Granulometric Control of Iron Ore Pellets Using a Fuzzy System.

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Abstract. Pellets are concentrates of different chemical and mineralogical, with specific properties and great application on steel manufacture. This work describes the practical application of a fuzzy control to an industrial iron ore pelletizing. The objective was to develop a model to detect quality pellet size standard on the process, and with the identification of the standard, execute the control the rotation and feed rate of the pelletizing disc, since a specific angular rotation speed of the disc is necessary for the formation of the pellet, because if the disc moves slowly, don't form pellets and also if the disc moves quickly, the centrifugal force generated raises the mass of the ore to the limit angle and at this point the mass will fall, not allowing the formation of pellets. When the disc moves at such a speed that the centrifugal force is overcome by the frictional force, the material is raised to a certain angle and then rolls over itself, forming the pellets by agglomeration. When we reduce the load on the pelletizing disc, we reduce the particle size dispersion of the disc product. The system developed aimed to improve the pellet formation yield, making the production better with quality.

Keywords: Fuzzy System; Process control; Palletizing Plants

1 Introduction

Disc pelletizer is widely used in the steel manufacturing industry in the agglomeration process to form powdered iron ore into iron ore green pellets. The raw material is fed into the disc and sprayed by water. With continuous rotation of the disc, fine particles are gathered and formed into larger pellets in the stable area, finally falling out of the disc as green pellets. The green pellets are then heat hardened to get the required properties in the induration process and finally be fed into the furnace. The pellet size in the disc should be constantly monitored to guarantee that it is in a desired size range, otherwise, the thermal process in the furnace will be greatly affected, leading to low heat transfer efficiency or bad product quality, Liu, et al [1].

The production of pellets in a pelletizing disc is basically due to two phenomena that occur simultaneously. The first and main one is the result of the centrifugal force, due to the rotational effect of the disc, which acts on the pellets in formation. The second is the natural drag caused by the circulating mass inside the disk, Nunes [2].

The relationship between the velocity and the mass of the expelled pellet is direct, i.e., the higher the velocity the greater the mass of the pellet must be in order for it to be expelled. Considering that the density of the ore is practically constant, we can say that the relationship between pellet size and disc velocity is therefore also direct.

In the other form of pellet ejection, by dragging, the quantity of pellets ejected does not depend on the speed of the disk but on the load of circulating iron ore. In this case we have an inverse relationship between the load of the disc and the mass of the pellet that is expelled. The higher the iron ore load on the disc, the higher the rate of entrainment of the pellets and the shorter their residence time and, consequently, the smaller the average size of the pellets produced Abouzeid and Seddik [3].

Therefore, the main factors that determine the particle size distribution of the green pellets and the productivity of the pelletizing disc are the disc speed and its feed rate.
In the vast majority of pellet plants these variables are manipulated by pellet operators. Through a visual analysis of the formation of pellets, the operator acts on the speed of rotation and the load of iron ore on the disc. A process that is closer to an 'art' than to a science.
From the above, one can deduce the great motivation for the development of a fuzzy control system for optimizing the pelletizing discs because fuzzy control systems are among the most efficient methods of optimizing production processes, minimizing production costs, ensuring productivity and deadlines. Fuzzy control systems use as input data the knowledge acquired previously by experts from operational and engineering areas. Moreover, to build the control strategy, fuzzy control systems use advanced mathematical tools, compared to conventional controls, making them robust and able to generate increments with great accuracy to control, Nunes [4].
From the above, this work aims to develop a fuzzy control system of the granulometry, through digital image feedback, of a pelletizing disk covering the quality of the formed product through granulometry control via digital image processing.

2 Materials and Methods

This chapter will discuss the theoretical bases used in the development of the work. Such bases are necessary for the best use of the work and the understanding of the methods and steps described.
Initially, the pelletizing process will be briefly presented. Finally, o Sistema de controle fuzzy será descrito.

2.1 The Pelletizing Process

According to Meyer [5], the purpose of pelletting is to obtain pellets within the desired size range and with sufficient mechanical strength to be safely transported from the pelletizing discs to the firing equipment. The agglomeration stage is a dynamic process, influenced by intrinsic characteristics of the ore and inputs, as well as conditions dependent on the operator's actions to obtain the desired granulometric range. The manual control depends exclusively on the performance of the area operators, in the search for the desired size of the raw pellet. The operator manipulates the rotation, feed rate, and inclination of the pelletizing disks according to visual observations of the pellet size at that given moment. The quest to control all these process variables is a complex task. Figure 1 shows how was the operation, manual, to control the growth rate of raw pellets, before the implementation of the fuzzy control system.

