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Determination Of The Optimal Parameters Of The Equipment To Obtain Fine Powders

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Abstract.

Currently, in terms ofconsumption ofcementoccupies a leading positionamong constructionmaterials, butitsproductionis expendeda lot of energy, as in buryingandgrindingonmaterialsat variousstages.To reduce thepower consumptioncan beundergrindingclinkerand additives ina closed cycle. However, given the large numberof external factorsto maximize theefficient use ofa large number ofco-operating complicated equipmentis difficult task.To optimizethe process of obtainingfine powdersis proposed to obtainmathematical modelsderived fromexperimental results, taking into account thefeaturesincluded in theline ofapparatuses.On the basis ofthesemathematical modelsis proposed to obtainthe objective functionto ensureoptimum working conditionsasallmilling equipment, as well as individualelements included inits composition. The obtained expressionsallowalso to obtain theproduction of powderswith guaranteedtechnological properties.

Keywords:fine powders, the regression equation, a closed circuit, anair separator, capacity, specific power consumption, efficiency.

Introduction.
Preparation offine powderswith minimal costinmodern conditions ofthe industryisvery important task[1].In most cases, this is possible onlywith the use ofa closed circuitmilling[2, 3, 4]. However, given the large numberof external factorsto maximize theefficient use ofa large number ofcooperating complicated equipmentis difficult task [5, 6]. The solution of suchproblems is possiblein the preparation ofmathematical models andfind the optimum, in which there ismaximum efficiency the equipment operation.Given the complexity ofthe processes occurringin each of theapparatusincluded inthe process lineproductionof fine powder, analytical expressions describingthe whole processbecomes socumbersomethat they were beinglostthe original meaning ofthe event.

Methods.
To study theprocessof grindingcement clinkerand additives, we have developed an experimental installationclosed circuitbasedon a ball millshown in Figure1.

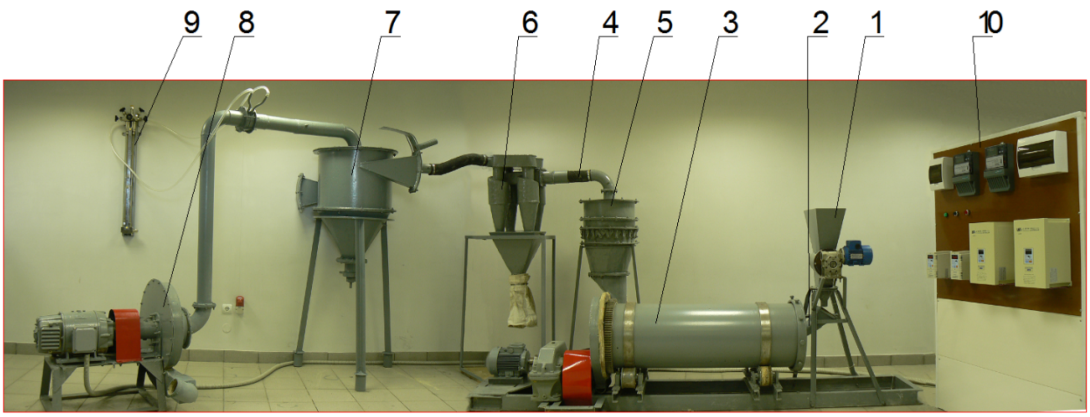


Figure1. Experimental installation closed circuitbased on a ball mill: 1 –drumfeeder; 2 –distributor; 3 –ball mill; 4– the air;5 – separator; 6 –cyclone; 7 –grainfilter; 8 – blower;9 –liquiddifferential pressure gauge; 10 –remotecontrol

To optimizethe process of obtainingfine powdersis convenient to build mathematical modelsderived fromexperimental results, taking into account thefeaturesincluded in theline ofapparatuses.Given the largenumber offactors of the experimenttostudythe workof the grindingunitweselected as themain planof the experimentcentralcompositerotatableplanfull factorialexperimentCCRP 2^{5-1} FFE [7].In accordancewith the planestablishedfive levels offactors:-1 –lower;0–average; +1–top; -2, +2–star.

