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Positioning Systems for Bed Profiling in Hydraulics Physical Models

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1. Introduction

Physical hydraulic models are commonly used to study complex flow problems in the field of coastal engineering, estuaries, rivers, reservoirs and hydraulic structures. Laboratório Nacional de Engenharia Civil (LNEC) and other hydraulics research institutions developed some kinds of devices for recording bed profiles in flumes and hydraulic basins with varying types of bottom materials (sand, plastic, among others), most of which are based on servo-controlled positioning systems (Cardoso, 1964; Azevedo & Morais, 1989; Delft Hydraulics, 2005; HR Wallingford, 2006; Palma et al, 2008).
A common type of apparatus for this purpose consists of a vertical position controlled device driven by a small electric motor with a mechanical transmission actuating a rod as depicted in Fig. 1. At the lower end of the rod there is a probe which is the bottom sensor used for the tracking the rod point under water closely to the sediment bed. Sediments like sand or mud are often very weak materials and require contactless detection in order to prevent their destruction by the sensing probe itself. The vertical displacement of the moving elements out of water is converted into an electric signal representing depth.
The longitudinal profile recording is performed by the horizontal motion of the vertical servo controlled device, usually placed in a carriage or chariot, with rail or beam guidance; the horizontal (translation) movement may be done either by motorized or manual displacement.
A delicate part in this domain of application is the capability to detect very closely the bottom of a hydraulics flume or basin without effective contact and with good tracking capability, in order to avoid the penetration and destruction of the bed material. The problem will be addressed by appropriate design of multi-electrode conductivity probes taking into account also the need for compensating disturbance effects. Rough bed surface, variable granular sediments, water conductivity variations due to temperature and salinity, and also electromagnetic interference, are among the most disturbing causes that influence the sensing and servo-control performance.
In the following sections a number of problems and solutions for sediment bed profile tracking in hydraulics laboratory studies are discussed. An overview of solutions for vertical and horizontal motion control will be presented and discussed in the following, as regards both to the mechanical and the electrical drive subsystems. Experimental results from its

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application to a particular hydraulics study are shown. Particular attention is devoted to special phenomena and details that, not surprisingly, are decisive for achieving high-quality implementations.

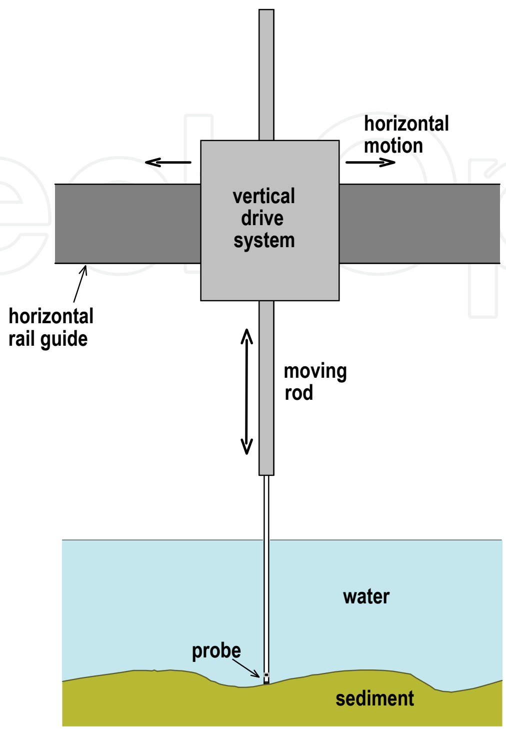


Fig. 1. Conceptual principle of a servo driven bottom follower.

2. Positioning and measurement apparatuses for bed profiling

2.1 Solutions for bed profiling instrumentation

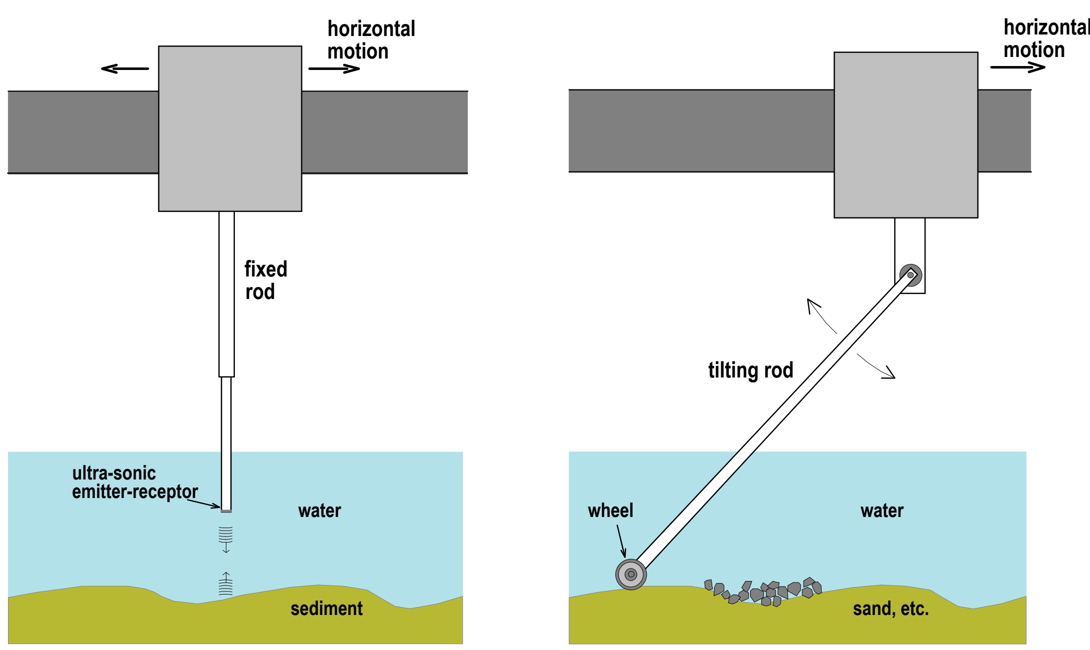
The method that will be described in detail is based on the principle of a servo controlled vertical rod having a tip probe to detect the bottom by rapid electric conductivity variation. This method of transduction is used in several institutions (e.g. Delft Hydraulics, 2005; HR Wallingford, 2006). Its merits consist of providing high accuracy (reaching the order of tenths of a millimetre), good spatial resolution (in the order of the tip diameter that may be of a few millimetres) and the ability to track even rather inclined profiles (over 30º) as well as irregular ones.

The same type of instrument can also be used to measure varying water levels – a function denominated *limnimeter*. It can be used to track tide levels in laboratory basins, but the speed of response usually does not allow the tracking of waves.

In a brief review of other bed profiling methods ultrasonic transduction appears as an attractive alternative for depth measurement based on the transit time of acoustic pulses emitted from inside the liquid mass towards the bottom until the reception of an echo, as shown in Fig. 2a. This static technique has low maintenance requirements and has deserved major preference for batimetry studies in rivers or at the sea (e.g. Ernstsen et al, 2006) although it is identified with some difficulties in measuring very inclined or irregular bed surfaces. Laser profiling is also of an expensive kind of method that has good metrological characteristics (Yeh et al, 2009) but need careful flume or basin empting operations to leave dry surfaces which is not always acceptable.