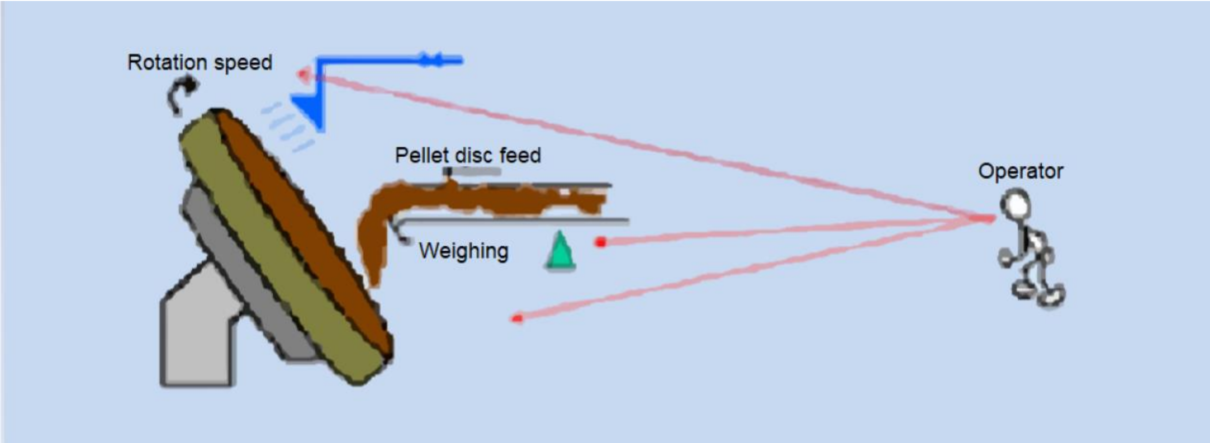

Figura 1: Controle Manual do Processo de Pelotamento

2.2 Sistema Fuzzy

The green pellet size distribution control system consists of two main components, the granulometer, which measures the pellet size distribution, and a fuzzy control system, responsible for executing the control strategy, Yang et. Al.[6].

In Figure 2 we have a schematic diagram of the components that were arranged in the plant. Basically the system is composed of the following equipment:

1. Analog Camera
2. Image Analysis Station
3. Control Station (Ni MyRio)
4. Supervision Station (Labview)
5. Platooning Disk

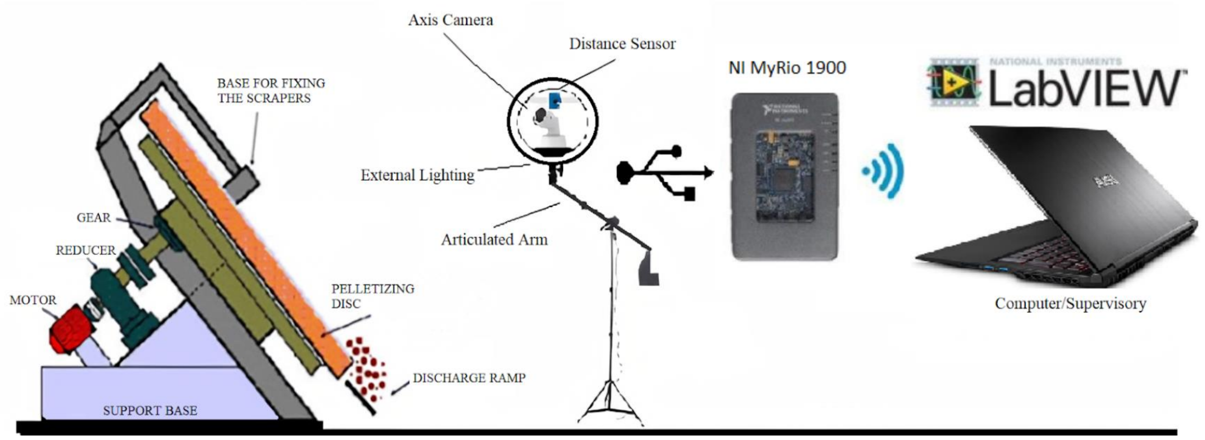

Figure 2: Schematic representation of the measurement system and granulometric control of the discs.

The analog camera was positioned on a stand and placed at a location on the disk, where it will capture the pellets produced on the pelletting disk.

The function of the Ni MyRio in this control is to "translate" the command from the control system, which comes to it as revolutions per minute (RPM), into an instrumentation signal in 4 to 20 mA for the adjustment of the disc rotation in the frequency inverter.

The supervisory system acquires the data from Ni MyRio in real time and makes it available to the fuzzy control system.

