UM NOVO IMPORTANTE AVANÇO E DESENVOLVIMENTO PARA DISCOS DE PELOTAMENTO: CONTROLE E AUTOMAÇÃO DE INCLINAÇÃO*

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Resumo
O efetivo controle do pelotamento tem desafiado engenheiros e pesquisadores por mais de 60 anos. Desde o início da década de 1950, quando ele era inicialmente encarado mais como arte do que ciência, muito têm sido feito paraentender seu comportamento e fenômenos. Na última década, com o progresso tecnológico de instrumentação e o desenvolvimento de controles especialistas e modelagens, o homem começa a domar este complexo e inerente oscilatório processo de fabricação de pelotas verdes. O presente trabalho apresenta o mais recente e inédito avanço aplicado industrialmente: a automação e controle de inclinação de discos que permitiu a operação harmônicado granulômetro (medidor óptico de diâmetro de pelotas) na melhor faixa de velocidade rotacional para produção de pelotas de tamanho médio ótimo e que evitam a geração/descarga de finos sobretudo em condições adversas..
Palavras-chave:pelotamento, discos, inclinação, pelota verde.

A NEW IMPORTANT ADVANCE AND DEVELOPMENT TO BALLING DISCS: CONTROL AND AUTOMATION OF INCLINATION

Abstract
The effective control of balling process has challenged engineers and researches for more than 60 years. Since its beginning in the 1950s, when it was firstly faced more as an art than a science, much has been done to understanding its behavior and phenomena. In the last decade, with the progress of instrumentation technology and development of specialist controls and modeling, man begins to tame the complex and inherently oscillating process of green pellets making. The present work introduces the most modern and unprecedented advance applied in industrial scale: automation and control of inclination of discs that allowed discs harmonically work with granulometer (optical measurer of pellets diameter) at the best range of rotational speed producing pellets of optimum mean diameter and concomitantly avoiding fines generation mainly under adverse conditions.
Keywords: balling, discs, inclination, green pellet.

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1 INTRODUCTION

1.1 Literature Review

According to SILVA (2017), balling is considered the heart of the pelletizing process since it determines the pace of production and plays an important role on bed formation and permeability. Due to its position at the boundary between mineral processing (grinding, filtering, pressing and mixing) and high-temperature metallurgical processing, it acts as an interface, being strongly governed and affected by the response of the previous stages but also carrying great influence to downstream operations, namely: pellets burning in Lurgi travelling grate, rotary or shaft kiln.

In the 1950s, DOR *etal*. *apud* WELLSTEAD *etal*. (1978) were concerned about the lack of understanding of balling operations, which was considered more an art than a science since the beginning of pelletizing. Effective control strategies had not yet been put in practice and most installations were overdesigned to compensate for such limitations. Drums, which were the only type of balling equipment in operation until 1956, present some inherent surging phenomena at their production discharge which are harmful to indurating machine feed rate and pellets quality. Such non-linear oscillating response (similar to a sine wave trend) is result of drums and screens constitutive relations in a closed loop circuit and screening. The result is that fluctuations on production and recycle load rates usually drift 20 % around their own average damaging bed stability, sintering operation and indurated pellets quality.

Pellet feed fineness and its specific surface area, type (calcium or sodium, doped/activated or not) bentonite addition, and mixture moisture content are the most important parameters of control in upstream processes of preparation because they strongly influence the kinetics and effectiveness of green pellets formation pellets formation. For such reason, they were already widely investigated in literature. KAPUR and FUERSTENAU (1964) were the first to describe the kinetics of green pellets balling. They verified how significant moisture content is during nucleation. KAPUR *apud* KAPUR *etal*. (1973) determined a similarity solution to an integrodifferential equation (Equation 1) of balling kinetics by the non-random coalescence mechanism results in the following expression for the median granule-size:

