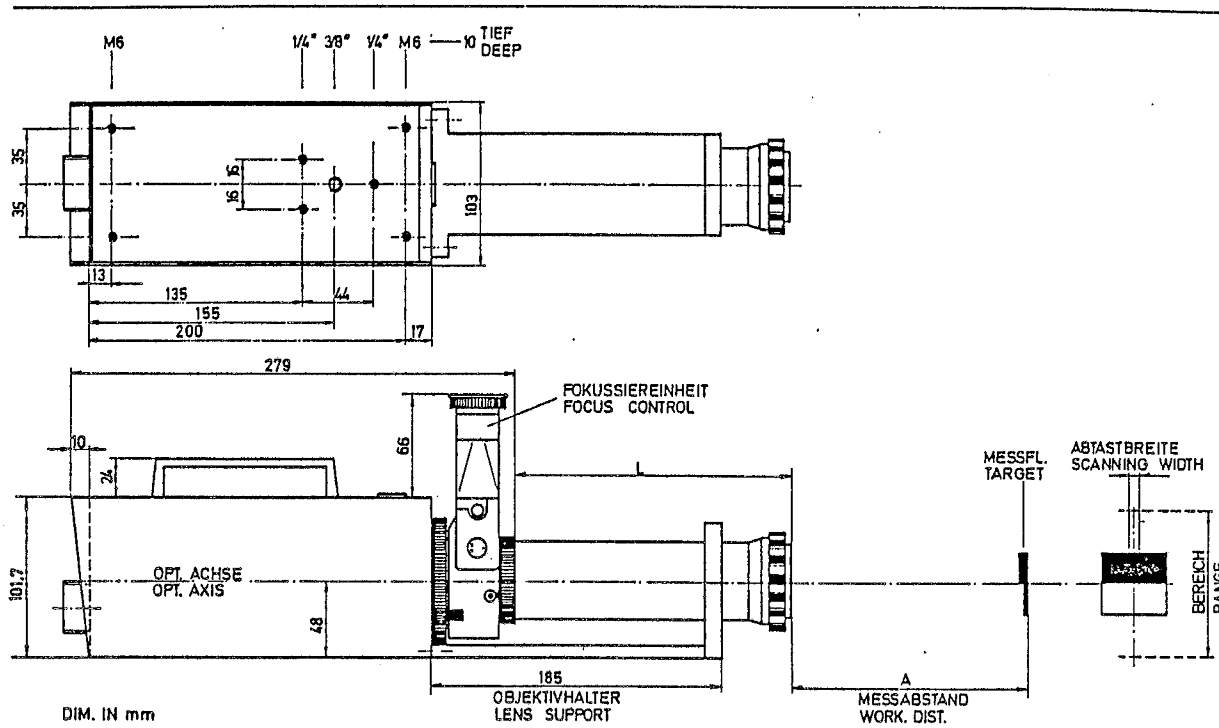
Specifications

Displacement Range: 0.2 mm to 20 m full scale[1]
Working Distance: 5 mm to 200 m[1]
Resolution: 0.008 % of range[2]
Response: 0 to 400 kHz, (−3dB), flat within 1 % from 0 to 200 kHz
Rise Time: < 1 µs from 0 to 63 %
Low Pass Filter: first order lag, 100 kHz, 20 kHz, 5 kHz, 1 kHz, 100 Hz, 10 Hz
Output Noise:

Low pass (Hz)	Noise (mV ptp)[3]
W. Band	45
100 k	30
20 k	15
5 k	7
1 k	3
100	1.5
10	0.8

Mono Scan: Single event recording, with reset button
Recapture Time: < 2 µs
Error, Linearity: ± 0.2 % of range[1]
Target Illumination: > 500 Lux
Scanning Width: 3.3 % of range[1]
Spectral Response: 400 nm to 650 nm
Axis of Detection: adjustable from the vertical ± 100° accuracy ± 0.5°
Output: ± 5.0 V for full scale displacement[1]
Output Impedance: 50 Ohm
Output Loading: ± 10 mA, short circuit proof against ground
Output Terminals: 2 BNC sockets in parallel
Output Drift: < ± 5 mV (0.05 %) per 24 hours[3]
Operating Temperature: + 10° C to + 50° C
Dimensions Camera: 103 × 101.5 × 269 mm (W, H, L)
Weight Camera: 3.5 kg without lens
Max. Acceleration Camera: 10 g in 3 axes
Dimensions Control Unit: 19″ rackmount, 132.5 high, in cabinet 280 mm deep
Weight Control Unit: rackmount unit only: 5 kg
mounted in cabinet: 9 kg
Target Illuminator: 6 V DC, 10 W halogen point light source with dual condensing lens system, driven from a power supply in the Control Unit via a short circuit proof output. Cable 5 m long with connectors.
Life of Lamp: 2000 hours cont. operation
Cable 101 B – 100 B: 3 m long with connectors on both ends
3 m extension cable upon request
Power Requirements: 100 to 240 V, 50–60 Hz, max. 32 VA
Length of power cable: 2 m
Battery operation upon request
Power Fluctuations: at ± 10 %: drift and calibration errors < 0.01 %
Delivery Items: An operational Model 100 B System comprises:
- 1 Camera 100 B with focus control and dust cover
- 1 Control Unit 101 B with dust cover
- 1 Power Cable, 3 core, 2 m long
- 1 Interconnecting Cable 101 B – 100 B, 3 m long
- 1 Target Illuminator 6 V, 10 W
- 1 Stand with rod and clamp for mounting Target Illuminator
- 1 Lens support with screws and allen wrench
- 1 Spare Lamp for Target Illuminator
- 1 Instruction Manual
- 1 Lens according to customer requirements[4]
- 1 Carry Case

[1] Depending on Lens used
[2] In filter position 10 Hz
[3] Typical values which can vary by ± 30 %, measured with 100–1
[4] To be ordered separately



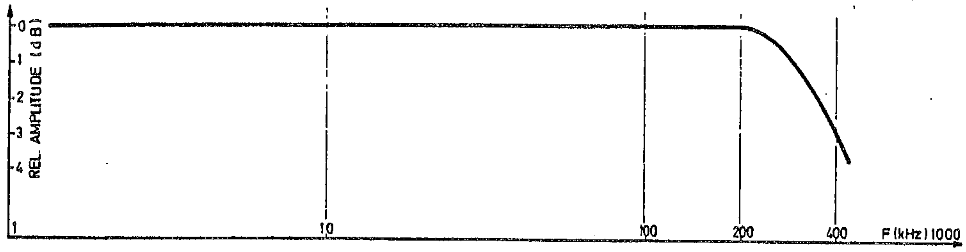
(8) Abmessungen Camera 100 B – Dimensions Camera 100 B

Liste der Standardobjektive — List of Standard Lenses

Modell Nr. Model No.	Meßbereich Displ. Range	ungef. Meßabst. Approx. Working Distance A	Auflösung Resolution (B = 10 Hz)	Objektivlänge Lens Length L (mm)	Lichtübertragung Light Transmission T (%)
100–002 S	200 µm	2 mm	0,02 µm	365	0,75
100–002	200 µm	60 mm	0,02 µm	366,5	0,096
100–005 SS	500 µm	6 mm	0,05 µm	73	5,5
100–005 S	500 µm	16 mm	0,05 µm	470	0,5
100–005 L	500 µm	150 mm	0,05 µm	307	0,21
100–01 S	1 mm	45 mm	0,08 µm	359	7,2
100–01 HS	1 mm	135 mm	0,08 µm	276	1,6
100–02 S	2 mm	50 mm	0,16 µm	267	21,5
100–02	2 mm	200 mm	0,16 µm	210	1,3
100–05	5 mm	210 mm	0,4 µm	292	48
100–1	10 mm	310 mm	0,8 µm	178,5	100
100–2	20 mm	480 mm	1,6 µm	130,5	165
100–5	50 mm	550 mm	4 µm	29,5	225
100–5 L	50 mm	1,2 m	4 µm	127	188
100–10	100 mm	1 m	8 µm	23,7	290
100–20	200 mm	2 m	16 µm	20,9	290
100–50	500 mm	5 m	40 µm	19,5	290
100–50 L	500 mm	9 m	40 µm	91	290
100–1 m	1 m	10 m	80 µm	18,5	290
100–2 m	2 m	16 m	160 µm	55	480
100–5 m	5 m	40 m	400 µm	55	480
100–10 m	10 m	80 m	800 µm	55	480
100–20 m	20 m	160 m	1,6 mm	55	480

Objektive mit einer Lichtübertragung T < 1 % können nur im Durchlicht verwendet werden.

Lenses with an Light Transmission T < 1 % can only be operated in back lighting mode.



(9) Frequenzgang – Frequency Response

Sonderzubehör

Dreiachsentisch 105
Dient zum genauen Ausrichten der Camera 100 B auf die Meßfläche.

Einachsentisch 106
Bewegt die Camera 100 B in Richtung der optischen Achse und wird nur zum Fokussieren verwendet. Zum Aufbau an Stativ „P" geeignet.

Doppeldifferentiator 131 A / 131 B
Ein Zusatzgerät zum Messen von Geschwindigkeit und Beschleunigung. Gerät verarbeitet wegproportionales Signal des Systems 100 B durch aktives, zweifaches Differenzieren in ein Geschwindigkeits- und Beschleunigungsproportionales Signal.

Autocollimator 140
Optischer Vorsatz vor Camera 100 B zum Messen von Winkelbewegungen. Einheit besteht aus dem Autocollimator Adapter 140 und einem von 4 wählbaren Collimatorobjektiven für einen vollen Meßbereich zwischen 30′ und 2°.

Differentialimpedanzwandler 160 D
Findet bei der Dehnungsmessung mit 2 Systemen 100 B Anwendung. Gerät hat 2 Eingänge, von denen wahlweise die Summe oder die Differenz gebildet werden kann.

Polyaxialtisch 205
Besteht aus 2 Dreiachsentischen und nimmt 2 Cameras 100 B auf. Wird bei Dehnungsmessungen verwendet. Tisch kann auf Universalstativ montiert werden.

Bandpass 702
Schmalbandiges Bandpass-Filter für Frequenzanalyse. Arbeitet auch als Nachlauffilter.

Doppelprofilstativ „P"
Stabiles Aluminiumprofil-Stativ mit Neigekopf zur Aufnahme der Camera 100 B.

Universalstativ
Fuß aus Grauguß mit Teleskophöhenverstellung der Montageflanschen, auf den die Tische 105 und 205 aufgebaut werden können.

Special Accessories

Three Axis Table Model 105
Is used for the accurate alignment of the Camera Model 100 B in respect to the target.

Single Axis Table Model 106
Moves the Camera Model 100 B in direction of the optical axis and is used for focusing only. It is intended for mounting on the Heavy Duty Tripod Model "P" (see text for further details).

Double Differentiator Model 131 A / 131 B
An Accessory for the measurement of velocity and acceleration. It computes the displacement signal from the Model 100 B by electronically differentiating and double differentiating to provide signals which are directly related to velocity and acceleration.

Autocollimator Model 140
An accessory used with the Camera Model 100 B to provide measurements of angular motion. The unit consists of an Autocollimator Adapter Model 140 and one lens selected from a range of 4 to cover angular measurements from 30′ to 2°.

Differential Impedance Converter Model 160 D
Primarily intended for strain measurement applications when it is used with two Camera Systems Model 100 B. Two separate BNC input sockets are provided and the output can be switched to provide a signal proportional to the sum or difference of the two inputs or each individual input.

Poly Axis Table Model 205
Is a combination of two Three Axis Tables and is intended for mounting two Cameras Model 100 B. It is used for strain measurements. Table can be mounted on a Universal Stand.

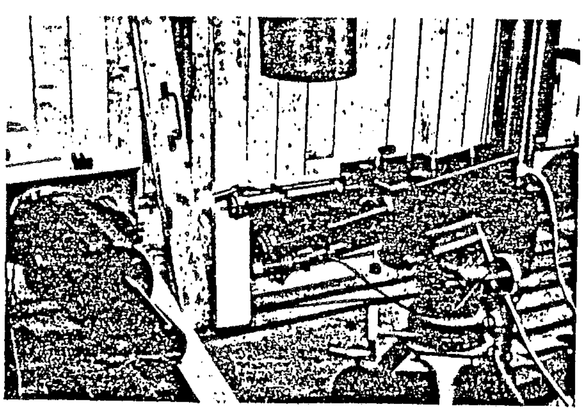
Bandpass Filter Model 702
Narrow Bandpass Filters for frequency spectrum analysis and tracking application.

Heavy Duty Tripod Model "P"
Rigid aluminium profile tripod with pan and tilt head for mounting Camera Model 100 B.

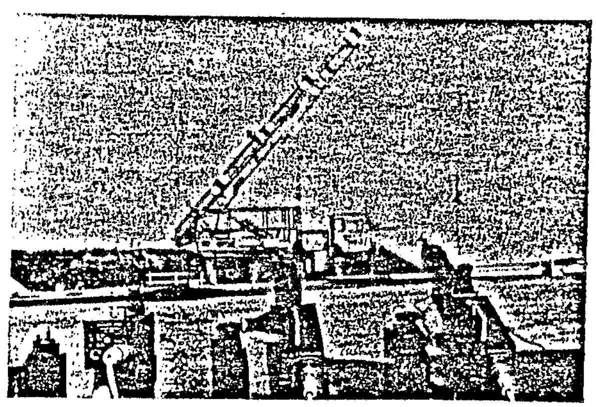
Universal Stand
Cast iron base with telescopic height adjustment of mounting platform which will accept tables Model 105 and Model 205.