The above techniques are applicable when the bottom is composed of sediment grain sizes several times less than the diameter of the tip probe or of the ultrasonic beam. For beds of granules or stones of a size up to several centimetres the profile can be tracked by a trolley lean rod with wheels at the end in contact with the bottom (see Fig. 2b) being dragged horizontally by the axis of rotation in the upper end (Rao & Rao, 2004). The depth is calculated by geometric relations as a function of the tilt angle, the wheel diameter, the rod length, the axis height and the horizontal coordinate. The measurement of inclination (Fraden, 1993) can be made by a potentiometer, an inclinometer or even by an optical pulse encoder.

The latter solution, which can be used both inside and outside water (amphibious method), can only move in one sense – dragging the rod with the wheels behind – thus requiring an automatic lift up mechanism or a manual procedure to allow the return motion. The spatial resolution is poor and the contact of the wheel with the bottom may also crush the sediment if it is not consistent enough.



a b

Fig. 2. Other bed profiling solutions: a) ultrasonic transit time; b) trolley with tilting rod.

There is another servo-controlled solution with a vertically moving rod like the one in Fig. 1, in which the bottom surface is detected by sensing a small force of contact applied to the sediment by a wheel placed at the lower end with a force cell (Delft Hydraulics, 2005). Although insensitive to changes in the conductivity of the water, this method is amphibious like the previous one, has poor spatial resolution and may not be used in weak sediment beds.

2.2 Horizontal motion of bed profilers

Different solutions may be conceived for diverse motion requirements in laboratory instrumentation positioning. All of them have advantages and disadvantages when taking into consideration factors like cost, maintenance, reliability and adequacy to the problem at hand. In Fig 3 shows several types of devices for linear movement.

The rack and pinion device (Fig. 3a) is one of the oldest that is still being used to provide precision slippage-less horizontal linear movement of bed followers. With proper accessories it can be set to eliminate any backlash. Due to a very high cost is inadequate for very large applications. It also requires additional devices to avoid damage in case of movement blockage. The rack can be used to drive a position measuring device like a potentiometer for small applications or an optical encoder.
The systems based on flexible elements to convert rotary motion into linear motion like the toothed belt or chain and sprocket driven systems (Fig 3b) or the cable driven systems (Fig. 3c) provide a low cost solution for large applications. Both types are much less precise than the rack and pinion device. Also, the cable driven systems are prone to slippage problems; an additional system is required in order to reliably measure position.

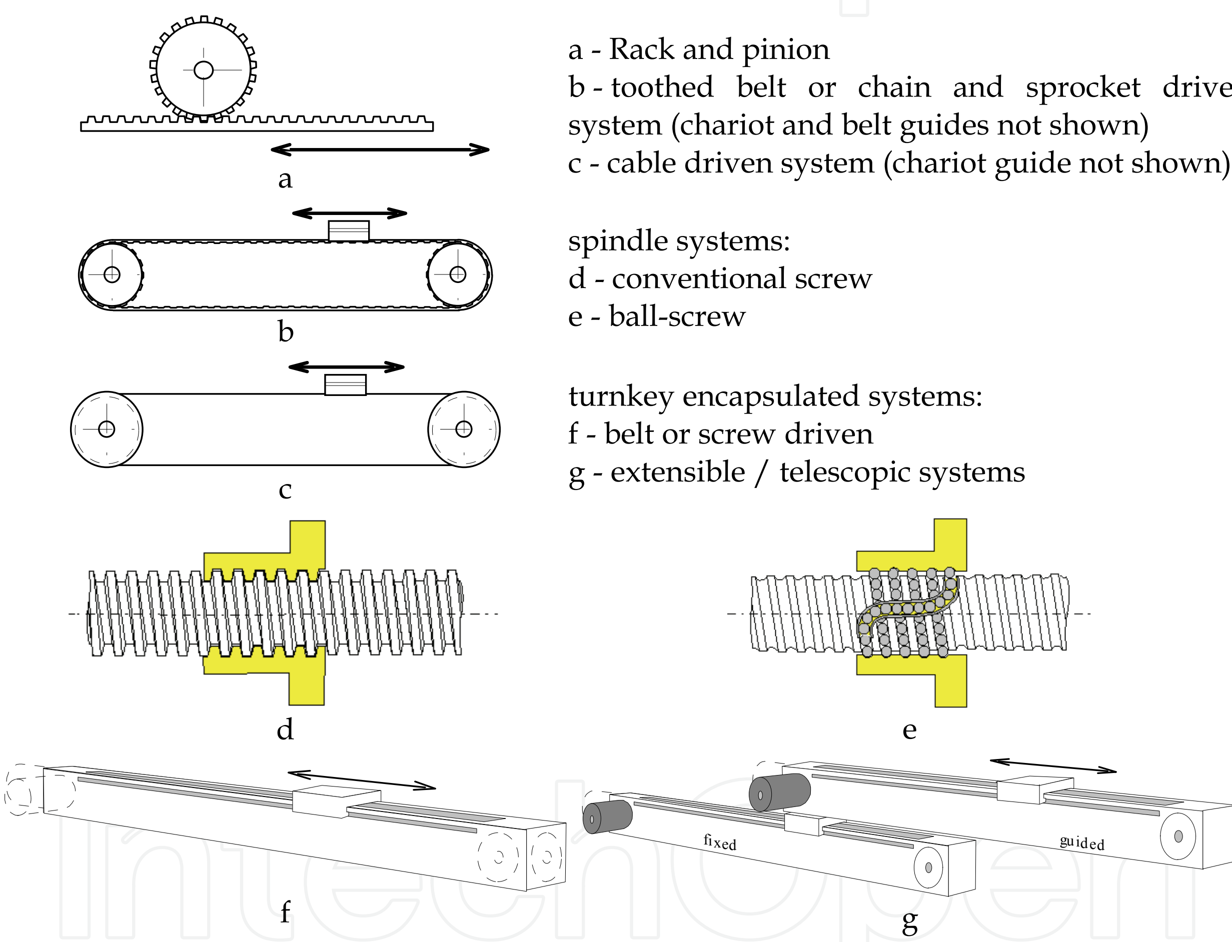


Fig. 3. Typical solutions for horizontal movement of bed profiling devices

Spindle systems are primarily used to drive heavy applications or for particular cases where a very large dynamic performance is required with large accelerations and decelerations. They are primarily used to drive equipment for wave generation but nonetheless can be used to provide horizontal motion of bed following devices. The conventional spindle (Fig. 3d) is very cost effective but has backlash problems, higher friction and if not maintained properly very high wear in the short term. The ball-screw device avoids all of the main defects of the conventional screw device for a much higher initial cost. In the long run the ball-screw devices have proven much more cost effective for demanding applications under higher duty cycles.

In the last decade several suppliers of dedicated high performance positioning systems have entered the market of turnkey encapsulated solutions (Fig. 3f). These systems use the same type of devices already described in a compact ready to use format including chariot guides, electric drive motors, end travel switches and control hardware. Cost efficiency is the main criterion to consider in this type of solution. This type of system is compatible with complex situations requiring combination of two or more linear motions (Fig. 3g).
Other electromechanical motion schemes for hydraulics models include those for wave generation (both in flumes and in basins, and consisting of single paddle or multimachine arrangements (Palma et al, 2002), instrument chariot motion control, floodgates, tide gates, and repartition valves for controlling sea currents, each one with peculiar requirements.