$$D_m(t) = Ct^{\alpha} \qquad (1)$$

where*t* is granulation time, exponent *α* depends on the growth mechanism and the specific rate constant *C* is a function of water and bentonite contents of the granulation charge. SASTRY and FUERSTENAU (1972) summarized the regimes of agglomerate growth by analyzing the rate of change of the average diameter of pellets made using taconite iron ore with 0.5 % of bentonite and 10.8 % of moisture. They also identified the mechanisms of agglomerate growth by applying tracer techniques. Two calcites, one from Texas and the second from New Jersey, presenting approximately the same kinetics behavior, could be identified on agglomerates when submitted to ultraviolet light: nucleation, coalescence and layering. ABOUZEID *etal*. (1979) and ABOUZEID *etal*. (1980) evaluated green pellets diameter growth rate for three different Egyptian ores for different levels of all the afore mentioned properties of mixture and pellet feed. SASTRY *etal*. (2003) analyzed the amount of feed layered by varying the amount of feed added and the moisture content in a laboratorial pelletizing drum. They concluded that the rate of layering is fast in the beginning and then it decreases continuously, coming to zero. Such exponential kinetic decay was also observed and mathematically defined by OUCHIYAMA and TANAKA *apud* IVESON *etal*. (2001) who assumed that granules were held together by capillary pressure of binder, ignoring viscous layer influence (Equation 2). The reduction rate of agglomerate inner porosity, ε, occurs as long as pellets grow:

$$\frac{d\varepsilon}{d\tau} = -\left[1 - \frac{(1-\varepsilon)^2}{\varepsilon K_\varepsilon}\right] \tag{2}$$

where$K\varepsilon$ is the dimensionless granule compaction rate which is proportional to the impact energy, particle size and inversely proportional to interparticle friction and binder adhesion. The parameter n describes the distribution of granule impact energies and τ is the dimensionless compaction time which is proportional to the frequency of impacts.

ENNIS (1991) model only considered viscous binder forces on coalescence growth although they have estimated the error of capillary negligence (Equation 3). According to the author, the exponential decay would be done by:

$$\frac{\Delta x_d}{h} = 1 - \exp(-St_v) \tag{3}$$

Δx_d is the reduction on interparticle gap distance, *h* is the viscous outer layer enveloping the agglomerate and St_v is the viscous Stoke Number.

Later, SASTRY *etal*. (2003) evaluated the amount of feed layered by varying the amount of feed added and the moisture content in a laboratorial pelletizing drum. They concluded that the rate of layering is fast in the beginning and then it decreases continuously, coming to zero. The cut-off size of seeds used was 4 mm. Authors verified that the percentage of feed layered decreases, as more fresh feed fines were added to the granulation process because others faster mechanisms such as nucleation and coalesce increase their participation. Following the aforementioned Kapur model, layering mechanism dependence on moisture content was demonstrated in such study as follows (Equation 4):

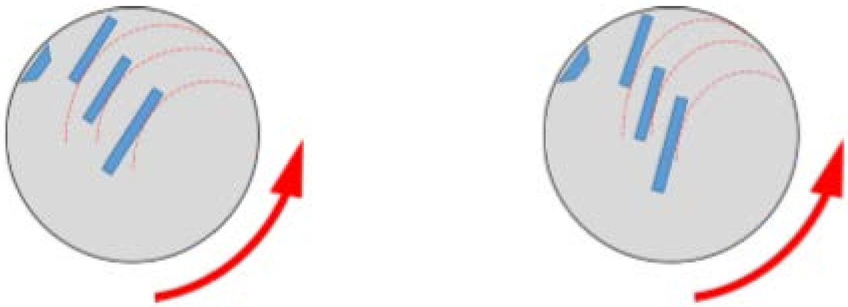
$$M_L^{max}(W) = k_0 \exp[-k_1(W - W_0)] \tag{4}$$

Where k_0 and k_1 are arbitrary constants, M_L^{max} is the maximum layered feed and $W_0$is the minimum moisture content where layering mechanism occurs.

