AUTOMATIC LEVELLING IN ROAD CONSTRUCTION

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SUMMARY

The fulfilment of today's demands for particular pavement course thicknesses and a particular evenness in the construction of road surfacings is one of the main tasks set to road building equipment. This aim can be reached through the use of electro-hydraulic control facilities for the working units of the corresponding construction machinery.

The subject of this paper is to deal with the automatic control technique used for the levelling systems on bulldozers, graders, milling machines, asphalt pavers and concrete finishers. Starting out from theoretical considerations, the experience gained from practical operation of the levelling systems employed nowadays will be described, as well as the limits set to these systems.

Keywords: Levelling Systems, Road Construction Machinery, Road Pavers, Automatic Control

1. EVENNESS

The behaviour under traffic and the longevity of a pavement substantially depend upon the evenness achieved during construction of the pavement courses.
The surface of the finished pavement is to be on the prescribed level. For the pavement surface a certain deviation, over a distance of 4 m, is admissible depending on the type of course, see Figure 1. Attention is to be paid that the deviations only appear gradually and do not occur at short and regular intervals.
As far as airport runways are concerned it is not the short undulations that matters, as in the case of roads, but the irregularities over a length of 50 - 60 m causing vibrations on aeroplanes at high speeds. According to YANG* irregularities, in taxiways, should be no more than 5 mm (over a length of 6 m) and in runways no more than 6 mm (over a length of 16 m).

The high demands made on the quality of pavement evenness and the endeavours towards achieving high laydown rates necessitate the use of constuction machinery equipped with control facilities for the laying of all of the pavement courses.

*YANG, N.C.: Design of Functional Pavements.
New York, McGraw-Hill, 1972

2. SELF-LEVELLING / BEHAVIOUR OF THE CONTROLLED MEMBER

The self-levelling property of a road construction machine is expressed by the achieved quality of evenness when placing a pavement course on an irregular base without using any levelling facilities. The precise knowledge of the self-levelling property is of decisive importance, as it characterises at the same time the behaviour of the controlled member within the control loop for levelling. The self-levelling properties of the machinery applied in road construction differ considerably and may, according to type of travelling gear and kinematic location of the working unit, be divided into 3 groups:

2.1 GROUP I: BULLDOZERS

Bulldozers make up the first group. Here the working unit (earth levelling scoop), adjustable in height, is arranged in front of the crawlers. The self-levelling properties are determined by the length of the crawler tracks LF, the constructional design and arrangement of the earth levelling scoop and the working process itself, as irregularities in front of the crawlers are planished through the earth levelling scoop (Figure 2).

2.2 GROUP II: TRACTOR SCRAPER, GRADER, MILLING MACHINE, SLIPFORM PAVER

The second group comprises road construction equipment on which the working unit, adjustable in height, is arranged between the running gears. The self-levelling properties of these machines are determined by the geometric size of the running gear (diametre of tyre D or length of crawler track LF), the distance between running gears LR, and the distance between the running gear at the front and the working unit LA (Figure 3).

2.3 GROUP III: ROAD PAVER - SMOOTHING SCREED

The third group comprises road pavers (on wheels and on crawlers). This road construction equipment differs substantially, as far as self-levelling properties are concerned, from the afore-mentioned groups I and II.

Due to the geometry of the screed and due to the fact that the side arms are pivoted to the paver frame in the places most favourable from the kinematic point of view, the screed is towed over the paving material (Figure 4). This is the reason why the smoothing screed is also designed as "floating screed". Through adjustment of the screed tow points in height, the screed planing angle α and thus the surfacing thickness h_B is modified (Figure 5). On a scale provided on the paver and connected with the side arm the surfacing thickness is indicated as approximate value. The irregularities in the base under the screed are levelled out through the paving material. It is only at the tow points of the side arms that irregularities existing in the base are introduced through the tractor unit.

