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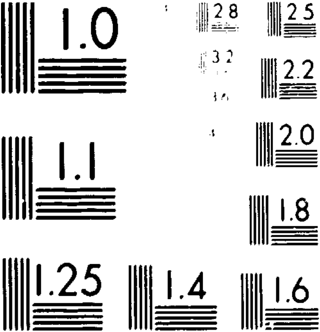

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KILN CONTROL *

by

Villy Egesø**

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Kiln Control

To-day's state of technology within the field of electronics has enabled the cement producer to automate important parts of the cement manufacturing process. An example of such successful automation is the raw meal preparation, which in many modern cement plants is now fully controlled by X-ray analyzer and computer.

Quite naturally, many trials to apply similar principles to the kiln control have been made, but for obvious reasons, so far, with very little success. A simple proposal for computerised kiln control is outlined in fig. 1. However, the difficulties arise already when it comes to procure the necessary operation parameters. Some of the more important ones are hard to monitor continuously in a reliable manner. Although, for instance, accurate and reliable gas analyzers are available, it is difficult to sample the kiln gas due to the severe conditions prevailing at the inlet end. Also it is noted that the burning zone conditions are not directly accessible for measuring, but are reflected in the clinker quality only after a substantial delay.

One other obstacle to have the kiln control computerised is the fact that the mathematical kiln model, which in that case should be programmed into the computer, is very complex. As an example can be taken the calculation of the heat transmission within the proper kiln. Particularly the heat transmission in the chain and calcining zone of long kilns is difficult to describe mathematically, and yet it is very important to the behaviour of these kilns.

The practical approach to kiln control has so far been based on a belief in that as long as the conditions imposed from outside on the kiln system can be kept well controlled at constant rates and qualities, then the kiln will usually behave well and very little corrective control will be needed on the part of the operator.

In these circumstances the efforts have mainly been centred on developing equipment and techniques enabling the accurate domination of raw meal feed, fuel supply, and draught control.

For the satisfactory kiln performance it is very important to feed a raw meal of adequate composition and homogeneity. How raw meal of such quality is procured falls outside the scope of this paper, but as for the homogeneity it is often found that most kilns are noticeably affected by quality variations exceeding what can just be detected in the normal laboratory analysis. Or, in other words, the kiln feed should preferably be no less uniform than:

Standard deviation on LSF = 1
" " " M_s = 0.1
" " " M_a = 0.1

An acceptable kiln feeder should have an accuracy of not worse than ± 1%. Most commonly, the kiln feeder is "synchronized" to the kiln speed in such a way that the material charge in the kiln remains unaffected by varying the kiln speed. Of importance to the uniformity of the kiln feeding is the question of how the precipitator dust is reintroduced to the kiln system. Usually at dry kilns this dust is returned directly to the silo extraction and passes over the kiln feeder. In wet kilns the precipitator dust is in most cases insufflated directly into the kiln at the firing end, without passing any intermediate buffer silo. None of these procedures are ideal, but provided that the dust varies only slightly in quality and quantity, the interference with the kiln operation is tolerable.

When dealing with fuel oil and natural gas, the constant fuel supply to the kiln can easily be achieved. The important properties - such as calorific value and viscosity - usually vary very little if the fuel temperature and pressure are kept within narrow limits. Therefore, the fuel flow to the kiln can be controlled at a constant rate by means of a simple PID-loop.

If the kiln fuel is coal dust, the control becomes more difficult, especially if the coal mill is ventilated to the kiln. In addition, the coal properties often fluctuate more than is the case with non-solid fuels. A number of coal feeding systems have been developed, spanning from simple volumetric feed screws to complicated feeders of the loss-of-weight type, but none of them are able to compensate for a fluctuating heat value of the coal dust.

The fuel supply to the kiln should preferably not vary more than ±0.5%, but for coal firing variations of about ±1% have to be accepted as the best achievable.

A constant draught, i.e. supply of combustion air and the simultaneous disposal of flue gas at an adequate and steady rate, is normally controlled manually by the operator. The flow of flue gases can theoretically be measured by means of a venturi built into a gas duct, but in practice such measurement is rarely reliable nor sufficiently accurate. At preheater kilns the suction after the preheater is a good indication of the gas flow rate, but, of course, the measured value is affected by any built-up in the kiln and the preheater. It has been suggested instead to rely on the pressure differential over the two top stages of cyclones, as these are usually free from coatings.