1.2 BallingDiscsVariables

In balling, green pellets growth rate is influenced by the following variables: angle of scrapers, inclination of discs to horizontal, discs bottom height, feed rate, discs rotation speed. The influence of them can be better understood taking in account their change on the time of residence of green pellets inside the disc. Any modification that causes the increase of such time by making pellets discharge less probable, make discs produce bigger pellets. The examples below explain the change on pellets mean diameter if any of such variables is change while all the others are kept unaltered.

- Angle of scrapers: if more angled to vertical axis, smaller is solids rolling trajectory on discs (Figure 1). Smaller pellets are produced, as they are more propitious to exit earlier from the disc;



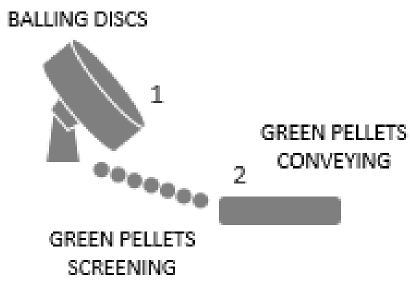
(a) (b)

Figure. 1- (a) smooth and (b) sharp angle position of scrapers.

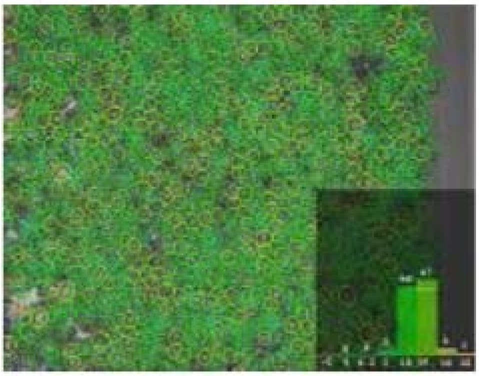
- Discs angle: when discs are more inclined, i.e., the angle define by the pelletizer and the horizontal, the time of residence increases and pellets mean diameter as well;
- Discs bottom height: “deeper” discs, i.e., as more distant the bottom layer of the edge of the disc, works with higher filling charge and produces bigger pellets due to bigger time of residence;
- Feed rate: when feed rate is increased the time of residence is decreased because discs filling degree is raised. Smaller pellets reaches discs edge discharge more easily and reduces production mean diameter.
- Rotation speed: the energy and frequency of collisions among the solids and the rolling trajectory inside the disc are increased when rotation speed is raised. As consequence, the rate of growth follows the same tendency and bigger pellets are produced.

1.3 State of art and strategies of control

BORIM and FREITAS (2009) detailed the control of pellets mean size by automation of balling disc control. The camera analyzer can capture the change in pellets diameter and modify disc rotation speed. The effectiveness of such advanced control is notable if the camera is properly used (Figure 2). Usually, the camera is placed at the discharge of the discs (1) but it can also be located at the production belt at roller screen downstream (2). In the second case, any operational change or failure can introduce harmful errors to system control. For example, if there is an excessive opening gap between rolls placed at the bottom of the roller screen, larger pellets which are supposed to be part of oversize can be misguided to the on-size stream and have their image analyzed. The camera then indicates to the control process that the mean diameter size captured increased. As a result, disc rotation speed is reduced in order to reduce the size of pellets produced; i.e., a gap distance fail on roller screen misconduct a control action to discs which can increase the amount of fines and result in a wider dispersion of pellet sizes. As such, installation of devices for size analysis after the roller screen is only recommended if there is not enough room at the discharge of either discs or drums.