2.3 Hydrodynamic interactions due to horizontal motion

Fluid flow patterns around an immersed body depend on the *Reynolds* number (Simiu, 1996; Blake, 1986). Taking as an example a cylindrical body, a very common shape for probe supporting rods, by increasing the flow velocity a number of different flow situations can be created, each situation being identified by a specific *Reynolds* number range (Fig. 4). For all cases it is assumed that the undisturbed flow is laminar. For very low values of *Reynolds* number ($Re < 1$) the flow remains attached to the cylinder through all periphery (Fig 4a). For $1 < Re < 30$ the flow remains symmetrical in shape but flow separation occurs downstream of the cylinder as shown in Fig. 4b giving origin to stationary vortices. For values of *Reynolds* number $40 < Re < 4000$ alternating vortices of symmetrical intensity are shed downstream of the cylinder forming the so called "*von Kárman* vortex trail" (Fig. 4c). For *Reynolds* number values above the last range the flow downstream of the cylinder became turbulent as shown in Fig. 4d.
The alternate shedding of vortices is responsible for forces acting on the cylinder that can be analyzed as the result of two fluctuating components, one due to drag is aligned with flow and another transverse to flow is due to lift (Naudasher, 1985; Blevins, 1977).
The fluctuating component due to lift has a frequency (f) that can be given by:

$$St = \frac{f\,d}{V} \tag{1}$$

where V is the velocity of the flow, d is a characteristic dimension of the body projected on a plane normal to mean flow velocity. The fluctuating component due to drag has a frequency that is double the transverse one.
The non-dimensional number St, usually known as *Strouhal* number, is a function of body cross-section geometry, fluid viscosity and flow velocity usually expressed through the *Reynolds* number which is given by the following expression

$$Re = \frac{V\,d}{\nu} \tag{2}$$

where ν is called the *kinematic viscosity*. A typical value for water kinematic viscosity is ν_{water}=0.01 cm^{2}s^{-1} at 20ºC (Simiu, 1996).
Considering the flow around a cylinder with circular cross-section, St is approximately constant and equal to 0.2 in the range of $30 < Re < 10^5$ (see Fig. 5) (Naudasher, 1985).
The fluctuating component due to lift can induce vibration in the body especially if the vortices shedding frequency is close to one of the natural frequencies of vibration of the

body that could lead to resonance problems. In either case the rod vibration can easily lead to bed following problems and excessive strain on the vertical movement control system.

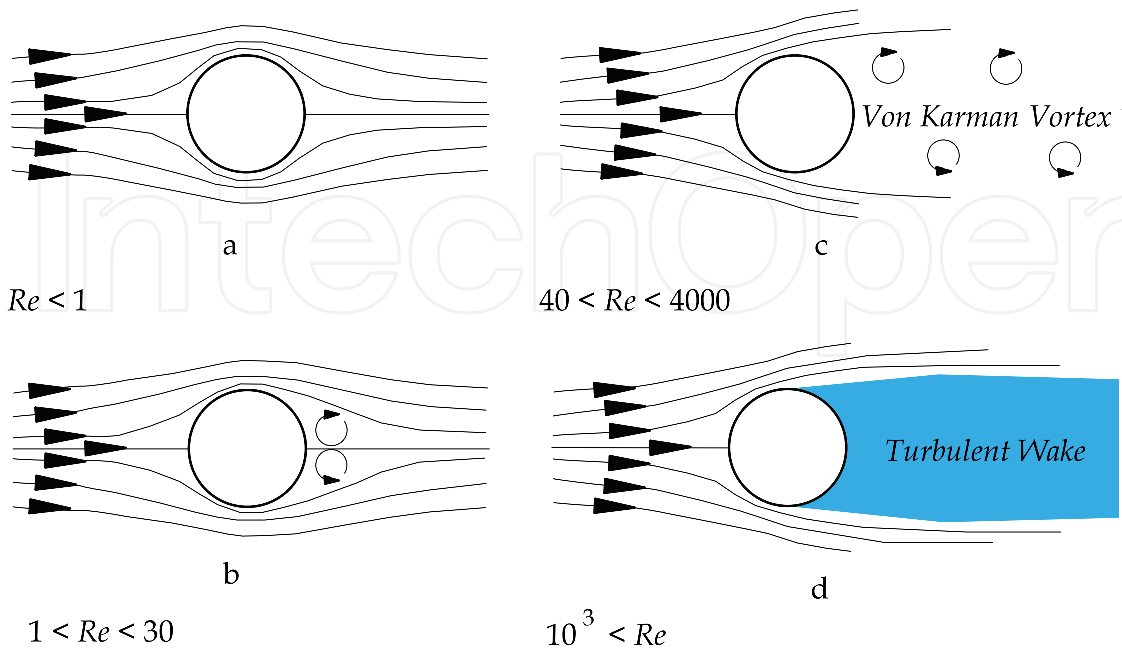


Fig. 4. Different types of flow around a cylinder as a function of the *Reynolds* number

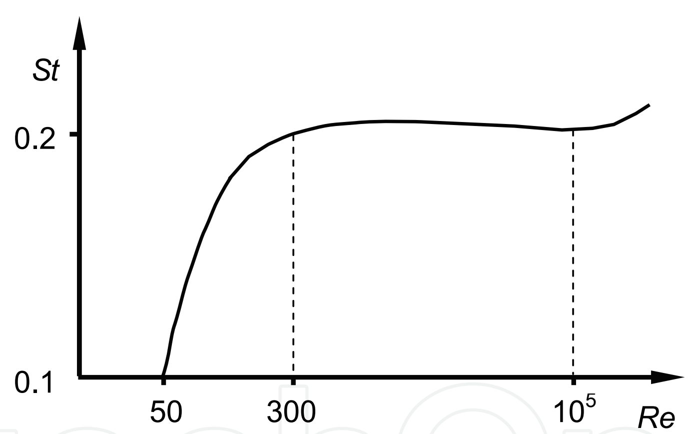
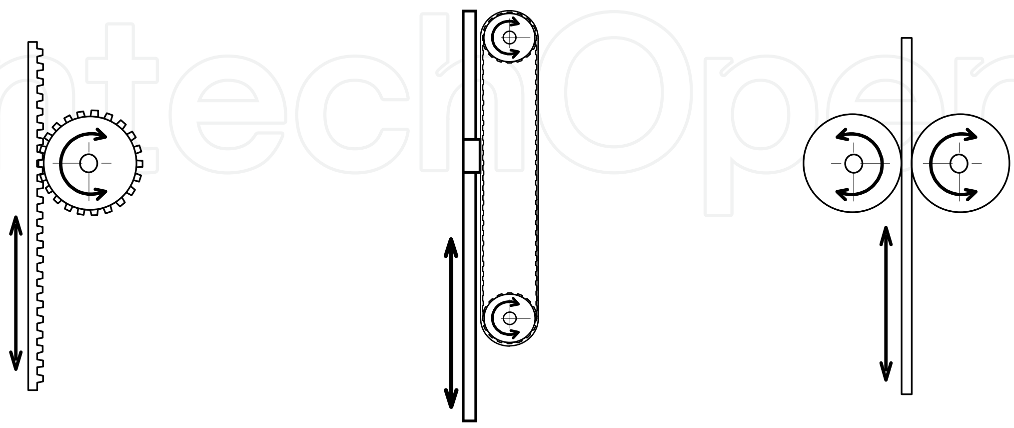


Fig. 5. *Strouhal* number as a function of *Reynolds* number for flow around a cylindrical body

When a body immersed in a fluid vibrates even when the fluid is stationary it gives origin to a non-stationary flow that generates additional forces. Those forces are in phase with the body displacement and can be seen as the effect of an *additional mass* also designated as *hydrodynamic mass*. As a direct consequence the immersed body natural frequencies became lower as the virtual fluid mass was directly attached to the vibrating body. The *hydrodynamic mass* is usually a function of the geometric characteristics of the body and fluid properties. In case of vibrating cylindrical bodies in water the *hydrodynamic mass* can be taken to be equal to the mass of the displaced volume of water (Naudasher, 1985; Simiu, 1996). These phenomena have to be taken into account in the mechanical design of the support structure and driving mechanisms of a bed profiler to work also under rapid horizontal displacement, especially when long immersed rods are required by the water depth and simultaneously light moving parts are necessary for obtaining high vertical accelerations.