The slope of the screed (Figure 5) is:

$$\boxed{m = \frac{h_z - h_B}{l'}} \qquad (1)$$

h_Z = Height of screed tow point
h_B = Height of screed
l' = Length of screed arm l projected to base
m = Slope

For small slopes applies l'=l, and it results for the slope of the screed:

$$\boxed{m = \frac{h_z - h_B}{l}} \qquad (2)$$

This relation is, according to the exponential function

$$\boxed{y_{(x)} = (y_\infty - y_0)(1 - e^{-\frac{x}{\tau}}) + y_0} \qquad (3)$$

similar to the equation for the slope

$$\boxed{m = \frac{y_\infty - y_0}{\tau}} \qquad (4)$$

and the equation for the height of the screed must, in analogy, be:

$$\boxed{h_{B(s)} = (h_z - h_{B0})(1 - e^{-\frac{s}{l}}) + h_{B0}} \qquad (5)$$

The same result can also be obtained through direct calculation. By substituing the equation for the distance S = $V_E t$, the following time function results:

$$\boxed{h_{B(t)} = (h_z - h_{B0})(1 - e^{-V_E \cdot \frac{t}{l}}) + h_{B0}} \qquad (6)$$

with the time constant being $\tau = l/V_E$

and the operating speed V_E

In this time function changes in height are superimposed by other influences, such as compaction of paving material or flowing of the material under the pressure exerted by the screed, i.e. that in such a case the levelling of the screed will be determined not exclusively through vertical modification of the screed tow points. The correction of the screed thus is, on the basis of force equating with weight, closely correlated to the length of the screed arm l and the covered distance S.

Changes in height of the tow point, caused by undulations at short intervals, are attenuated due to the delaying inertia of the paving system. Disturbances, however, caused by an undulation whose length exceeds that of the side arm, are attenuated only slightly or not at all, and cannot be compensated without active regulation (Figure 6).

3. AUTOMATIC LEVELLING

For meeting in road construction today's requirements of accuracy when placing pavement courses, the self-levelling properties of a road paver are not sufficient.

In the 60ies the first automatic levelling systems for road pavers were applied. Nowadays, as technical development in road construction progresses, the large majority of road pavements is placed by using automatic levelling systems.

Figure 7 shows the levelling system in a schematic representation. Through external commands for "raising" or "lowering" the thickness of the pavement course (nominal height) is predetermined via a servo mechanism. By measuring the actual paving height it is then possible to gain, through direct comparison with the nominal height, the information "too high" or "too low". This information will be processed by a control unit into the control signals "raising" or "lowering".

The servo mechanism provided on either side of the paver consists of an electro-magnetically operated 4/3 way valve and a hydraulic ram. Both elements together make up the correcting unit within the control loop (Figure 8). The valve is characterized by a delay behaviour of first order (VZ1), the hydraulic ram by an integrating behaviour (I). The paving system comprising the subsystems of side arm, smoothing screed and paving material, constitutes the controlled member within the control loop which, in Section 2.3, has been characterized by a delay behaviour of first order (VZ1). The level sensor serving simultaneously as the transmitter of the nominal value, is marked by a proportional behaviour.

The task to be fulfilled by the control system is to ensure evenness in a longitudinal direction, and a preset slope of the pavement in a transverse direction. The controlled variable used for reaching this goal is the paving height. Any deviation of the actual value from the nominal value of the system, in a longitudinal direction, is detected by means of a level sensor tracing a reference line (tensioned wire, towed avaraging beam etc.). In addition, any deviations from the preset transverse slope are detected through the slope sensor. In the control unit the deviations from the nominal values, made available in the form of inputs, are processed into control signals analogous to frequency and emitted to the valves in the correcting units.

3.1 DETECTION OF DISTURBANCES

Disturbances can, in principle, be introduced into the levelling system in three different places.

The first place is the paver itself. During paving the machine moves on an uneven, coincidental base. In doing so, vertical movements are carried out which, by way of the pivot points of the side arms, may be transmitted to the towed screed. The objective of the control system must be to compensate these vertical movements completely and without any time delay through an opposed movement of the correcting ram, so that any influence upon the paving height will be prevented from coming into existence.

The next risk of disturbance feedforward is on the screed itself, either in the form of irregularities in the base or through an inhomogeneous paving material. These disturbances lead to a direct deviation of the actual height from the nominal height. They must be compensated completely, and this compensation is to take place gradually in order to avoid the formation of steps.

The third place apt for the influence of disturbance is the reference line. Disturbances in the reference (e.g. wire break) cannot be taken into account from the part of the control system, as it is not possible to distinguish them from other kinds of disturbances.