(a)

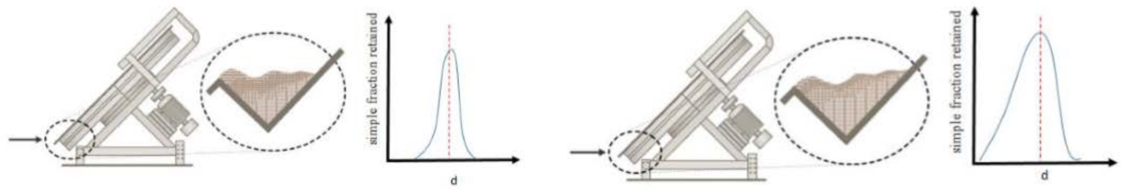


(b) (c)

Figure. 2- (a) Installation positions for size analysis device: 1- disc discharge; 2- production conveyor at roller screen downstream; (b) camera device in operation; (c) image capture and processing.

1.4 Motivations

The specialist regulatory control has as main input parameter the average size of production pellets analyzed by images captured by the optical device camera. Its logic of action is given by the increase or decrease of the speed of rotation for maintenance of the optimum size requested by set-point. This control responds continuously to variations that alter the rate of granulation or the rate of growth of pellets and consequently their average size. As previously mentioned, these oscillations can be caused by intrinsic factors such as mineralogical characteristics of the feed (mineral phases, loss of ignition); by physical properties of the mixture obtained by the predecessor processes such as specific surface area and moisture; and also by changes in balling process that modify the residence time of the pellets in the disc. The rotation control will act in a wide rotation speed range in order to produce pellets of the average size set. Often, this target value is only achieved at lower or higher speeds. In these situations, discs production may reduce bed permeability downstream and impact indurated pellets quality or heat consumption. At higher speeds, the discs may work at their maximum operational speed and the average diameter of pellets may be smaller than the one set. At lower speeds, larger amounts of fines are discharged in production stream (Figure 3). Such fines not only increase the return rate but also increase the packing level of pellets bed in travelling grates being extremely harmful to heat exchanges during sintering. Although optical measurement systems have presented good results in recent years by supplying information to advanced process controls, they have limitations of resolution that hardly identify objects smaller than approximately 8 mm (OptProcess Manual, 2009) and are totally unable to distinguish pellets smaller than 5 mm.



(a) (b)

Figure. 3- (a) ideal rotation speed; (b) lower rotation speed (Adapted from JESUS, 2013).

Nevertheless, balling discs may concomitantly produce the aimed average size and work at the best rotation speed. If these conditions are reached, return rate (products out of specification) and size dispersion of pellets produced are reduced. Generation of fines and coarse are thus avoided.

2 MATERIALS AND METHODS

Discs at Vargem Grande plant have an inclination mechanical drive system in order to modify their angle to horizontal. It is composed by a drive motor of 20 Hp and a gear reducer 12:1. The vertical movement of the disc base is promoted by the rotation of the shaft attached to the drive system that has gears at its edges that rotate on worm screws on both sides of the disc structure (Figure 4). All those components weight 1470 Kg. Two limits switches are installed in order to define the maximum and minimum inclination and to prevent/avoid any collision between moving parts and static structures around the disc. A laser linear meter is positioned parallel to disc structure and transmit the distance measured via PLC (Power Line Communication). An inclinometer was used to convert this linear length to value of angle of disc to horizontal.

The control consists in maintain discs operating at the best range of rotation speed when pellets produced reach the mean size set and size distribution is narrower. The inclination logic does not act on the search for the optimum size because it would cause conflicts with the control of rotation speed commanded by the optical camera device. Inclination and rotation have strong influence on kinetics of pellets formation and they would interact with/against each other. Then, such control works as an assistant/slave to rotation that continue. If the disc reaches the minimum or maximum limits of rotation speed defined, the inclination control changes its angle and reestablish the operation to the best speed range.