2.4 Vertical motion of bed profilers

Vertical motion of bed profilers can be achieved by usage of some of the devices already described for horizontal motion with some restrictions. The major problem of vertical motion is related with dynamics, elimination of backlash problems and motion feedback to control system. This set of characteristics reduces the number of viable solutions to a smaller group as shown in Fig. 6.



a - rack and pinion b - toothed belt c - friction wheel

Fig. 6. Typical solutions for vertical movement of probe of bed profiling devices (guide wheels, dumpers, brakes, backlash and vibration suppressors not shown)

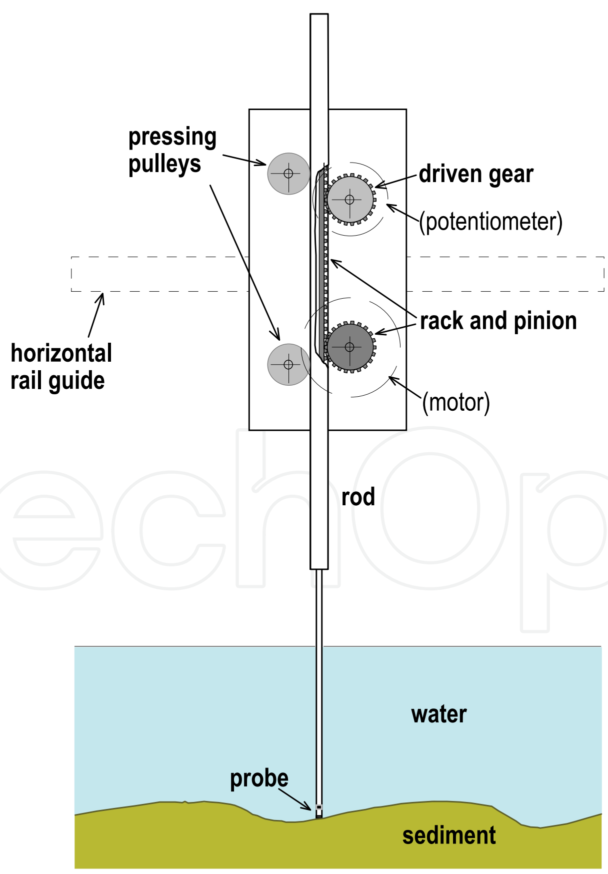


Fig. 7. Pictorial description of a complete mechanism for vertical motion of a bed profiler; the electric motor, the potentiometer and the pressing leaf spring are mounted on the back face; guide wheels are not shown.

The final solution adopted for the bed follower can be seen in the Fig. 7. The vertical motion is achieved by a rack and pinion device. Rod guidance and backlash reduction is provided by two pressing pulleys mounted on swivelling arms acted by a leaf spring and two fixed pulleys on the opposite side. The rack also drives a gear coupled to a multi-turn potentiometer to measure the vertical coordinate. Parking of the movable vertical rod is achieved by self-locking of the gear reductor coupled to the electric motor. A photo of the front side of the system built is presented in Fig. 13.

Some particular features of the electromechanical drive for this type of application result from the fact that it usually requires a micro machine of a few watts. Given the very low power involved some kind of linear electronic amplifier is preferred to the conventional switching converters that are inevitable for power ratings higher than a few tens of watts. This option is also a convenience in order to avoid harmonic interference in transduction circuits which are very sensitive and have to work relatively close to the power stage.

Linear motors could also apparently be used but are generally more expensive and disadvantageous in relation to the solutions with rotating motorization; in this case a gear reduction having self-braking capacity can avoid additional devices to counteract the effect of the gravity force which is required in a linear motor solution.

3. Bottom sensing and tracking control for a laboratory flume

3.1 Bottom sensing

Bed materials in hydraulic basins or flumes consist mostly of sediments with a variety of sizes which are not electrically conductive. Contactless bottom sensing can then be made with a tip probe located at the lower end of the vertical rod, with electrodes for sensing electric resistance.

Rough bed surface, variable granular sediments, water conductivity variations due to temperature and salinity, and also electromagnetic interference, are among the most disturbing causes that have a considerable influence on the sensing task and, at some extent, on servo-control performance.

The design of a tip sensing probe with three electrodes as shown in Fig. 8a solves two problems simultaneously: the transduction to an electric quantity indicating the proximity of the sediment surface and, additionally, the automatic compensation for disturbances that affect water conductivity. The distance from the probe to the bottom is transduced by the unbalance between impedances R_A and R_B. Under homogeneous temperature and salinity conditions R_A increases when the probe approaches the bottom narrowing the electric current field between A and C, while R_B remains constant.

Bridge circuits are widely used in instrumentation owing to its inherent merits for creating solutions with automatic self-compensation capability to certain disturbing effects (Fraden, 1993; Pallas-Areny & Webster 2001). The bridge circuit shown in Fig. 8b provides a fair compensation for water conductivity variations with temperature and salinity. In fact, conductivity variation affects simultaneously and proportionally R_A and R_B, still yielding an equilibrium condition:

$$R_1 R_A = R_2 R_B \rightarrow R_1 \alpha R_A = R_2 \alpha R_B \tag{3}$$

The bridge excitation is carried out in high frequency (10 kHz) ac voltage in order to avoid electrolytic polarisation of electrodes (see Fig. 8c). The bridge output is then dc decoupled, rectified, peak detected, amplified and filtered. The resulting voltage u_y vary nonlinearly with the distance y to the bottom, but may be linearised in a vicinity of less than 3 mm from the bottom surface (i.e. the working range) being suitable for linear control design techniques (D'Azzo & Houpis, 1981).

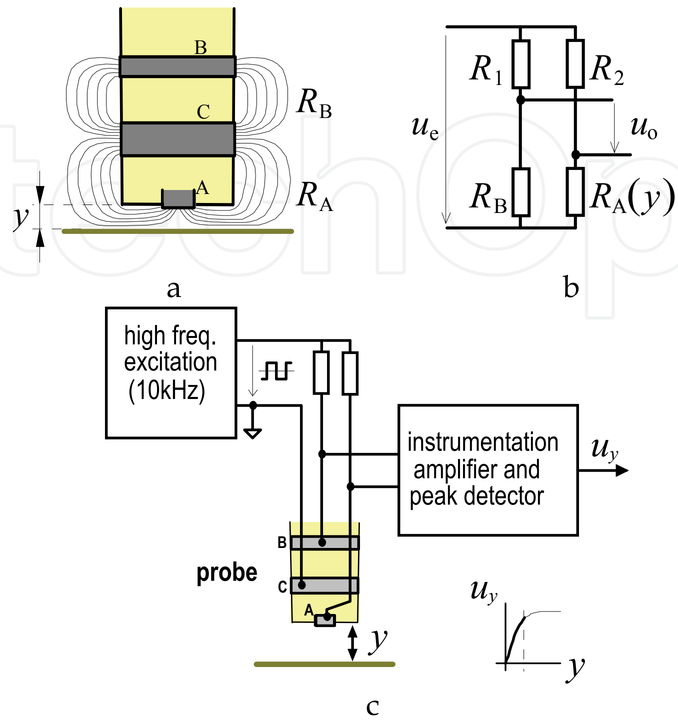


Fig. 8. a) Details of the bottom proximity sensor probe showing the fields of currents between electrodes; b) Bridge circuit for transducing the distance y to the bottom; c) block diagram showing excitation and signal conditioning stages.