Anwendungen

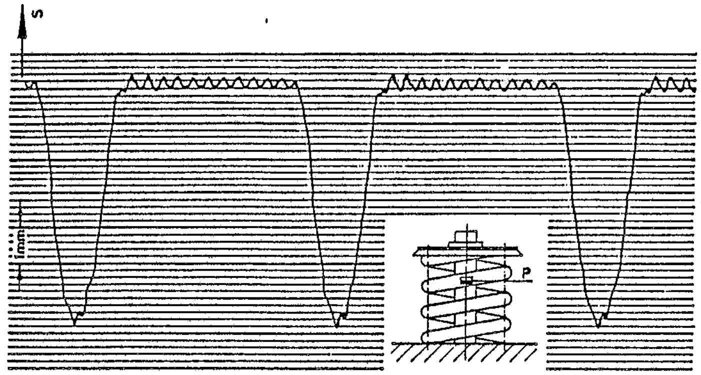
Applications



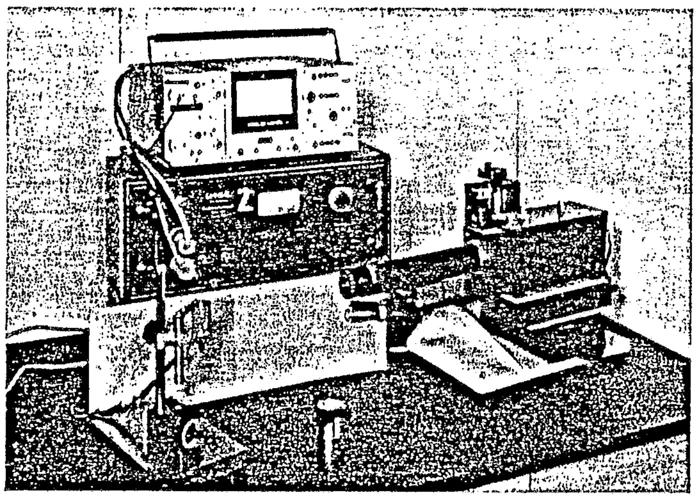
(10) Relativbewegungsmessung bei der Waffenforschung
Measurement of relative motion for weapon research

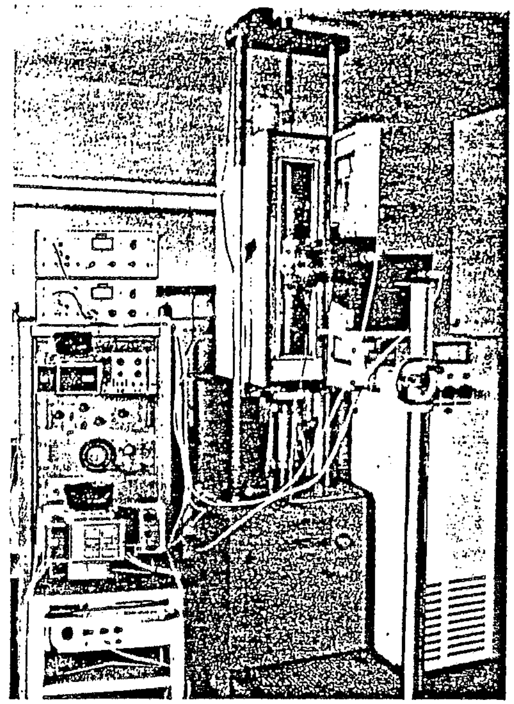


(11) Bewegungsmessungen an Mobilrampe
Motion measurement at mobile launcher



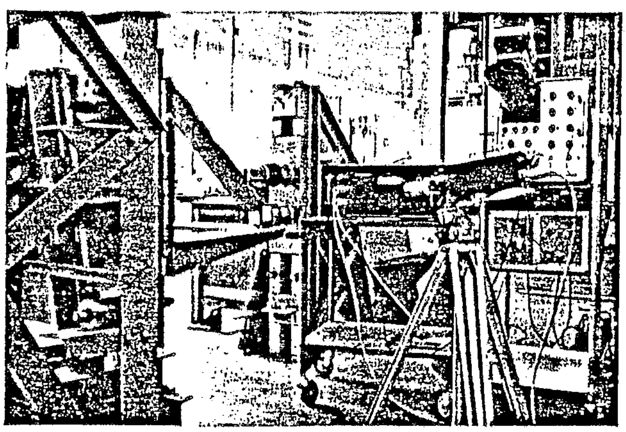
Weg — Zeitdiagramm einer Ventilfeder
⑫ Displacement versus time diagram of a valve spring



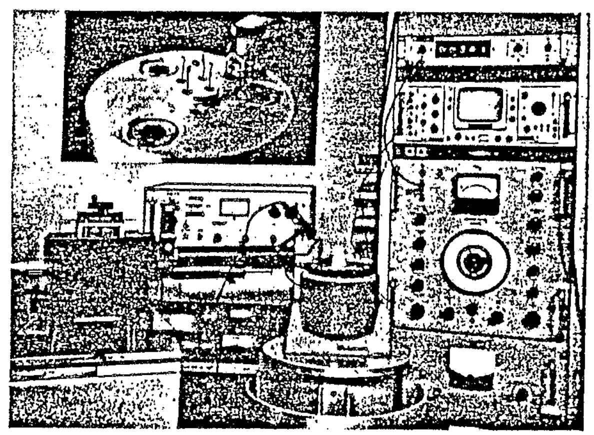


⑬ Dehnungsmessung mit 2 Geräten bei der Hochgeschwindigkeitszugprüfung
Strain measurement with 2 instruments for high speed tensile testing

⑭ Hubmessung eines Zugmagneten
Stroke measurement of a magnetic actuator



⑮ Bewegungsmessung bei Schockprüfungen
Displacement measurements during shock tests



⑯ Messung des Resonanzverhaltens kleiner Bauelemente
Measurement of the resonant behaviour of small components

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FUGRO

Equipment Data Sheet

Pile Driving Recorder

Introduction

Fugro, in their capacity as geotechnical consultants for offshore foundations, are frequently involved in installation studies for piled structures and in the subsequent installation supervision.

Installation studies involve, amongst other aspects, preparing predictions of pile drivability. Such predictions form the basis of the long term strategy of the operating oil companies and their installation Contractors.

The skills developed by Fugro for making reliable predictions are based on high quality investigations of the relevant soil parameters and back analyses of previous installation records. The recent rapid increase in the capacity of steam hammers has entailed frequent extrapolation of the available data.

Assumptions are made within each prediction of the useful energy that a steam hammer's ram can provide over prolonged periods of driving. This is known to vary with time, steam parameters, valve settings and hammer condition. Current practice normally involves estimating visually the ram stroke length, which bears an approximate empirical relationship with hammer energy. Occasionally, measurements have been made of the ram's terminal velocity using high speed photography, but this method is unreliable since the interpretation leaves much to the judgement of the analyst. Optical displacement transducers have been successfully employed but these are both expensive to operate and require a stable support, rarely available in the offshore environment.

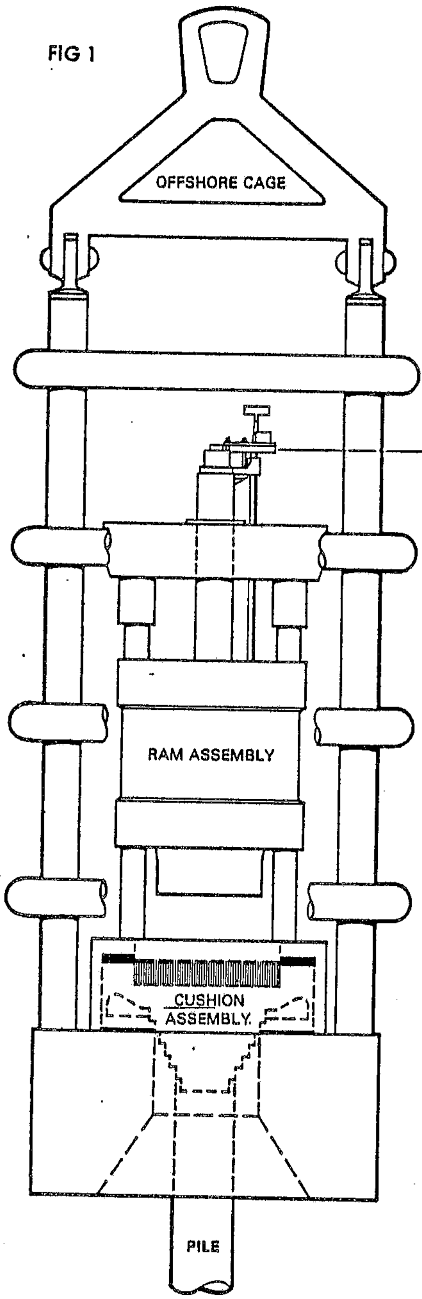
Fugro have developed a simple device which provides an accurate measure of the terminal velocity of the ram for each blow. It provides reliable data without any delays to the pile installation procedure.

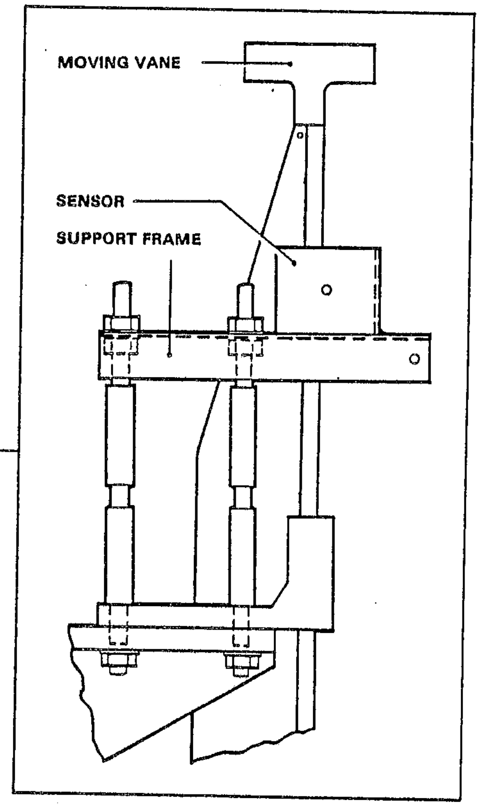
Description

The system consists of five components:

- a sensor
- a support bracket
- a moving vane
- the connecting cable
- the recorder

FIG 1





The sensor is a robust device mounted on to a fixed part of the hammer by means of the support bracket. In its present form the device has been developed for use on Menck steam hammers, where the cross head provides a convenient reference point in relation to the hammer cushion. (See Fig 1).

The vane, which is the only moving component, is fixed to the ram assembly in such a way that in the final stage of the ram's downward motion the vane passes through an optical beam generated by the sensor. For the Menck hammers, the vane is mounted on the control bar which operates the steam exhaust valve.

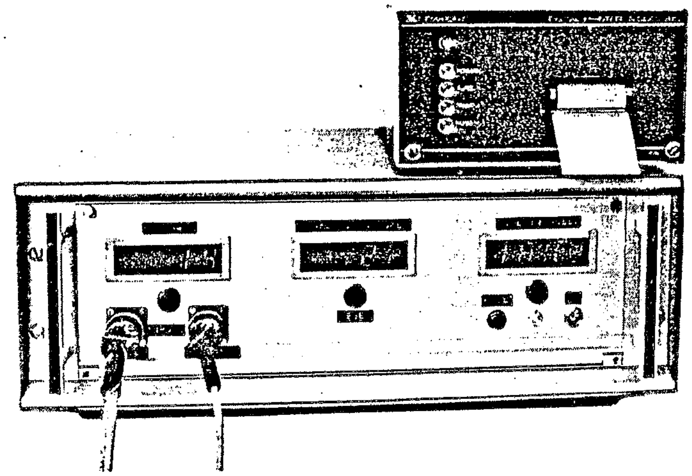
The recording equipment is housed on the derrick barge from which the hammer is operating. The signal from the sensor indicating the breaking and remaking of the optical beam is transmitted to the recorder along a cable which can be fixed, for convenience, to the hammer steam supply hose.

The recorder provides the following facilities:

- Accumulative count of blows 0000 to 9999
- Duration of the breaking of the beam 0 to 99.99 milliseconds by 0.01 millisecond.
- Pre-set footmarker 0000 to 9999 adjustable positively or negatively by a hand control on a flying lead.

The above information is presented visually as an illuminated display and is also printed out on a line printer for each blow delivered by the hammer. The digital output is also available in a suitable form for input into a punch tape data logger.

PLATE 1

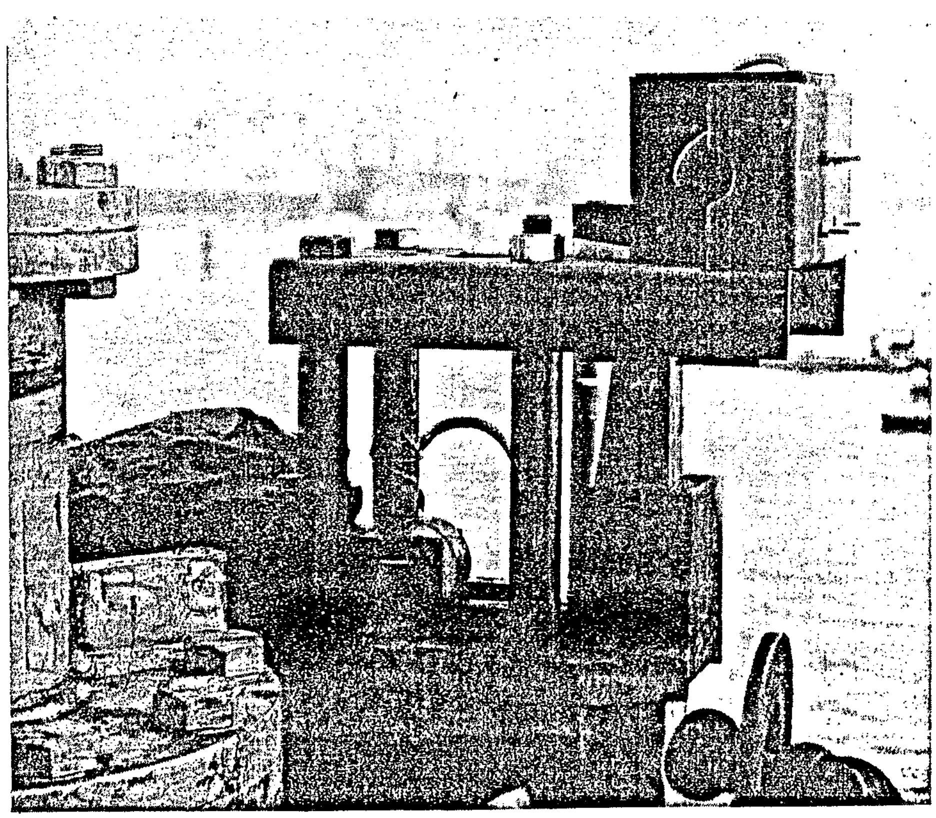


Operation

A sensor is mounted on each hammer when these are on the deck of the derrick barge, a task which takes about 30 minutes per hammer to perform. When the cable is supported on the steam hose, one electrical connection has to be made upon completion of the steam hose connection, a task which takes only a few seconds to perform.

After switching on the recorder, the follower footmark lying immediately below the recording datum is preset on the footmarker. Piling can then be fully monitored, the only action required by the operator being to depress the hand control whenever a new foot mark reaches the recording datum. The ram velocity and hence the hammer operating efficiency can be calculated from the known width of the vane. Plate 1 shows the recorder and line printer. Plate 2 shows a prototype sensor mounted on a Menck 8000 hammer during a test made at Hamburg.

PLATE 2



Applications

The device can be usefully employed on any pile driving contract either onshore or offshore where the hammers employed provide their energy output wholly from the kinetic energy of the ram at impact.

Particular applications where immediate benefits would accrue include:

- Sites where predictions indicate possible refusal conditions. Under such conditions it is advantageous for the contractor and the client to establish that the hammer is operating efficiently.
- Wherever pile drivability differs greatly from the predicted behaviour.
- Where a new hammer is being commissioned and the steam valve and exhaust port settings need final adjustment.
- Where detailed back analysis is required to establish the optimum driving procedure for subsequent piles and to provide an accurate back assessment of actual soil conditions.
- To provide contractors and hammer manufacturers with a reliable data bank for research into cushion life and fatigue stresses on hammer components.
- To provide an accurate dynamic basis for establishing the static capacity of a pile.

Conditions of use

The pile driving recorder has been developed as a tool for the use of Fugro personnel whilst supervising pile driving contracts. The equipment is not normally available on a purchase basis. Hire rates for the equipment, which can be obtained on application, include the cost of a trained operator.

