VOL. 9, NO. 11, NOVEMBER 2014 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

KINEMATICS OF THE BALL LOAD IN THE TUBE BALL MILLS WITH INCLINED INTERCHAMBER PARTITIONS

Yuri Mikhailovich Fadin, Andrei Vladimirovich Gavrilenko, Ksenia Gennadyevna Arkatova, Jan Alexeevich Avdeev and Nikita Eduardovich Bogdanov
Belgorod State Technological University named after V.G. Shukhov, Russia, Belgorod, Kostyukova St. 46.

ABSTRACT

In this paper we have studied features of kinematics of spherical loading in pipe spherical mills with inclined interchamber partitions. Calculation of a separation of a sphere from a drum of a mill and from an inclined partition has been made. Coordinates and sphere speed at the time of collision with a drum of a mill and an inclined partition have been calculated. Change of kinetic energy of a sphere in a mill with an inclined partition has been shown. Cross-length trajectories of movement of spheres depending on their situation on a partition have been defined. Diverse nature of impact of spheres creates conditions of vibration impact on a crushed material. The scheme for definition of an active area of coverage of a partition has been submitted. The size and nature of kinetic energy allow to increase efficiency of process of crushing and to improve power of spherical mills. Schemes of movement of loading have been presented depending on an inclined angle of a partition and on rotation frequency.

Keywords: ball mills, ball load, grinding bodies, interchamber partition, kinematics, kinetic energy, separation corner, rotation frequency, drum, angle of rotation, trajectory movement.

INTRODUCTION

For a grinding of a clinker and additives we suggest to use roller [1, 2] and horizontal [3] mills, but the main ones are the drum spherical mills. Great attention is paid to the increase of their efficiency [4, 5, 6].

Definition of the main dynamic characteristics of interaction of grinding bodies represents a typical problem of movement of many objects. At the solution of the practical tasks connected with description of spheres' movement in mill loading, we usually use model offers, leading, as a rule, to essential deviations from the real situation.

Installation on mills of the inclined interchamber partitions for the first time offered in works [7, 8], leads to essential change of movement nature of grinding objects. Therefore calculation of the main characteristics of this process (speed of a sphere, its energy, number of impacts, etc.), defining actually the grinding mechanism, power consumption, loads of a drum, a basic running gear and intra mill devices, can't be executed in the framework developed in so far models [9, 10].

RESULTS AND DISCUSSIONS

The model describing kinematics of grinding bodies in mills with inclined interchamber partitions has been offered, and also photos, graphic results of calculations and their analysis have been provided compared with the mills equipped with vertical partitions.

The greatest interest represents calculation of parameters (a trajectory of movement, corners of a separation and falling, energy) of the spheres which are situatedin a zone of a partition work. Movement of the spheres which are situated out of the zone of inclined partition's work is described by Davies's model [11, 12].

Let's look at the sphere at the time of separation from a drum (Figure-1, Figure-2).

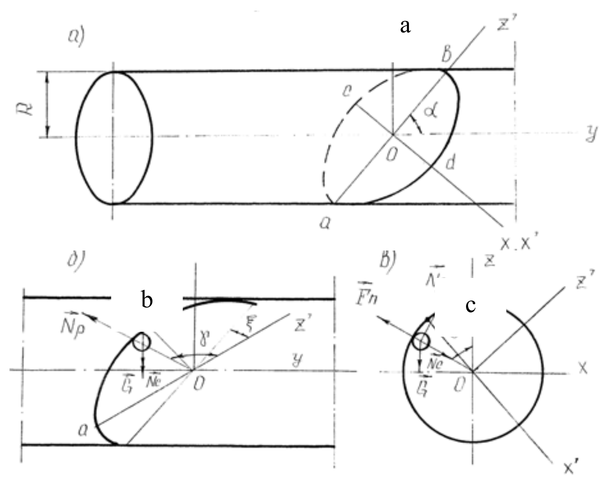

Figure-1. Scheme of section of a mill drum.

Coordinate systems:
a) immovableoxyzand movablex'oy' of coordinate system at[zeta]=0;
b) section of the drum on the plane yoz;
c) section of the drum on the planexoz.