In practice R_2 is a potentiometer used to adjust the equilibrium distance to the bottom. With the right compensation for conductivity variations by means of the third electrode that distance can be maintained reasonably constant without allowing the tip probe to go too close to the sediments with an added risk to get in touch with them in transients during the horizontal motion.

When the probe is close to the water surface a reciprocate effect occurs with R_B increasing while R_A remains constant. If this condition is explored the same instrument becomes a surface follower (or *limnimeter*). A similar phenomenon, but with catastrophic consequences, occurs in the opposite sense if the probe tip penetrates in the bottom sediment: in fact, resistance R_A increases again if the probe enters into the low conductive bed material which initiates an instability of the motion control as will be mentioned at the next section.

The sediment bed sensing function (or the water surface sensing function in a limnimeter) just described is required for motion control of the upright moving rod. A displacement transduction should be made additionally in order to acquire the vertical coordinate measurement at each point of the bed profile. A multi-turn linear potentiometer with a gear attached to a rack in the rod is a practical mean to produce a good resolution measurement.

The horizontal coordinate is easily obtained from an incremental encoder actuated by a system of two pulleys and a thin steel cable. Resolutions better than 1 mm are easy to obtain with a 500 ppr encoder in a pulley with a diameter of 120 mm. This method requires initial zeroing in order to produce absolute x coordinate values, by resetting the pulse count when the carriage is positioned at the conventional origin point.

3.2 Tracking control system

Very small direct current motors of about 12 V with gear reduction are typically used owing to their low cost, the simplicity of the necessary electronic drive circuits, and high acceleration capacity, as compared e.g. to stepper motors which could be the competitors at such low power ratings. DC motors having ironless rotor armature are especially interesting due to their extremely low moment of inertia: values of peak torque/moment of inertia over 100 krad/s^2 in the 10 W range are presently reported by manufacturers[1].

Older versions of servo controlled bed profile followers had greater stability problems due to the dc motor control method by direct armature voltage adjustment (Fig. 9a). In fact, the brush contact voltage drop of 1 to 2 V is quite significant in a 12 V motor giving rise to a strong nonlinearity, especially in the vicinity of zero speed. An alternative implementation made with a subordinate current control loop (Fig. 9b) allows overcoming the above difficulty and gives explicit torque control (Leonhard, 1996).

The approximate linear system model adopted for the servo control system is represented in the block diagrams of Fig. 10 with an inner loop for current control and an external loop for position control, without explicit speed regulation: $K_a\Phi$, R, τ_a, K_D and τ_m represent torque constant, rotor resistance, armature time constant, viscous damping coefficient and mechanical time constant, respectively, of the motor; the amplifier time constant, τ_e, in this case can be neglected; K and τ represent the equivalent gain and time constant, respectively, of the current control loop 1[st] order approximation. The effect of the gravity force is reported to the motor shaft as torque T_g=$M\,r\,g$ (M=linear moving mass, r=gear radius, g=gravity acceleration). The reference signal to the subordinate loop represents the reference value of current demanded by the position control loop and allows the application of a limiting device in order to protect the motor and the amplifier against over-currents (Fig. 10b).

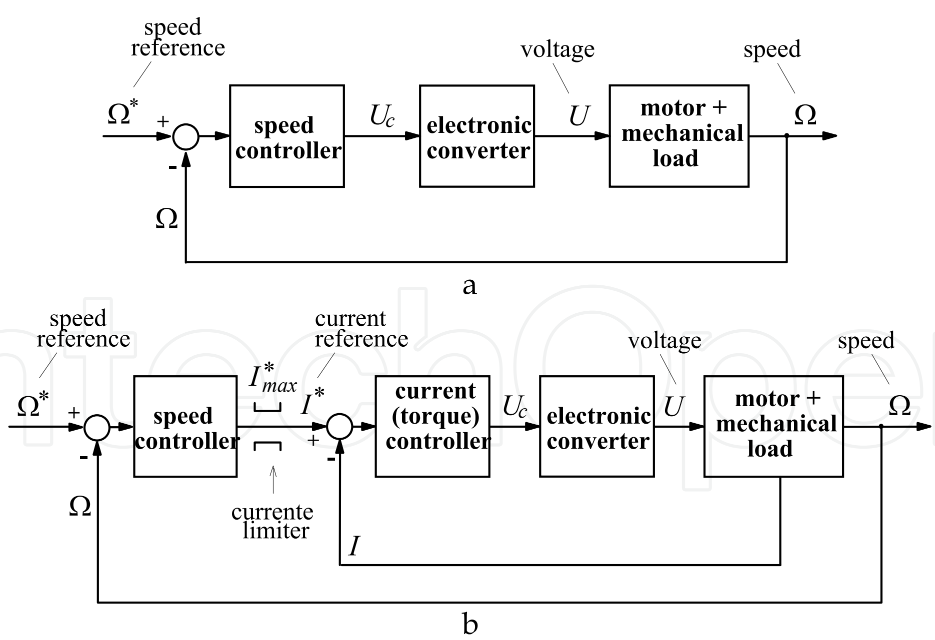


Fig. 9. Closed loop dc motor speed drive methods: a) with direct voltage adjustment; b) with a subordinate current control loop.

[1] E.g. www.maxonmotors.com, www.faulhaber.com

Lag-lead and PI structures were sought for the tracking controller C_p in order to get a compromise between error and response speed. Whenever possible simple controller structures have the important practical advantage of a reduced set of parameters to adjust. The PI controller type is also common in current control loops; however a C_i of proportional type can also be tolerated given that this is not a final controlled quantity.