All acceptedfactor levelsare implementedon the model ofa ball milloperating incontinuous modeand correspondto the actualworking conditionsofball millsclosed circuit(Table1).Asthe separationdeviceusedseparatorsofair-flow centrifugal type.

Table1. The investigatedfactors andvaryinglevelsCCRP 2^{5-1} FFE

Factors	the code denoted	varying interval	*X*= -2 (star level)	*X*= -1 (lower level)	*X*= 0 (average level)	*X*= +1 (top level)	*X*= +2 (star level)
Circulatingload, *c*, %	X_1	50	50	100	150	200	250
Airvelocity, *V*, mp/s	X_2	0.1	0.5	0.6	0.7	0.8	0.9
Partition position, l_2/l_1	X_3	0.25	0.50	0.75	1.00	1.25	1.50
Specific area partition[nu], %	X_4	2	8	10	12	14	16
The frequency of rotation of the drum[psi], %	X_5	0.07	0.62	0.69	0.76	0.83	0.90

To study theoperation of the airseparatoruschosen asthe basic planof the experimentcentralcompositerotatableplan full factorial experimentCCRP 2^3 FFE (Table2).

Table2. The investigatedfactors andvaryinglevels CCRP 2^3 FFE

Factors	Codedenoted	varying interval	*X*=-1.682 (starlevel)	*X*= -1 (lowerlevel)	*X*= 0 (averagelevel)	*X*= +1 (toplevel)	*X*= +1.682 (starlevel)
Separatingthe airflow, *L*, m^3ph	X_6	50	216	250	300	350	384
Rotor speed, *n*, rpm	X_7	240	600	760	1000	1240	1400
The degree of overlapgate, [mu], %	X_8	24	20	36	60	84	100

The mathematicalmodel obtainedas a result oftreatment-experiment, aregression equationas a quadratic function:

$$P, Q, q, e, R = b_0 + \Sigma b_i x_i + \Sigma b_{ij} x_i x_j + \Sigma b_{ii} x_i^2, \qquad (1)$$

where P, Q, q, e, R–parameters investigatedin this case, accordingly, power consumption, capacity, specific energy consumption, efficiencyof the airseparationand the quality ofthe final productis determinedin the controlsieveresidue, calculated during the experiment;b_0–free termof the equation; b_i, b_{ij}, b_{ii}–coefficients, accordingly, withlinearparameters, whenthe effects ofthe interactionandquadratic terms; x_i, x_j–varyinglevels offactors.

The main part.
The resultingregression equationof the experimentsallow tosay the magnitude ofthe influence of differentfactors andtheir interactioneffectson the value ofthe parameters$P$, Q, e, R and their derivatives.But, given the large numberof members ofthe regression equations, andimpossibleselection of the optimumpossibilitiessimple enumerationvaluesof factorsweperformedan experiment in theoptimization ofconditions for a minimumpower consumption$P$, Qhighcapacityball millclosedcircuitwith guaranteed qualityof the finished productdefined by parameter$R$.The challenge istofindsuch a correlationfactor, which would be observedatthe maximum efficiency ofthe grinding process: minimum energy consumptionwith maximumperformance.To findthe optimumof the objective function, factor space, constitutingarea of admissiblevalues of the function, represented in the formof a hypercubewithside equalto four units.To solve the problemof optimization ofthe grinding processin ball millsclosed circuitis necessary to formulatea criterion ofoptimality, in other words –a qualitativeassessment of the effectivenessof the processunder variousvalues of theadjustable parameters.