Conside rintheforceofp ressure of the inclined interchamber partition, the condition of the sphere balance is:

$$\vec{G} + \vec{F}_n + \vec{N}_p = 0; \quad (1)$$

where $\vec{G}$ - sphereweight, H; $\vec{F}_n$ - inertiaforceofthe sphere, H; $\vec{N}_p$ - pressure force of the partition on the sphere, H.

VOL. 9, NO. 11, NOVEMBER 2014 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

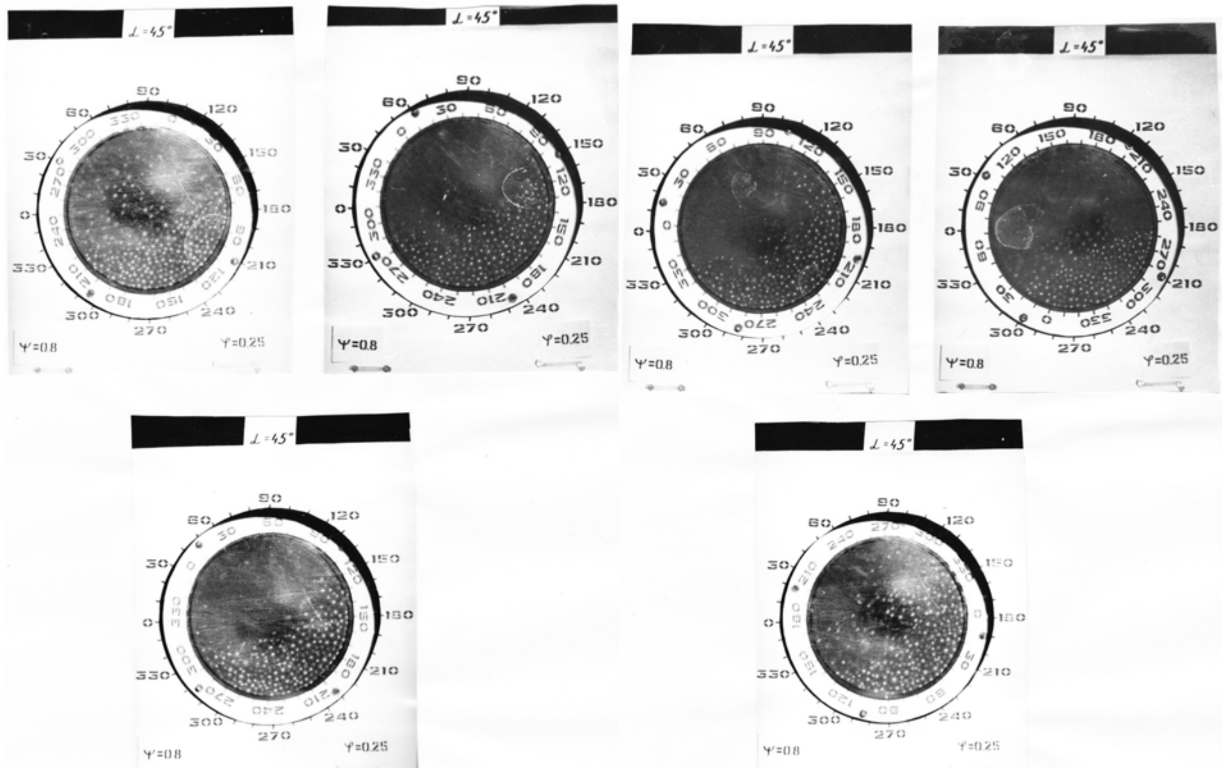

Figure-2. Definition of a corner separation of grinding bodies from the inclined partition, from a mill drum depending on a inclined angle of a partition [alpha], coefficient of filling [phi] and relative frequency of rotation [psi].