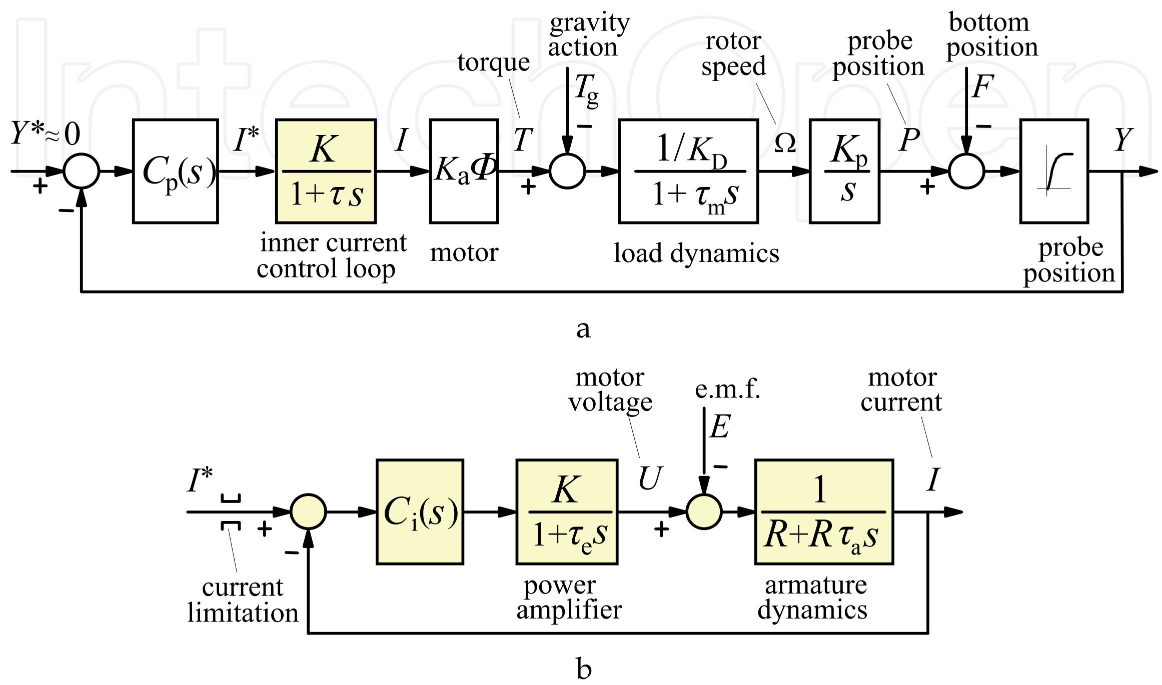


Fig. 10. a) Block diagram of the bottom tracking system. b) Detail of the inner current control loop.

A switching converter would be essential for higher power machines (Leonhard, 1996), due to efficiency requirements and also for the sake of semiconductor rating and heat dissipation. In this particular application, however, movable parts are relatively light thus allowing for a very low power motorization (approximately 10 W). Moreover, in many instrumentation applications with delicate transduction processes the interference caused by the harmonics generated by switching converters are a major concern. Thus a linear amplifier was preferred instead of a chopper given the almost insignificant heat losses involved in order to reduce the electromagnetic noise and interference in the sensing process.

The bed tracking control system was implemented with analogue electronics, as shown in Fig. 11. A current control scheme was adapted to an H-type power amplifier using a probe resistor R_p for current sensing and a triple operational amplifier arrangement (U_3,U_4,U_5): subtractor U_1 provides the current measurement signal from the voltage at R_p terminals, U_2 performs as the linear current source controller driving directly the left bridge arm and U_3 creates the inverted signal for the right bridge arm. The bridge is formed of BD 680 PNP and BD 681 NPN Darlington transistors. Current control was achieved with less than 2 milliseconds settling time. Overcurrent limitation is made by zener diodes coupled to the position controller (U_1 in Fig. 11) in order to prevent wind up when the PI function is set.

The system may be set to keep the probe at a constant distance of 1 to 3 mm from the bottom by adjusting the potentiometer R_2 (see Fig. 8b). Far from the linear region the output signal

saturates (Fig. 8c), the maximum actuating torque is demanded and so is the current limitation in the inner motor control loop, corresponding to a situation of cruise travel.
Control design is based on the previous linear model where three major poles are found: a fast electrical one (P) due to the inner current control loop (with aprox. 1 ms time constant), a slow mechanical pole (P_m) of the motor and load model (with aprox. 40 ms time constant), and a pole at the origin resulting from the integration of speed that yields the position.

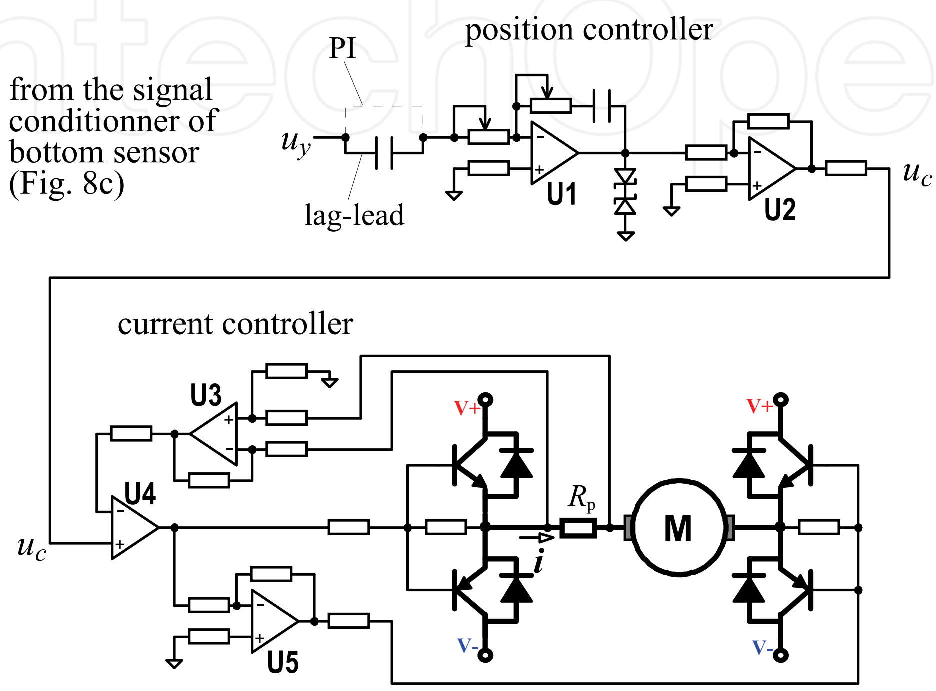


Fig. 11. Electronic power stage and controller circuit schematics.

The controller synthesis is described with the aid of the root locus sketched in Fig. 12. The controller consists of a pole P_c and a zero Z_c in a lag-lead arrangement. In fact the pole and zero placement may be chosen such that different emerging locus patterns can be found (see Fig. 12b) ranging from the lag-lead type to the PI type controller (when P_c is placed at 0). Stability is theoretically possible with both types and was experimentally confirmed. The PI controller, that gives no steady state error, generates two dominant complex poles that can be adjusted to produce a moderate overshoot. Neglecting the effect of pole P, given the dominance of P_m, the ITAE analytical criterion (D'Azzo & Houpis, 1981) was used as the guideline to obtain a global transfer function of the form shown in equation (4)

$$\frac{Y(s)}{Y^*(s)} = \frac{K\omega_o^3}{s^3 + 2\omega_o s_2 + 2\omega_o^2 s + \omega_o^3} \tag{4}$$

There is a high uncertainty in the gain of the linearised bottom sensor characteristic which implies a final experimental adjustment of the PI controller parameters – in practice, the reduced number of parameters allows uncomplicated empirical procedures for adjustment.
A faster speed response with still less overshoot was found with P_c slightly displaced from 0, i.e. in the lag-lead mode.

A more complex controller structure with one pole and two zeroes has been studied and tested in laboratory with good results, nevertheless the simpler versions are preferred for the sake of future adjustment needs.
The penetration of the probe tip inside the sediment mass is highly unwanted and should be avoided by all means: at a certain extent it is only lightly destructive of the bed materials, but if it goes deeper an instability occurs in the motion control reinforcing the downward movement due to the inverse variation of R_A (see section 3.1). Careful control adjustment or special logic detection schemes have to be implemented in order to avoid this kind of occurrence. Older versions of bed followers were significantly more prone to it.