The optimality criterioncan be adoptedfollowingobjective function:

$$F(c,V,k,\upsilon,\psi,L,n,\mu)=a_1\frac{P}{Q}+a_2\left(R-R^*\right)^2+a_3 f(c,V,k,\upsilon,\psi,L,n,\mu), \quad (2)$$

wherea_1, a_2, a_3–weightsregulatorysignificance (contribution) of aterm, and taking into account thedifference in theabsolute valuesand thedimensionsof the corresponding quantities; P–power consumed by theplant, calculated bythe regression equation; Q–capacitymillingunit, calculated according tothe regression equation; R–quality of the finalproduct, calculated by theregression equation; R^* –required quality ofthe finished product, and definedin the calculation;f–function of theinput parameters, limiting the search foroptimizingthe values ofthe hypercube; c, V, k, [nu], [psi], L, n, [mu] – circulatingload, the air velocityin the drumof the mill, the ratio of the lengths ofmill chambers, the living sectionpartitions, frequencyof rotationof the milldrum, the flow separationair, velocityof the rotor inthe air separator, aerodynamicparameter.

Optimization ofthe grinding processcarried outby minimizing thefunction$F$ (c, V, k, [nu], [psi], L, n, [mu])by of fastest descent[8, 9, 10]. By choosing thevalues of the coefficientsa_1, a_2, $a_3$considered severalkinds of functions$F$–optimality criteriawithqualitative differences. Before proceeding todiscuss the results ofthe calculationsnecessary tomake the following notice.Since theexperimental installation, as in some sensethe grindingunitgeometrically similarindustrial installations, anddynamic similaritydoes not, we were interested inis notthe absolutevalues of the inputfactors andtendencies of theirchangeswhen you changethe requirements forthe results ofthe process parametersorgrinding.With that saidtype of functionhas been selectedandarrangednumerical calculations.The results ofthe first series ofcalculations are shownin the figure.The calculations were performedwitha_1=0, a_2= 10, a_3=0for different values of$R$.Thus, we studied the effectonthe values of inputfactorsincreaseor decrease thefinenessof the finished product.

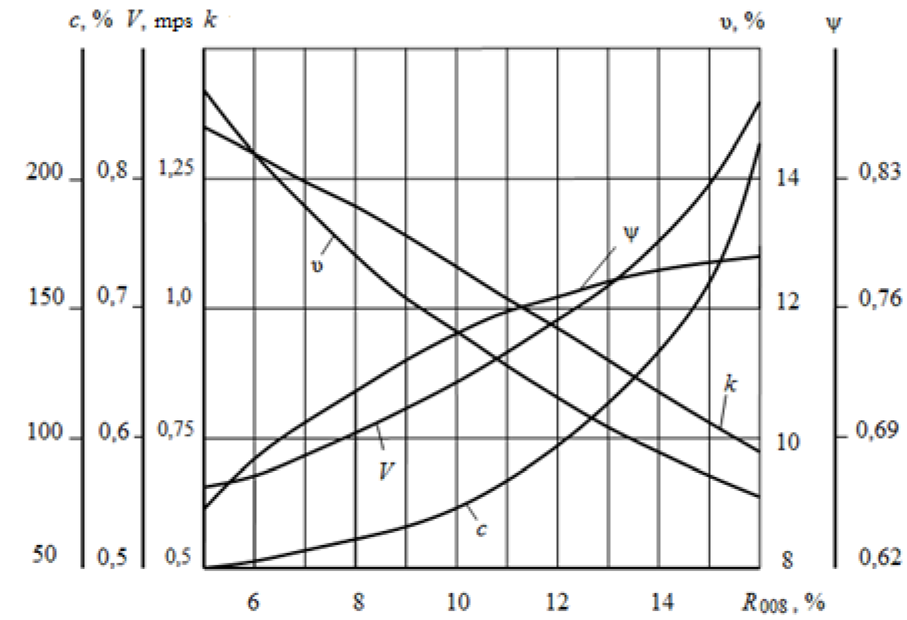
As seenin Figure2a, to obtain a productwith smallresidueson the sieve 008mustprovidea minimalcirculating in the systemload;velocity of the airin the drummill, shift towards lowervalues of the parameter$V$;minimum length offine grindingchambercorresponding tothe adopted planof the experiment; minimumcarrying capacityinclined mill partitionof the parameter[nu], the design to the second, and vice versa, and the minimum frequencyof rotationof the drummill[psi].This providesa longertimein the drumof the milland, therefore, higherdegree of comminution.