Projections of forces from the previous expression on a normal to a drum and a partition:

$$\begin{cases} G\cos\beta - F_n + N_P\cos\alpha\cos(\beta+\alpha) = 0; \\ N_P + F_n\cos\alpha\cos(\beta+\xi) - G\cos\alpha\cos\xi = 0; \end{cases} \quad (2)$$

where [alpha] - a partition of inclined angle to an inclined axis of a mill drum, in degrees; [beta] - a corner of a separation of a sphere, in degrees; [xi] - an angle of rotation of a drum (partition), in degrees.
From conditions that

$$G = mg; \quad (3)$$

$$F_n = m\omega^2 R = mg\psi^2; \quad (4)$$

where m - mass of a sphere, kg; g - acceleration of gravity, m/ s^2; [omega] - the circular frequency of rotation, rad / s; R - radius to a point of support, m; [psi] - the relative frequency of rotation of a mill drum, s^{-1}
The equality will be:

$$\cos\beta - \cos^2\alpha\cos\xi\cos(\beta+\xi) + \psi^2[\cos^2\alpha\cos^2(\beta+\xi) - 1] = 0; \quad (5)$$

The size of pressure of the partition on the sphere at the time of its separation is:

$$N_P = mg[\cos\xi - \psi^2\cos(\beta+\xi)]\cos\alpha; \quad (6)$$

The provision of a sphere on a partition is defined by the corner [gamma], in degrees:

$$tg\gamma = \sin\alpha tg(\beta+\xi). \quad (7)$$

Thus, the angle of separation [beta] and the angle of rotation of a drum [xi] at which there is a separation, is calculated taking into account preset values [psi], [alpha] and [gamma].

The dependence [beta] ([gamma]) executed on the basis of the listed above formulas, is presented in Figure-3. The character of the curve [beta] ([gamma]) gives the basis to draw the following conclusions: the spheres located on the left side of a partition (0°< [gamma] <180°) after separation from the drum start sliding on the partition, thus the separation corner on the site 0°< [gamma] < 25° decreases to 42 °, and then it increases to 72 ° (25°< [gamma] < 150°); on separation of the spheres located on the right side of the partition (180°< [gamma]< 360°), the partition does not have any influence, i.e. they move as well as in mills with vertical partitions ([beta] ≈ 54 °).

VOL. 9, NO. 11, NOVEMBER 2014 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

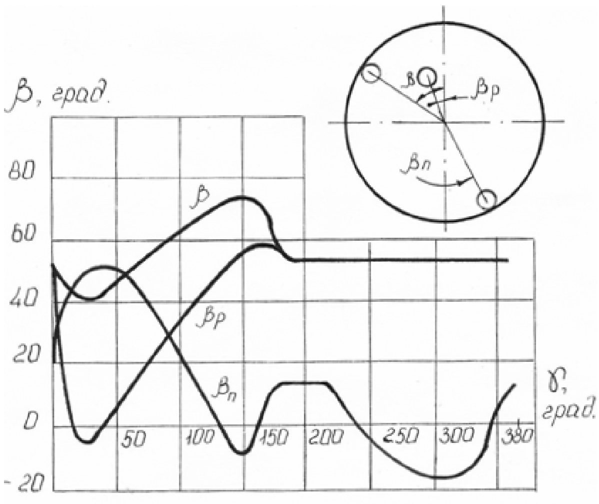

Figure-3. Dependence of angles of the sphere separation on the drum [beta], partitions [beta]$_P$, and also dependence of the sphere hade on the drum [beta] from its arrangement on the partition.

All this is due to the fact that at the angles of 300° < [gamma] < 360° and 0° < [gamma] < 40° partition supports balls, preventing their separation. Component of pressure forces of the partition N_P is directed from the periphery to the center of the drum. The angle separation decreases, lifting height and impact energy increases, the efficiency of grinding process increases. At 40° < [gamma] < 120° radial component of the force of partition N_P is directed to the center of the drum and causes earlier separation of the ball.

Let's define the sphere separation from an inclined partition.

Nature of the sphere movement on the surface of an inclined interchamber partition is defined by its weight and partition pressure force on the sphere (sphere friction force at the partition we neglect is):

$$m\vec{r} = \vec{N}_P + \vec{G}\,, \tag{8}$$

In projections to axes of coordinates the previous formula will be:

$$\begin{cases} m\ddot{x} = N_P \cos\alpha \sin\xi; \\ m\ddot{y} = -N_P \sin\alpha; \\ m\ddot{z} = N_P \cos\alpha \cos\xi - mg; \end{cases} \tag{9}$$

where $\xi = \xi_B + \omega t;$

[xi]$_B$-the size of rotation angle of a drum at the time of a sphere separation, degrees; [omega]-angle speed of the drum rotation, radius/seconds; t–time of rotation on the drum, seconds.