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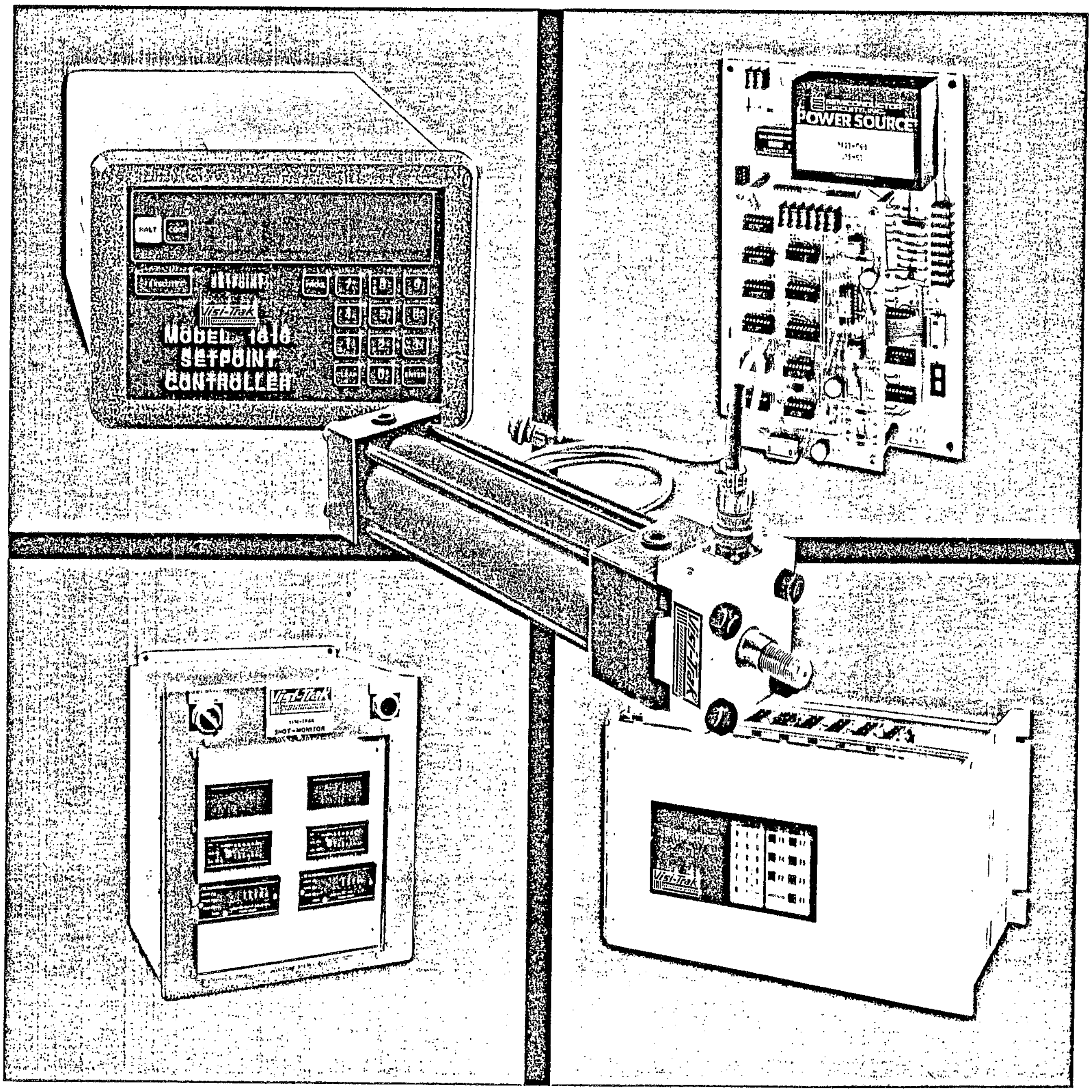
Linear Position and Velocity Sensors, Monitors, Controls



UNIDIRECTIONAL SQUARE WAVE PULSE

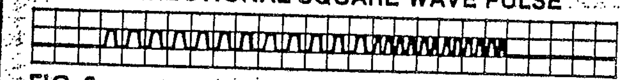


FIG. 2

BIDIRECTIONAL QUADRATURE PULSE

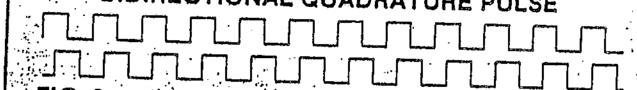


FIG. 3

TRANSDUCER ALTERNATIVES

The standard Visi-Trak transducer is available in two basic assemblies — Unidirectional and Bidirectional.

The unidirectional assembly contains one sensor and provides a single digital square wave pulse train (Fig. 2) The unidirectional sensor is not capable of directional sensing since the pulses are added regardless of direction of linear actuator movement. The bidirectional assembly contains two sensor elements positioned in such a manner that one pulse train leads the second pulse train by 90 electrical degrees. This quadrature pulse train (Fig. 3) allows direction sensing capability by electronically looking at the phase relationship between the two pulse trains.

ROD MODIFICATION — POSITION RESOLUTION

There are two standard discontinuities provided in the modified piston rods or standard signal generating rods — 0.1P and .05P. The 0.1P rod modification provides 20 groove discontinuities per inch. The .05P rod modification provides 40 discontinuities per inch. When combined with the uni-directional or bidirectional transducer assemblies the following position resolutions per pulse result:

1. UniDirectional transducer (x2 count logic)
   a. 0.050" Resolution with 0.1P Rod.
   b. 0.025" Resolution with 0.05P Rod.
2. Bidirectional transducer (x4 count logic)
   a. 0.025" resolution with 0.1P rod
   b. 0.0125" resolution with 0.05P rod

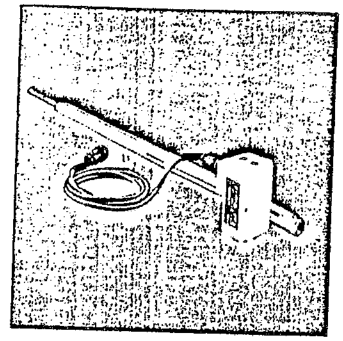
Finer position resolutions can be provided on a custom basis by adding additional transducers. Consult the factory for details.

TRANSDUCER SPECIFICATIONS

Power Supply:	5 to 12-VDC
Operating Temperature:	−25° to 90° C
Sensed Frequency:	Up to 10 KHz DC
Output Voltage:	TTL Compatible, 50±15% duty cycle: Logic 0: +0.6V peak maximum with 50 mA sink current Logic 1: $\frac{RL1 \times Es}{RL + 25\ ohms}$
Output Impedance:	2k ohm
Power Supply Current:	20 mA typical with 12-V power supply
Transducer/Rod Gap:	.012-in.
Housing:	Delrin
Output Connection:	Mates with MS31064-145-25.

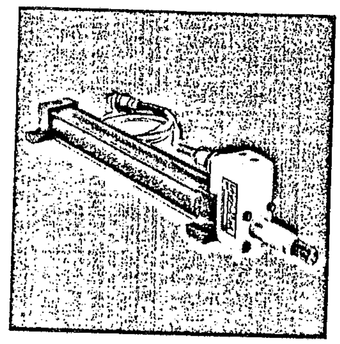
SENSOR — ALTERNATE FORMS

Generally for simplicity and economy, existing cylinder piston rods can be modified for Visi-Trak signal generating capability. All modifications are made by Visi-Trak. The rod is returned with functional dimensions to original specifications with .003" smooth hard chrome plate surface over the entire O.D. If preferred, Visi-Trak will supply a new rod to your drawing — complete with modifications. The transducer housing is custom designed to mount directly to the rod end or packing gland of the cylinder. Piston rod diameter, stroke and overall rod length are required for price quotation. Rod drawings and dimensional information for transducer mounting are required with the order.



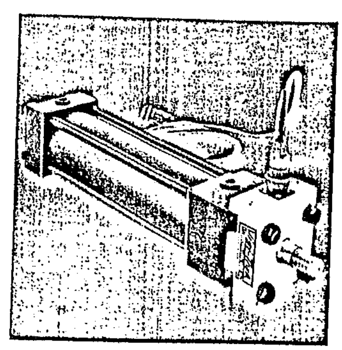
Modified Cylinder Piston Rods

Occasionally, because of piston rod size, easier field retro-fit or other factors, it can be more economical or easier to install standard Visi-Trak signal generator assemblies. These units are designed to mount to and move in parallel with your cylinder or linear actuator. These units are either uni-directional or bi-directional and can be ordered with .1P or .05P signal rod modifications depending on your position resolution requirements. The standard signal generator consists of: 1½" bore aluminum tube for housing and guarding the rod, 2 aluminum heads with foot mounts, 1" diameter signal generating rod with phenolic piston on one end and tapped hole on the rod end to facilitate connection to your piston rod or actuator with appropriate bracket and standard uni-directional or bi-directional delrin transducer housing with integral M.S. connector. These units can be ordered for any sensing length required.



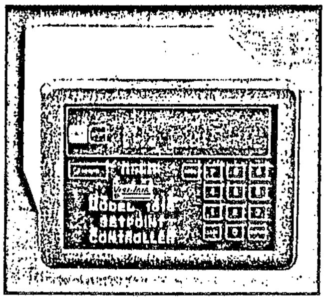
Standard Visi-Trak Signal Generators

Standard J.I.C. Cylinders up to 6" bore with piston rods to 2½" diameter are available with integral Visi-Trak sensors as shown. Consult the factory or your Visi-Trak sales representative for order information.



Standard J.I.C. Cylinders

Visi-Trak® Monitors and Controls



Model 1616 Programmable Setpoint Controller

The 1616 controller is a micro-processor-based multiple set point controller, intended for electronic replacement of electro-mechanical limit switches in machine and hydraulic system control circuits. This unit provides 12 VDC power supply for the Visi-Trak transducer — Takes quadrature digital square wave pulse input from the transducer — Provides easy operator keyboard entry of up to sixteen position setpoints in memory — Provides up to sixteen control outputs at set point coincidence.

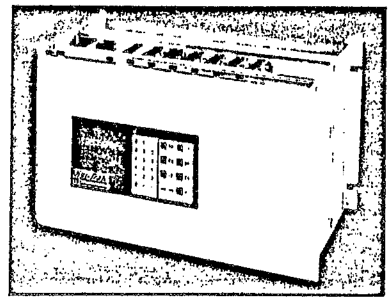
Outputs are easily programmable for:

1. Toggle (Latch at setpoint up count/unlatch at setpoint down count
2. Momentary up and down (Timed from .1 to 9.9 seconds)
3. Momentary up only (Timed from .1 to 9.9 seconds)
4. Momentary down only (Timed from .1 to 9.9 seconds)
5. Reversal of output states/toggle — Turn on output off

This allows complete control circuit flexibility and versatility. Outputs are N.P.N. open collector outputs for direct interfacing with P.C. controlled machines or can drive external electro-mechanical relays for interfacing with relay controlled machines.

Non volatile Earom memory allows retention of position and program data indefinitely despite loss of power.

Model 32-100 Automatic Monitor/ Servo controller

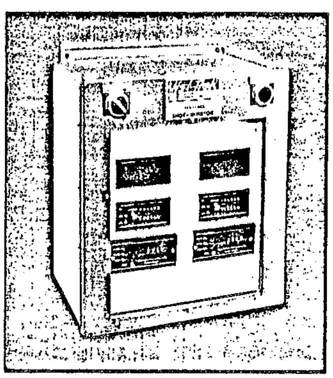


The model 32-100-micro-processor based monitor allows user to store full stroke profiles of position, velocity or pressure in memory as reference for all subsequent machine cycles. Unit automatically compares all subsequent velocity, pressure or position profiles to stored reference and generates out of tolerance indication if any one of 100 points falls outside pre-programmed limits. Sample rate is adjustable from one milli-second per sample up to 250 milli-seconds per sample. Analog playback is provided at any time with selection from stored profiles, last cycle or deviation from stored profile. C.R.T. option allows continuous display of reference profiles, hi - lo limits and all subsequent cycles.

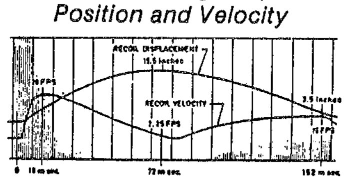
This extremely versatile monitor allows continuous observation of machine performance without an operator or process control personnel in attendance.

Addition of the servo control printed circuit board makes the model 32-100 controller an extremely accurate and versatile servo controller which provides accurate control of linear velocity and acceleration in respect to position. Up to 32 velocity acceleration and position commands can be entered by keyboard. In operation the unit automatically compares feedback to command and generates the servo valve error signal for accurate closed loop servo control.

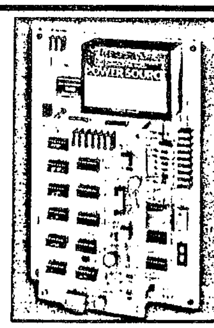
Model D-1025 Monitor



Provides full stroke analog outputs of position, velocity and pressure for set-ups, periodic quality checks and diagnosis of system or process problems. Also provides sample, hold of linear velocity on continuous basis or at user selectable position set point with digital L.E.D. readout for cycle to cycle observation. Digital comparator also provides hi - lo settings and hi - lo go indication with hi - lo relay output for driving counters, alarms, or for use in adaptive control circuits. Simultaneous display can be provided for pressure at user selectable set point with hi - lo comparison and relay output. (As shown)



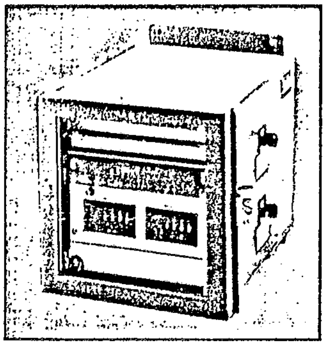
Typical Analog Output Position and Velocity



Model 400 and 600 Analog Position And Velocity Cards

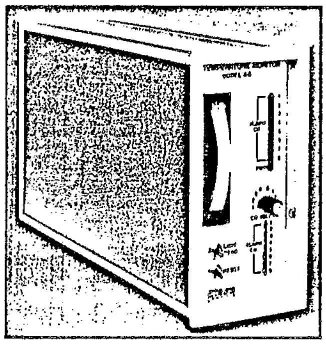
Visi-Trak standard analog position and velocity cards provide 12VDC transducer power, take digital pulse input from Visi-Trak transducer and provide 0 - 10 volt outputs proportional to linear position and velocity. Can be used in conjunction with oscilloscope, oscillograph, chart recorder, X-Y plotter or C.R.T. for process monitoring applications. Also provides accurate feedback signal for process control applications. Standard calibrations provide 0 - 10 volt full scale output of 0 - 10V = 0 - 12.5", 0 - 25" or 0 - 50" for position, and 0 - 10V equal 0 - 8 F.P.S.; 0 - 20 F.P.S.; or 0 - 40 F.P.S. for velocity. Can be calibrated for any other full scale output on request. Analog cards can be purchased for customer panel mounting or prewired in NEMA 12 enclosure with manual reset push button, bulkhead M.S. connector for transducer input, 110V power input, and B.N.C. connectors for analog outputs.

These units provide 12 volt power for the Visi-Trak transducer, take unidirectional or bidirectional pulse input from the transducer, and provide L.E.D. readout of position count and logic level or relay output when count reaches coincidence with setpoints for electronic replacement of electro-mechanical limit switches. Pulse output can be paralleled from this unit *to provide input to other Visi-Trak monitors and controls.*



Model 120, 220, 320 Setpoint Position Controllers

The model 88 is a digitally accurate, 8-channel RTD temperature monitor. It provides a large, easy-to-read meter, LED indication of channel alarm, and individually adjustable alarm limits with separate relays in a compact panel-mounted case. The unique digital design and LSI circuitry allow for virtually drift-free operation and easy field change of range without recalibration.



Model 88 Temperature Monitor Controller

- **Pressure Transducers —**
  Provides 0 - 5 volt outputs proportional to pressure. Model 5 - 10 requires 12V or 15V regulated power input and provides 0-5V output proportional to 0 - 10,000 P.S.I.