In fig. 2 is given a proposal for a practicable kiln control system. The operator executes manually all adjustments to the rate of feeding and firing and to the draught. The control loops then automatically maintain these at set values. The operator's decisions are based on a series of observations among which could be mentioned:

- A visual assessment of the burning and outlet zone of the kiln - either directly from the platform or via a closed circuit TV-screen in the central control room. Although many kilns are dusty and the visibility so poor that only few details can be distinguished, the TV-screen might still give valuable information to the operator. He observes whether the clinker charge in the cooling zone is sliding jerkily as a solid cake or if it is turning over steadily. Also the angle of repose of the clinker bed and the clinker granulation are signs of how well burnt the clinker is.

- Many of the fluctuations passing on inside the kiln are reflected in the load on the kiln drive motor (kiln torque). If the burning zone tends to go on the hot side of normal, the angle of repose of the clinker bed and consequently the kiln torque will increase and vice versa. Therefore, especially at the short 4-stage and precalciner kilns, a kiln torque recorder would be a useful tool for the operator. At the long kilns, especially the wet ones, the effect of the burning zone conditions might be overshadowed by the effect originating from fluctuations in the chain zone. The operator would judge the situation from the trend of the torque (rising - steady - dropping) rather than from the absolute torque value.

  The interpretation of the kiln torque has always to be done with some critisism, particularly if the kiln is in an upset situation. For instance, a fast drop in kiln torque could be a result of the burning zone being in melt. In the case of loss of coating, the torque recording has to be disregarded for a while until a new coating has stabilized.

- The clinker quality, which of course is of primary concern in the kiln control, is followed closely. It is common practice to make the litreweight every hour, i.e. check the bulk density of a screened clinker sample and in this way get a fast indication of the degree of burning.

  The clinker litreweight may not always be a good control parameter. Kilns with a dense circulation of clinker dust between the cooler and the burning zone in some cases produce a coke clinker of which the granules actually are agglomerates of micro-size clinker. The litreweight of such clinker is always very low even by overburning.

Also the content of uncombined lime (free CaO) is frequently determined. In some plants is deliberately burnt to a very low free CaO - 0.3 to 0.5% - and in that case this control will only serve the purpose of indicating an underburning of the clinker, because an overburning will not cause any noticeable reduction below the target value for free CaO.

In a few plants the use of frequent microscopic examination of the clinker structure has been practiced for some years now as an integrated part of the kiln control. The value of this so-called Ono method shall not be discussed here.

- In the control, especially of long kilns without cyclone preheaters, some key temperatures are useful. The back-end temperatures (smoke chamber and slipring) tell the operator how to set the draught to achieve a proper balance between the situation in the burning zone and the conditions at the inlet end of the kiln.

  An optical pyrometer installed at the bottom of the riser pipe of a short 4-stage kiln may serve to avoid overheatings and thus to keep coating formation at this often critical location at a minimum.

  A thermocouple attached to the burner pipe near to its tip is sometimes found to give good guidance to the operator. It measures the secondary air temperature, although not in a very exact way, since it is also affected by the radiation from the hot clinker in the cooling zone of the kiln. At any rate, such an instrument would reflect the situation in the burning zone only after a certain delay, say 10-20 minutes.

The difficulty in measuring the actual material temperature in the burning zone by for instance a radiation pyrometer is due to the varying dust burden of the secondary air. Sometimes a two-coloured radiation pyrometer is installed at the kiln hood, which measures the temperature by comparing the intensity of radiation at two distinct wave lengths of the spectrum, but in practice only in exceptional circumstances such a pyrometer has worked so well that a direct, automatic control of the firing rate has been possible.

- Although at first glance the control of a precalciner kiln would appear to be more complex than that of a conventional kiln, experience proves that this is not the case. The rate of firing in the calciner is accurately controlled by the gas temperature after its collecting cyclone (PID-loop). In this manner a very uniform degree of precalcination is achieved of the material passing into the kiln, resulting in a very steady kiln operation with practically no need for corrective interference.

- On request of the health authorities many kilns, especially in Japan and the USA, have in recent years been equipped with continuous NO_x analysers in the smoke stack. The NO_x content of the flue gases originates partly from the high temperature synthesis in the flame from elementary oxygen and nitrogen of the combustion air. The intensity of the NO_x generation depends on a number of factors, among which the temperature conditions in the burning zone are found to have a strong bearing. Therefore, at these plants the kiln operators quite naturally take advantage of this additional control parameter and it becomes more and more frequent to install a NO_x analyser, even if not required by the authorities. The trend of the NO_x curve on the recorder tape appears to be a very fast indication of changes in the burning zone situation (fig. 3).

