AUTOMATION AND CONTROL IN CEMENT INDUSTRIES

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Contents

1. Introduction

The cement production industry is one of the most fundamental industries from several points of view. Its product can be found almost everywhere in the everyday life, and the industrial society cannot survive without cement. This industry is a great power consumer, one of the main power consumers in many countries.

The technology has been known for a long time, so it is not accidental that many authors have already written about it. The main problems in the automation of the production are also well known from such excellent survey papers.

It is very difficult to write considerable new works, in comparison to the above papers, however, the possibilities of the applications of certain methods and algorithms of the modern control theories have been considerably increased by the widespread control engineering applications of the microprocessors and computers in general.

The so-called application threshold has been decreased by these advanced technologies. Therefore, this article aims to give a new and comprehensive survey of references which discuss the possibilities of applying advanced control theories, because the continuous processes of cement production always give good pioneering, experimental works right from the beginning.

2. Description of the Technology

The recent technologies of cement production have been known for about 100 years and only the machinery, and the specifications (effectiveness, capacity, controllability) have been improved gradually since that time. The technology itself is a continuous process, however, large material storages are applied between the main technological units that make the separate, batch operation of them possible.

These units consist of several parallel elements (mills, kilns, etc.) for the same purpose (perhaps with different capacities) to increase the overall capacity and reliability of the production. The main parts of the cement production can be seen in Figure 1. Here, some blocks can be missing in a given factory, but thick lines denote those that can be found in most cases.

Next, the consecutive five main parts of the technology are surveyed. The basic technology has many variants, differing in extent, all over the world. Here the common properties will be described.

2.1. Quarrying and Preparation

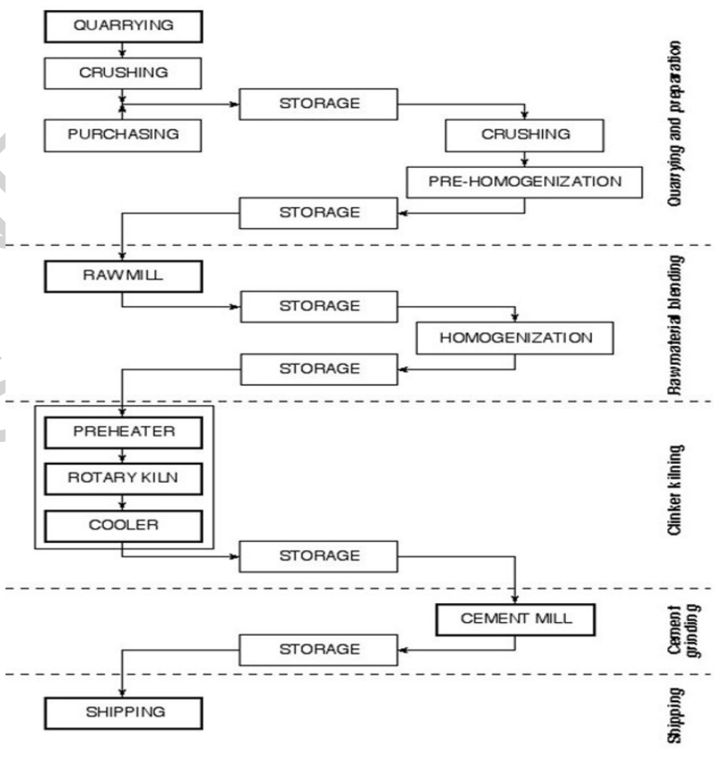

Figure 1. Typical basic technological operations

The raw materials for cement production are selected based on their chemical compositions. The main component is a calcium oxide (CaO) source. Mostly, limestone is used, but chalk, marl, dolomite and oyster shells can also be applied. The next two components are silica (S_iO_2) and alumina (Al_2O_3) obtainable from clay or shale.

Quartz and bauxite or other minerals can also be used. The fourth important component is ferric oxide (Fe_2O_3) which can be ensured from iron ore, pyrite or blast furnace slag. These materials are quarried or purchased and are transported on road, railway or conveyor to the cement factory. The raw materials are usually crushed in the quarry, sometimes in the factory, up till the size as machinery can handle or grind.