Before the ball separation from the inclined partition $N_P > 0$, and its coordinates satisfy to the partition equation:

$$x \sin\xi - ytg\alpha + z\cos\xi = 0. \tag{10}$$

The force N_P according to the formulas is:

$$N_P = m\cos\alpha[y\cos\xi + 2\omega(z\sin\xi - x\cos\xi) + \omega^2(x\sin\xi + z\cos\xi)]; \tag{11}$$

Angle of a separation of the ball from the partition [beta]$_p$ and the angle of rotation of the partition [xi] in this timepoint are equal to:

$$\begin{cases} \beta_P = arctg(-x_i / z_i); \\ \xi = \xi + \omega t_i. \end{cases} \tag{12}$$

One of versions of solution of the equations is presented in the form of curve [beta]$_p$ ([gamma]) in Figure-3.

The comparative analysis of sizes of angles of the sphere (ball) separation from a drum [beta] and from a partition [beta]$_p$ shows that sphere sliding on a surface of a partition reduces a separation angle. Especially it is characteristic for the spheres located on an inclined partition in places, corresponding to values of an angle of the drum rotation0°< [gamma] < 100°. Here it is necessary to pay attention that unlike the theories describing movement of spheres in mills with vertical partitions, the sphere (ball) at the time of a separation isn't in contact with a drum of a mill and the vector of its speed has a longitudinal component. It in particular, is confirmed by the fact that even at very small corners of a separation spheres are not centrifuged.

Let's define movement of spheres to trajectories of a free fall.

After the sphere separation from the drum (if there is no sliding on an inclined partition) or from the inclined partition, the free movement (falling) of a sphere happens only under the influence of weight and is described by the following system of equations:

ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

$$\begin{cases} x = x_1 + V_{x_1} t; \\ y = y_1 + V_{y_1} t; \\ z = z_1 + V_{z_1} t - gt^2/2; \\ V_x = V_{x_1}; \\ V_y = V_{y_1}; \\ V_z = V_{z_1}; \end{cases} \quad (13)$$

where $x_1; y_1; z_1; V_{x1}; V_{y1}; V_{z1}$ -coordinates and speeds of movement of a sphere along the corresponding axes at the time of sphere separation.

The sphere makes free fall before collision with a drum (loading) of a mill or with an inclined interchamber partition.

Let's determine coordinates and sphere speeds at the time of collision.

Time of a sphere's free fall of before the blow at a drum is defined at the condition that sphere coordinates at the time of falling satisfy to the equation of internal surface of a drum:

$$(x_1 + V_{x_1} t_{2B})^2 + (z_1 + V_{z_1} t_{2B} - 0{,}5t_{2B}^2)^2 = R^2; \quad (14)$$

where t_{2B} -time of sphere movement from the moment of separation to the moment of falling, seconds;
R-radius of the mill drum, m.

Time of sphere movement to the possible allingothe inclined partition t_{2P} is defined on the formula:

$$(x_1 + V_{x_1} t_{2P}) \sin\xi - (y_1 + V_{y_1} t_{2P}) tg\beta + \\ + (z_1 + V_{z_1} t_{2P} - 0{,}5gt_{2P}^2) \cos\xi = 0; \quad (15)$$

Where

$$\xi = \xi + \omega \cdot t_{2P}. \quad (16)$$

Depending on which value $-t_{2P}$ or t_{2P} will be smaller, the sphere makes impact according to the drum or the partition.

In case of impact at the partition the sphere speed after collision will be $\vec{U}_2$:

$$\vec{U}_2 = \vec{V}_2 + 2(V_{pn} - V_{2n})\vec{n}_p; \quad (17)$$

where V_{2n} - projection of thesphere speed to a normal to the partition at the time of collision; V_{pn} - projection of speed to a normal of that point of the partition in which there is its collision with the sphere; $\vec{n}_p$ - single vector of a normal to the partition plane.