The kiln operator at intervals assesses the situation by means of his preferred control parameters of which some are available to him as exact figures and some are of a more vague apprehension in his mind. He assesses not only the actual situation, but he also looks at how the development has been in the nearest foregoing period.

He then makes his decision on what to do, if anything at all. If the kiln is unbalanced or if it tends to develop away from the desired situation, the operator can interfere according to one of two different strategies:

- he can either vary slightly the kiln speed and - thanks to the synchronisation - automatically the rate of feed changes accordingly. He will then leave fuel and draught untouched.

- or he can remain with the same kiln speed and feed and correct the firing in the kiln and the draught accordingly.

As said previously, the operator is assisted in his job by a few automatic control loops which maintain the various rates of input at set-point values. In fig. 4 two more such loops are shown which have proved useful in the case where the flue gases are utilized in a raw mill:

- The pressure at the delivery side of the ID-fan (-10 to -20 mm WG) remains constant by controlling the filter fan speed or its damper. In this manner the effect of mill starts and stops will be compensated for automatically and the kiln draught will not be affected.

- The gas temperature after the cooling tower controls automatically the water spray in the tower. This loop helps to maintain steady conditions at the precipitator, and this is very important to the filter efficiency. The control loop must be combined with a programme automate which automatically switches the water spray between a large and a small quantity of water, depending on whether the raw mill is operating or not.

The PID-controller is too slow to cover such changes to the situation fast enough.

If a 4-stage or precalciner kiln is equipped with a by-pass, the operation of it would normally be fully automatic (fig. 5). One loop controls the cold air fan and keeps the volume of cold air constant at a pre-set value. Another loop makes the temperature of the gas/air mixture after the mixing chamber control the main fan to extract exactly so much hot kiln gas that when mixed with the pre-set volume of cold air, the desired mix temperature is maintained. If needed, the by-pass percentage is altered simply by changing the set-point for the cold air insufflation.

As already explained, the fully computerized kiln control based on a strict mathematical model has never really been able to take over the responsibilities from the operator. The so-called "fuzzy" control attacks the problems from a different angle (fuzzy = unprecise). The fuzzy control is based on empiric techniques rather than on scientific calculations. The technique intends in each situation to copy the actions taken by a skilled operator.

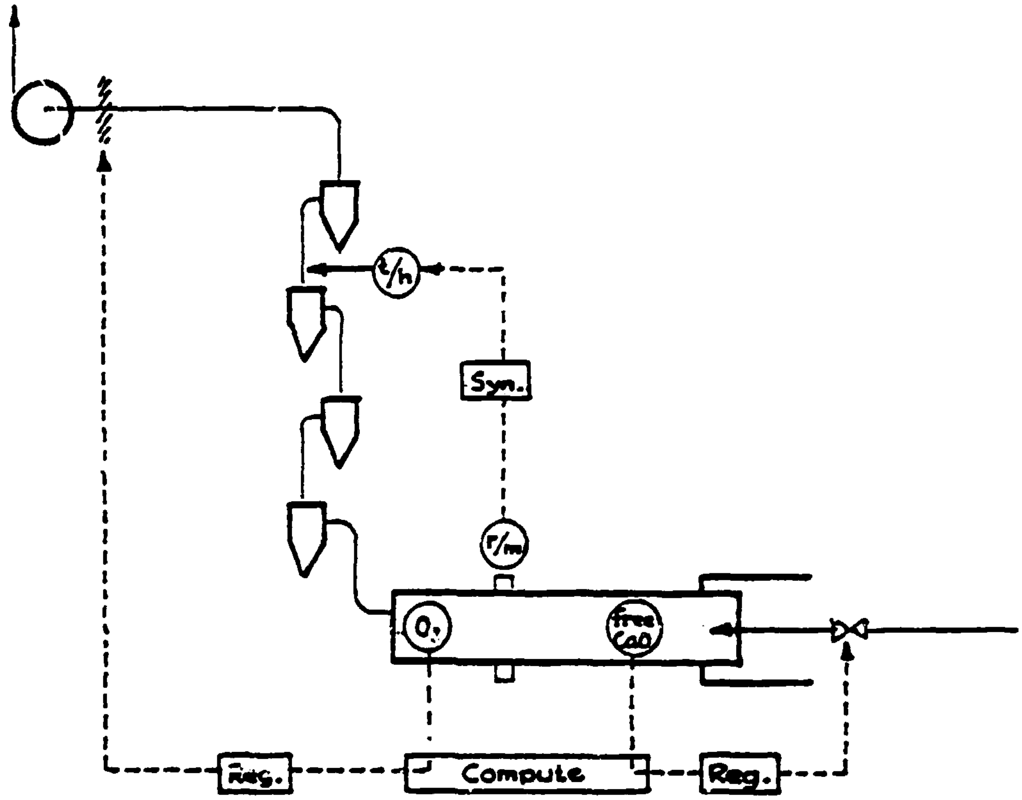
A series of typical states in which the kiln could be encountered is defined and an equivalent series of actions to be taken is established. Although some of the important control parameters are not available to the computer in the form of exact figures, they can somehow be quantified.