Figure2b shows thetechnologicalcharacteristics of the processofgrindingin ball millsclosed circuitfor the corresponding valuesof inputfactors.These values areinputfactorsare explained as follows: to provide greaterfinenessin the drummillshould bethe minimum amount ofmaterial to be ground, which is provided with a minimumcirculationload.The air velocityin the milldrum shouldthus notprovideintensiveremovalof material fromthe grindingmill drum, thus increasing timein the drummill.

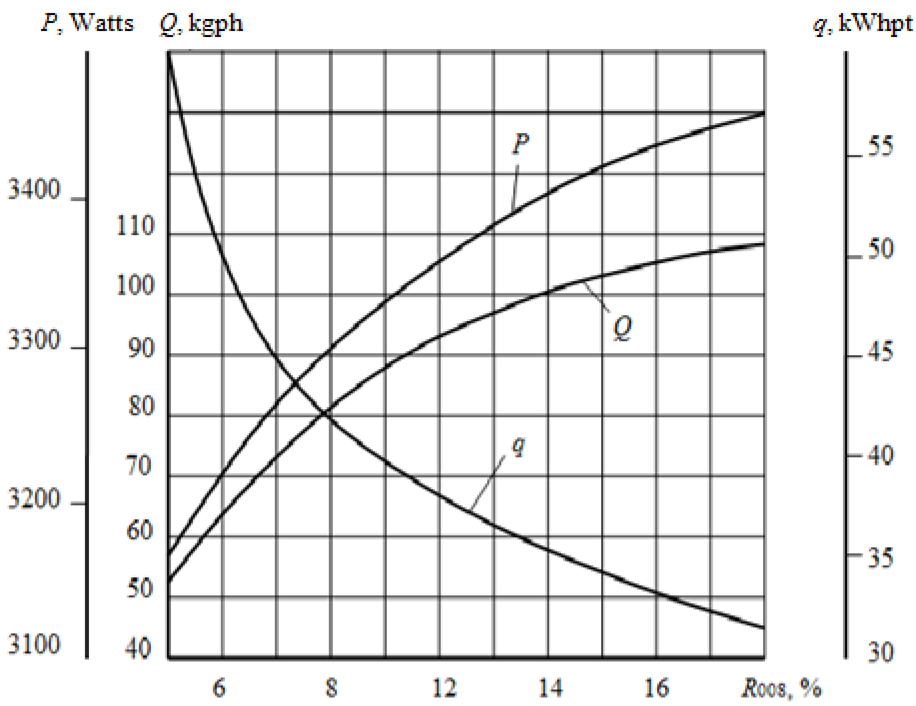
Increasing the length ofthe second chamberallows you toincrease thefine grindingfinenessat the expense oflong term exposuresmall ballload onsample materialandtransport capacityreductiondue topartition[nu]possiblemovement materialfrom the firstchamber to the secondand back, crankmill drumto360ºalso increases thetimematerial in the milland, therefore, leads to increasedfinenessof the grinded material.

Minimum residues ofgrinding materialon the controlsieveare obtainedat lowerdrummillvelocity[psi], due tothe predominance ofthe abrasiveeffects ofgrinding mediaonthe ground material.