If the composition of the raw material is strongly varying, a pre-homogenization process is usually applied. This can be done in so-called mixing beds, however, the simplest solution is to build large stockpiles. Their purpose is partly the intermediate storage, but the pre-homogenizing possibility is much more important, if appropriate vertical or horizontal layering and perpendicular random or controlled extraction is applied.

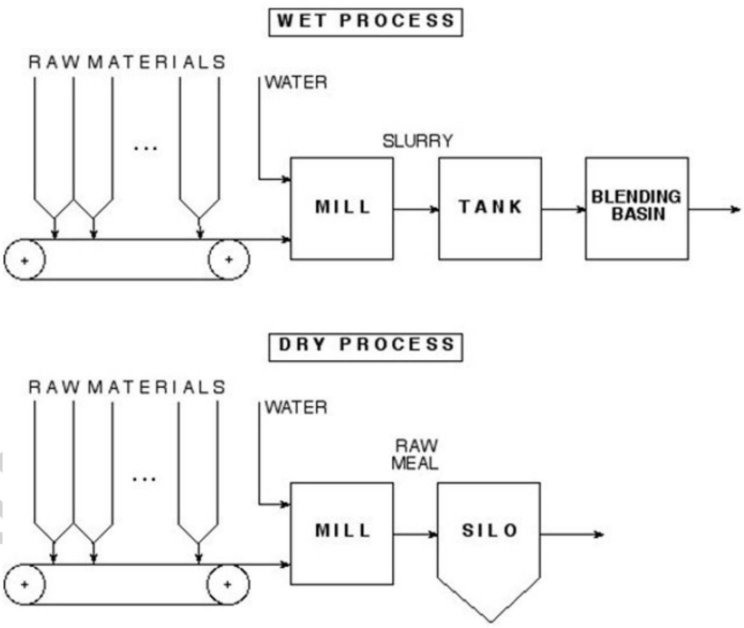

Figure 2. Typical blending systems

The prepared raw materials are stored in silos for the next technological step, which is the raw material grinding and blending system.

2.2. Raw Material Blending

At the next technological unit, the prepared raw materials are mixed during a grinding operation by dry process or together with water in wet process. The materials are proportioned using a control system to ensure the desired chemical compositions in the final ground mix produced by ball mills generally.

The raw materials are ground and mixed more easily by adding water to them (grinding is possible separately, too), however, the evaporation of the water later is very disadvantageous from an energetic point of view. This is the main drawback of the wet process, therefore in the next parts, mainly dry processes will be discussed, but the energy consumption still remains one of the most vital questions.

The wet or dry grinding is continued until the particle size which still increases the speed of the next technological step, namely the clinker kilning.

In the case of the dry process, the so-called raw meal is ground until the prescribed fineness, and is then mixed according to the given chemical compositions, and then stored in silos. Often, these silos are homogenizing ones, using air to mix the whole silo content in batch operation before feeding the raw meal into the kiln. Under the wet process, the slurry is stored in basins under continuous blending. Grinding is generally made using ball mills, many times by applying a pre-crusher with hammers. The efficiency of grinding is very low, only a few percent of the invested energy is devoted to the real comminution, therefore the technology is continuously developed to increase the effectiveness. Recently the closed circuit ball mills are most widely used with a cyclone (or a hydrocyclone) separator. At the dry process, the middle outlet (feeded at the two ends) closed circuit mills are also frequently applied. Typical blending systems are shown in Figure 2.

2.3. Clinker Kilning

In this step, the mix of the raw materials (raw meal or slurry) is burned to clinker in a rotary-kiln. This is the heart of the entire technology, and the most sophisticated chemical and physical processes can be found here.

The rotary kiln is a long cylindrical steel tube inclined downward from the feed end and lined with refractory brickwork. It rotates around its axis. The raw meal (or slurry) is fed in at the upper end while heating is applied at the lower end. Natural gas, fuel oil or pulverized coal are generally used. The fuel (with the primary air) is burned and combined with the preheated (secondary) air and the hot combustion gases go up the kiln toward the entering raw material forming a special counter current heat exchanger. An induced drought fan at the feed end of the kiln speeds up the heat current.