A simplified fuzzy kiln control is drawn up in fig. 6. The control is based on two parameters only - free CaO and kiln torque. At short intervals (10 sec.) the two parameters are scanned and filed in the computer. At longer intervals (10 min.) the situation is evaluated. At even longer intervals the trends are evaluated and the situation is corrected if called for. The two variables give rise to 9 different situations in which the kiln may be found. Every time the actual situation is verified, a comparison is made to all 9 possible situations and points (0-1) are given to express the degree of resemblance to each one of the 9 situations (fig. 7). Also 9 contributions to a change of firing rate are calculated, and at the end, the resulting fuel correction is worked out and executed together with the necessary draugth regulation (fig. 8). The action taken by the computer is formulated in a set of rules in the form of

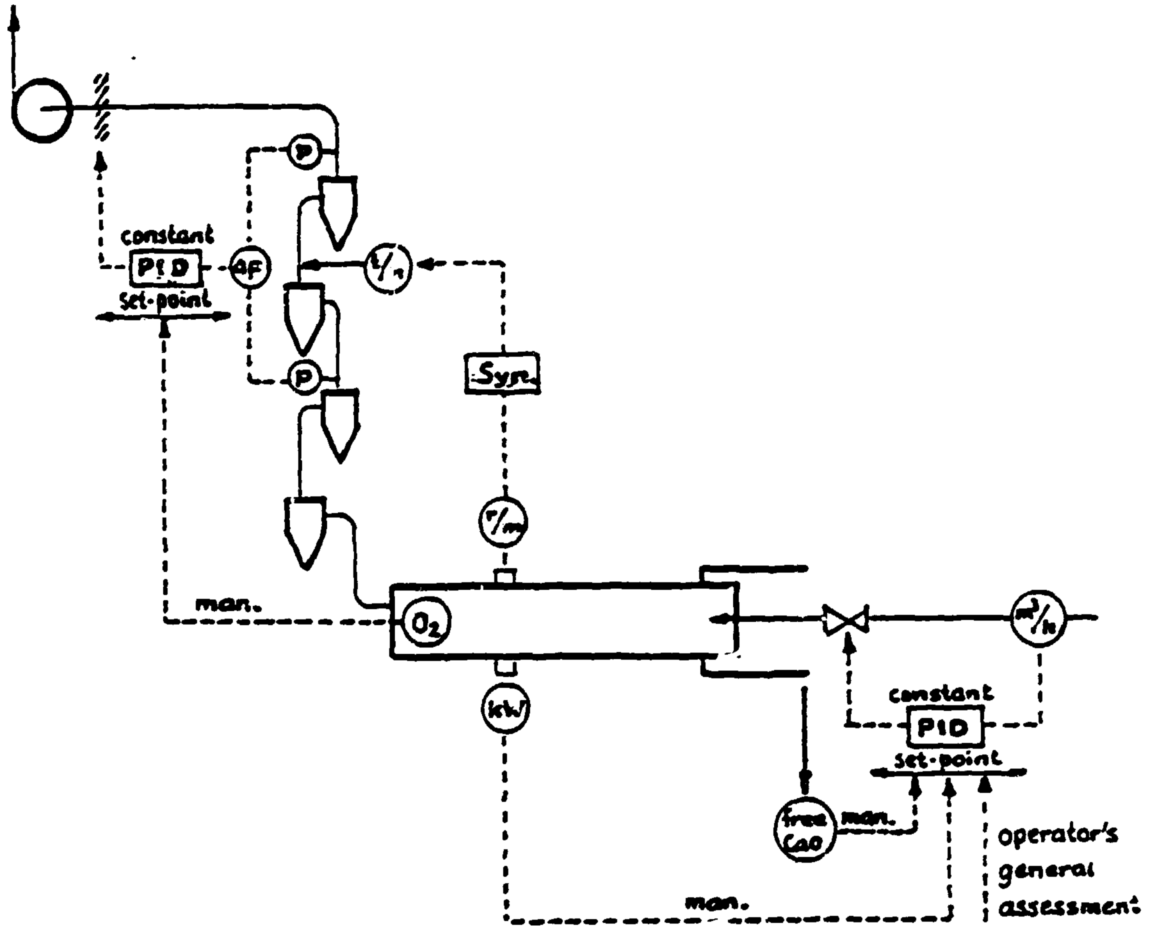
if .... and if .... then ....,
if .... or if .... then ....,
.
.
.
.

