Regular Article

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Experimental tests of the antiresonance vibratory mill of a sectional movement trajectory

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Abstract: The results of experimental tests of the antiresonance vibratory mill of a sectional movement trajectory are presented in this article. The application of the antiresonance effect in the vibratory mill operations is the unique solution. It allows us to achieve a high amplitude of mill chamber vibrations at a negligible influence of the machine suspension on foundations and the surrounding environment. This article is focused on the determination of the filling degree of the mill chamber on the antiresonance effect pathway as well as on the possibility of its application under industrial conditions.

Keywords: vibratory mills, antiresonance, experimental tests

1 Introduction

A constant increase of demands for fine-grained materials, formed mainly in the milling process, is seen in the world. Its effect constitutes growing needs for larger and more efficient mill structures. This article is focused on the new solution of a vibratory mill, being an alternative to gravitational balls mills in which a kinetic energy of milling balls and the intensity of their interactions – mutual and with milled materials – depend on the acceleration of gravity and mill chamber diameter. The kinetic energy of balls in vibratory mills is transmitted from the vibrating chamber, where the energy and intensity of interactions of milling balls – mutual and with milled material – depend on movement parameters,

such as amplitude, frequency and chamber movement trajectory, introduced by the designer and user [1].

Vibratory mills are known from the beginning of the twentieth century and their constructions are intensively developed, all the time. One of the most often applied present solutions is the over-resonance tube mill of an inertial excitation and a circular or elliptical chamber movement trajectory [1–3]. This type of structure characterised by the chamber capacity of up to 100 m³ and the installed power of up to 2 MW is applied in the majority of powder production technologies. Vibratory mills have much wider technological possibilities than gravitational mills. Significantly finer graining can be obtained at 4–10 times lower energy demand, 6–8 times lower cost of milling balls and in addition, they are of smaller masses and require smaller building areas.

Their main disadvantages, especially concerning resonance mills [4], are strong influences on foundations [5] and high loads of inertial vibrator bearings, which force monitoring their temperatures and applying complex cooling systems [1]. A limitation of these negative effects is possible by an application of the new structure solution. Such solution, based on the antiresonance effect [6,7], was presented in the previous work [8]. This mill, as compared to other solutions of a similar structure [10], allowed us to achieve the sectional and circular trajectory of the chamber movement and its higher filling degree. The application of the antiresonance effect allowed us to reduce forces transmitted to foundations, while the structure specificity allowed us to decrease drive units sizes. The results presented in the cited paper concerned the mill with an empty chamber. In turn, investigations presented in this article concern the chamber filled with a material, at the sectional and vertical trajectory of the movement.

2 Research set-up

Investigations were performed on the research set-up equipped with the laboratory antiresonance mill as well

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Figure 1: Schematic presentation of the research set-up.

as the control and measuring systems (Figure 1). This laboratory mill (Figure 2), was of periodical operations allowing us to obtain circular, elliptical and sectional vibratory movement trajectory of a chamber. Forcing of a vibratory movement of the chamber, filled with balls (1), and stiffly mounted to the chamber frame (2), was realised by means of inertial vibrators (3). The system of the chamber and its frame was spaced by four springs (4) in X system inside the drive frame (5). This system provided identical stiffness of an elastic support in the vertical and horizontal plane. The drive frame was supported by four springs on the foundation frame (7). The control system of the mill contained the frequency converter (9), allowing for smooth changes of the rotational speed of electrovibrators. Two piezoelectric accelerometers (PCB 356A02) (8), equipped with the magnetic base, were included in the measuring equipment.

One of the accelerometers, centrally situated on the chamber cover in the vertical and horizontal axis of symmetry of the mill was responsible for measuring vibrations of the mill chamber. The second accelerometer placed on the bottom edge of the drive frame in the vertical axis of the mill, was responsible for measuring

vibrations of the drive frame. Accelerometers were connected with dynamic signal analysers (NI 9232) (10), placed in the docking station (NI cDAQ-9174) (11). This station was connected with the computer (12) responsible for the data gathering and processing. Sectional-vertical trajectory of the chamber movement was achieved due to self-synchronising of electrovibrators [9], vibrating in contrary directions with respect to each other. An amplitude of chamber vibrations was changed by means of the set of unbalanced masses placed on vibrator shafts (3), allowing for smooth setting of excitation forces, at retaining the constant mass of the system. It was possible to shape the amplitude-frequency characteristic of the mill by the proper selection of elastic elements of the chamber and drive frame suspensions.

3 Results of experimental tests

The determination of the amplitude-frequency characteristic of the mill loaded with the charge, which consists of steel milling balls and model material in a form of high-silica glass-making sand, and the investigation of the influence of this charge mass on the antiresonance zone depth were the aim of experimental tests. In order to achieve this aim the quasi steady start ups at various filling degrees of the chamber such as 0.40, 0.65, 0.80, and 0.85 were carried out. The selected filling degrees correspond to values applied in classic industrial vibratory mills of a circular trajectory of vibrations, where the chamber filling degrees are within the range 0.65–0.90. In addition the filling degree 0.40 was considered, since it was used in the previously mentioned solution [10].