For the measurement of the pellet size a Deep Learning presented in Santos [7] was used, this product was developed by the Ifes/Vale partnership in a research project.

The image analysis done by the software provides the percentage, in mass of pellets, inside the disk:

- % of pellets smaller than 8.0 mm
- % of pellets between 8.0 and 10.0 mm
- % of pellets between 10.0 and 12.0 m
- % of pellets between 12.0 and 16.0 mm
- % of pellets larger than 16.0 mm

The measurement performance analysis was performed by an evaluation of the fundamental errors of representativeness of the samples analyzed in the laboratory, according to Pierry Gy's theory. Table 1 shows the comparison of the results obtained by manually measuring and imaging the pellets.

Table 1: Comparison of Measurement Results

	Manual Measurement	Yolact
Average diameter (mm)	13.4891	13.1833
Standard Deviation	0.7521	0.7011
Relative error		2.2672%

The control strategy was developed based on an expert system where the control rules are programmed and the fuzzy inference is calculated, where signal filters and statistical calculations such as trend, gradient and moving average are made. Figure 3 presents the architecture of the fuzzy system.

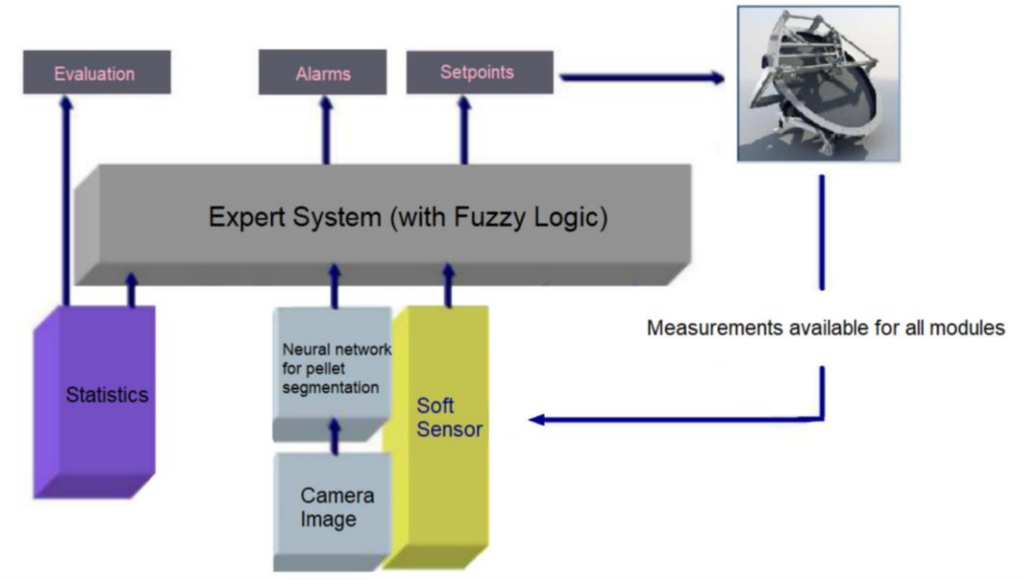

Figure 3: Schematic representation of the control measurement system

The choice of fuzzy system for the development of the control strategy is justified by the fact that it has a robust expert system characteristics very desirable in advanced control systems. Other control technologies were considered in the development of the project, but are not suitable for this application. The mathematical modeling through differential equations was difficult to develop, mainly because it is a strongly non-linear process.

The control strategy is built from human knowledge of the process, captured through interviews, discussion forums, and plant observations. Such knowledge is formalized and reconstructed around a rule base and an efficient inference mechanism. This knowledge represents the know-how and experience of the plant's engineers, technicians, and operators.

The control strategy is composed of two components, one for each variable that we can manipulate in the pelletizing discs: (i) rotational speed, measured in revolutions per minute (RPM), and (ii) feed rate, measured in tons per hour (t/h).

The two control logics, although using different manipulation variables, use the same variables measured in the control algorithm: (i) the percentage of pellets with diameter less than 8mm, (ii) the percentage of pellets with diameter greater than 16mm, and (iii) percentage of pellets with diameter between 8mm and 16mm.

To facilitate the understanding of the control algorithm each control logic is analyzed separately in the following paragraphs.