3.2 DETECTION OF ACTUAL VALUE

The above-mentioned disturbances are, as far as the levelling system described is concerned, not measured directly.

A level sensor attached to the screed traces the reference line for the screed height. In doing so, the angle is measured between the side arm and the level sensor. The nominal height is given through the basic setting of the sensor ($\beta = 45°$), so that any deviation from this angle can be directly interpreted as a deviation from the nominal value. By means of a system like this neither the height of the screed h_B nor the inclination of the side arm can be determined, as for a mathematical description of two lines (side arm and refernce) an angle alone is not sufficient. Figure 9 illustrates this circumstance.

Despite identically measured angles of $\beta = 45°$, the inclination of the side arm and the height of the screed may be different in the cases A and B. Yet this measuring system is suitable for height control of the screed, as inclination of the side arm and height of the screed are correlated. Provided only small changes in angle, the trigonometric functions are negligible and the height of the level sensor h_F is proportional to the change in the angle β.

When examining separately the change in the height of the screed and the one of the tow point, then two relations result for the measured height of the level sensor h_F (Figure 10).

In case of a change in height of the screed, the height of the level sensor h_F is:

$$h_F = \frac{h_B - h_{Bnominal}}{1} (1 - a) \tag{7}$$

at $h_Z = h_{Znominal}$

In case of a change in height of the tow point, the height of the level sensor h_F is:

$$h_F = \frac{h_Z - h_{Znominal}}{1} \cdot a \tag{8}$$

at $h_B = h_{Bnominal}$

The superimposition of the two influences leads to the following equation for the deviation from the nominal value measured at the level sensor:

$$R = - \frac{1-a}{1} (h_B - h_{Bnominal}) + \frac{a}{1} (h_Z - h_{Znominal}) \tag{9}$$

3.3 CONTROL UNIT

The behaviour of the control unit depends upon the amount of the deviation from the nominal value. In the case of deviations R smaller than ± 0.3 mm a dead range exists, i.e. the control unit does not react.

In the event of deviations larger than ± 0.3 mm the control unit changes the solenoid valve to impulse operation (progressive operation) (Figure 11). Then the correcting speed of the levelling ram is adapted proportional to the deviation, i.e. processing of the deviation takes place according to sign and amount. The actuation of the solenoid valve is effected analogous to frequency, i.e. the impulse recurrence frequency is proportional to the amount of the deviation.

In the case of deviations larger than ± 5 mm the control unit changes to continuous operation which means full modulation of the solenoid valve. Processing of the deviation takes place according to sign only. Irrespective of the mode of operation the control unit the control unit always aims at a value of R = 0. From equation (9) the desired nominal height as a function of the actual deviation in height results as follows:

$$0 = \frac{1-a}{1}\,(h_B - h_{Bnominal}) + \frac{a}{1}\,(h_Z - h_{Znominal}) \qquad (10)$$

$$(h_Z - h_{Znominal}) = -\frac{1-a}{a}\,(h_B - h_{Bnominal})$$

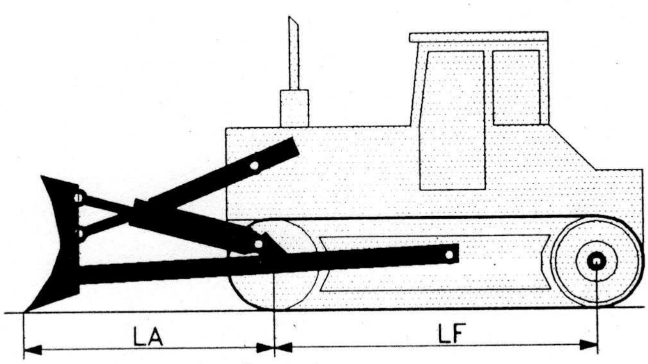
Any deviation of the screed in height is opposed, according to equation (10), by a (1-a)/a - fold change in height of the tow point. The levelling ram imaginarily rotates around the level sensor fitted in front of the screed at the distance a. On condition that the change of the screed in height and the modification of the tow point take place almost simultaneously, the following applies for the resulting vertical speeds:

$$v_Z = -\frac{1-a}{a}\,v_{Sceed} \qquad (11)$$

v_Z = Correcting speed of the levelling rams

PAVEMENT COURSE	EVENNESS	LENGTH	DEVIATION CROSSFALL
Surface Course	≦ 3– 4 mm	4 m	≦ 0,4 %
Binder Course	≦ 6 mm	4 m	True to line and level within ≦±10–20 mm of nominal height
Base Course	≦10 –20 mm	4 m	
Soil Stabilization	≦ 20 mm	4 m	

Figure 1: Required Evenness in Road Construction



LA Distance between the running gear at the front and the working unit.