The accelerations of vibrations in the vertical direction of the drive frame and chamber were measured and on their bases the vibration amplitudes were determined. It was noticed that the filling degree had an essential influence on the mill operation and the antiresonance effect occurrence. At low filling degrees such as 0.40 and 0.65 the antiresonance was not seen. Results of experimental tests for the mentioned cases, presented as the dependence of the vibrations acceleration amplitude on the excitation frequency, are shown in Figure 3 – for the filling degree 0.4 and in Figure 4 – for the filling degree 0.65, respectively. Their amplitude-frequency characteristics are presented in Figures 5 and 6. For higher degrees 0.80 and 0.85, the antiresonance was very distinct. This situation is shown in Figures 7 and 8, where the dependence of the acceleration of chamber and drive frame on the excitation frequency, for the filling degrees: 0.8 and 0.85, is

Figure 2: Photo of the mill.

Figure 3: Quasi steady start up. Accelerations of the chamber and drive frame for the chamber filling degree equal to 0.4.

Figure 4: Quasi steady start up. Accelerations of the chamber and drive frame for the chamber filling degree equal to 0.65.

Figure 5: Amplitude–frequency characteristic of the antiresonance mill for the chamber filling degree equal to 0.4.

presented. Their amplitude–frequency characteristics are shown in Figures 9 and 10. It can be seen that the amplitude characteristic of drive frame vibrations has a characteristic shape of a zone with a distinct minimum for frequency of 13.5 Hz – which the authors attempted to present clearly in Figure 11 – showing amplitude–frequency characteristics for all filling degrees.

The zone in contrast to the narrow and steep shape, classic for dynamic dampers, falls gently towards the

Figure 6: Amplitude–frequency characteristic of the antiresonance mill for the chamber filling degree equal to 0.65.

Figure 7: Quasi steady start up. Accelerations of the chamber and drive frame for the chamber filling degree equal to 0.80.

Figure 8: Quasi steady start up. Accelerations of the chamber and drive frame for the chamber filling degree equal to 0.85.

minimum and also gently ascends in the direction of higher frequencies. This fact is extremely favourable on account of maintenance properties of the device since it makes it less sensitive to changes of operational conditions, providing the possibility of maintaining the machine work point in the minimum of the amplitude–frequency characteristic. The presence of damping unfavourably influences the minimum value of the zone. However, due to a possibility of the development of chamber natural vibrations

Figure 9: Amplitude–frequency characteristic of the antiresonance mill for the chamber filling degree equal to 0.80.

Figure 10: Amplitude–frequency characteristic of the antiresonance mill for the chamber filling degree equal to 0.85.

Figure 11: Quasi steady start up. Accelerations of the chamber and drive frame. Overall figure.

excited by balls impacts on chamber walls, obtains – in this case – a positive meaning, since it contributes to turning off these vibrations. In the work point, corresponding to the minimum in the drive frame characteristic, the high value

of the chamber vibrations amplitude allowing to mill efficiently a material, is obtained.

4 Conclusion

The performed experimental tests confirmed explicitly the possibility of utilising the antiresonance effect in vibratory mills of the sectional (vertical) trajectory movement of the chamber loaded to various filling degrees. The stable operation of the device, high amplitude of chamber vibrations as well as the very low amplitude of forces influencing the foundation was achieved for the presented case. The last value constitutes only 1.1% of the machine weight. The influence of the charge mass on the antiresonance frequency value was – of course – revealed. In the case of a high filling degree of the chamber mill, this frequency corresponds to the case in which the mass of the charge is directly connected with the mass of the chamber [11,12]. On the basis of the chamber movement, it was possible to state a positive influence of the milled material presence on decreasing natural vibrations of the system excited by balls impacts on chamber walls. The range of the mill operational frequency as well as values of the chamber vibrations amplitudes were within the ranges corresponding to ranges of efficient milling of materials. In general, it can be stated that the presented solution has the value in use and can constitute a reference for designing industrial solutions.

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References

- [1] Sidor J, Klich A, Współczesne maszyny do rozdrabniania - kruszarki i młyny. Gliwice: Instytut Techniki Górniczej KOMAG; 2018.
- [2] Gock E, Kurrer LE. Eccentric vibratory mills – theory and practice. Powder Technol. 1999;105:302–10.
- [3] Michalczyk J, Cieplak G, Sidor J. Numerical simulation model of the rotary-vibrational mill working process. Archive Metall Material Polish Acad Sci Committ Metall Inst Metall Material Sci. 2010;55(1):343–53.
- [4] Urakaev FKh. Resonance and it application to a vibratory mill. Mineral Eng. 2014;61:88–91.
- [5] Cieplak G. Verification of the nomogram for amplitude determination of resonance vibrations in the run-down phase of a vibratory machine. J Theoret Appl Mech. 2009;47(2):295–306.

- [6] Cieplik G, Sikora M. Two-mass dynamic absorber of a widened antiresonance zone. *Arch Mech Eng.* 2015;62(2):257–77.
- [7] Klemiato M, Czubak P. Control of the transport direction and velocity of the two-way reversible vibratory conveyor. *Archive Appl Mech.* 2019;89(7):1359–73.
- [8] Cieplik G, Piekaj P. Movement properties of antiresonance vibration mill with symmetrical construction. *Vibrat Phys Syst.* 2020;31(3):1–11, art. no. 2020302.
- [9] Peng H, Hou Y, Fang P, Zou M, Zhang Z. Theoretical and experimental investigation on synchronization of secondary vibration isolation system with two exciters. *J Sound Vibrat.* 2021;511:116351.
- [10] <https://www.generalkinematics.com> (29.04.2020).
- [11] Michalczyk J, Bednarski Ł, Gajowy M. Feed material influence of the dynamics of the suspended screen at its steady state operation and transient state. *Archive Mining Sci.* 2017;62(1):145–61.
- [12] Plavinskij V, editor. *Masiny nepreryvnogo transporta.* Moskva: Nauka; 1969.