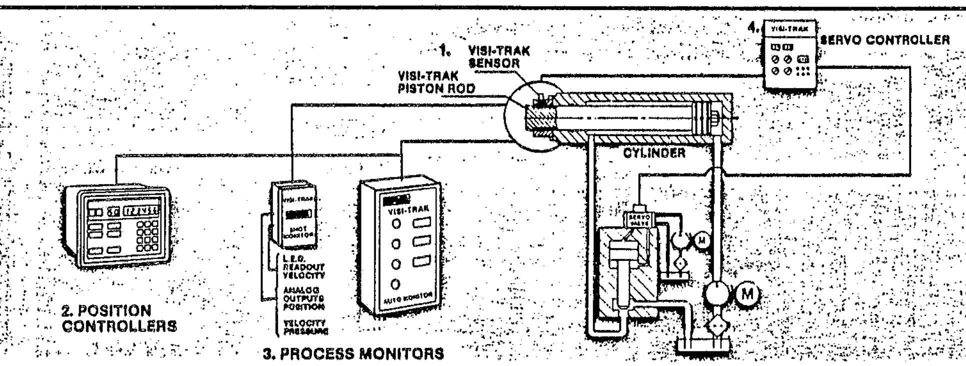
- **In Line Signal Amplifiers**
  Amplify pulse output from Visi-Trak transducer to permit transmission of signal to remote monitors or enable multiple hook-up of various monitors and controls to single pulse source.

- **Totalizing counters**
  Provide digital readout of position in pre-calibrated engineering units with high visibility L.E.D. display.

- **C.R.T. Displays**
  Interface with Visi-Trak monitors to provide high resolution, graphical display of variable monitored.

- **Custom Systems**
  Visi-Trak's highly skilled engineering and technical staff combine many years experience in process monitoring and control instrumentation and are ready to discuss your application in detail and design an appropriate system to meet your requirements. We have complete software and hardware design capabilities.

Visi-Trak SYSTEMS FOR MORE PRODUCTIVE MOTION CONTROL



The *Visi-Trak* Productivity Payback

Today's highly competitive worldwide economy demands more productive machinery, systems and processes. Visi-Trak's complete line of high quality, simple and reliable machinery instrumentation and controls offers you a major opportunity for achieving the productivity increase payback required to survive and prosper in a highly competitive industrial environment.

Visi-Trak Sensors Provide

- More reliable, accurate, and repeatable monitoring and control system performance.
- Fast easy installation, maintenance free operation and capability to operate on continuous basis in rugged environments mean more long term cost effectiveness and greater machine or system up time.

Visi-Trak Position Controllers Provide

- Greater control circuit reliability for less machine down time.
- Easier and thus faster machine set-ups.
- More accurate machine set-ups.

Visi-Trak Process Monitors Provide

- Accurate frame of reference for faster machine set-ups enabling more productive use of your machine.
- Frame of reference for periodic or continuous quality checks to insure more consistent higher quality production.
- Capability to diagnose machine system or process problems for faster corrections.

Visi-Trak Automatic Controls Provide

- Capability to completely automate a machine or process for more consistent higher quality production.
- More accurate positioning or velocity control.
- Fast, accurate machine set-ups.
- Consistent repeatability of process (position and velocity) regardless of changes in process variables.
- Greater system flexibility and performance capability.

Visi-Trak SYSTEMS FOR MORE PRODUCTIVE MOTION CONTROL

SENSOR SELECTION

Sensor Alternative	Transducer Alternative	Rod Modification	Position Resolution 0.1P	Position Resolution 0.05P	To order Specify
Modified Piston Rod	Unidirectional	0.1P or 0.05P	0.050"	0.025"	0.1P or 0.05P Modification to insert your P/N with unidirectional or bidirectional transducer
	Bidirectional	0.1P or 0.05P	0.025"	0.0125"	
Standard Signal Generator	Unidirectional Model 965	0.1P or 0.05P	0.050"	0.025"	965-0.1P or 0.05P-specify length to be sensed in inches
	Bidirectional Model 985	0.1P or 0.05P	0.025"	0.0125"	985-0.1P or 0.05P-specify length to be measured in inches
J.I.C. Cylinder with Integral Visi-Trak sensor	Unidirectional	0.1P or 0.05P	0.050"	0.025"	Consult factory or your Visi-Trak sales representative for order information
	Bi-directional	0.1P or 0.05P	0.025"	0.0125"	

MONITORS AND CONTROLS SELECTION

Application	Applicable Visi-Trak Mode	Description	Inputs	Function
Position sequencing Replacement of limit switches	Model 1616	Programmable Setpoint Controller	Unidirectional Bidirectional	Count, 16 setpoints, 16 open collector NPN transistor or relay outputs
	Model 120,220,320	1,2,3 Setpoint position controller	Unidirectional Bidirectional	Count, three setpoints, three logic level or relay outputs
Analog Position and Velocity Outputs	Model 400	Position P.C.B.	Unidirectional or Bidirectional	Provides 0-10V DC output proportional to position
	Model 600	Velocity P.C.B.	Unidirectional or Bidirectional	Provides 0-10V DC output proportional to velocity
Process Monitoring	Model 955 (NEMA 12 enclosure)	Profile Monitor	Unidirectional or Bidirectional (pressure optional)	Provides full stroke 0-10V DC analog outputs proportional to position and velocity. Optional 0-5V DC output proportional to pressure
	Model D-1038 or D-1025	Profile monitor with velocity sample hold. Pressure sample hold optional	Unidirectional or Bidirectional	Provides full stroke analog outputs as above with L.E.D. readout velocity or pressure at user selectable setpoint. With hi-lo comparison and relay output
Automatic Monitoring/ Servo Control	Model 32-100	Monitor/Comparator Servo Controller	Unidirectional or Bidirectional	Continuous automatic monitoring of velocity and pressure profiles with out of tolerance indication. Closed loop servo control with 32 command steps. velocity, acceleration position

MACHINERY PROCESS INSTRUMENTATION

Visi-Trak Incorporated/A Division of Vitec Incorporated
23645 Mercantile Road, Cleveland, Ohio 44122 • (216) 464-4670 Telex 98-5354

SENSOTEC

40 SERIES PANCAKE-THIN

40 SERIES "PANCAKE" Load Cells
Tension/Compression — Model 41
Compression only — Model 43

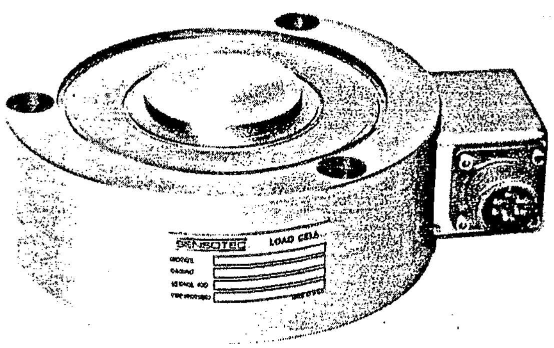
features:
- All Stainless Steel
- Low Profile for Limited Space
- Availabe for All Load Ranges
- General Purpose
- Precision Accuracy

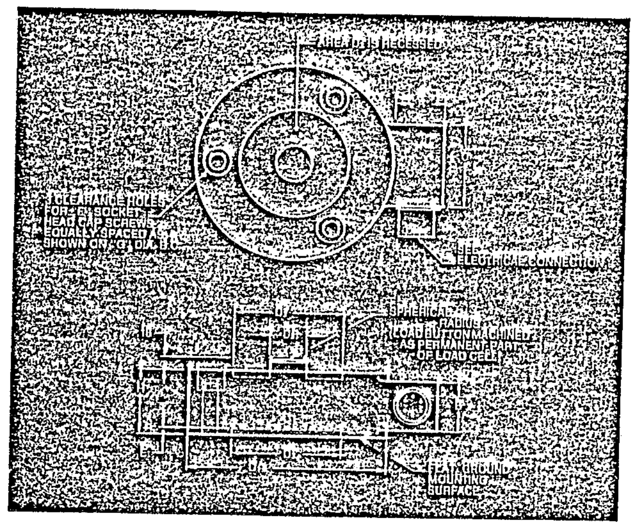
The 40 Series is a complete line of low profile, "pancake", bonded foil, strain gage load cells. All the cells are constructed of welded stainless steel. The 40 Series is available in two basic designs; (a) tension/compression Model 41 and (b) compression only Model 43. Hermetic construction is available as an option.

ELECTRICAL CONNECTION
1. 5# thru 5000#
   Bendix PT1H-10-6P
   Mate: Bendix PT06E-10-6S
2. 7500# thru 400,000#
   Amphenol MS3102E-14S-6P
   Mate: Amphenol MS3106A-14S-6S
3. All ranges available with waterproof neoprene cable and gland as an option.

600°F OPTION: Ranges 100 lbs. through 100,000 lbs.
A version of the 40 Series is available on special order with different construction for continuous operation in temperatures uo to 600°F. Dimensions and specifications have to be quoted from factory for each load range. See page 15.

MODEL 43 (Compression only)





The compression only design, Model 43, must be used on a flat, smooth surface in order to achieve the rated specifications. The load button on the 43 model is fixed as an integral part of the load cell and cannot be removed or changed.

SPECIFICATIONS

Excitation:	10 to 15 Volts
Output:	3 MV/V Nominal
Bridge Resistance:	350 ohms Nom.
Linearity:	0.1%F.S.
Hysteresis:	0.08% F.S.
Repeatability:	0.03% F.S.
Temp. Range	
Compensated:	60°F to 160°F
Operating:	– 65°F to 250°F
Temp. Effect:	
On Zero:	0.002% F.S./°F
On Span:	0.002% Rdg./°F
Safe Overload:	50% F.S.

Capacity	D_1	D_2	H[1]	A	B	C	D_3	E	F	G
5, 10 & 25 lbs.[2]	2.5	.38	0.8	.75	.75	1.25	1.7	.03	#8	2.000"
50, 100, 250, 500 & 1000 lbs.	3.0	.56	1.0	.75	.75	1.25	1.8	.03	¼"	2.250"
2,000, 3,000, 4,000 & 5,000 lbs.	3.5	.69	1.0	.75	.75	1.25	2.0	.03	5/16"	2.625"
7,500, 10,000, 15,000 lbs.	4.5	1.6	1.8	1.25	1.5	2.0	3.2	.10	⅜"	3.790"
20,000, 30,000 & 50,000 lbs.	4.5	1.6	1.8	1.25	1.5	2.0	3.2	.10	⅜"	3.790"
60,000, 75,000 & 100,000 lbs.	4.5	1.6	1.8	1.25	1.5	2.0	3.2	.10	⅜"	3.790"
150,000 & 200,000 lbs.	5.5	2.0	2.0	1.25	1.5	2.0	4.1	.10	⅜"	4.812"
300,000 & 400,000 lbs.	7.0	2.5	3.0	1.25	1.5	2.0	4.5	.10	⅜"	5.750"

[1] The permanent load button is about 0.18 inches higher (e.g. total height for 100 lbs. is 1.2 inches).
[2] Specifications for these ranges are linearity = 0.2%; Hysteresis = 0.1%; Repeatability = 0.1%; and output is 2MV/V Nominal.

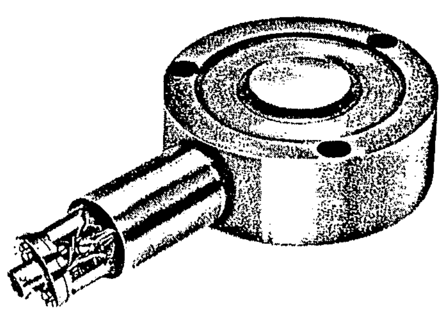
ALLOWABLE EXTRANEOUS FORCE
The double diaphragm all stainless construction of the 40 series provides low sensitivity and minimum interaction from extraneous forces. The total of the applied load and all forces should not exceed 100% of rating.

% OF RATED LOAD CAPACITY

Load Capacity	Side Load (Shear)	Bending (Moment)	Torque
25 to 500 lb.	50%	40%	25%
1000 to 5000 lb.	30	25	25
10 K to 50 K lb.	20	20	15
100 K and 200 K lb.	20	20	10

OPTION:
5 VOLT OR 4-20 MA INTERNAL AMPLIFIERS

The Model 41 and 43 load cells can be provided with 0-5 volt or 4-20 ma internal electronic amplifiers. The amplifiers are contained in the connector housing on the side of each of the load cells. Dimensions A, B, and C (some range H increases) are increased to accomodate the internal amplifier and the connector is changed to the Bendix PT1H-10-6P for all capacities. (See page 16 for details)



A.L. DESIGN, INC.
2070 NIAGARA FALLS BLVD.
TONAWANDA, N. Y. 14150

1982
TECHNICAL BULLETIN

HIGH CAPACITY LOAD CELL

MODEL ALD-H

THE MODEL ALD-H HIGH LOAD TRANSDUCER COMBINES ECONOMY, ACCURACY AND RELIABILITY.

SMALL SIZE AND LIGHT WEIGHT ARE COMBINED WITH BONDED STRAIN GAGE DESIGN TO PROVIDE AN EXCELLENT TRANSDUCER FOR GENERAL PURPOSE APPLICATION.

THIS TRANSDUCER IS OFFERED IN LOAD RANGES OF 1,000 LBS. TO 300,000 LBS. (*OR 500 KG TO 150,000 KG*), WITH FOUR ARM WHEATSTONE BRIDGE BONDED TO THE HARDENED STEEL SENSING ELEMENT.