On an experimental basis a few kilns have for some time now been controlled by the fuzzy-logic principles. The computer is certainly not any better in operating the kiln than is the experienced operator, but the automatic controller can take off a great deal of the dull routine work from the operator's shoulders.

Idealised Kiln Control



Kiln Control in Practice



Kiln Control

Temporary overheating of burning zone (idealised)

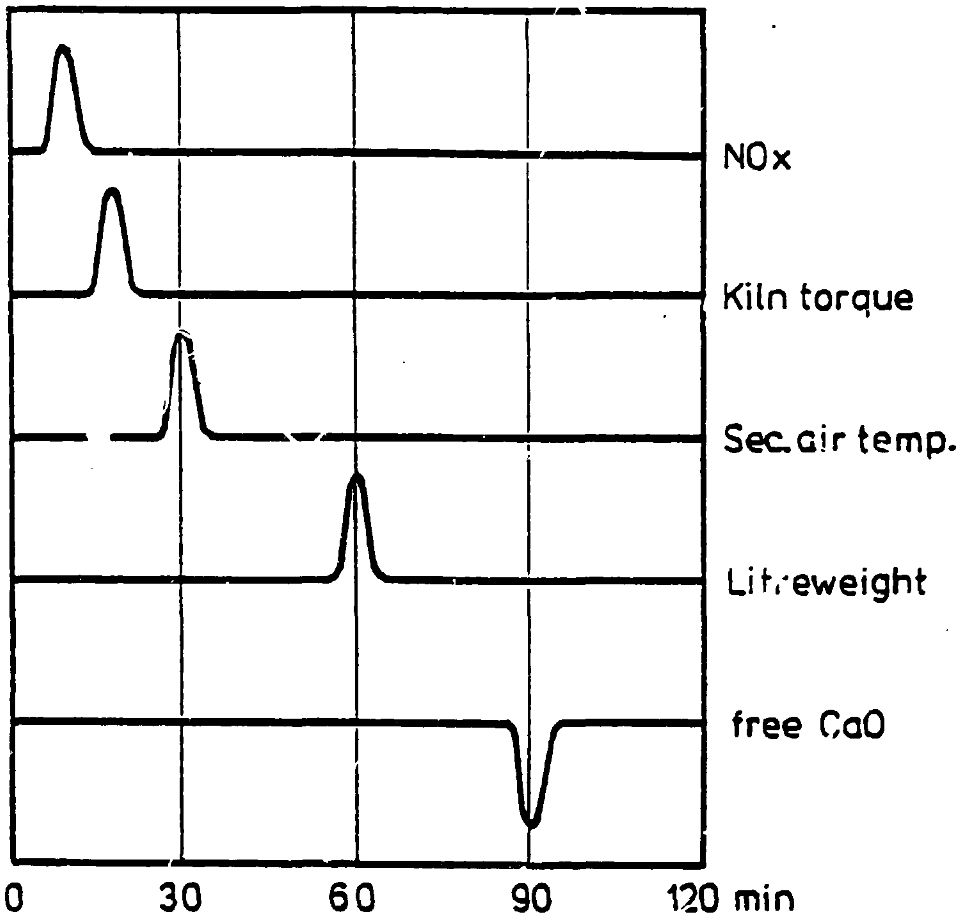
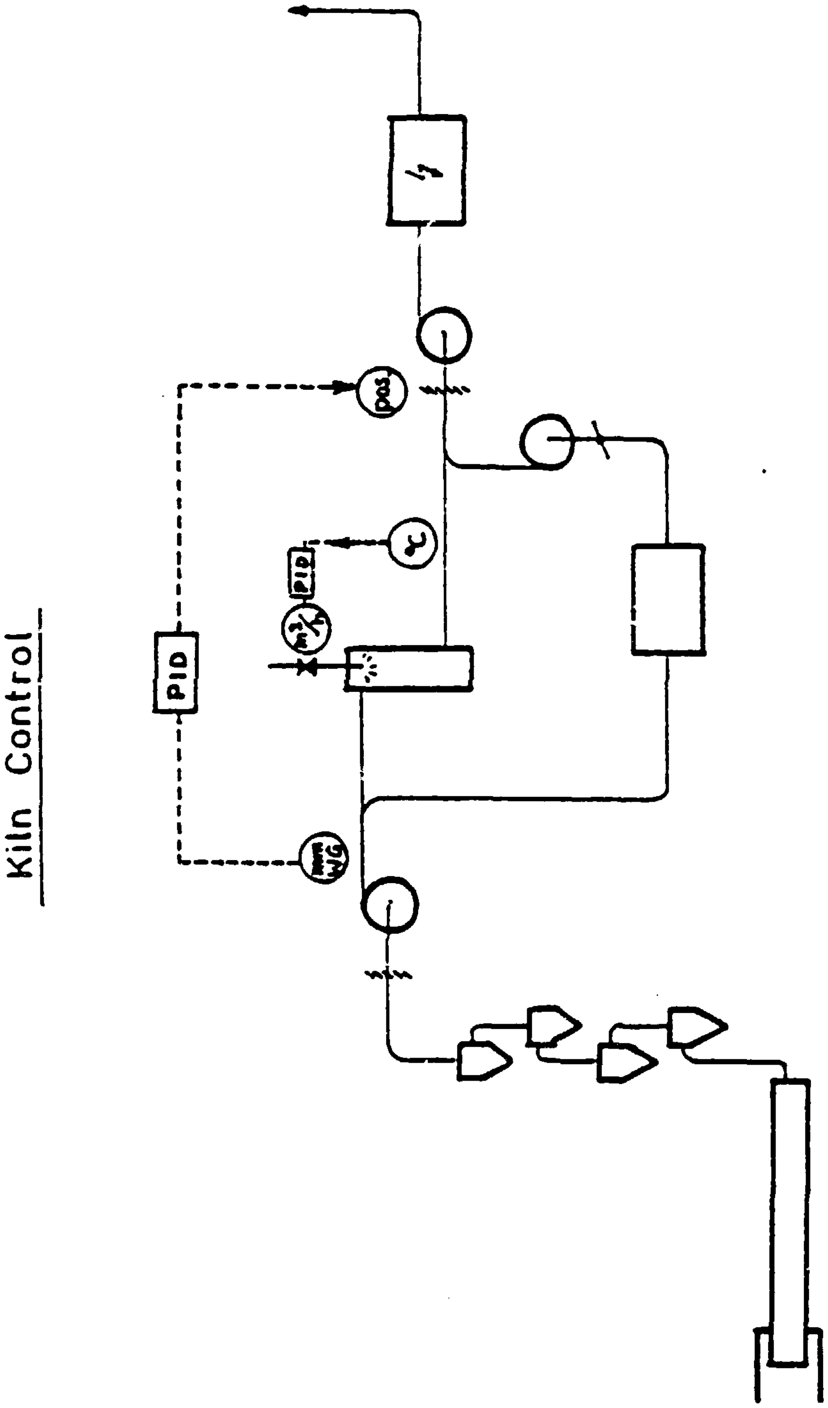


FIG. [illegible]