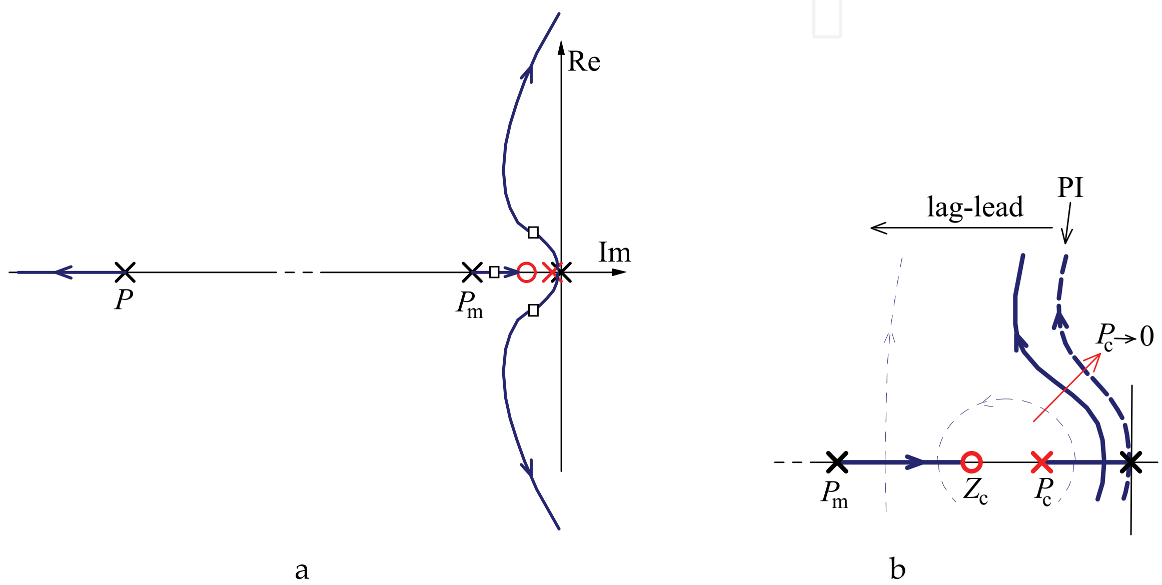


Fig. 12. Root locus sketch of the closed-loop system: a) general plan; b) enlarged view near the origin showing the effect of varying the controller pole P_c from lag-lead to PI.

4. Experimental application of a bed profiler

4.1 Computer command an data acquisition

This type of instrument has to be used in conjunction with PC based data acquisition and command equipment. In addition to the analogue part used for the vertical motion control of the profiler, a digital unit was developed (Palma et al, 2008) for converting the vertical coordinate analogue data, counting the pulses from the encoder for the horizontal coordinate, communicate with a computer to send data and state information as well as to receive commands. The horizontal coordinate data resolution is 1 mm and the vertical coordinate resolution is better than 0.1 mm, after the digital conversion.
Since the system may be at rest for long periods there are commands for (de-)energizing the power supply for amplifier and motor; the gear reductor coupled to the motor prevents gravity downwards movements after de-energisation. During rapid carriage travel (e.g. for return to origin) an order can be issued to suspend the bed tracking operation of the profiler and to commutate it for surface tracking. Fig. 13 shows a photo of the instrument apparatus in a carriage over the flume.

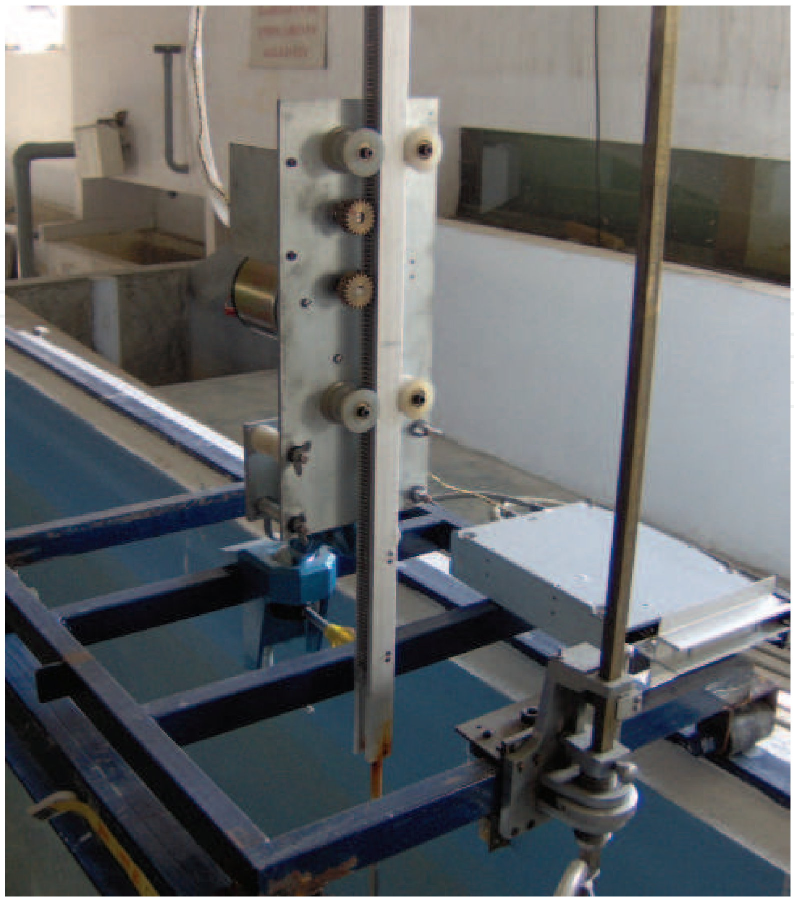


Fig. 13. Photograph showing the instrument block in a chariot over the flume.

4.2 Experimental results

The system as shown in Fig. 14 was used in a flume of the Department of Hydraulics and Environment of LNEC for the study of the sedimentation process in dam reservoirs, based on successive bed profile surveillances (González, 2007; Alves, 2008). The sedimentation results from de deposition of coarser sediments that form a delta and fine sediments (turbidity currents).

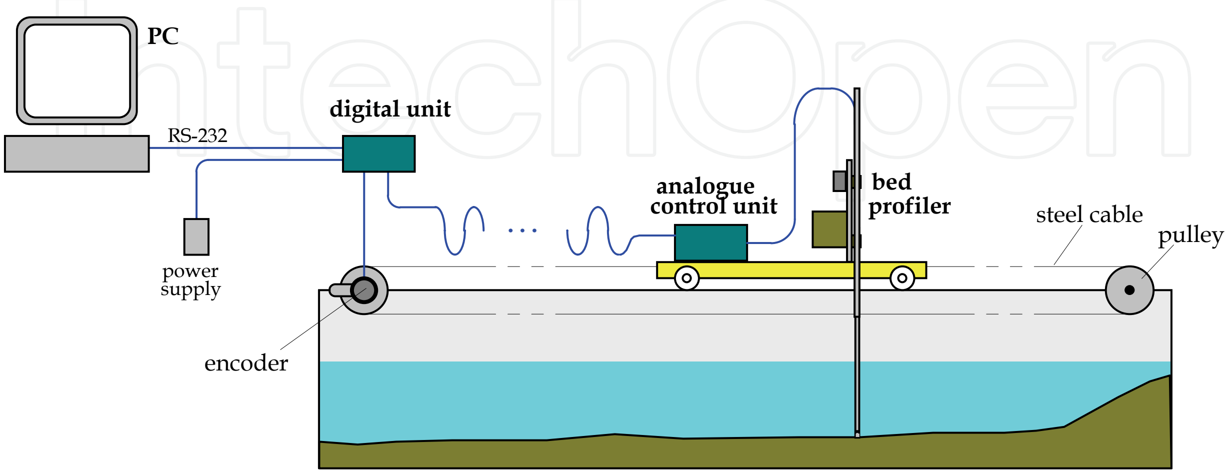
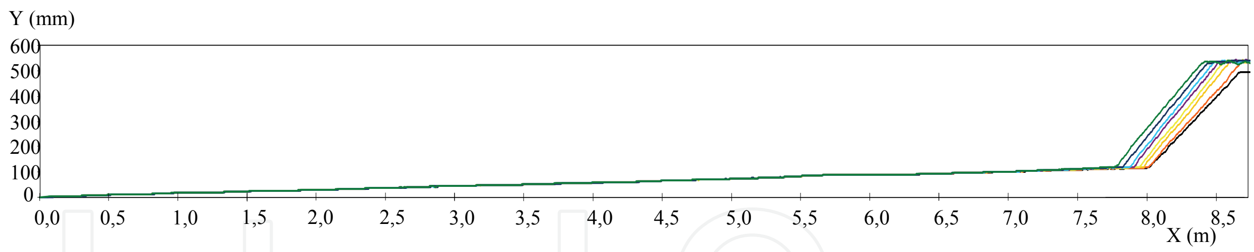