In the wet process four main sections with different operations can be distinguished along the kiln system:

(1) Starting from the feed end, the first section is the drying zone, where the water is evaporated from the slurry. The heat transfer is helped by hanging chains, so this part is also called the chain section.
(2) The material moves down to the next section and its further heating causes the start of the decomposition of the calcium carbonate. The released carbon dioxide leaves the kiln with the gas stream through the upper end. This sector is called the calcining zone.
(3) The material enriched with calcium oxide moves closer to the fuel combustion area of highest temperature. This sector is called the burning zone (about 1400°C). The

reactions occurring are more complex and they result in clinker, by combining CaO, S_iO_2, Al_2O_3 and Fe_2O_3 to form dicalciumsilicate (C_2S), tricalciumsilicate (C_3S), tricalciumaluminate (C_3A) and tetracalciumaluminoferrite (C_4AF).

(4) The clinker, some centimeters in diameter, leaving the kiln must be cooled, which is done by a planetary cooler installed on the surface of the kiln around or by a traveling grate located under the kiln end. If the cooler is of the grate type, then the air is blown through the hot clinker bed supplying the preheated air to the kiln. The clinker is cooled to a degree necessary for mechanical handling then it is stored in large quantities.

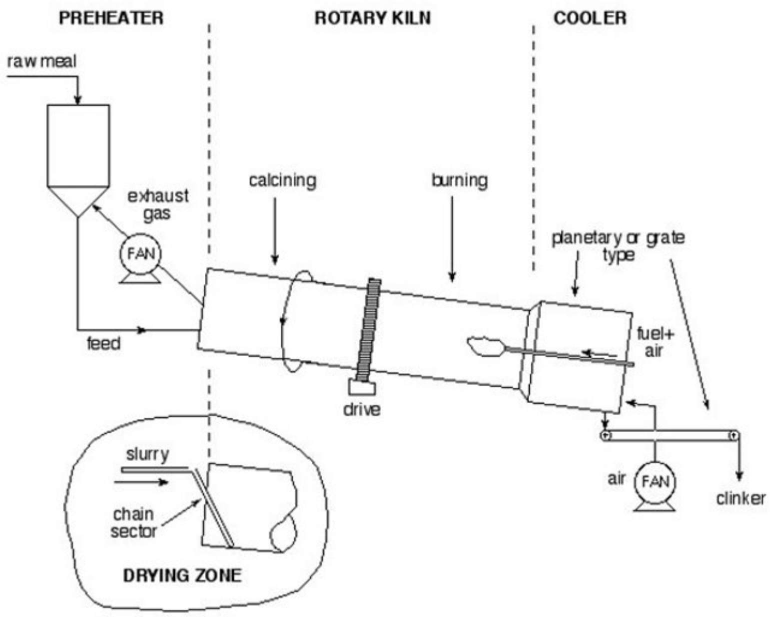

Figure 3. Typical kilning system

In the dry process, the raw meal passes through counter current cyclone based pre-heaters (in many cases through a precalciner short kiln, too) into the rotary kiln generally. The heat demand of the pre-heater is supplied by the hot exhaust gas of the kiln. There are many variants of these preheating equipments.

The gases leaving the kiln system get into a dust-collector and are expulsed to the atmosphere or to other heat recovery equipments. The dust collected is usually returned to the kiln mostly with the raw material. Typical cement kilning systems are shown in Figure 3.

2.4. Cement Grinding

The clinker with average diameter of some centimeters is ground, to reduce its particle size adding a small amount of gypsum $(CaSO_4)$ to inhibit fast setting. Closed circuit ball mills are generally used to reach the given size distribution and specific surface area. A very simple technological scheme can be seen in Figure 4.

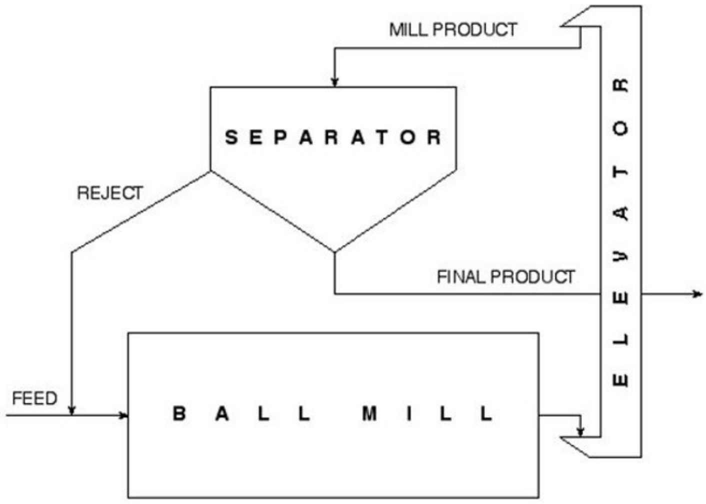

Figure 4. Typical cement grinding mill

A closed circuit consists of three main parts: the ball mill itself, the elevator lifting the mill product to the separator and the separator returning the oversize material to the mill as reject. The separator splits the final (fine) product out of the system.