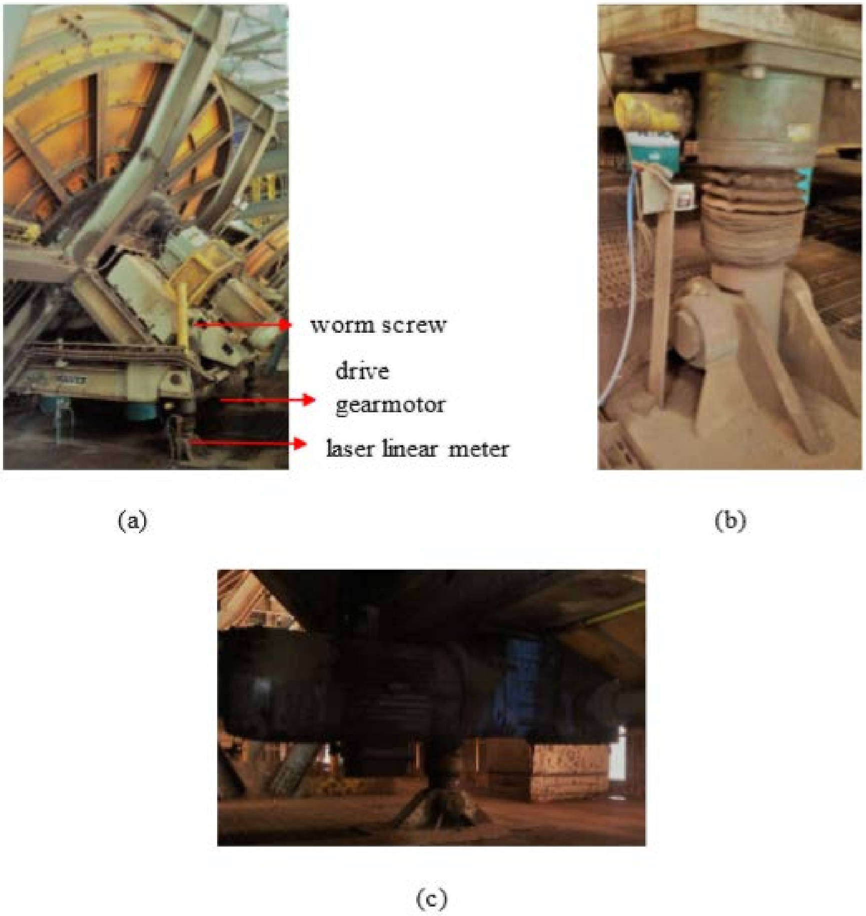


Figure. 4- (a) inclination system overview; (b) detail of laser linear meter; (c) detail of drive gearmotor under discs inclination structure.

3 RESULTS AND DISCUSSION

Database was extracted from PIMS (Plant Management Information System) at Vargem Grande pelletizing plant, one of the thirteen that belong to Vale Pelletizing Department. Data was worm screw drive gearmotor system laser linear meter analyzed with the aid of Minitab 16®, from Minitab Incorporation, and licensed to Vale. According to historical data, lower total return rates are achieved when discs rotation speed is between 7.2 and 7.5 rpm as illustrated in Figure 5.

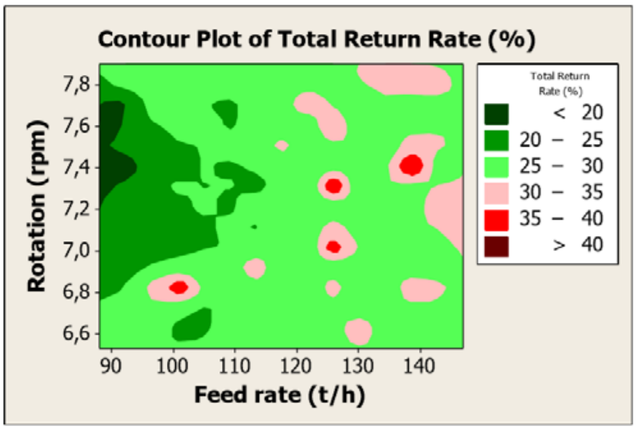


Figure. 5- Contour plot of total return rate (%).