2.2.1 Manipulation of the Rotation Speed of the Disks

Based on the theoretical precepts and the experience of operators, a set of fuzzy rules was developed with the objective of controlling the rotation speed of the pelletizing discs. It was decided that the control reaction should take place in two different ways, depending on the absolute error and the error variation rate:

- When the granulometry is close to the set-point and with little tendency to vary, a speed increment or decrement of less than 0.15 RPM should be used every 5 minutes. This increment is defined by a set of fuzzy rules that considers the error and the rate of error variation.
- When the granulometry is oscillating with a high rate of variation, i.e. a steep gradient in the control curve, a separate set of rules is used that acts more aggressively on the control output and the execution interval of the algorithm.

Figure 4 shows the correlation between the rotation speed of the disc and the average size of the pellet size distribution. The higher the speed, (i) the larger the average size, and the lower the rotation, (ii) the smaller the average size. In this mathematical simulation the other factors affecting the result (feed rate, moistures, etc) were not.

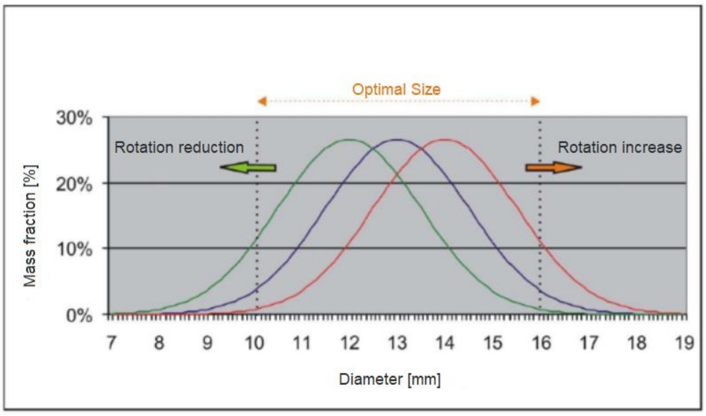

Figure 4: Reaction of the pellet size distribution to the variation of the pelletizing disc speed.

2.2.2 Manipulating the Feed Rate of the Disks

Changing the feed rate of ore into the pelletizing disc has an inverse relationship with the particle size distribution of the pellets. When we reduce the load on the pelletizing disc we reduce the particle size dispersion of the disc product.

In possession of this information, and because there is absolutely no mathematical approach to this question, it was decided to interview some operators and reproduce, in the expert system, the control methodology they use to control the pelletizing disc.

Figure 5 demonstrates the effect of feed rate on the particle size distribution of the green pellets.

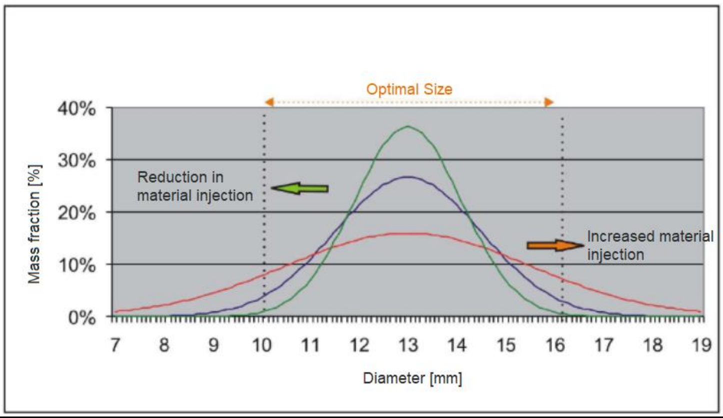

Figure 5: Reaction of pellet size distribution to variation in feed rate into the pelletizing disks.

3 Results

The Fuzzy Control System processes the following input variables: the pellet ratio request made by the operator, the granulometry information provided by the image analyzers and the information of speed and feeding of the discs coming from the automation system. After processing (calculations and control rules), the control system returns to the automation system the speed variables and disc feed, duly incremented. Finally, the automation system sends the outputs that control the platooning disks. The system interface with the process values can be seen in Figure 6.