SPECIFICATIONS:

LOAD RANGE:	1,000 LBS TO 300,000 LBS CAPACITY
OVERLOAD:	150% CAPACITY
EXCITATION:	5 V - 10 V AC or DC
OUTPUT:	2 mv / V NOMINAL
BRIDGE RESISTANCE:	350 OHMS NOMINAL
TEMPERATURE RANGE:	15° F - 150° F COMPENSATED
TEMPERATURE RANGE:	0° F - 200° F OPERATING
REPEATABILITY:	0.1 % F.S.
THERMAL ZERO SHIFT:	LESS THAN .02 % FS / F

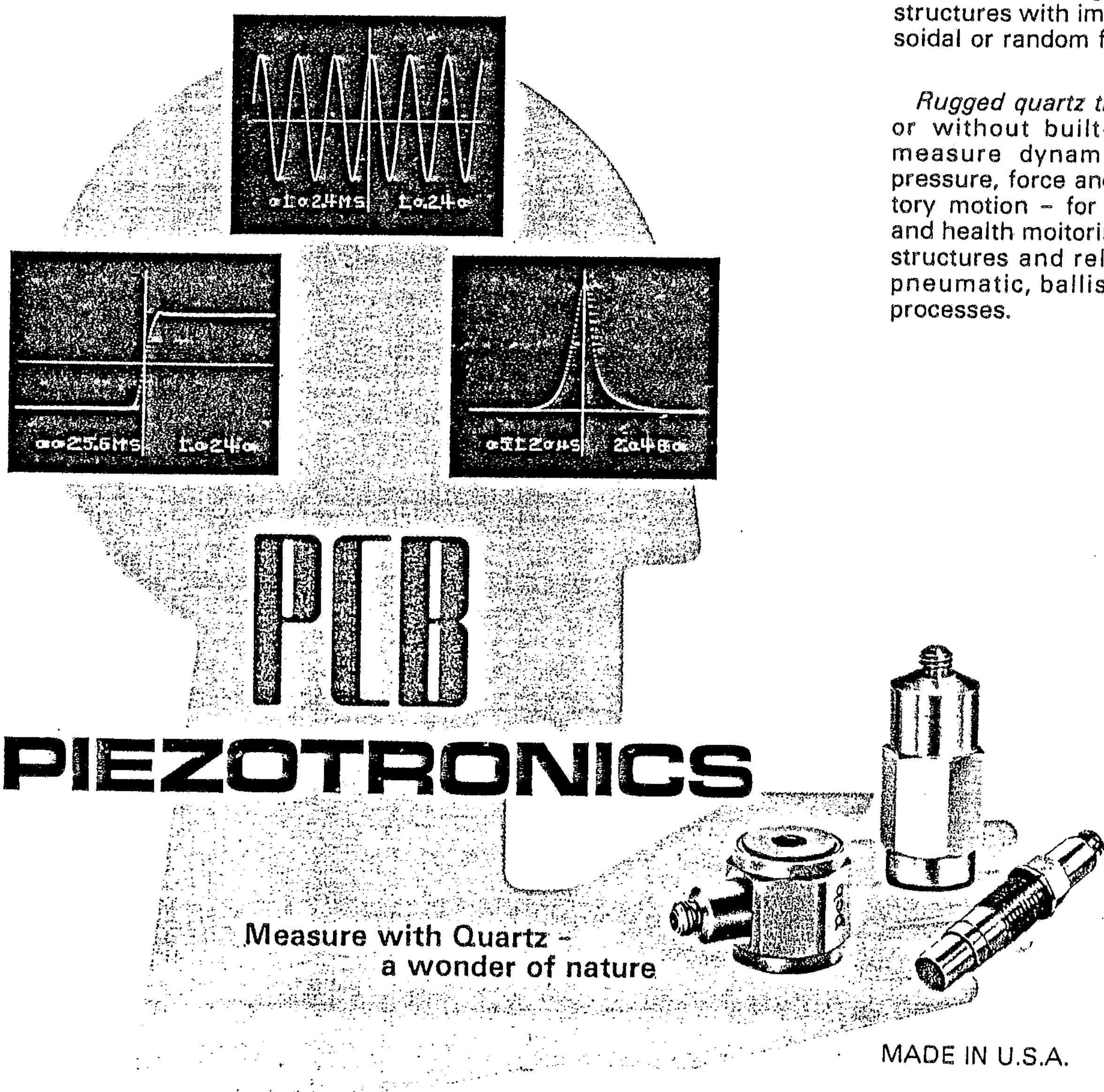
Quartz sensors date back to pioneering work with ballistic galvonometers at the National Bureau of Standards during World War I. For the past half century rugged quartz instruments have solved tough measuring problems like: gun and ammunition pressures, closed bomb pressure; engine cylinder pressure; fuel impingement force, atomic bomb shock and blast wave pressures; impact hammer force; punch and tablet press forces; structural motion to 150 000g; rocket motor combustion instability; cryogenic pogo oscillations; airborne, fluid-borne and structure borne noise, and nuclear power plant, vehicle and machine vibration.

Today, a variety of sophisticated quartz transducers offer exceptional performance and value, even for routine measurements. Each transducer covers a linear measuring range of 10 000:1; the equivalent of several instruments in one. Most models calibrate statically, operate dynamically, return to zero after shock loading, and maintain a near constant sensitivity with temperature, time, mechanical stress and use. Because of the high rigidity of the crystalline quartz stress-gage element, the measuring transaction doesn't appreciably change the process being tested nor the quantity being measured. Moreover, quartz transducers generate exceptionally clean sharp signals.

Most quartz transducers are now available in either charge mode or voltage mode versions. Charge mode models require external charge. amplifiers and low-noise cable. Voltage mode models with built-in microelectronic amplifiers couple directly to readout or analyzing instruments with an ordinary coaxial cable conducting both signal and power – enhancing simplicity, reliability, and economy.

Modern, low-impedance, voltage mode quartz sensors are used extensively to monitor machines and adapt oscilloscopes and analyzers for mechanical measurements. With FFT analyzers, quartz force and motion sensors measure both the stimulus and response in functional transfer and transactional behavior testing of mechanical structures with impulse, step, sinusoidal or random forcing functions.

Rugged quartz transducers, with or without built-in electronics, measure dynamic phenomena: pressure, force and shock or vibratory motion – for behavior testing and health moitoring of mechanical structures and related hydraulic, pneumatic, ballistic and acoustic processes.

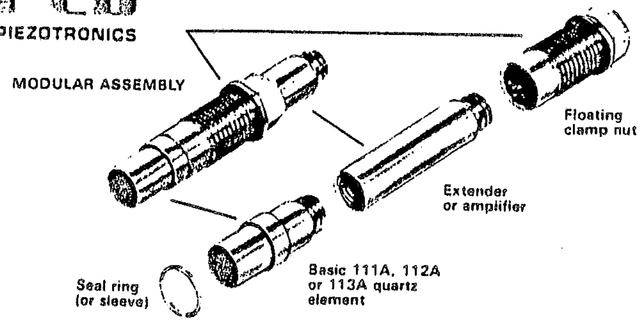


MADE IN U.S.A.

MINI CATALOG 476

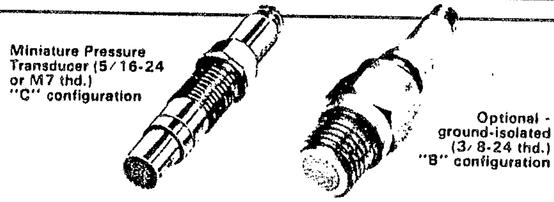
DYNAMIC PRESSURE
AND SOUND

PCB PIEZOTRONICS



VALUED FOR THEIR RUGGEDNESS, stability and range (10 000 : 1) quartz transducers have long dominated the tough field of dynamic pressure measurement. Most models calibrate statically, follow long duration transient events and measure small changes at high static pressure levels.

MODULAR CONSTRUCTION speeds up delivery and facilitates repair of damaged units. The miniature transducer illustrated, features a floating American (5/16-24) or metric (M7) clamp nut. To appreciate the separate clamp nut, just install one in your existing port and feel the difference. There are no interference or alignment problems and you can remove it. Latest versions also have a more rugged connector pin and lower vibration sensitivity, especially cross-axis.



The classical miniature quartz pressure transducer is now a family of low, medium, and high range models, with or without built-in microelectronic amplifiers, specifically structured for general, high-frequency, high-temperature, cryogenic acoustic, nuclear, hydraulic, pressure-rate and underwater applications. Frequency-tailored models provide nearly non-resonant, one-microsecond response.

Typical transducers and mounting adaptors are illustrated. Transducer options include welded hermetic seal, welded on hard-line cable and ground isolation.

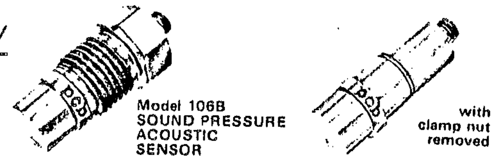
CHARGE MODE SENSORS (for charge amplifiers)

	General Purpose	General, Hi-Sens., Accel. Comp.	Hi-Freq., Accel. Comp.
MODEL NO.	111A	112A	113A
Range psi Sensitivity pC/psi Resonant Freq. Hz	0.1 - 3000 0.35 400 000	0.1 - 3000 1.0 250 000	0.1 - 3000 0.35 500 000
MODEL (0.01 - 100 psi) MODEL (1.0 - 10 000 psi)	111A02 111A03	112A02 112A03	113A02 113A03

VOLTAGE MODE SENSORS w/built-in amplifiers & Acceleration Comp.

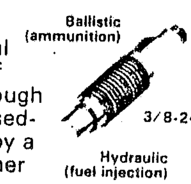
	High Sensitivity	General Purpose	Frequency Tailored
MODEL NO. ("C" Config.) "B" CONFIG. (Gnd.-Isolated)	112A21 102A05	111A26 101A06	113A21 102A15
Range psi Sensitivity mV/psi Resonant Freq. Hz	0.01 - 100 50 250 000	0.05 - 500 10 400 000	0.02 - 250 20 500 000
OTHER RANGES: ("B" Configuration)			
Sens. 5 mV/psi; 0.1 - 1000 psi Sens. 1 mV/psi; 1 - 5000 psi Sens. 0.5 mV/psi; 2 - 10 000 psi		101A04 101A02 101A03	102A04 102A 102A03

NEW



SOUND PRESSURE Structured with delta-compression quartz elements, high sensitivity quartz microphones measure sound pressure from about 90db to above 200db. An integral accelerometer cancels out most vibration sensitivity. A high temperature version monitors nuclear power plants. Larger versions resolve 80dB.

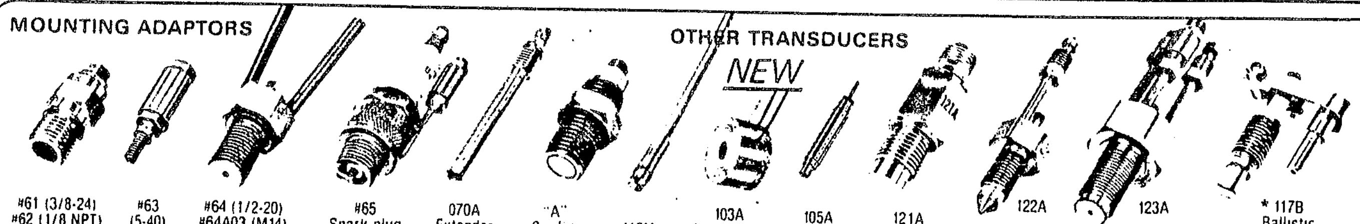
SOUND PRESSURE SENSORS MODEL NO.	106B Voltage Mode	116B Charge Mode
Range psi Sensitivity Resonant Frequency Hz	0.001 - 10 250 mV/psi 60 000	0.01 - 100 10pC/psi 60 000



BALLISTIC Ceramic-coated integral diaphragms greatly prolong the life of rugged PCB ballistic transducers in tough applications like ammunition and closed-bomb testing. Standard models employ a stainless steel shoulder seal ring. Other welded-diaphragm models retro-fit existing ports requiring shoulder conical or face seals. The hydraulic version in a life test on a fuel injection pump experienced over 500 000 000 cycles, 0 to 10 000 psi, with no problems.

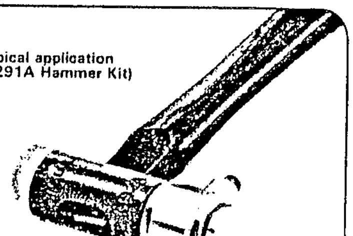
BALLISTIC SENSORS MODEL NO.	108A Voltage Mode	118A Charge Mode
Range psi Sensitivity Resonant Frequency Hz	8 to 80 000 0.1 mV/psi 300 000	8 to 80 000 0.2 pC/psi 300 000
HI-PRESS. (Accel.-Comp.) Model HYDRAULIC Model WELDED-DIAPHRAGM Model	109A 108A02 (0.5 mV/psi)	119A 118A02 (20 000 psi) 167A

MOUNTING ADAPTORS / **OTHER TRANSDUCERS** *NEW*

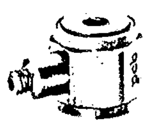


* U.S. Patent No. 3886792

FORCE
AND IMPACT



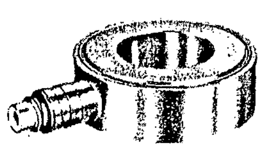
Typical application
(K291A Hammer Kit)



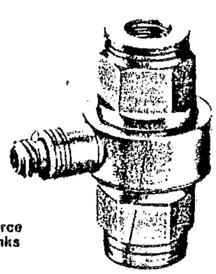
General
Purpose
(5/8 hex. x 0.62 lg.)

With a rigidity approaching that of solid steel, quartz stress-gage transducers measure dynamic forces without appreciably changing the force being measured or the rigidity of the structure being tested. They statically calibrate, follow long duration events, eliminate static signal components, and operate reliably in industrial environments. From a variety of models, choose the size and configuration that conveniently installs in your structure. The micro 10-32 connector on most models gives some concept of size. General purpose models stud mount and measure tension, compression or impact.

GENERAL PURPOSE CELL.		Volt. Mode	Volt. Mode	Volt. Mode	Charge
MODEL NO.		208A	208A03	208A05	218A
Range	lb	+10 -10	+500 -500	+5000 -500	+5000 -500
Sensitivity	mV/lb	500	10	1	20pC/lb
Resonant Frequency	Hz	70000	70000	70000	70000



Force
Rings

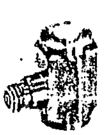


Force
Links

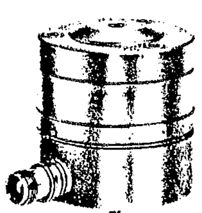
LOAD RINGS AND LINKS are available in seven sizes for American and metric threads. Rings measure both tension and compression when preloaded by a central stud, as in the force link assembly. Characteristics of some voltage mode models with built-in unity-gain amplifiers are charted. Corresponding charge mode models are Rings, Series 211A through 217A and Link, Series 231A through 237A.

RING MODEL NO. (V.-Mode)		201A05	203A	205A	207A
Bolt Dia.	in	¼	½	¾	1½
Outside Dia.	in	0.65	1.10	1.58	2.96
Range, Compression	lb	5000	20000	60000	100000
Sensitivity	mV/lb	1.0	0.25	0.1	0.05
Resonant Freq.	Hz	70000	50000	20000	15000
LINK MODEL NO. (V.-Mode)		221A05	223A	225A	227A
Range Compression / Tension	lb	+3000 -1000	+12000 -4000	+35000 -12000	+50000 -30000

Series 200A
Force or
Impact



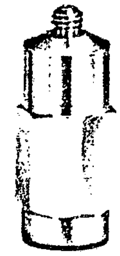
209A Hi-Sens.
(+5 lb. 2200
mV/lb)



229A
Industrial press
(+50000 lb, 0.1 mV/lb)

MOTION
SHOCK AND VIBRATION

PIEZOTRONICS



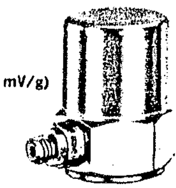
302A
Vibration
and
shock

302A02
Shock
(long
events)

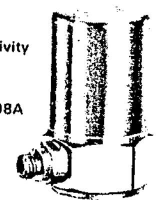
070A09 Solder
Connector Adaptor

Quartz Accelerometers with built-in microelectronic unity-gain amplifiers lower costs, enhance performance and simplify the task of shock and vibration measurement. Permanently standardized output signals couple directly to readout and analyzing instruments. One accelerometer, covering most ranges operates over any length of ordinary coaxial or 2-wire cable in industrial or field environments. And there are no knobs, dials or other adjustments in the sensor system to worry about.

GENERAL-PURPOSE MODEL 302A routinely measures both vibration and shock. To simplify ordering, specify the K302A (battery-powered) or KL302A (line-powered) KIT, which includes the accelerometer, power unit, cables and accessories. Optional Model 302A04 is ground-isolated.



308A03 (50 mV/g)



High sensitivity

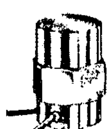
308A

HIGH-SENSITIVITY MODEL 308A measures the vibratory motion of heavy machines and structures, where mass loading is no problem. Optional Model 308A10 is hermetically-sealed; Model K308A02 has 1000 mV/g sensitivity. Model 308A06 operates to 350°F.

HIGH-SHOCK SERIES 305A solves cable, connector and noise problems in applications to 150000g.

MINIATURE MODEL 303A, for high frequency vibration measurements, combines high sensitivity with low mass and low noise.