Total return stream is composed by out of specification pellets sieved by single deck roller screens at discs discharges and by DDRS (double deck roller screen, also called feeder) at induration machine entrance. The first set of screens removes fines and coarse pellets unavoidable produced by discs and the feeder sieves fines not removed by such screens and the amount generated due inherent breakage/degradation of green pellets during handling on transfers between conveyors belts. SILVA (2017) deeply studied by modelling green pellets screening efficiency on both roller screens using the discrete element method. The statements aforementioned about fines increase and wider size distribution of pellets discharged by discs could be verified by data analysis presented in Figure 6. Feeder return stream is lower when discs rotation speed is between 7.2 to 7.5 rpm and evince how harmful is the operation when discs are slower than the minimum advisable.

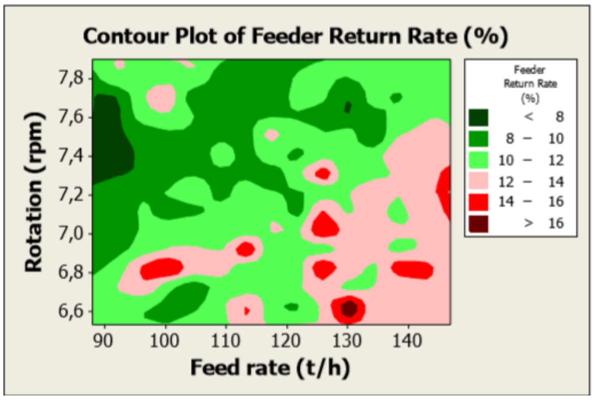
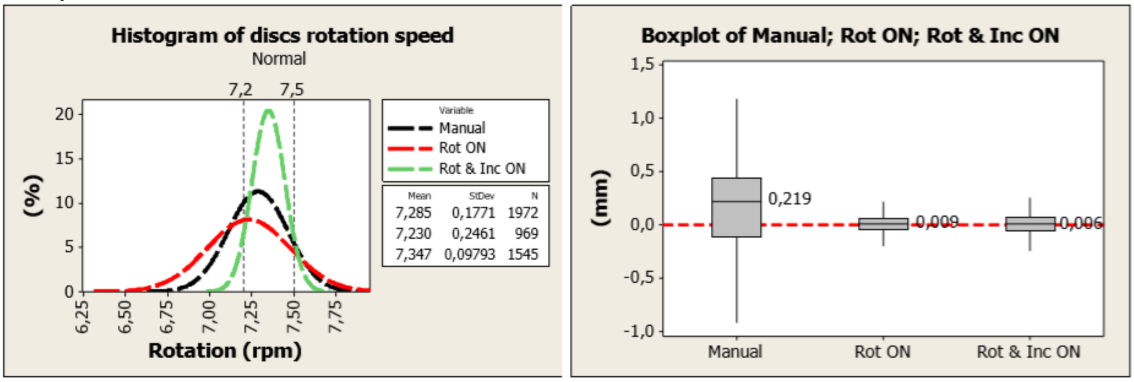


Figure. 6- Contour plot of feeder return rate (%).