For example, to obtain a productwitha 5 % $R$with a minimum consumptionof electric powerneededtocirculatingloadequal to50 %; air velocity$V$in the drummill– 0.56mps;the ratioof the lengths ofthe chambers(l_2/l_1) – 1.4;livingsection ofthe partition[nu] –15 %, andthe relativevelocityof the drummill[psi] – 0.665.With the increase incirculating loadwe can see increase inthe parameter R.The growthparameterwith the same parameters$V$causescoarseningof the materialby increasingthe average sizeof thecarrying off the drummillgrinding materialparticles. Analysis ofexpressionsuggeststhat thecoarseningof the materialshould be reducedthe chamber offine grindingandincreasethe relativevelocityof the drummill.Firstly, this is due tothe fact thatincreasesthe mass fraction ofthe crushed materialin the drummill(increases circulationload)thatis neededfora greater share ofthe impactof the grinding mediaandensuredthatbiggerlength ofthe first chamberand, secondly, the greater frequency ofrotation of the drummillthatincreasesaccordingly, the impact forces.



a



b

Figure2. Dependence of theoptimizationof inputfactors (*a*)and the values ofthe process parametersball mill closed circuit(*b*) of thefineness ofthe finished productatminimizationof specific energy consumption

Substituting theresultingsolutionof the objective functionvalues of the variedfactors initsminimization (x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8)inthe correspondingregression equationsdefineconsumedpower setting*P*, its capacity isof appropriate qualityof the final product*Q*, andspecific energy consumption*q* ongrindingwhile maintainingthe defined qualityindicatorsgrindingsystem (seeFigure2b).

Increasing thecapacity of the plantis accompanied byincreasing levels ofconsumptionanditspower. The maximumcontribution to theincrease in the parameter*P*exertincreasing the frequency ofrotation of the drummill and thevelocity of the airin the drummill and, to a lesser extent– the growth ofcirculating load. The remaining twoparameters–*k*and[nu]a significant impacton the value of*P* does nothave, as it does notalter thecharacter of the movementof the grindingloadduring grindingmaterial.With thecoarsening ofthe materialfrom 5 to16% increase power consumptionis 9.5%, i.e.from3154to3456Watts.In order tooptimizethe closedcircuitball millto obtain the minimumpower consumptionin the formula(1) takethe followingvalues of weightingcoefficientsa_1= 10, a_2=0, a_3=0.

Calculations based onthe abovegivenmethodshowed that theminimal power consumptionis observed at*c* =208%; *V* = 0.87mps;*k* = 1.45;[nu] =8%and[psi] = = 0.85andis24.28kWhpt.At the sameplant capacityis100.4 kgph andconsumptionofenergy –2437Watts.

Maximum capacityball millis111.36tphfor the following valuesof the varied factors: *c* =110%; *V* = 0.9mps;*k* = 0.78;[nu] =8%, and[psi] = 0.75.The power consumed bythe installation, in this case is3125Watts, with specific power consumption*q*, equal to28.06kWhpt.

Withoptimization ofonlyanair separator(ball mill was turned offand the powerof the air separatoris carriedautonomously) with specific surfaceofpowderequal to3500cm^{2}pgmaximum capacity*Q*airseparatoris observedfor the following valuesof variable parameters: airflowseparation*L*is 375.4m^{3}ph;separatorrotor velocityis 732.2rpm;aerodynamicseparatorparameter[mu]93.14% and *Q*is 366.5kgph.

The separation efficiencyof anair separatorfor these valuesis 74.5%.

The maximumseparation efficiency*E*airseparatoris observedfor the following valuesof variable parameters: airflowseparation*L* is355.1 m^{3}ph;rotational velocity of the rotor is1348.3rpm;aerodynamic parametersseparator[mu]is 79.68% and*E*86.33% is.The capacityof a separatorat these valuesconstitutes302.56kgphat a specificsurface of the finishedproduct4200cm^{2}pg.

Conclusions.

Inthe course of theresearchwere obtainedregression equationsworkgrindingunitclosed circuitball millandanair separatorand theproposedobjective function, which allows to determine theoptimal operating conditionsofboth thegrindingunitas a wholeand itsindividual elements.The values ofthe factor levelsat which aminimumenergy consumption ofthe entiregrindingunit, itsmaximum capacity, the maximum capacityof anair separatorand its maximumefficiency.

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