LF Length of crawler track

Figure 2: Bulldozer

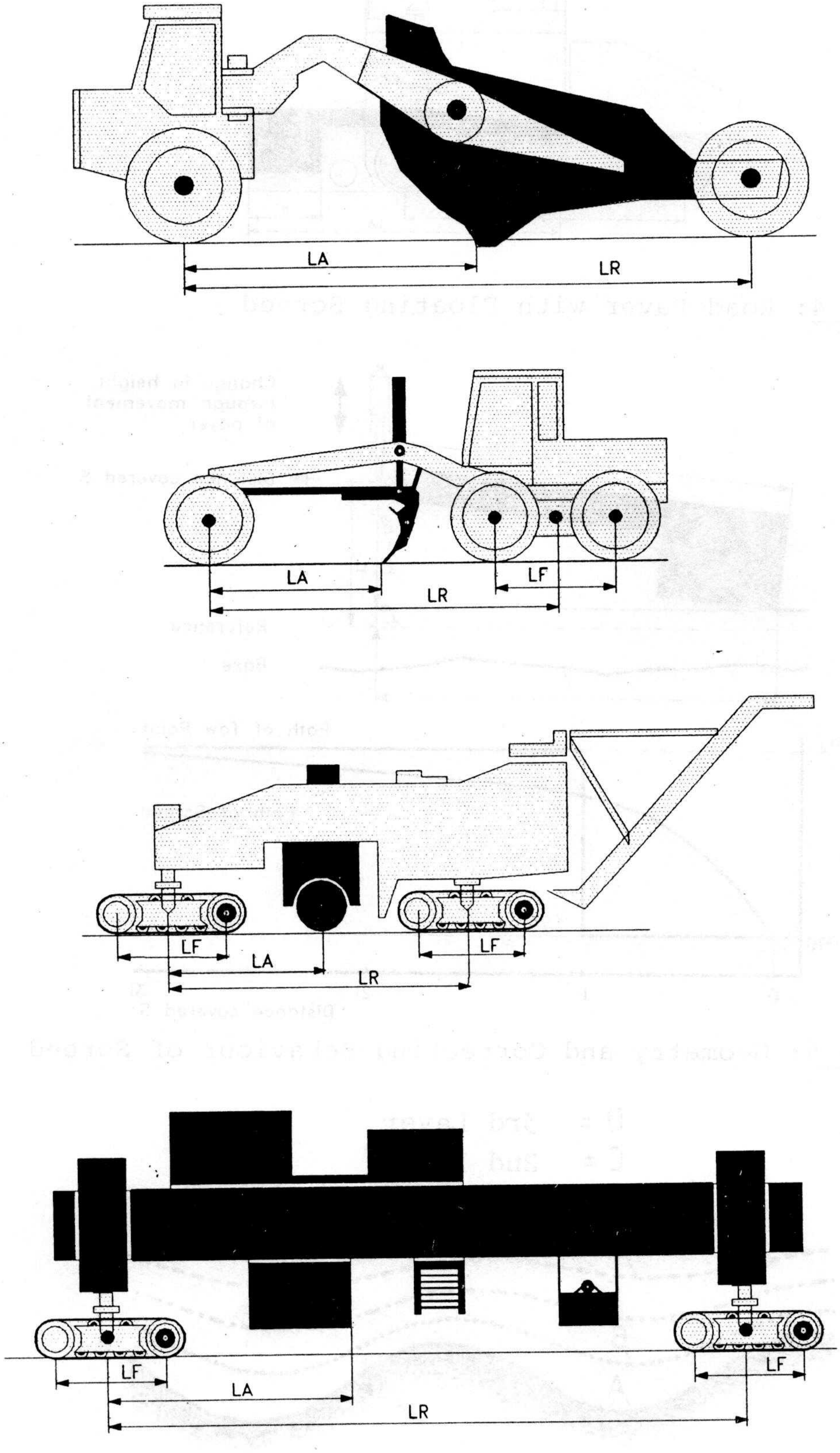


Figure 3: Tractor Scraper, Grader, Milling Machine and Slipform Paver

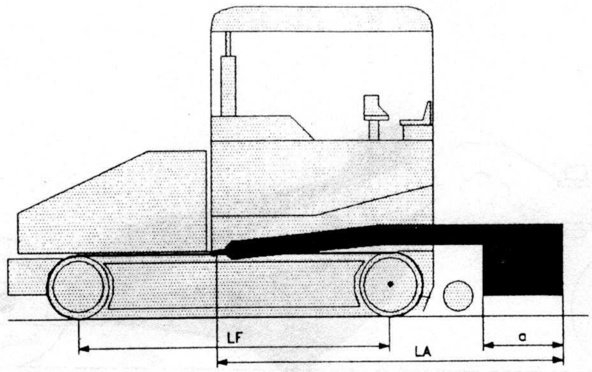


Figure 4: Road Paver with Floating Screed