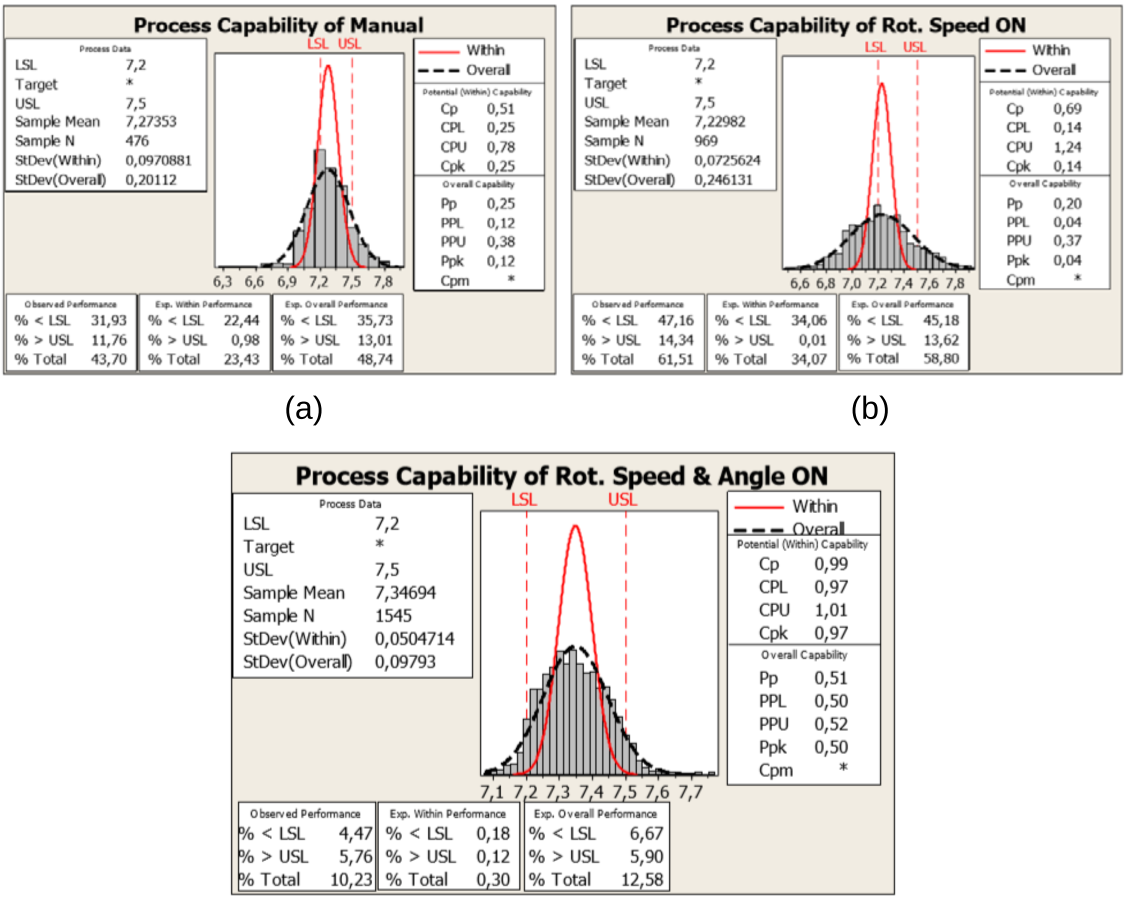
With such information in hands, the aforementioned limits were set and inclination control enable. In Figure 7, it can be seen how operation was changed and important inferences can be done.



(a) (b)

Figure. 7- (a) comparison of discs rotation speed; (b) difference between produced and set mean diameter.

When discs is operating in manual, the balling operators in field usually set the disc at faster rotation speed in order to avoid fines discharge that are easily seen. As consequence, the mean target pursued is nor reached and bigger pellets produced that are tougher and slower sintered Pellets mean size is very relevant mainly for abrasion index (GUDENAU *etal*., 1964; UMADEVI *etal*., 2009). In opposite hand, optical measurer does not identify fines with efficiency and set the disc in a wide range of rotation speed in order to achieve the set mean size. Nevertheless, with the implementation of inclination control, both objectives can now be achieved: produce pellets of set average diameter at the best range of rotation speed. Figure 8 illustrates how capability of discs rotation speed improved.



(c)

Figure. 8- Capability analysis for rotation speed operating (a) in manual; (b) with only the control of rotation speed enable and (c) with inclination auxiliary control.

4 CONCLUSION

Results gotten presented excellent perspectives. Discs control and automation of discs have potential to be a very important development for balling process as the control of rotation speed was in the last decade. Such unprecedented regulatory auxiliary control could let discs work with excellence producing pellets of optimum diameter and reducing fines generation when circumstances of process forces increases pellets growth rate and discs reduce their rotation speed.

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