Fig. 14. Synoptic sketch of the bed profiler and the data acquisition system used in the flume model



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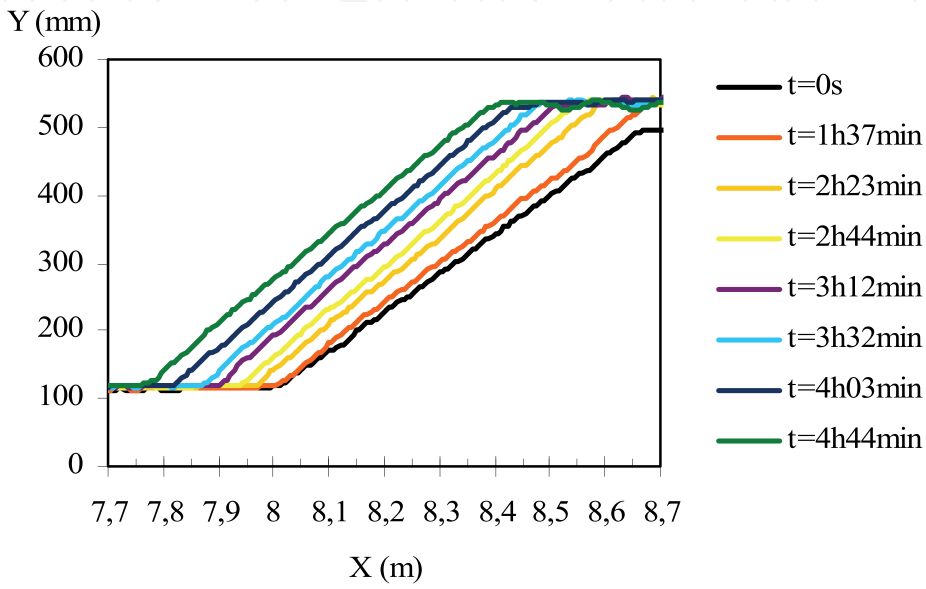

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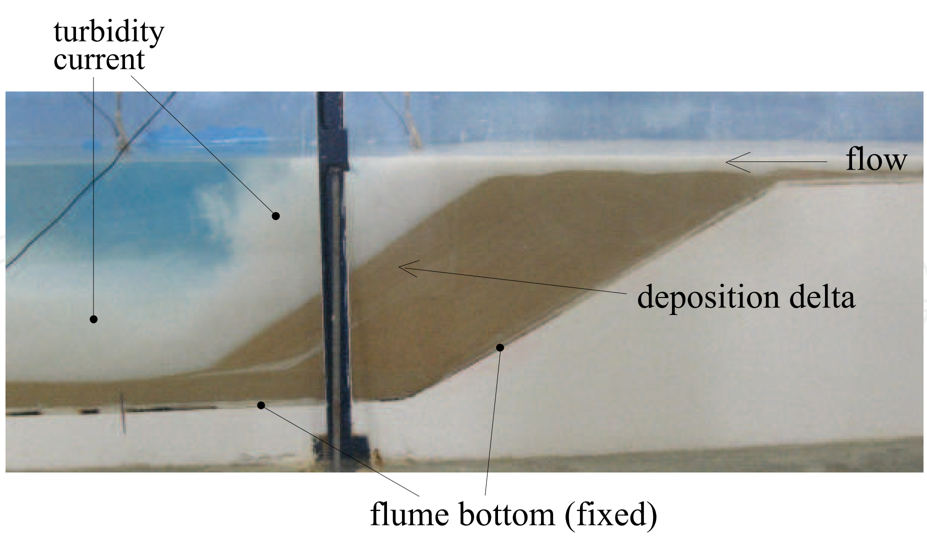

c

Fig. 15. a) Graphic view of the data acquired for whole flume length. b) Enlarged view of the profiles in the region of interest; c) Photo taken through the last sections of the transparent acrylic wall of the flume.

The flume has 10.60 m length, in which a segment of 8.7 m was used for this test, 0.30 m wide and 0.75 m maximum height, having a transparent acrylic wall on one side.
The shape of deposited sand after 4 h 44 min of test is shown in Fig. 15. The diagrams represented in Fig. 15a and 15b correspond to data collected from several profiles at given time intervals, and show the progress of the delta front edge. The shape of the delta can be seen in the photograph of Fig. 15c.
The study demonstrated that the equilibrium tilt angle of the front edge is approximately 33º and was attained about 2 h and 23 min after the test start.

5. Conclusion

Significant advancements had to be introduced in servo-controlled sediment bed profilers in order to obtain reliable solutions for these particularly demanding motion control tracking systems. Improvements in robustness and performance were achieved in the motion mechanisms as well as in the tracking control system in terms of higher stability, response speed and bottom sensing accuracy.
A number of mechanical refinements namely for backlash absorption, vibration reduction, guidance friction minimization and weight optimization have a great influence on the overall performance. The introduction of a subordinate control loop attenuates the nonlinearity effect of the collector-brush voltage drop, while simultaneously self-protects the motor and the amplifier against overcurrents. The bridge topology used in the amplifier for the current-source loop expands the capacity for producing high force peaks in transient acceleration/deceleration periods.
The penetration in the sediment by the probe tip, which occurred at times in the past, and was a critical kind of event, has been effectively avoided with the new design, owing to the servo controller improvements and to the re-shaping of the geometry of electrodes at the probe tip. The improvement in control performance is another important feature in order to avoid occasional destruction of sediments and to prevent instability. The addition of digital communication with a computer brings other advantages for command, diagnostics and data acquisition.
Experimental results demonstrated the appropriate performance of the proposed solution. After initial tests and adjustments the system has been used with success in a study of sedimentation caused by turbidity currents, for monitoring the progress of a relatively steep front edge of a delta with an approximate tilt angle of 33º.
The type of application described embeds the contribution of several disciplines. A number of particular details concerning physical measurements, mechanical design, electronics and electromechanical drives had to be tackled in order to develop the appropriate motion system.

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The book reveals many different aspects of motion control and a wide multiplicity of approaches to the problem as well. Despite the number of examples, however, this volume is not meant to be exhaustive: it intends to offer some original insights for all researchers who will hopefully make their experience available for a forthcoming publication on the subject.

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