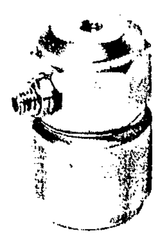
NEW



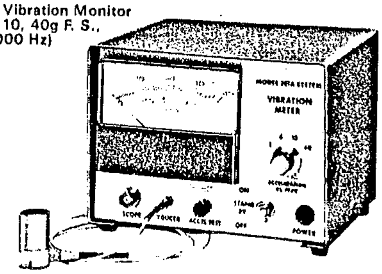
303A
Miniature
high-frequency

305A
High-Shock

ACCELEROMETER		302A	303A	305A	308A
Sensitivity	mV/g	10.0	10	0.5	100
Resonant Freq	Hz	45000	70000	60000	25000
Range (to)	±g	500	500	100000	50
Resolution	g	0.02	0.02	0.4	0.002
Size (hex. x height)	in	0.5 x 1.2	0.28 x 0.4	0.31 x 0.7	0.75 x 1.5
Weight	gm	18	2	4.5	87



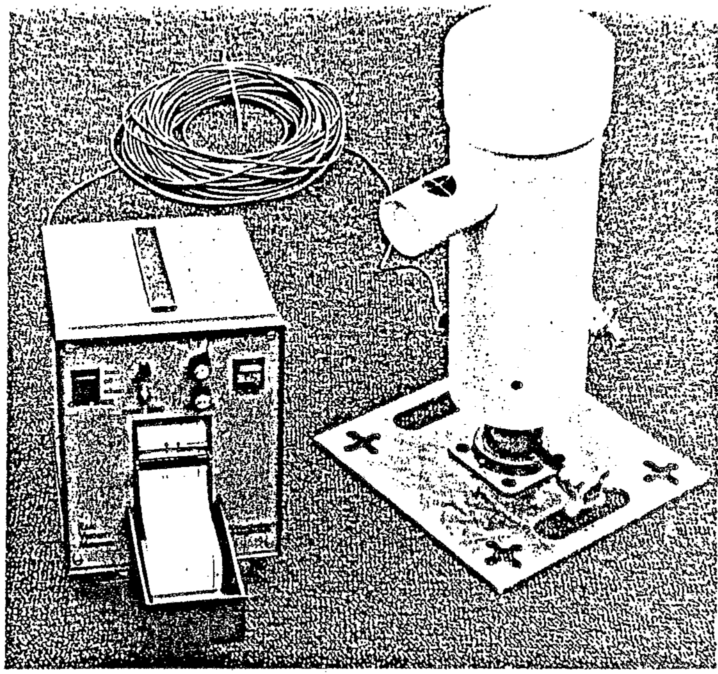
394A03 Vibration-
Calibration Standard



381A Vibration Monitor
(1, 4, 10, 40g F. S.,
2 - 2000 Hz)

TERA, Inc.

RAM VELOCITY MONITOR



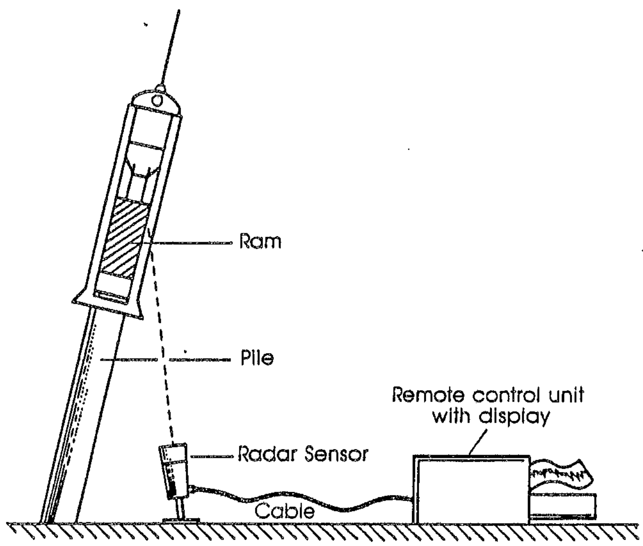
RVM components: remote strip chart unit, lead cable, and radar sensor

The success of many pile installations is dependent on the performance of the pile driving hammer. Our new Ram Velocity Monitor (RVM) provides an economical method for evaluating hammer performance in terms of ram impact velocity. With this system, easily-interpreted recordings of ram velocity are made available for each blow as it occurs. The RVM has served our clients on offshore and onshore projects since October, 1982.

System description

The RVM is based on a Doppler radar sensor, similar to those used to measure the speed of baseballs. The sensor is placed several feet away from the pile to be driven and pointed toward the hammer. No physical link to the driving system is required, thus eliminating problems associated with damage to connecting wires, and preventing delays to construction operations. A separate signal conditioning and readout unit allows an operator to monitor ram velocities at a convenient remote location.

The strip chart unit of the RVM gives a continuous and immediate record of ram velocity. A 2-speed strip chart allows compact records or detailed information to be produced. The higher chart speed yields details of ram acceleration and impact for diagnosis of problems. The slower chart speed provides a graphic display of variations in hammer performance. The output is conveniently calibrated to allow measured velocity levels to be determined directly from the strip chart record.



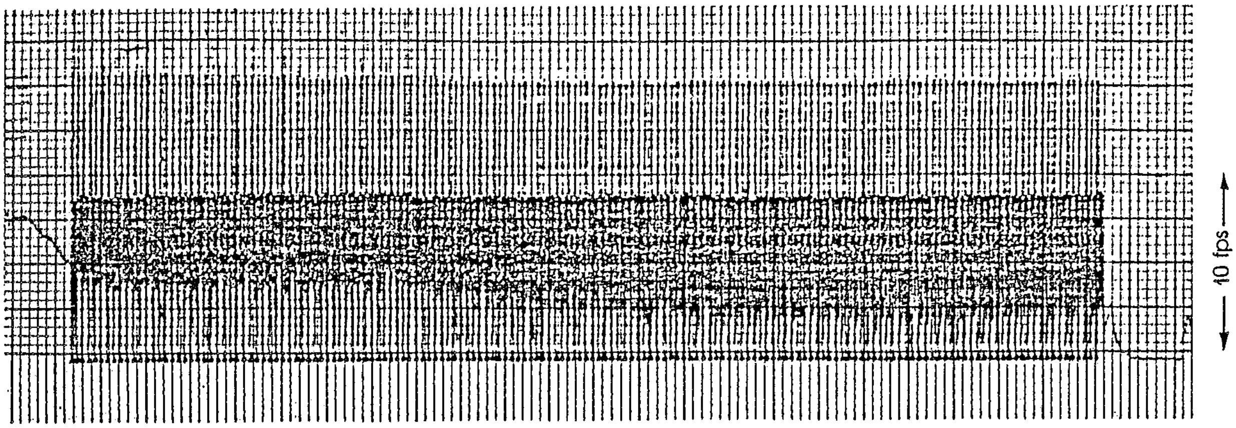
Schematic of Ram Velocity Measurement System

Applications

Results from the RVM are used to verify hammer performance and, if problems occur, to help locate the source of inefficiency. As a part of a contractor's quality control program, the RVM can increase productivity by providing timely information for construction control. As a quality assurance tool for owners, offshore operators, and consultants, the RVM is used to monitor hammer performance and to enhance interpretation of blowcount records. Ram velocity measurements also complement measurements of pile response with our DMS system in more extensive monitoring programs.

The RVM system requires only one operator and is packaged in a single case for maximum portability. For more information or to arrange for the RVM to be used on your project, please contact us.

RAM VELOCITY MONITOR



Compact records from RVM provide a graphic display of ram velocity

Operating features

- Direct Measurement of Ram Velocity
- Continuous Real-Time Recording
- Hard Copy Record of Velocity Measurements
- No Physical Connection to Hammer
- Simple Field Calibration
- One-Man Operation
- Full Backup Provided

System features

- Doppler Radar Sensor
- Remote Signal Conditioning and Strip Chart Output
- Rugged, Waterproof Sensor Housing
- Versatile Sensor Mount
- Lightweight, Compact Packaging

System specifications

Range	: 5 to 100+ ft. (1.5 to 30+ m)
Accuracy	: within 5 percent
Velocity Range	: 3 to 24 fps (1 to 8 m/s)
Power Requirements	: 115 v AC
Operator Controls	: Sensitivity Calibration
System Output	: Continuous Analog Velocity Plot
Weight (with container)	: 40 lbs (18 kg)
Container Size	: 10″ x 18″ x 18″ (25 x 46 x 46 cm)

TERA, Inc.

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Tel. (713) 772-0876 • telex 762447

McClelland Engineers, Corporate Headquarters, McClelland Center
6100 Hillcroft • P.O. Box 740010 • Houston, Texas 77274
Tel. (713) 772-3700 • telex 762447

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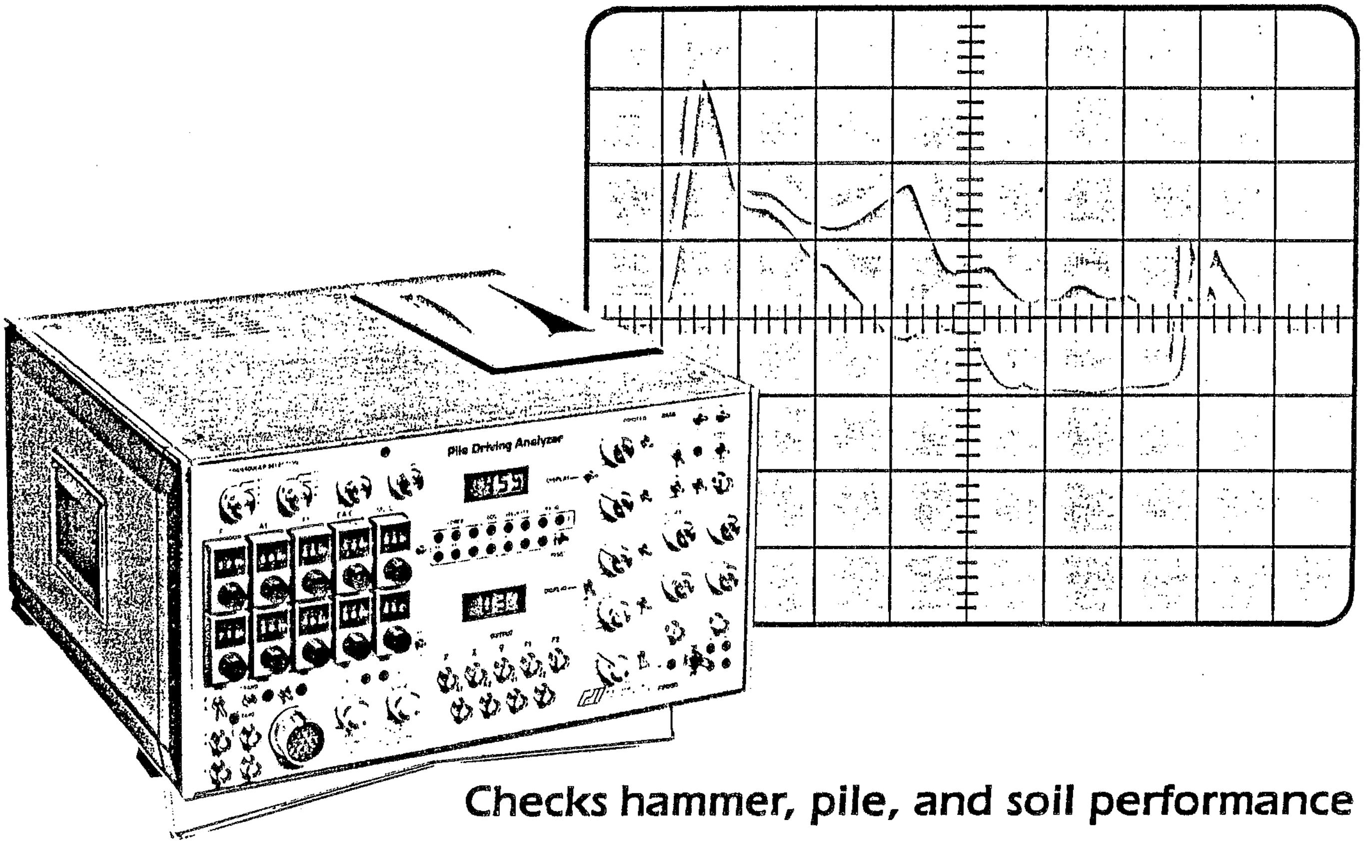
Pile Driving Analyzer™

Cuts construction costs, eliminates problems



Checks hammer, pile, and soil performance

- Significantly faster and less expensive than static tests
- Provides over 30 different dynamic results
- Improves quality control; dynamically tests many piles in one day
- Backed by twenty years of experience by the developers of dynamic pile testing

- Immediate results for every hammer blow during driving for bearing capacity vs. penetration to avoid static test delays; restrike defines soil set-up and relaxation
- Reduces or eliminates static load tests; used where static tests are too costly or physically impossible
- Cost effective in preliminary tests or at start of construction in determining best driving criteria; often reduces pile length
- Gives soil resistance distribution

- Determines maximum tensile and compressive stresses to assist safe and efficient installation
- Indicates extent and location of pile structural damage
- Measures hammer efficiency; detects malfunction
- Checks effectiveness of different pile types, hammers, cushions
- If driving is unusual, determines if problem is hammer, pile or soil
- Checks assumptions or provides correct input for wave equation analysis; decisions then based on actual measurements, not just speculation

PILE DYNAMICS, INC.

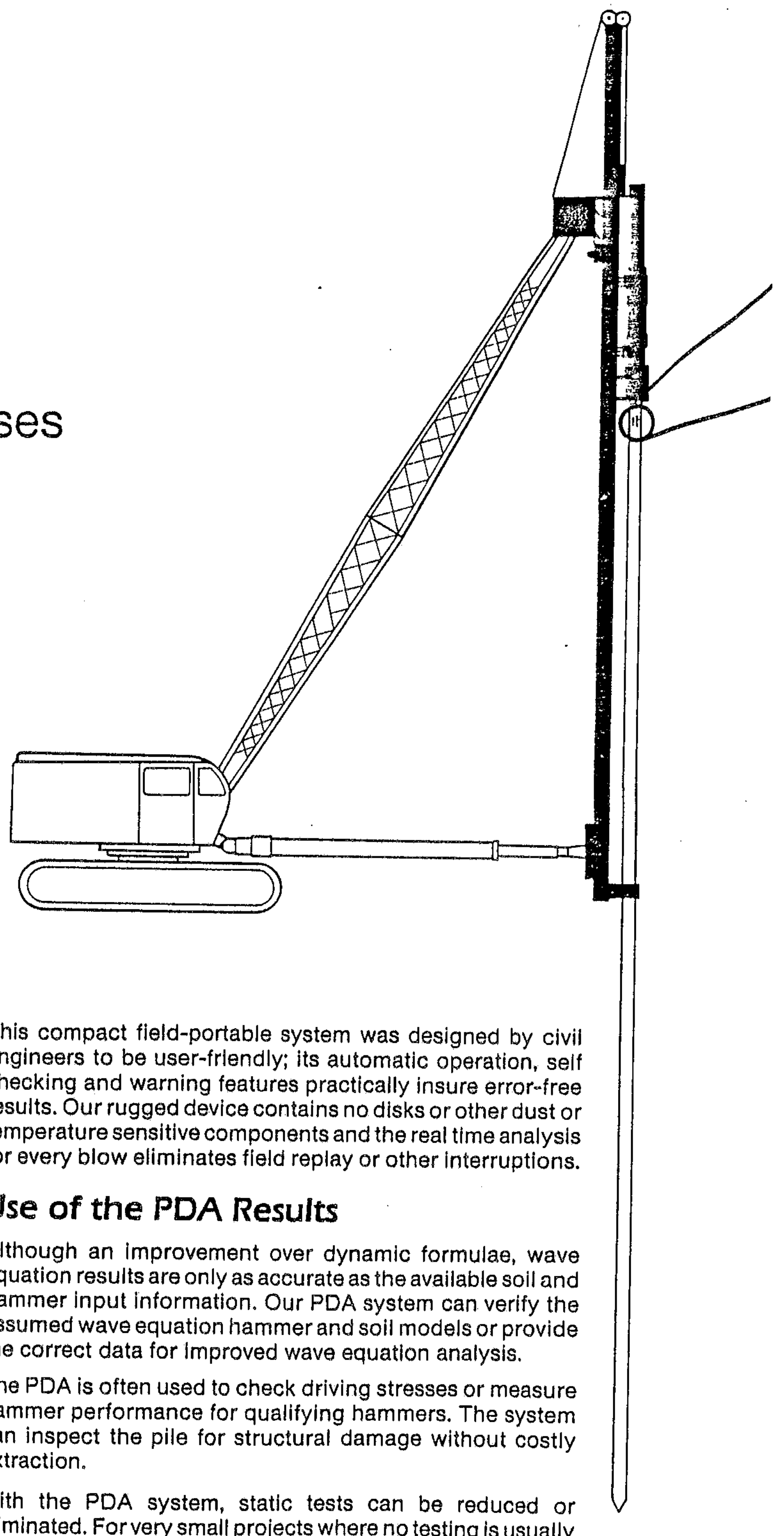
PILE DYNAMICS INTERNATIONAL, INC.