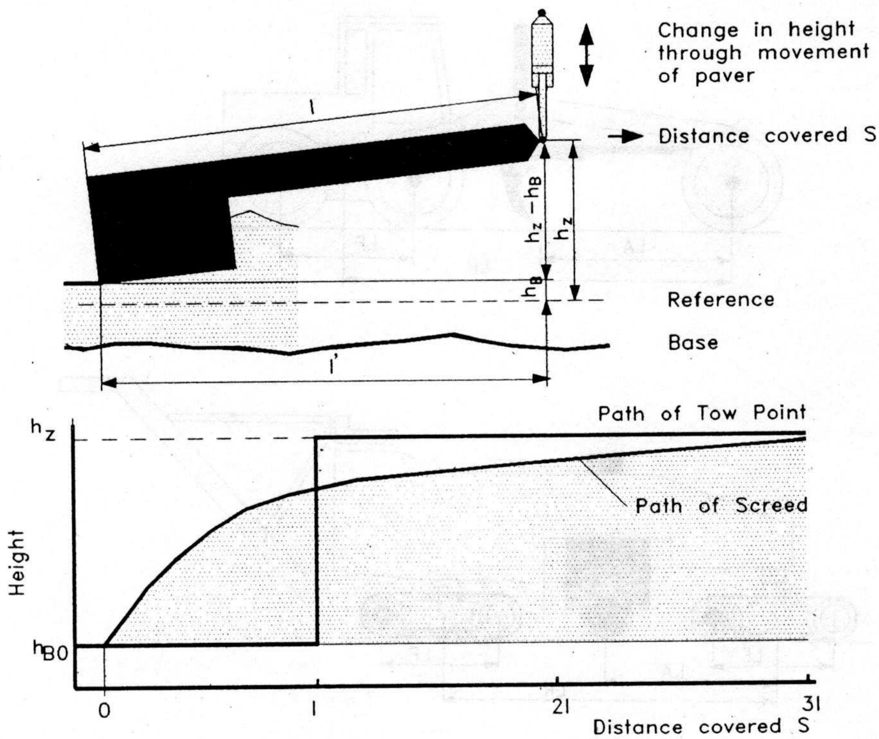


Figure 5: Geometry and Correcting Behaviour of Screed

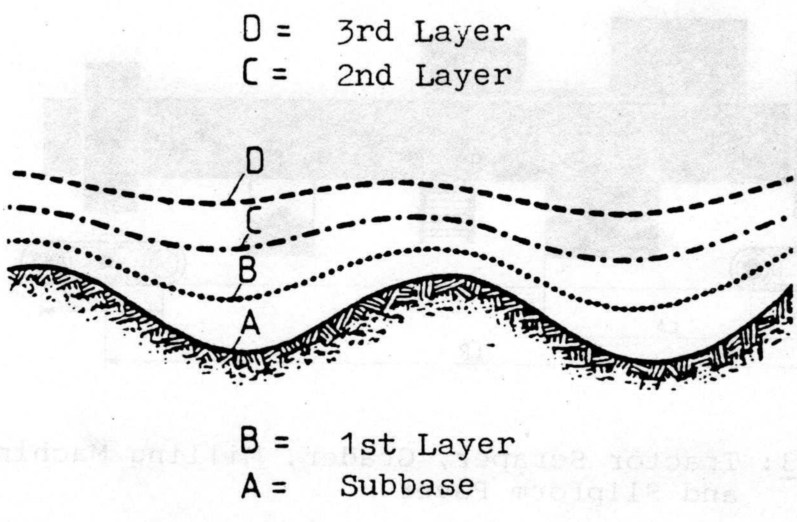


Figure 6: Levelling Effect of Self-Levelling

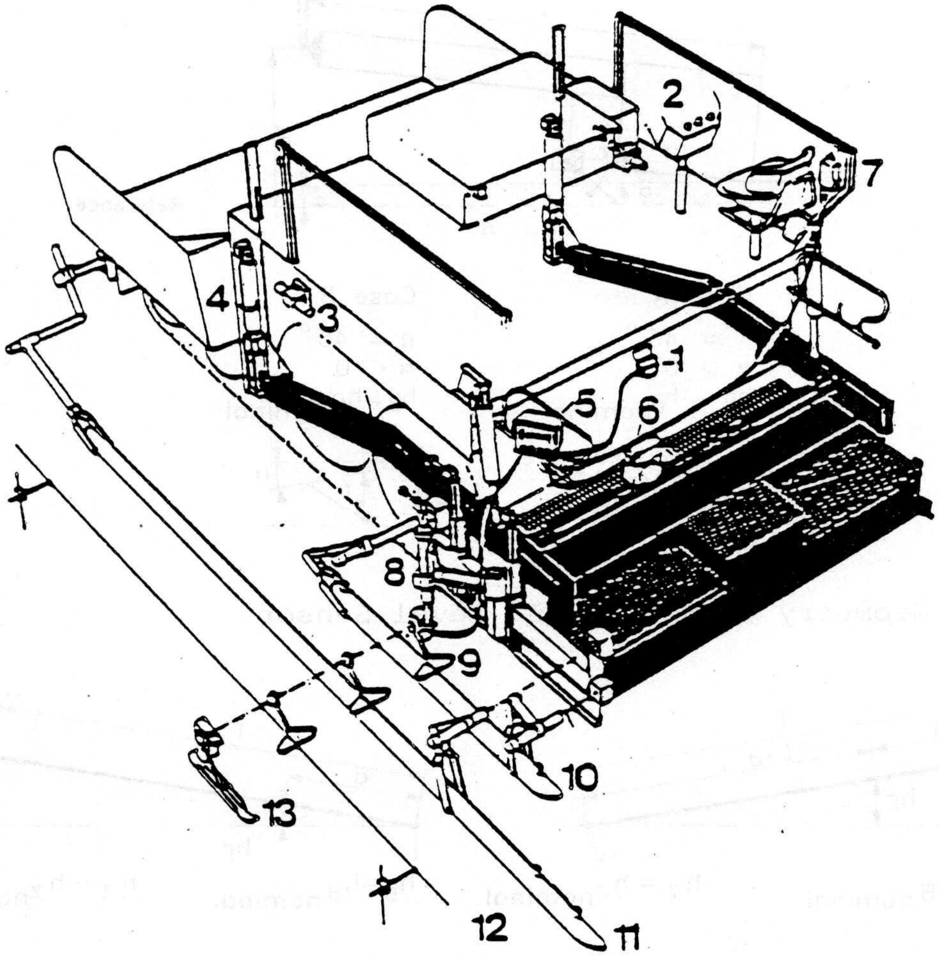