3. Control Problems and Systems

The quality of the produced cement depends on the raw materials and also on the processing operations. The control system of the cement production controls these operations to produce the maximum quantity of the cement with prescribed quality and minimum cost.

The quality also depends on many variables. The appropriate rate of the basic components determining the setting time, strength, heat of hydration, expansion, etc., is the most important. The free lime content (FLC) also influences the quality to the size distribution and the relative surface area.

A great many open and closed loop controls can be found in the cement production, however, the proper control of the operation-triplet, i.e., proportioning — burning — grinding can ensure that the overall control aim is reached, and that the other controls are auxiliary ones. Therefore, these three areas are investigated next.

The above operations-triplet can theoretically be controlled together, however, this seems to be, in practice, a large-scale system, therefore a reasonable decomposition is necessary. The practical decomposition is solved by controlling these units separately, maintaining intermediate materials (raw meal, clinker) of constant quality for the consecutive units. In this way disturbances arising at a unit propagate to the next unit in a least extent.

In consequence of the drastic increases in the energy prices, a much higher attention has been paid to the dry process, therefore — not disregarding the widely used wet process — only the dry one is discussed, and only the most important control philosophies and systems are treated, because it is impossible to survey all existing strategies.

3.1. Quarrying and Preparations

The following objectives should be achieved:

- to produce crushed stone of prescribed average composition and proper size as demanded by the next technological processes
- to achieve the desired production rate with minimum cost, maximizing the life of the quarry.

Usually an off-line computer control is used to reach the above goals. The exploitation of rocks is controlled by probe-drilling analyzing the layers. The main idea is not using only the best rocks, but the worse ones, too.

The control can help to receive an optimal allocation and reallocation of the big machines and to minimize the transport and production costs. This control can be considered a management guide.

The role of a computer can be much higher at the pre-homogenization stage, where optimal strategies based on the average stockpile (or blending bed) layer compositions can be obtained for the vertical or horizontal extraction. This control ensures the average chemical compositions and decreases their fluctuations by mechanical tools.

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Biographical Sketch

László KEVICZKY was born in Ráckeve, Hungary, on April 2, 1945. He graduated with a Higher Education Honors Degree from the Electrical Engineering Faculty of the Technical University of Budapest (TUB) in 1968, and received the Doctoral Degree in system identification from the same school in 1970. He was given the Candidate of Sciences Degree (Ph.D) in design of regression experiments in 1974 and the Doctor of Sciences Degree in adaptive control in 1980 from the Hungarian Academy of Sciences (HAS). In 1985, he was elected Corresponding Member of the HAS. In 1991, he became the founding member of the Hungarian Academy of Engineering and was appointed as a Foreign Member of the Royal Swedish Academy of Engineering Sciences. Since 1993, he has been a Member of the HAS, and was elected as the Secretary General of the HAS. In 1996, he was elected for a second term of three years ending in 1999. In 1999, he was elected as Vice-President of the HAS.

He had been working with the Department of Automation at the TUB since 1968, where he became the head of the Advanced Control Group. In 1981, he joined the Computer and Automation Research Institute (CARI), HAS, where he was Head of the Department of Process Control until 1985. He was the director of the institute between 1986-1993. In 1994, he was appointed as Professor of the Department of Automation at the TUB. Since 1999, he has been research professor of CARI.

Between 1981-84, he was the vice-chairman, then chairman (1984-90) of the Applications Committee in IFAC. From 1990-93, he was vice-chairman of the Technical Board. He was the member of the Council for the period from 1993-99. Presently, he serves as the vice-chairman of the Policy Committee.

He has written 314 papers, including two books in English. The number of citations is currently 569 (2002). His special fields of interest are system identification and parameter estimation, adaptive optimal, and the robust control of industrial processes.