Atchange of into $t_{2p}\vec{V}_2$ is defined from the equation to define the coordinates and the speeds of the sphere motion, and V_{pn}, V_{2n} and $\vec{n}_p$ are defined with the help of the system:

$$\begin{cases} V_{pn} = \omega \cos\alpha (z_2 \sin\xi_2 - x_2 \cos\xi_2); \\ V_{2n} = V_{X_2} \cos\alpha \sin\xi_2 - V_{Y_2} \sin\alpha + V_{Z_2} \cos\alpha \cos\xi_2; \\ n_{PX} = \cos\alpha \sin\xi_2; \\ n_{PY} = -\sin\alpha; \\ n_{PZ} = \cos\beta \cos\xi_2; \end{cases} \quad (18)$$

where n_{PX} , n_{PY} , n_{PZ} - projector oft he single vector $\vec{n}_p$ on the axis of coordinatesX , Y, Z.

Results of the numerical definition are presented in Figures 4, 5, 6.

From the characteristics of [beta] n ([gamma]) it is seen, that at 0°< [gamma] < 180° the angles of spheres' falls [beta] n = 55° - are the largest ones (Figure-3). Spheres' falling on the drum can beat mall angles [xi] of the partition turning. Onthi sphase of motion the reis "ladling" of grinding bodies of the inclined partition. They reach the highest point of lifting, considerably larger, than in mills with vertical partitions. Thereof, despite large angles of falling [beta] n , the main mass of the spheres, situated in the smaller angles [gamma], hits not at fettling as it can be in a mill with vertical partitions but at other spheres of loading, grinding the material (Figure-3).

ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

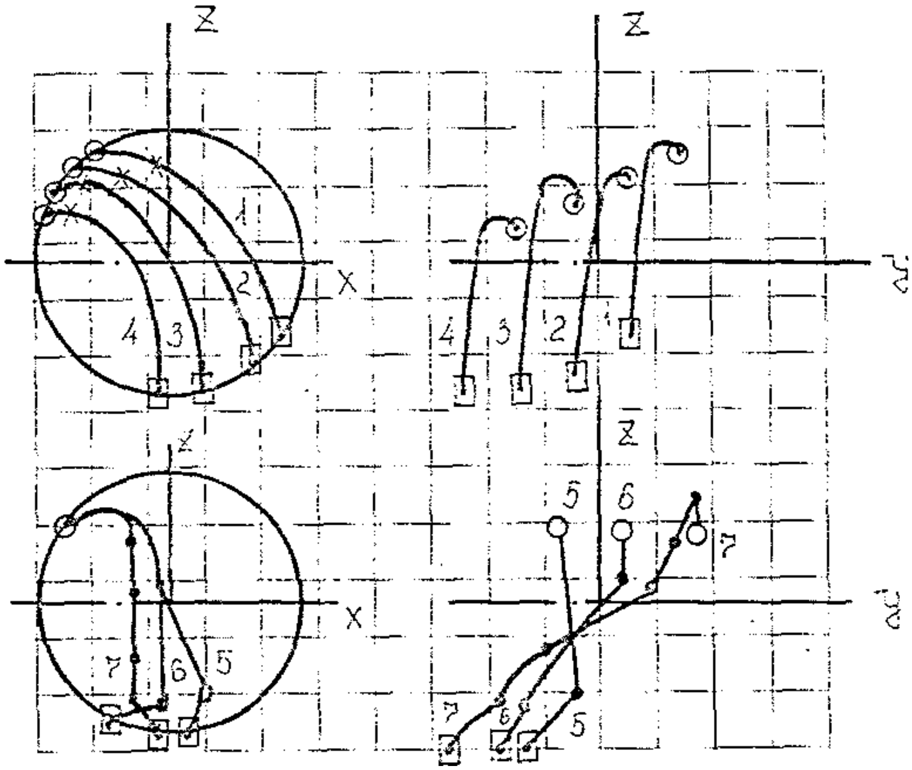

Figure-4. Cross-length trajectories of spheres' movement of spheres in dependences on their situation on a partition:

1- [gamma]=40°; 2- [gamma]=80°; 3- [gamma]=120°; 4- [gamma]=160°;
5- [gamma]=240°; 6- [gamma]=280°; 7- [gamma]=320°;

Symbols:

0 - tearing off the drum;
X - tearing off the partition;
• - falling on the partition;
□ - falling on the drum.

At The Following Motion of the Inclined Partition, spheres begin to tear off, their position is at angles 110°< [gamma] < 180°.