Figure 7: VÖGELE Progressive Automatic Levelling System

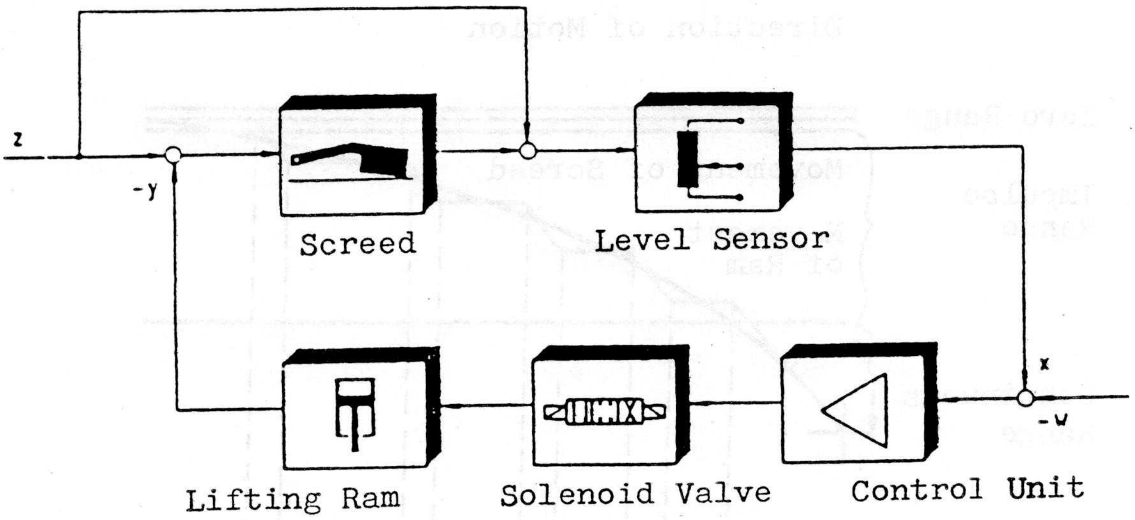


Figure 8: Block Diagram of Control Loop for Automatic Levelling System

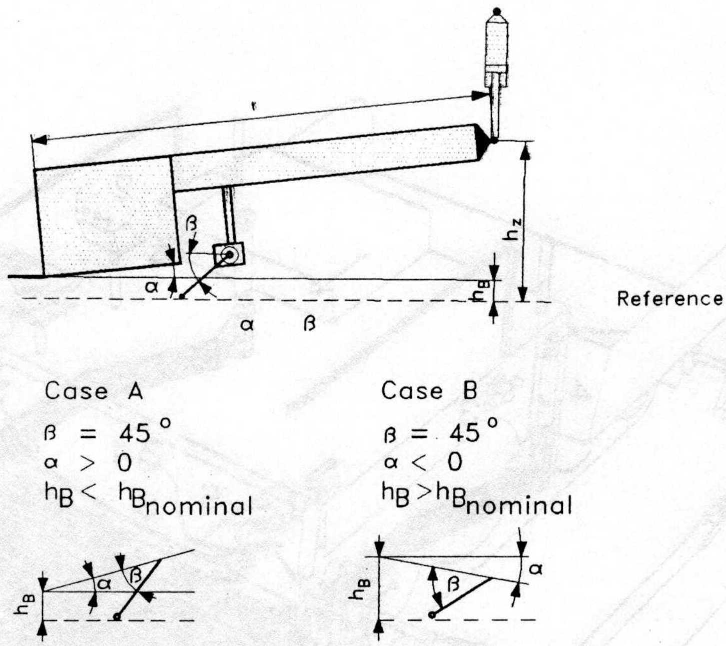
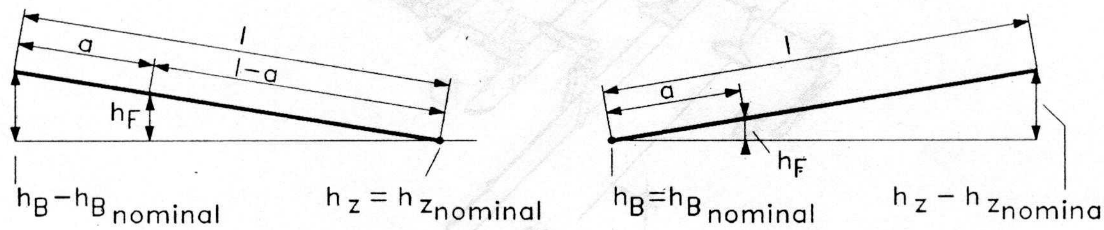


Figure 9: Geometry of Screed and Level Sensor



$$h_F = \frac{h_B - h_{B\,nominal}}{l}\,(\,l-a\,) \qquad\qquad h_F = \frac{h_z - h_{z\,nominal}}{l}\,a$$

Figure 10: Geometric Influences on Level Sensor