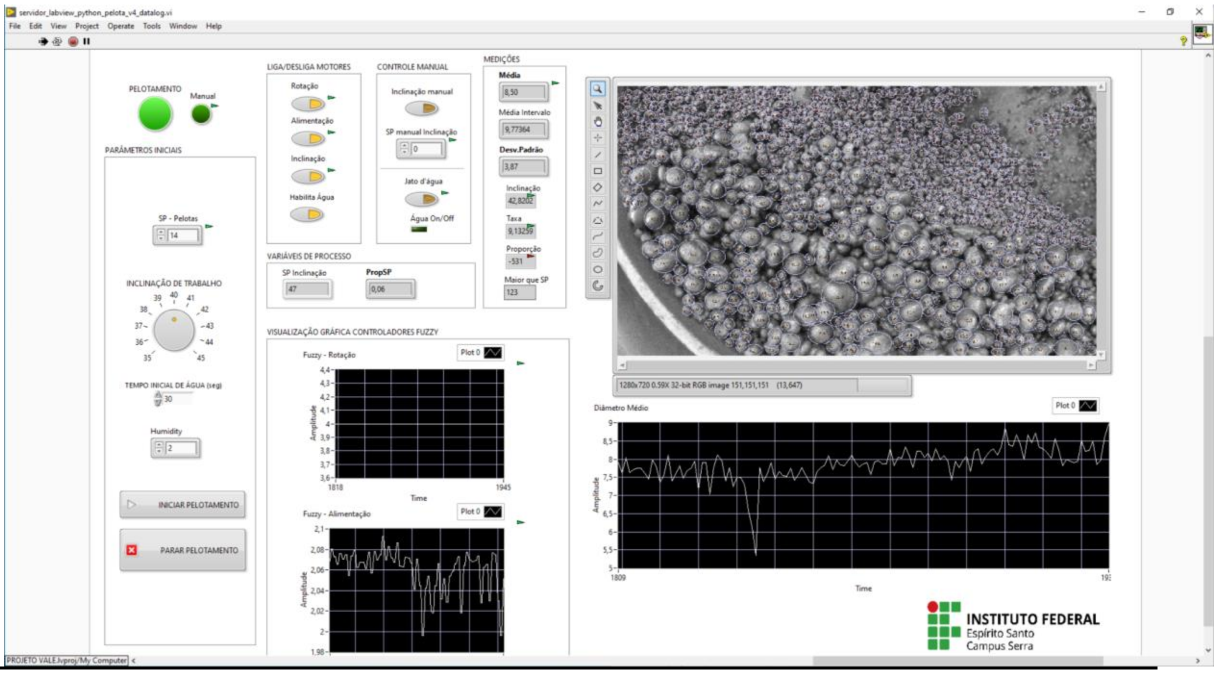

Figure 6: Human-Machine Interface.

SCAP processes the input information by means of conventional calculations and statistical calculations allied to crisp and fuzzy rules. The control strategy contains the system intelligence, which generates output increments with great control accuracy.

4 Conclusions

The objectives of the proposed control system were met, since this process was done manually and now, it is performed without the need for operator intervention.

The use of a particle size distribution meter based on image analysis proved to be fully suitable for application in an industrial environment, having met the requirements of the control system, as shown in Table 1.

Finally, the use of an expert system for the development of the control strategy also proved to be perfectly adequate. The process of pellet production by agglomeration of fines in a rotary disk was practically treated as 'an art', leaving to the operator all the operational decisions, based on subjective perceptions that, not always lead to the best performance. The incorporation of the knowledge accumulated in the operation of this process in the expert system resulted in a robust control system strongly oriented towards optimization.

As future work, a statistical analysis will be done comparing the pellet production rates of the developed system with the pellet production by the operator.

References

[1] X. Liu, C. Mao, W. Sun and X. Wu, "Image-based method for measuring pellet size distribution in the stable area of disc pelletizer". ISIJ International, Advance Publication by J-Stage, 2018.

[2] S.F. Nunes, "Influência da Carga Circulante do Pelotamento na Qualidade Física das Pelotas Cruas e Queimadas da Samarco Mineração". Dissertação (Mestrado em Engenharia de Materiais) – Escola de Minas, Universidade Federal de Ouro Preto, Ouro Preto, 2007.

[3] A.Z.M. Abouzeid. and A.A. Seddik, "Effect of Iron Ore Properties on Its Balling Behaviour". Powder Technology, 29(2), pp. 233 – 241, 1981.

[4] J.E.F. Nunes, "Controle de um Processo de Pelotização: Realimentação por Imagem". Dissertação (Mestrado em Engenharia Elétrica) – Universidade Federal de Minas Gerais, Belo Horizonte, Brasil, 2004.

[5] K. Meyer, "Pelletizing of Iron Ores". Germany: Springer – Verlag Berlin Heidelberg New York, 1980.

[6] G. Yang, X. Fan, X. Chen, X. Huang and Z. Li, "Intelligent Control of Grate-kiln-cooler Process of Iron Ore Pellets Using a Combination of Expert System Approach and Takagi-Sugeno Fuzzy Model". Journal of Iron and Steel Research, International. v. 23, n. 5, p. 434 - 441, 2016.

[7] C.M.C.V Santos, "Redes Neurais na Segmentação e medição de Pelotas de Minério de Ferro; Um Comparativo entre Mask R-CNN e Yolact". Trabalho de Conclusão de Curso, Instituto Federal do Espírito Santo, 2020.