The Way of the Spheres' movement [gamma]> 220° changes completely, as in this situation after the turn off of the drum the spheres hit at the inclined partitions. At 220° <[gamma]< 280° there is a simultaneous hit of the sphere at an inclined partition, at 280°<[gamma]< 300° - there is a double hit, at 300°<[gamma]< 310° - there is a triple hit and so on (Figures 3, 4, 5).

In Figure-5 thereis ratio of relative speeds in mills with vertical partitions $V_0^{ВП}$ and with the inclined partitions $V_0^{НМП}$.

VOL. 9, NO. 11, NOVEMBER 2014 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

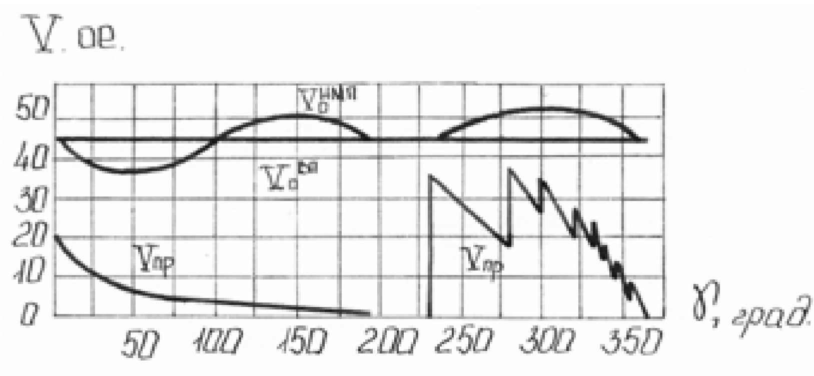

Figure-5. Relative and longitudinal speeds of a sphere at the time of its falling on a drum.

At 0° < [gamma] < 150° $V_0^{ВП} > V_0^{НМП}$. In other interval of sizes [gamma], $V_0^{ВП} \geq V_0^{НМП}$. If thus to consider that angles of falling of spheres in a mill with an inclined partition are less, than in a mill with a vertical partition (Figure-3), it is obvious that in mills with an inclined partition spheres make a lot of work on material crushing.

In mills with inclined partitions, diverse nature of impact of spheres (Figure-4, Figure-6) creates a condition of vibration impact on a crushed material, providing fuller use of the reserved kinetic energy.

Relative speed of falling of spheres $V_0^{НМП}$ slightly surpasses an indicator $V_0^{ВП}$. However existence of big in size longitudinal speeds $V_{ПР}$ says that when falling of a sphere, the hit occurs not of a drum surface, but of loading as $V_{ПР}$ is directed along a drum axis (Figure-5).

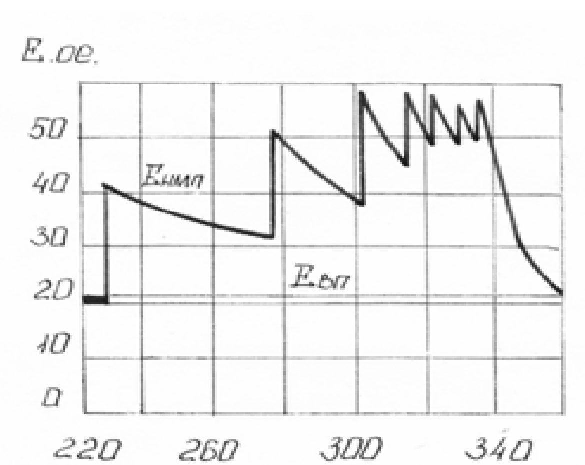

Figure-6. Kinetic energy of spheres in various points of their falling.

These features of movement of spheres in mills with inclined partitions lead to that:

- wear of lining in a zone of work of an inclined partition decreases,
- there is an active destruction of "a dead zone" - of a spherical loading,
- efficiency of use of kinetic energy of a sphere increases.

It is necessary to pay attention that the size of kinetic energy of a sphere in a mill with a vertical partition is constant at any position of a drum $E^{ВП} = const$. In mills with inclined partitions it is bigger also makes $E^{НМП} = (1{,}47 \div 2{,}83)E^{ВП}$ (Figure-6). And the curve $E^{НМП}$ ([gamma]) shows pulsing change of size of kinetic energy, its avalanche increase and decrease. It creates conditions of intensive crushing of a material by differently figurative methods: in pulse blow, crush, and also vibration influence.