4423 Emery Industrial Parkway
Cleveland, Ohio 44128
Telephone: (216) 831-6131
Telex: 985662 (PILE DYN)

Piles no longer have to be overdriven with resulting higher foundation costs. Equally valuable for large or small projects on land or offshore, the Pile Driving Analyzer provides immediate on-site answers with fast, simple, accurate and inexpensive solutions to your pile problems.

The Pile Driving Analyzer™ Determines:

Bearing capacity
Hammer performance
Tension/compression stresses
Pile integrity or damage



Dynamic Pile Testing — The Better Alternative

Perhaps you have noticed innovation in construction other than pile driving and wondered why blow counts and some 19th century dynamic formulae are still used to estimate pile capacity. Load testing of an arbitrary pile, usually not run to failure, is expensive and causes long construction delays. A quick, inexpensive test on several piles giving much more information may be more attractive.

Begun in 1964, research at Case Western Reserve University under Dr. G.G. Goble resulted in a reliable, theoretically sound, easy-to-use technique to predict pile capacity under dynamic loading (remolded strength during driving or service load including set-up/relaxation by restrike testing). To meet an increasing demand for this capability, Pile Dynamics, Inc. was formed in 1972 and developed the "Pile Driving Analyzer" (PDA), an easy-to-use, preprogrammed field computer designed for civil and geotechnical engineers.

After more than two decades of research and experience, our Pile Driving Analyzer has been proven worldwide at over 2,000 construction sites on over 20,000 piles in over 30 countries on six continents. The results of dynamic testing have been correlated with data from several hundred static load tests.

How the Pile Driving Analyzer Works

Reusable transducers measuring strain and acceleration are quickly attached with bolts or anchors to concrete, steel, or timber piles. The system has also been used for auger piles and drilled caissons. The PDA provides signal conditioning, and converts the measured signals to force and velocity for use in its digital processor. Using closed form solutions to wave propagation theory, the PDA then solves for activated soil resistance, maximum pile stresses, pile integrity and hammer performance. Immediate printout for each hammer blow provides a complete investigation of the hammer-pile-soil system as the pile is driven or during restrike. This fast, simple procedure can be easily applied to several piles, giving more information at a fraction of the cost.

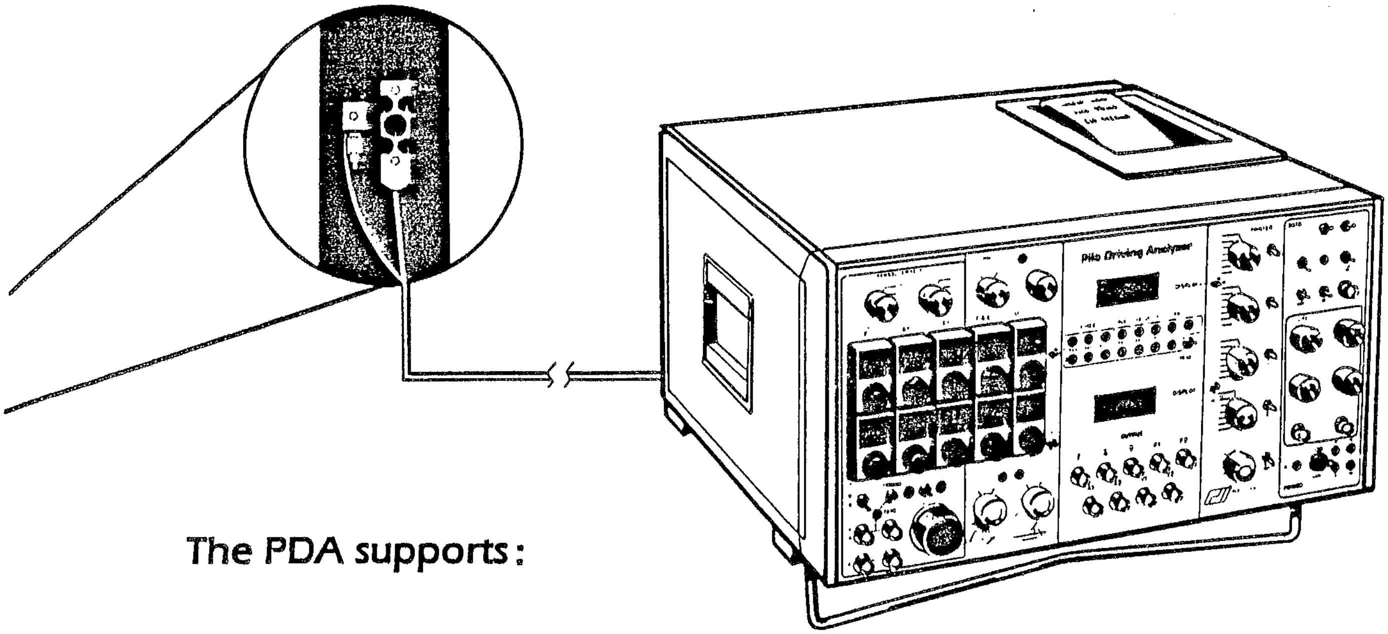
This compact field-portable system was designed by civil engineers to be user-friendly; its automatic operation, self checking and warning features practically insure error-free results. Our rugged device contains no disks or other dust or temperature sensitive components and the real time analysis for every blow eliminates field replay or other interruptions.

Use of the PDA Results

Although an improvement over dynamic formulae, wave equation results are only as accurate as the available soil and hammer input information. Our PDA system can verify the assumed wave equation hammer and soil models or provide the correct data for improved wave equation analysis.

The PDA is often used to check driving stresses or measure hammer performance for qualifying hammers. The system can inspect the pile for structural damage without costly extraction.

With the PDA system, static tests can be reduced or eliminated. For very small projects where no testing is usually performed, or on large piles or offshore projects where testing is prohibitively expensive, PDA tests provide a low cost tool for inspection. For major projects with multiple planned static tests, some static tests can be replaced with several dynamic tests, increasing quality control with substantial savings. Preliminary test programs prior to or at the beginning of a job become both practical and economical using the PDA and have often saved time and money by monitoring stresses



The PDA supports:

- Tape Recorder
- Oscilloscope
- Strip Chart Recorder
- Computer
- Digital Plotter
- Digital Storage
- Telecommunication

and preventing pile damage, detecting hidden difficulties in the hammer performance, and improving driving criteria or reducing penetration requirements. Regardless of project size, PDA testing will result in an improved foundation and fewer problems.

> Electronic measurements and computation have revolutionized the world of the civil engineer. With today's higher pile loads and more cost competitive foundations, the Pile Driving Analyzer produces answers . . . for every blow . . . in real time . . . to produce better, safer foundations at a lower cost.
>
> When experience counts . . . The Pile Driving Analyzer, a tool of knowledge.

Case Histories

Reduces Cost—For a sewage treatment plant, dynamic testing indicated that each pile could be shortened by at least 20 feet, later confirmed by static tests. Occasional PDA tests then provided the construction control for this 8,000 pile project, resulting in savings of $2,500,000.

Saves Time—About 120 days construction time were saved by replacing 30 static pile tests with 400 dynamic tests for the replacement of several railroad and highway bridges. The PDA's accuracy was verified by spot checking with static tests.

Saves Money—For a large bridge in Australia, twelve 1.1 to 1.5 meter diameter drilled caissons were tested dynamically. Ultimate capacities exceeding 2,000 tons correlated well with static tests. Dynamic tests then replaced static tests for 70 additional caissons saving $2,000,000.

Investigates Damage—The PDA tested 137 concrete piles in seven days at a sewage treatment plant to determine the extent and location of suspected structural damage.

Hammer Evaluation—During construction of a large processing plant where four air hammers were used, it became apparent that actual efficiencies varied and the blow count criterion was questioned. The PDA found that efficiencies of some hammers were less than half of other supposedly identically rated hammers. Driving criteria were adjusted for each hammer's measured efficiency.

Detects Problems—Testing was compared with the wave equation on H pile bridge foundations. The PDA detected poor hammer performance, resulting in inadequate capacity at the required blow count, a fact later confirmed by a static test. The PDA also found hidden major structural damage in several piles.

Offshore Uses—The PDA has been used on many offshore oil platform installations to check hammer performance and pile stresses and on exploration conductor pipes to obtain soil constants for later driveability analysis with wave equations.

Pile Driving Analyzer™

Model GB

Results for Each Blow

- Bearing capacity from Case-Goble Method
- Optional computations for large soil quakes, variable concrete or timber wavespeed, end-bearing and long skin friction piles
- Maximum compression stress, acceleration, velocity and displacement
- Maximum tension stress in pile
- Pile structural integrity; extent and location of damage
- Maximum transferred energy for driving system efficiency
- Ram kinetic energy at impact for hammer efficiency
- Hammer cushion stiffness; coefficient of restitution
- Blows per minute for hammer check
- Blow counter
- Input and reflection values of force and velocity and upward and downward force wave components
- Toe resistance and skin friction distributions
- Quakes and damping factors with additional analysis

State-of-the-Art Digital Processing

- Utilizes fast 16 bit Motorola 68000 microprocessor with maximum data rate 120 blows per minute
- Analog to digital conversion of force and velocity inputs, each at 10 kHz for 100 msec (5 kHz for 200 msec available for long piles, e.g. offshore)
- Memory; EPROM 32k bytes; RAM 16k bytes; 64k max. each
- High accuracy integration (energy, velocity, displacement, impulse)
- Easy updating of program procedures
- Modular circuit board designs

Automatic Signal Conditioning

- Two strain and two acceleration channels
- Seven-wire shielded hookup for high accuracy strain conditioning
- Automatic balance/zero reset
- Piezoelectric accelerometers with built-in amplifiers
- Velocity from special purpose, zero leakage integrators; automatic zero adjust
- Automatic trigger at 20% of previous blow maximum, 2.5 second retention, minimum 0.25 m/sec.
- Reanalysis from tape records
- Frequency response 1600 Hz (3dB)

Specifications subject to change without notice.

Quality Control Features

- Analog forces and velocities converted to same scale by EA/c impedance factor for fast data quality inspection
- Digital output to scope with analysis time indicators for data check
- Automatic documentation of printout changes and input constants
- Automatic shut-off of shorted or discontinuous transducers
- Warning indicators
- Internal calibration check
- User oriented controls

Warning Indicators

- Detects shorted or open circuit transducers
- Comparison of V1/V2, F1/F2, V/F for data quality and/or bending
- Maximum force for high stress or potential damage
- Maximum and final velocity for accelerometer performance
- Power supply monitors

Output

- Analysis for every blow
- Five column, 21-digit printer built-in; 2.5 lines/sec, buffered
- Printing of input values, column headings, warning indicators, blow count and results of each blow (or every 2nd, 5th or 10th blow as selected)
- Two 3-1/2 digit LCD displays
- Automated oscilloscope and strip chart set-up
- Analog outputs of average and individual transducer signals of force, acceleration and velocity
- Optional RS-232 interface available with selectable baud rates, to digital computers, digital plotters, digital recorders, or modems

Automatic Oscilloscope Control

- Compatible with simple X-Y oscilloscopes
- Continuous display simulates storage with better field intensity
- Displays measured force and velocity with input and reflection time markers
- Option to display downward and upward force waves, displacement, energy, or resistance as functions of time during blow; plot of any display
- Controls for horizontal expansion/position and vertical separation
- Simplifies use and data interpretation; improves quality control

Analyzer Calibration

- Force ±.3% of calibration standard
- Acceleration ±.2% and velocity ±.5% of transducer specification
- Built-in accuracy check

Environmental

- Power: 90 to 250 volts AC. Frequency 44-440 Hz. 250 Watts from portable generator
- Temperature: Operating -5° to +35° C, Storage -10° to +75° C
- Size: 16 x 18 x 9 inches (410 x 460 x 230 mm)
- Weight: 44 lbs (20 kg)