Kiln Control

Kiln Control

By-Pass

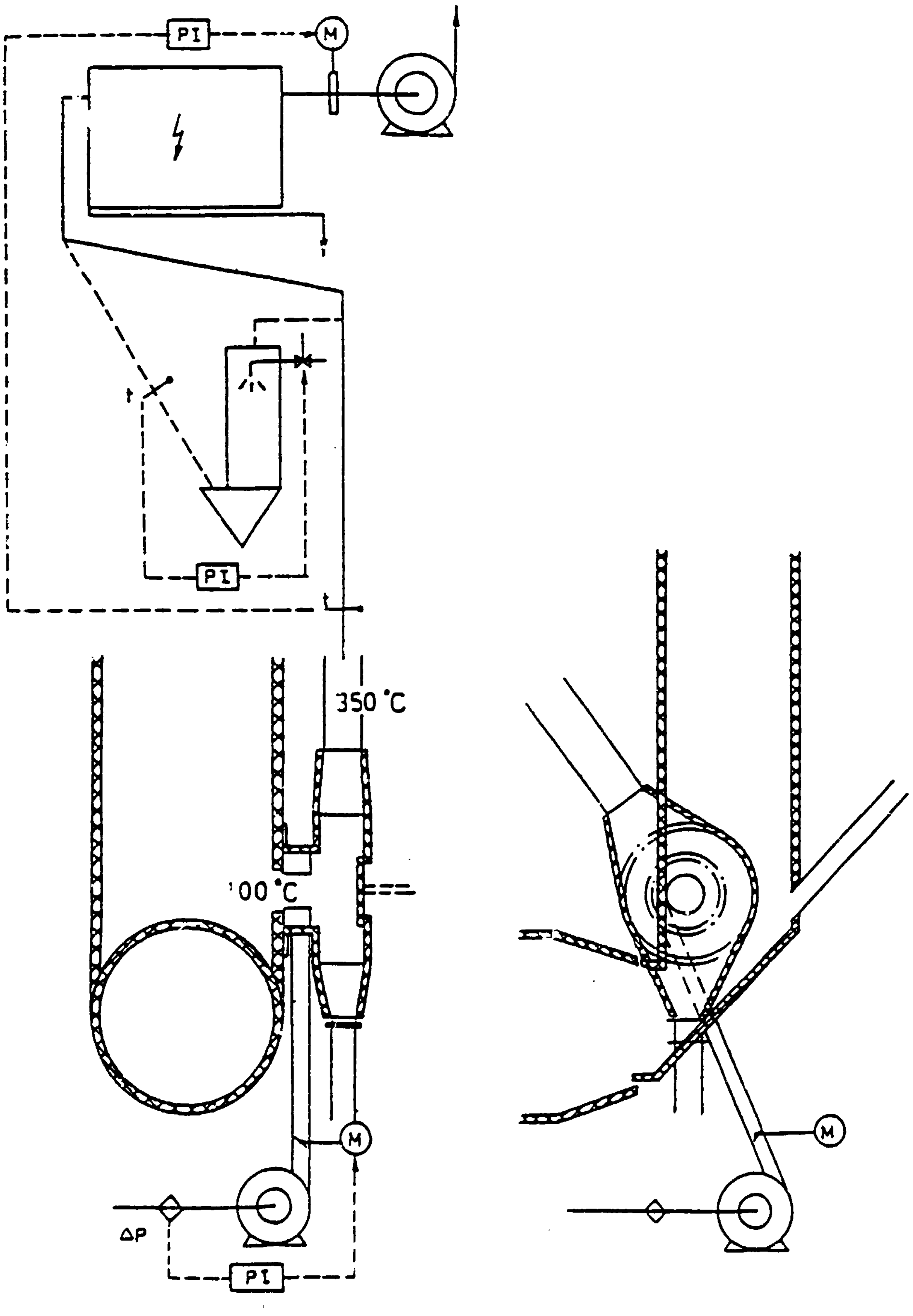


FIG. 6

Kiln Control

Situations with two Variables

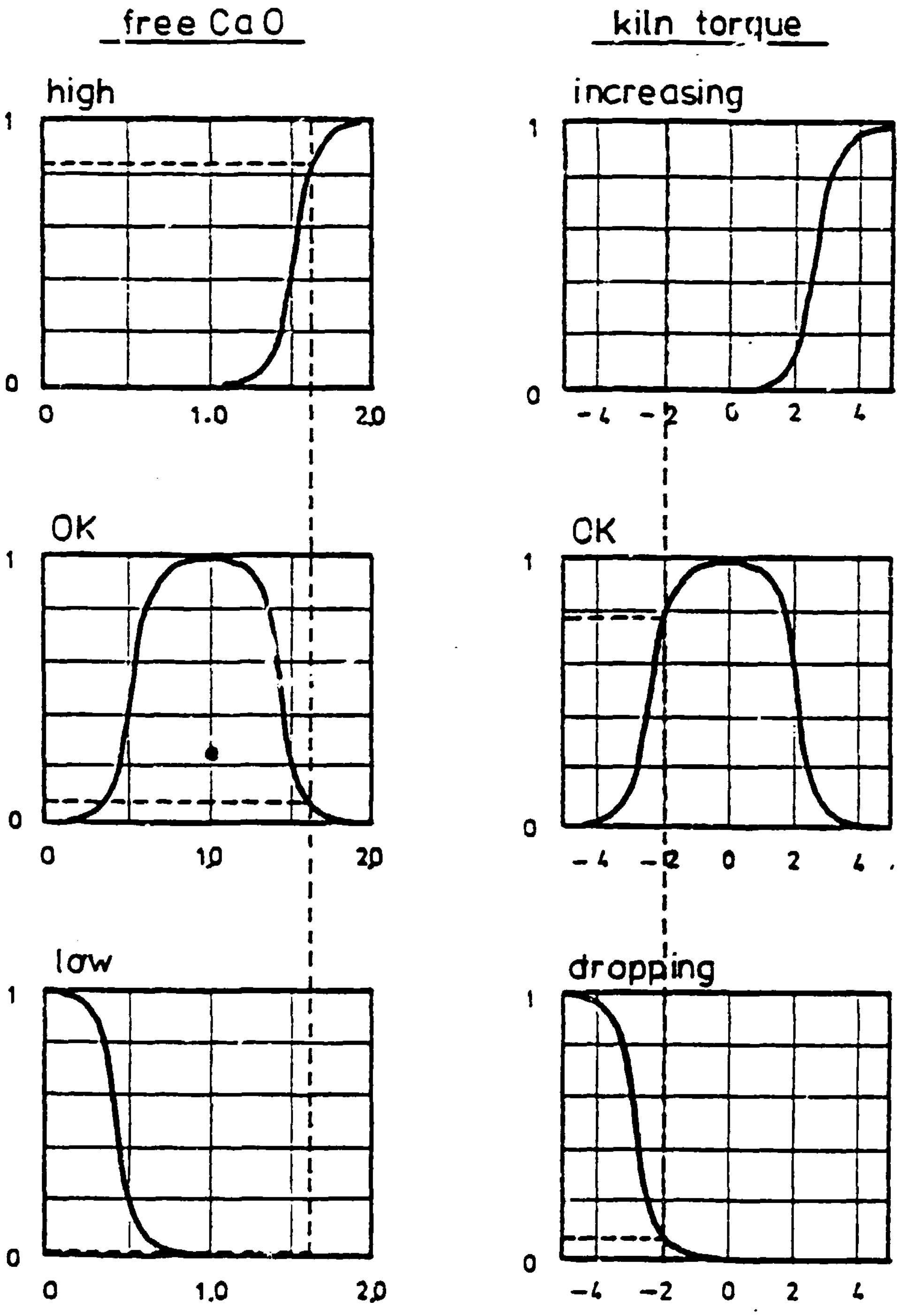
Situation no.	Free CaO	Torque	Fuel Correction
1	high	increasing	0
2	high	constant	small increase
3	high	dropping	large increase
4	OK	increasing	small reduction
5	OK	constant	0
6	OK	dropping	small increase
7	low	increasing	large reduction
8	low	constant	small reduction
9	low	dropping	0

Example: large increase : + 300 l/h
small increase : + 150 l/h
small reduction : − 150 l/h
large reduction : − 300 l/h

FIG. 7

Kiln Control

Resemblence of the Variables



Example: free CaO 1,6 % , torque −2 % / h

FIG. 8

Kiln Control

Computation of the Resulting Fuel Correction

Situat. no.	Free CaO		Torque		Final degree	Fuel Correction (l/h)
	-	degree	-	degree		
1	high	0.85	incr.	0	0	0 × 0 = 0
2	high	0.85	const.	0.75	0.75	+ 150 × 0.75 = + 113
3	high	0.85	drop.	0.08	0.08	+ 300 × 0.08 = + 24
4	OK	0.07	incr.	0	0	− 150 × 0 = 0
5	OK	0.07	const.	0.75	0.07	0 × 0.07 = 0
6	OK	0.07	drop.	0.08	0.07	+ 150 × 0.07 = + 11
7	low	0	incr.	0	0	− 300 × 0 = 0
8	low	0	const.	0.75	0	− 150 × 0 = 0
9	low	0	drop.	0.08	0	0 × 0 = 0

Resulting regul.: + 148 l/h