Thus, kinematics of movement of spherical loading in mills with inclined partitions significantly differs from kinematics of mills with vertical partitions, and speeds of the hits provided at this procedure, the size and the nature of kinetic energy allows to increase efficiency of process of crushing and to improve power of spherical mills.

One more important factor, which knowledge allows achieving high technological parameters of process of crushing, is the perfect method of calculation of lengths of mill chambers which are stated in [7].

Stability of indicators of multichamber mills' work with cross-length movement of a grinding loading in comparison with the two-chamber demands more strict approach to determination of lengths and number of chambers [13].

From experiences of the transparent model of a mill it is known that the active area of coverage of a partition is limited to the size $l = 1{,}5Dtg\beta$, where D - is diameter of a drum in light, [beta] - is an angle, adjacent to a partition, in degrees.

The scheme for definition of an active zone is submitted in Figure-7.

ARPN Journal of Engineering and Applied Sciences

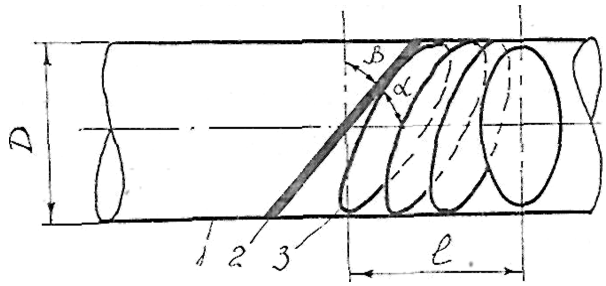

Figure-7. Definition of an active area of coverage of an inclined partition: 1 - mill drum; 2 - inclined partition; 3 - trace from the grinding bodies, which were left on the transparent case of a mill.

CONCLUSIONS

The active area of coverage of a partition decreases with increase in an inclined angle of an interchamber partition [alpha]; and at the inclined angle equal at about 55 ° it is completely excluded, therefore, there is an opportunity to use volume space of a mill more.

Researches and experiments showed that the size and nature of kinetic energy allow to increase efficiency of process of crushing and to improve power of spherical mills.

On the basis of literature of [2, 8] and previous statements, the following parameters of an arrangement of an inclined partition in a cement mill of Ø4x13.5 m were recommended:

- partition inclined angle - 55 °;
- length of an active zone - 2700 mm;
- length to a partition on axis - 4025 mm.

REFERENCES

[1] Jorgensen S.W. 2005. Cement grinding - a comparison between vertical roller mill and ball mill. Cement International. 2: 55-63.

[2] Salewski W. November 2003. Grinding Technology for the Future. World Cement. pp. 139-143.

[3] Stroiber W. Comminution. 2003. Technology and Energy consumption. Part 2. Cement International. 6: 90-97.

[4] Bogdanov V. S. 2002. Spheres drum mills (with cross-length movement of). MI: BSTU. p. 285.

[5] Deniz V. 2003. A study on the specific rate of breakage of cement materials in a laboratory ball mill. Cement and Concrete Research. 3: 439-445.

[6] Reinchardt Y. March 2008. Effective Finish Grinding. World Cement. pp. 93-95.

[7] Bogdanov V. S. 1986. Drum mills with cross-length movement of grinding bodies, M. S. thesis, BTIBM, MI.

[8] Bogdanov V. S., V. S. Platonov and N. S. Bogdanov. 1984. Cement. In Decrease in power consumption of process of crushing. pp. 7-9.

[9] Andreev S. E., S. E. Andreev, V. V. Zverevich and V. A. Perov. 1980. Grinding, milling and screening of natural resources. MI: Nedra. p. 415.

[10] Deshko Yu. N., B. Kreimer and G. S. Kryhtyn. 1966. Grinding of cement industry materials. MI: Stroyizdat. p. 275.

[11] Gyo Roge. 1964. Problem of crushing of materials and its development. MI: Stroyizdat. p. 112.

[12] Kryukov D. K. 1966. Improvement of milling equipment of ore dressing enterprises. MI: Nedra. p. 174.

[13] Fadin Y. M. 2011. Calculation of energy transferred to ball material loading by an inclined partition in a trumpet ball mill. Bulletin of BSTU named after V.G. Shukhov. 4: 62-64.