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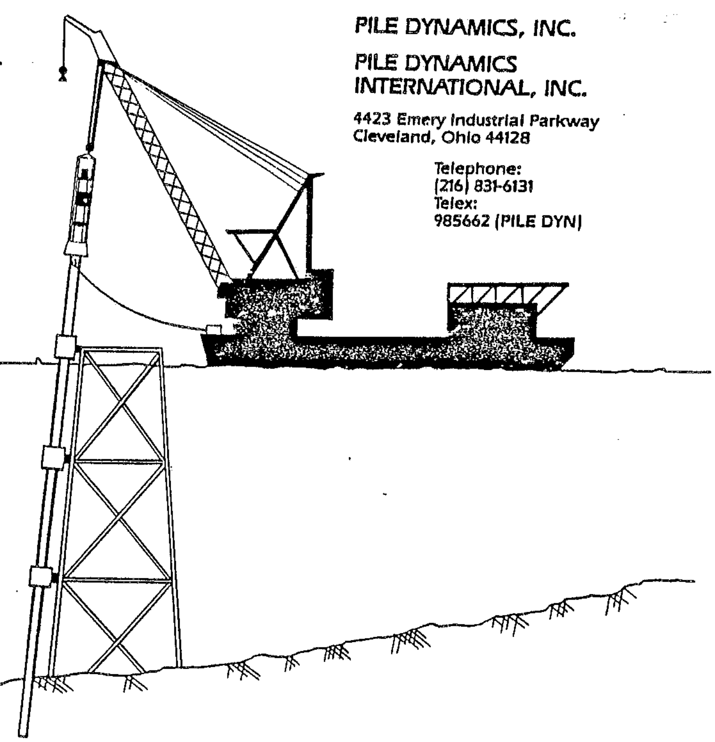
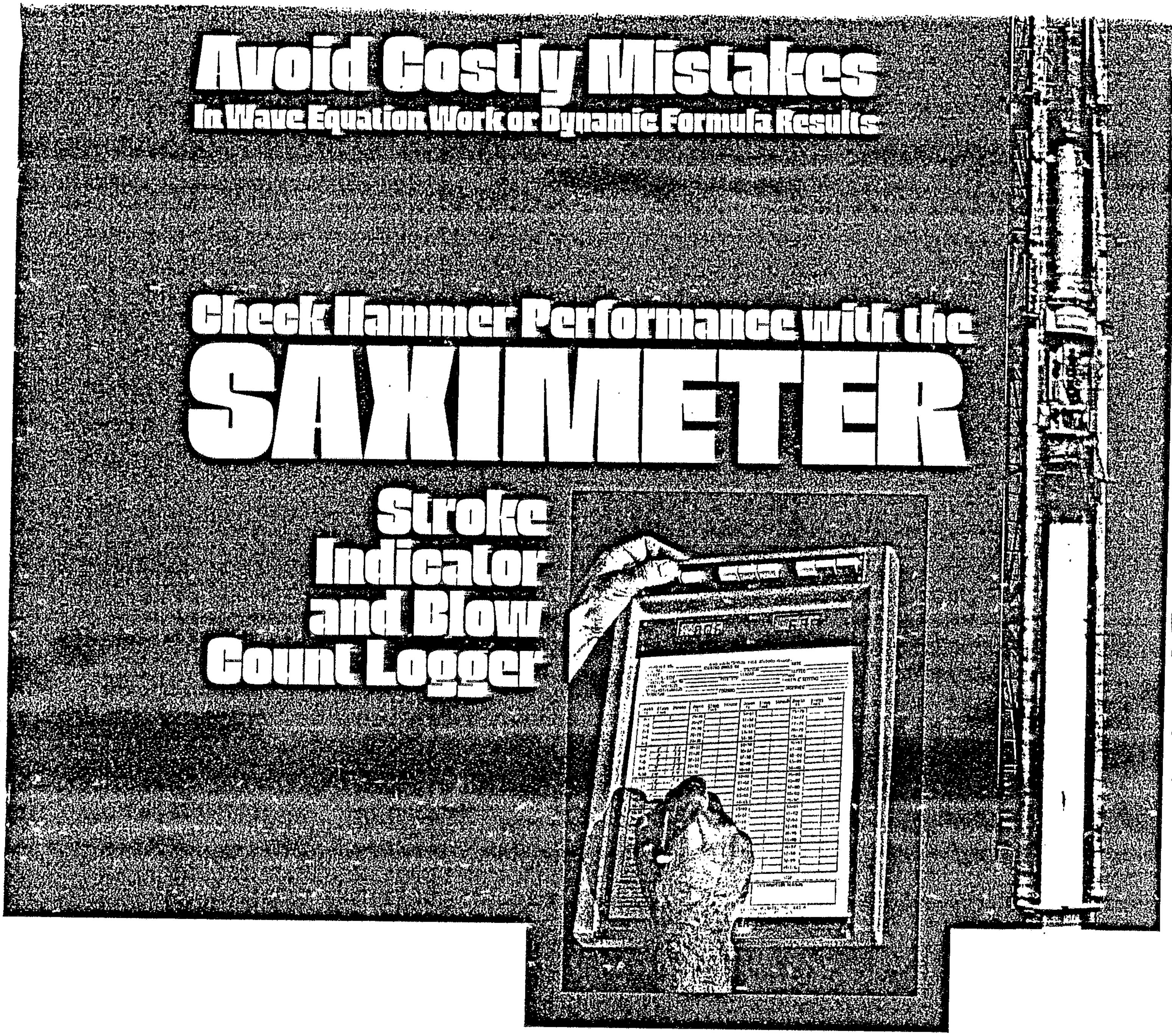




This "smart clipboard" determines the stroke of the ram and thus the available potential energy for open end diesel hammers. A built-in microphone provides automatic blow recognition; no transducers, wires, or jumpsticks are needed. This stroke/energy information is indispensible for the proper use of wave equation results and dynamic formula.

Two displays show individual ram stroke and the corresponding blow sequence number. With the push of a button, a stroke average is displayed. Thus, the SAXIMETER can be used to accurately count blows, giving blows per foot or inch with the average stroke. The SAXIMETER, powered by rechargeable transistor batteries, also has a warning feature which detects unusual or inconsistent behavior.

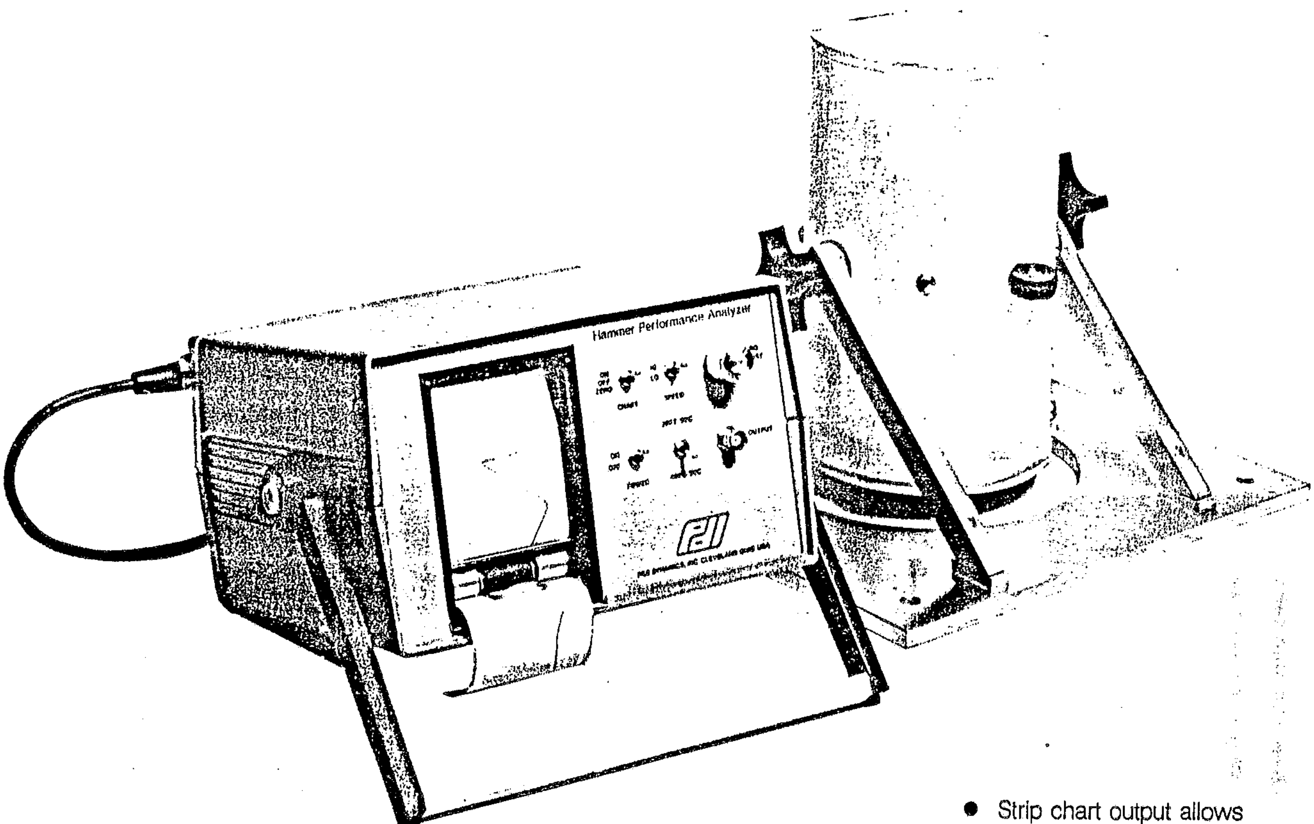
For additional information on this indispensible tool for quality construction control, contact:

Pile Dynamics, Inc. Goble & Associates, Inc.

12434 Cedar Road • Cleveland Heights, Ohio 44106 U.S.A.
Telephone: (216) 721-0220 Telex: 985-662 PILE DYN CLHS

Hammer Performance Analyzer™

Helps identify and eliminate hammer problems



- Uses radar technology to determine the ram speed and energy for each blow
- Identifies inefficient and underperforming hammers
- Highly accurate – within 2%
- Identifies specific hammer problems
- Allows optimization of hammer performance for increased productivity and lower construction cost
- No wires or other connections to pile or hammer required
- Strip chart output allows analysis of peak ram velocity for a series of blows, or detailed performance analysis of a single blow
- Can be used with all air/steam hammers where ram is visible, open-ended diesel hammers or SPT soil samplers
- Sets up in minutes
- Easy to operate

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Wave equation analysis techniques and monitoring with the Pile Driving Analyzer™ allow realistic driving criteria to be established based on an assumed or measured hammer performance. Now hammer efficiencies can be directly determined for use in Wave Equation analyses. This represents a cost-effective way for supervising engineers to ensure continued adequate hammer performance throughout a pile driving contract. Contractors can optimize the performance of their hammers to increase productivity.

Hammer Performance Analyzer™

The Hammer Performance Analyzer (HPA) by Pile Dynamics, Inc. simply and accurately determines the actual impact speed of the ram for each blow. Available hammer kinetic energy can then be quickly determined. The HPA can be used for any air/steam hammer where the ram is visible, open-ended diesel hammer or SPT soil sampler. The HPA will display the ram speed as a function of time on a strip chart, allowing identification of such problems as inadequate supply pressure, excessive friction, preadmission and preignition.

How the Hammer Performance Analyzer Works

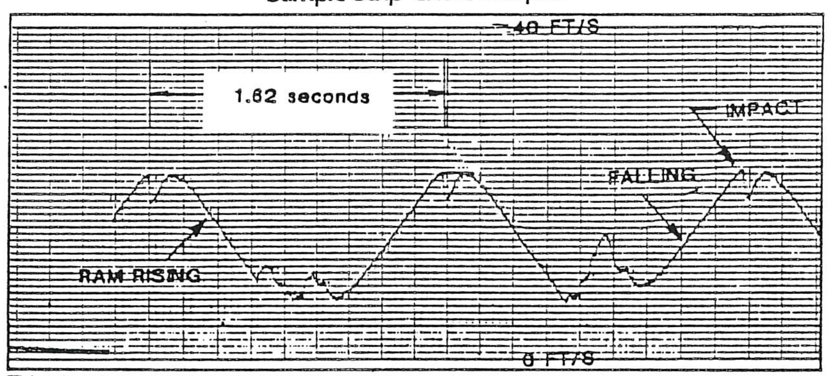
The HPA utilizes radar technology from vehicle speed measurements together with special purpose electronics. In this way, a proven transducer (the radar antenna) is adapted to hammer performance checks. The antenna is placed close to the base of the leads (or suspended above the hammer) so that the ram moves within the radar's active cone. No connections to the pile or hammer are necessary. The fastest moving object within the beam is automatically locked in. From the Doppler shift, the antenna generates a signal which is proportional to the speed of the moving object.

The ram impact speed can then be determined from the strip chart output. The strip chart output may be compressed to investigate the peak ram velocity for a series of blows, or expanded to obtain detailed plots for a thorough performance analysis. The analog signals can also be tape-recorded for further analysis.

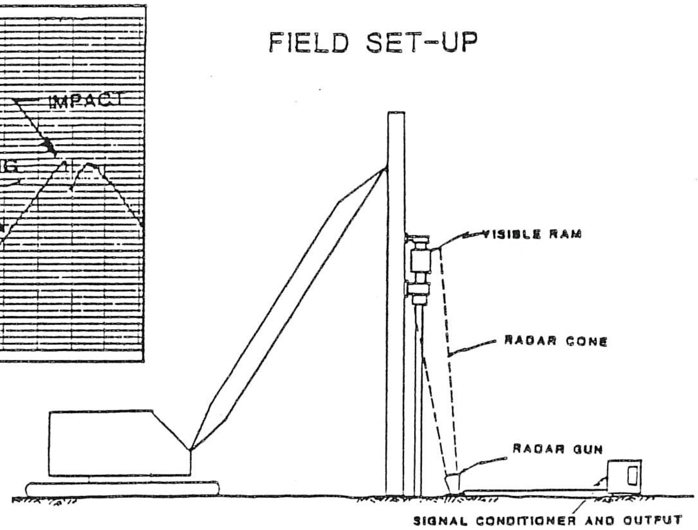
Specifications

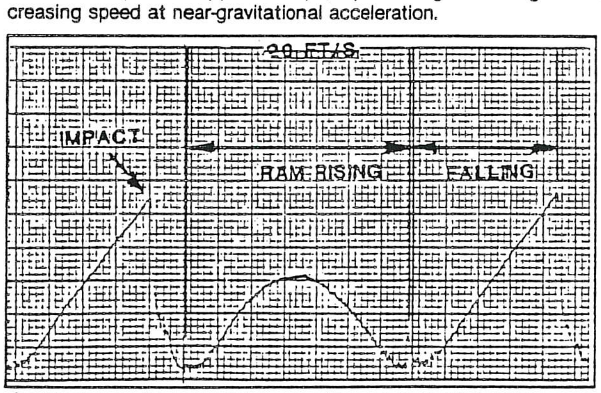
Size and Weight:	Electronics, 5″ x 9″ x 10″; 8 lb. Antenna, 12″ x 12″ base; 5.5″ o.d. x 9″ cone; total weight 10 lb.
Power:	90 - 265 volt AC @ 0.75 amp Optional 12 volt DC available
Operating Temperature:	−22° to +120° F.
Velocity Detection Range:	3 - 40 ft./sec.

Sample Strip Chart Output

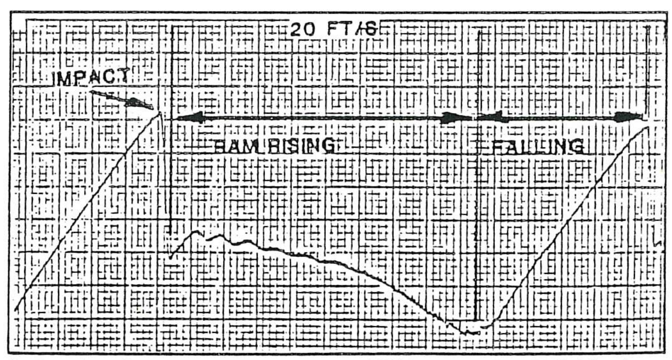


This plot shows the measurement taken on an open end diesel hammer. The downward and upward motions in these two examples can be seen as lines of equal but opposite slope, representing increasing and decreasing speed at near-gravitational acceleration.

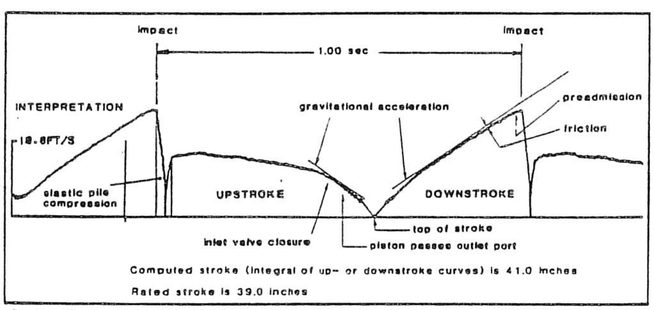




A typical record for an air hammer. The relatively high intial rebound speed is indicative of a refusal driving situation.



A plot taken from measurements on an SPT hammer. The SPT 'N' values are heavily dependent upon the input energy, which has been shown to have significant variability. Such measurements allow the SPT 'N' value to be rationally modified based on true input energy:



A detailed analysis of a record for a single-acting air hammer.

To learn more about the Hammer Performance Analyzer, and how it can help eliminate problems on your next project, call us today at (216) 831-6131.

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